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Borehole Geophysical Logging in Masvingo Province, Zimbabwe

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BOREHOLE GEOPHYSICAL LOGGING IN MASVINGO PROVINCE, ZIMBABWE

INTRODUCTION

In order to enable a greater understanding of regolith and basement aquifers a comprehensive study was undertaken fully to investigate geological and hydrogeological processes within six selected areas in the Masvingo Province of southern Zimbabwe. This investigation was undertaken in conjunction with various specialist inputs, namely: surface geophysical methods (EM, conventional resistivity and magnetometry), terrain analysis, thermal imagery, regional hydrochemical surveys and the data archiving of all existing boreholes within the study areas. This preliminary report outlines the various techniques employed during this visit and, on the basis of the log interpretation, attempts to correlate the data with hydrogeological parameters.

During the investigations within the Masvingo Province a total of twenty four boreholes were logged in six of the areas outlined for intensive study and it is the analysis of these results that form the basis of the interpretative techniques for this report. During previous drilling operations within this province, borehole geophysics had been employed by Hydrotechnica and the Japanese Aid programme on a limited basis, and where use had been made of this borehole geophysics the interpretation was relatively minor, with only the boundary between the regolith and the competent bedrock being delineated. In the case of the Hydrotechnica investigations, a fairly basic instrument operating on a point reading system was used, this measuring spontaneous potential, laterolog resistivity and total natural gamma radiation.

This study to characterise the formations under investigation and to delineate the potentially permeable horizons employed a more sophisticated suite of equipment operating on a continuous profile basis. The logging methods used during these investigations consisted of the following methods: spontaneous potential, point resistance, magnetic susceptibility, deep induction, temperature, fluid conductivity, borehole caliper, natural gamma radiation and spectral gamma radiation, and turbine flowmeter.

The objectives of the investigation were:

(1) to log geophysically all boreholes in selected sites were access was feasible
(2) investigate both the formation and hydrogeological parameters of the site
(3) supply third dimension control to the surface geophysical methods
(4) rehabilitate any hand pumps pulled during logging operations
(5) assess previous geophysical logging undertaken

All of the above objectives were achieved during the period of the fieldwork with investigations at each of the sites being achieved within one working day.

This study formed part of the Crystalline Aquifers Project to investigate the properties of both the regolith and basement formations underlying the study areas. The project was funded by the British Overseas Development Administration.

FORMATION CHARACTERISATION

The bulk of rocks termed igneous have probably formed by the cooling of a molten mass of magma, some of which may have formed by the melting and subsequent recrystallisation of sedimentary formations which might then have included a metamorphic stage. In most of these igneous formations silicon and aluminium are the major constituents with lesser but significant amounts of alkaline metals, sodium and potassium, and minor amounts of calcium, iron and magnesium. The dark coloured basic rocks may contain significant proportions of the heavy ferromagnesian minerals, which affect both the density and magnetic susceptibility logs.

The textures of igneous rocks are quite variable with the average crystal size being determined by the rate of cooling. Slow cooling, which usually occurs at depth below surface, produces the coarser-grained rocks, whereas the faster cooling, near a "cold" contact or close to surface results in the finer-grained formations.

There are two major secondary features of igneous and metamorphic rocks that not only affect the log responses but are important among results from the log analysis. These are hydrothermal alteration and fracturing. Hydrothermal alteration can serve as a guide to mineral deposits and is related to past or present movement of water within the formation. The location, orientation and characterisation of fractures is one of the most important results desired from geophysical logs of igneous and metamorphic rocks. Intergranular porosity and permeability are often quite low in these formations, thus fractures are the major conduits through which geothermal, altering or mineralising fluids will flow. Some fractures can be identified on geophysical logs but it is more important to determine their orientation and to characterise these fractures in terms of their water-bearing capabilities.

The primary porosity of most basement rocks is generally small, probably averaging less than one porosity per cent;

however, in comparison, vesicular basalt and tuff can have porosities greater than sixty porosity per cent. Compaction and cementation of basement formations are generally not important factors for geophysical logging analysis. Permeability in non-sedimentary formations is not likely to be related to the intergranular porosity. Fractures in igneous and metamorphic formations may exhibit an overall low porosity with a relatively high flow rate.

GEOPHYSICAL LOGGING TECHNIQUES

There are two major secondary features of the metamorphic and igneous rocks that not only affect the geophysical log response but are important in the analysis of the log interpretation. These features are hydrothermal alteration and fracturing. Hydrothermal alteration serves as a guide to mineral deposition within a massive formation whereas fracturing gives one of the most important results obtainable from the logs with regard to the location, orientation and nature of these fractures. In unweathered formations the intergranular porosity and permeability are normally very low and it is these fracture zones that contain the signatures for the log interpretation not only from the nature of the fracture but also with regard to mineralisation.

Each of the standard logging methods will react in different non-standard ways to these fractures and it is intended that the discourse below will show the limitataions and benefits to be obtained from this interpretation.

RADIATION LOGGING

As in sedimentary formations natural gamma radiation logging is useful in the determination of lithology in igneous and metamorphic rocks. Far less is known as regards the distribution of uranium, potassium and thorium as obtained from the spectral gamma radiation log, however the basic guidelines as for sedimentary formations would appear to apply. The potassium content is often quite constant in a single unaltered rock type as K^{40} is usually directly related to the potash felspar which has a fairly constant distribution. However, thorium and uranium may show considerable variation due to the concentration of these two elements in necessary mineral e.g. zircon and apatite. Under oxidising conditions uranium has been found to be highly mobile and it has been shown that uranium deposits in sedimentary formations have been derived from leaching of granite.

The analysis of spectral gamma radiation logging is an interpretative technique that is capable of yielding significant information on the movement of water through fractured formations or at various hold-up levels within the weathered basement complex (regolith).

Gamma-gamma logging has been shown to be equally useful in igneous rocks as well as in sedimentary sequences. Although the calibration of the logs is normally at the upper end or beyond the calibration scale, information is available for approximate densities to be obtained. Another factor affecting the performance of this logging technique is the relatively unknown chemistry of the formation which may not permit accurate matrix or Z/A corrections to be applied in the derivation of the formation density.

Whereas a sidewall (borehole compensated) density log may perform adequately within a massive igneous rock the altered and fractured zones may not permit correction for rugosity effects on the log. This failing may, however, be usefully exploited either as a fracture indicator where there are large departures on the correction curve oron a cross-plot technique against the neutron porosity log to give indications of potentially permeable zones within the profile.

Neutron logging suffers some of the shortcomings as above but has proven also to be a useful technique within these formations. Although this logging method has been normalised for use in limestone porosity units it cannot be expected to provide accurate porosity values within these crystalline basement formations, particularly at the lower values of neutron porosity. Again this log is a good indicator of fractured and altered zones within the profile but like the density log is susceptible to borehole rugosity effects. Of the minerals produced in altered zones there is a predominance of hydrous silicates and it is the hydrogen response of this of this method that will be observed in this circumstance. More precise values of neutron porosity may be derived with proper lithological control or by reference to other geophysical methods for the derivation of porosity.

ACOUSTIC LOGS

Probably the single most useful logging sonde for obtaining data on the orientation, location and character of fractures is that of the borehole televiewer. Due to the higher reflective index of the igneous rocks, a more definitive log is produced as compared to that of a sedimentary formation. This geophysical logging method, working on a high frequency (3 MHz) acoustic scanning technique is capable of not only providing information on fracture zones but also of lithological control where the different reflective indices of the formations result in a change in the amplitude of the reflected signal. This change in the amplitude of the signal will indicate changes in the hardness of the formation and hence yield further information of different cooling processes within the rock mass. The borehole televiewer is also capable of producing a four independent point acoustic caliper at the cardinal points and inspection of this output will correlate with the orientation of any fracture pattern as well as indicating borehole rugosity at this horizon. Further correlation of a fracture may be obtained by the inspection of borehole ovality as shown on the acoustic caliper.

Several types of sonic log can be quite useful in basement formations. By inspection of the acoustic velocity it has been observed that in massive formations the velocity tends to be quite high (c. 50 ft/sec) with lower velocities being recorded in hydrothermally altered zones or within fracture zones. Analysis of the acoustic velocity and the amplitude logs show good correlation with other logging methods and the tube wave amplitude logs are particularly effective in fracture detection. Attenuation of this signal seems to be greatest across fractures which are sufficiently open to transmit water between the borehole and any fracture. Inspection of the formation transit time logs enables differentiation between formation types with the microcrystalline formations exhibiting a higher velocity.

ELECTRICAL RESISTIVITY LOGS

Due to the very high resistivities encountered within igneous and metamorphic formations the interpretation of resistivity logs is particularly difficult due to the calibration difficulties in the range from 5000 to 10000 ohm metres, where the equipment response tends to be non-linear. However, altered and fractured zones exhibit lower resistivities and the presence of metallic minerals prove to be fairly conductive. The induction log, within these resistivity formations, tends to only give indications of resistivity due to calibration errors, however within the weathered or mineralised zones its calibration to clay minerals proves to be useful.

The quadrature signal obtained from the BRGM Romulus probe is a measure of the bulk magnetic susceptibility of the formation. In an isotropic medium, magnetisation induced into the formation due to a weak magnetic field being applied, is directly proportional to the intensity of the applied magnetic field. This is a dimensionless quantity and thus has no units, although the numerical value for a given specimen will depend on the system of units used for measuring the induced magnetism and the applied magnetic field.

Bulk magnetic susceptibility is related to the magnetic minerals within the formation. Certain minerals, notably magnetite and pyrrhotite, are highly magnetic and where present will dominate the magnetic susceptibility of the formation. The susceptibility is therefore dependent primarily on a few necessary magnetic minerals which are liable to be changed or destroyed by metamorphic effects, and which occur in widely differing amounts within different formation units.

Geological processes that could give rise to variations in magnetic mineral content can be envisaged to occur on two scales. On the micro scale where such variations could reflect processes such as small localised intrusions and their contact effects, local fracturing, development of coarse grained pegmatitic zones, localised alteration zones, or fine mafic/felsic mineral banding.

On the macro scale these variations would represent processes that were active over a much wider extent, e.g. gross lithological variations, broad shear zones, regional metamorphic effects, variations in regional fugacity, and temperature.

GEOPHYSICAL LOG INTERPRETATION

The interpretation of lithology from geophysical logs in igneous and metamorphic formations is largely a matter of experience and amount of corroborating data available. In the formations under investigation it is essential that core data is available to develop the interpretative criteria. Analysis of this core can be used for the calibration of the logs in terms of porosity, bulk density and the content of radio isotopes.

In the case of this report very little lithological information was available and with the limited logging techniques available, new or modified interpretative techniques had to be developed to enable analysis of the formations under investigation. Of the methods available for investigation of the weathered and competent formations the most useful was that of the spectral gamma radiation logging. By use of a selective filter system logging was run at four discrete radiation energies, 100 keV (total gamma radiation), 200 keV, Potassium (K^{40}),and the combined uranium and thorium energies (U+Th). Due to the relatively small size of the detection system and the relatively short integration times it was found necessary for the higher energy radioactive products to be combined, yielding count rates of 0.7 to 7 cps.

The six study areas of Masvingo Province, selected for intensive study, were logged using the complete suite of logging methods available and a resume of the geophysical logging undertaken is outlined in Table 1. Each of the study areas is commented on seperately and the observations on each site is described below.

AREA C

Borehole sites investigated	Formation type
GEMS 3089	
GEMS 3090	
EEC 80	

GEMS 3089: GEMS 3090

Of the above boreholes, GEMS 3089 and GEMS 3090, were selected for special investigation. These boreholes, located some 250 metres apart, were within similar formation types and yet GEMS 3089 had been designated as a failure, whereas GEMS 3090 was capable of sustaining normal hand pump operations (sp. cap. 1.000). Both boreholes had been completed in a similar fashion with plain steel eductor casing to 13 metres and 25 metres in GEMS 3089 and GEMS 3090 respectively, with open hole conditions to the total depth. This enabled a caliper log to be run within the open hole section to investigate the borehole rugosity and hence the intersection of these boreholes with fractures. Inspection of the logs showed GEMS 3089 to exhibit two significant enlargements at 17 metres and 32.5 metres, with GEMS 3090 showing considerably more enlargements in diameter across the zone 30.0 to 37.5 metres. Evidently in this case the increased specific capacity of GEMS 3090 was accounted for by the increased fracture density within the borehole profile.

Weathering within the formation was more pronounced at GEMS 3090 with the change to a more competent formation type being encountered at 25 metres. Spectral gamma radiation logging indicated a lower total gamma radiation from 25 metres where there was a reduction of clay mineral content within the bedrock. Across the fracture zone of 30.0 to 37.5 metres considerably more mineralisation was deduced with increased values of both the K 40 and U 238 content. The increase in K 40 is associated with the development of weathering around a fracture, as degradation of the parent rock occurs, and clay minerals are developed. The movement of water through a basement formation results in a negative redox (Eh) potential being developed. In the presence of organic matter, hydrogen sulphide or sulphur dioxide the available uranium ions are transported by the movement of the the water and are subsequently precipitated as uranium oxide.

Therefore, precipitated uraniun may be found concentrated around geological fault planes, natural fracture or fissure systems of some areal extent. This uranium is easily absorbed by clay minerals in a reducing environment particularly where carbonaceous minerals or sulphides are present. Thus, increases in the uranium content of a formation, as measured by the spectral gamma log, may be indicative of a fracture or where there has been a paleo water table, associated with the development of clays within a weathering profile.

The development of higher levels of uranium at specific horizons may not necessarily be indicative of permeable zones, but merely the development of slightly different genesis of the formation. These variations within igneous and metamorphic rocks are not unexpected and further interpretive techniques were developed to assess the significance of these variations. Normally the formation genesis results in an overall increase in radiation levels across the entire spectral range, but still maintaining the the overall ratio of low to high radiation energies. By considering the ratio of say 100 keV to that of the uranium, any departures from that of the ratio established for the formation type to that of a lower ratio, indicative of an increased uranium content, and due to the high mobility of uranium oxide, it may be inferred that a fracture exists. This technique was utilised for all the boreholes, particularly for those where no direct mechanical measurements could be made.

The ratio technique was applied to the spectral gamma logs for the above boreholes and at all of the fractures horizons delineated on the caliper log, a decreased ratio of 100 keV/ U+Th was observed in excess of the normal statistical variations associated with radiation logs. Thus, it is evident that the different fracture densities observed within the borehole profiles have determined the yield of the borehole, with the lower fracture density being associated the lower specific capacity of GEMS 3089.

During the investigations at this site further corroberative hydrogeological testing was undertaken on GEMS 3090 to assess the relative contributions of the fractures to the overall yield of the borehole. A short term pumping test was run for 90 minutes in association with a borehole flowmeter survey. Due to various technical difficulties the information from this testing was suspect and hence has not been in cluded in this report. Details of the pump test are included in Appendix 1, covering all investigations within area C.

EEC 80

Like all of the Hydrotechnica boreholes,well completion was in plastic casing and screen to the total depth of the well, with the gravel pack being emplaced from the total depth close to surface. Due to technical difficulties it was not possible for open hole measurements to be undertaken, and due to the complete screening and gravel packing of the borehole, the use of point resistance and spontaneous potential logging was limited as the depth of investigation of this logging method is very limited, usually ,in open hole conditions, not exceeding a penetration of one or two centimetres.

Spectral gamma radiation logging would be affected to a minor extent by the gravel pack, however due to the radiation of the formation exceeding exceeding the background level of the gravel pack useful data was obtained on the fracture/ fissure horizons. As noted previously, the 100 keV/ U+Th ratio yielded the best corroberative evidence on the location of high uranium oxide levels associated with the absorbtion of this mineral into clay minerals associated with fracture horizons. Inspection of the derived logs showed the weathering process to be fairly deep within the profile with competent bedrock being encountered at 38.0 metres.

The horizons of high uranium were observed at 11 metres and at 25 metres, with the upper uranium hold-up occuring within the transition zone between the weathered and less weathered regolith,where the change in relative permeability has indicated abase flow condition to exist. The lower horizon, still within the regolith, is probably associated with a fracture, still of relatively high permeability, being included within the deep weathering process. This fracture is delineated by an upper and lower more competent formation that has still retained some of it's origonal structure, as indicated by an increased ratio level.

The SP/PR log, although of limited use, still may be used qualitatively for formation changes of a gross nature reflecting through the gravel pack. The point resistance log at the 25 metre horizon only shows a minor change to that of a lower resistance, whereas the spontaneous potential log shows no significant change associated with the development of streaming potential at permeable horizons.

The magnetic susceptibility log is mainly measuring the heavy paramagnetic mineral that may be associated with fracture horizons and by inspection of the log it is noted that the are increased levels in the vicinity of the fractures at 11 and 25 metres. The induction log, measured in conjunction with the magnetic susceptibility, is mainly overrange for most of the profile and only shows minor variations in the above noted fracture zones. Due to the large integration volume of this tool (c. 0.8 metres), small scale variations as in the case of fractures may not be delineated. The well completion precluded the use of conventional resistivity logging methods, which would have provided resistivity values for the formation as well as delineating small scale fractures.

AREA E

Borehole sites investigated	Formation type
EEC 295B	Gneiss
EEC 300C	Dolerite
EEC 301C	Gneiss
GEMS 3095	

EEC 295B

This borehole, drilled to a total depth of 30.5 metres, and plumbed during geophysical logging operations to 29.8 metres, did not penetrate to the unweathered gneiss bedrock. Thus, all geophysical logging was confined to the establishment of potentially permeable zones within the regolith.

Inspection of the spectral gamma radiation log response showed a two layer system within the regolith with a minor change of lithology, probably due to different degrees of weathering, to be noted at 15 metres. This layered system is indicative in changes of grain size of the formation, with the coarser grained material undergoing a more pronounced weathering process. At only one horizon within this sequence is there any indication of a competent formation, or a formation type that still maintains the structural composition of the origonal bedrock. This was noted at 27 to 28 metres where the spectral gamma ratio was extremely high. Below this horizon the raio immediately decreased to that of the weathered formation ratio as previously established. It is proposed that a slightly different genesis may have resulted in the formation of a minor strata of a finer grained gneiss that was more resistant to the weathering processes.

The spectral gamma ratio profiles all exhibited fairly uniform levels to the total depth of the borehole, with the exception of the previously noted horizon at 27 to 28 metres, suggesting that the formation had been weathered to a similar extent. At no point within these profiles were there any indications of significant reductions in the 100keV/ U+Th ratio, beyond that of normal statistical variations, that showed indications of higher permeability, and hence increased uranium levels to exist. It is postulated that the degree of weathering had resulted in a uniform contribution of water throughout the profile of the borehole.

The SP/PR measured a fairly constant value of resistance of between 200 and 300 ohms, with a major increase in the resistance being observed across the horizon of 27 to 28 metres, thus supporting the hypothesis of a more competent formation type to exist at this level. This log was again limited in its interpretation by the presence of the well screen and gravel pack. No significant spontaneous potential was developed throughout the profile except at the 27-28 metre horizon, where different formation chemistry at the boundaries of this formation had resulted in a more positive potential.

The fluid column logs, temperature and electrical conductivity, had shown some variations throughout their profiles. Following a surface equilibrium zone, the temperature log indicated slight cooling with depth, particularly showing a steeper gradiant in the lower sections of the borehole. The fluid conductivity log showed minor variations in the order of 15 microSiemens/cm from 10.5 metres (base of casing) to 21 metres. These variations corresponded with minor formation changes and indicated the absorbtion of different ions by the saturating fluid from that of the formation chemical composition. The horizon between 27 and 28 metres contains relatively small quantities of soluble material, and this observation is confirmed by the constant value of the electrical conductivity.

The electrical conductivity log is particularly useful in this circumstance as it has indicated considerable discrete flow horizons to exist throughout the open hole, indicating that no single discrete inflow exists, but that the contributions are uniformly located throughout the borehole.

The relative levels of natural gamma radiation delineate the formation type being investigated with the lowest levels of radiation being encountered in gneiss, increasing to that of dolerite, and with the highest levels of radiation being measured in granitic formations.

This borehole, penetrating dolerite regolith and competent dolerite, again indicated clearly the gradation from regolith to bedrock, with the base of weathering being noted at 23.9 metres. From inspection of the spectral radiation ratios, several horizons indicating uranium mobilisation were observed at the following levels within the profile: 7 metres, 17 metres, 20 metres, 24-28 metres and at 32-33 metres. The increased uranium levels at 7,17 and 20 metres, within the regolith, are probably associated with high clay content strata having absorbed uranium oxide. The deeper zones at 24-28 metres and at 33 metres are within the competent bedrock and are indicative of the presence of fractures.

Further validation of the existance of fractures is bourne out by the inspection of the SP/PR log where major variations to that of a lower resistance value are observed at 33.4 and 27 metres, within the massive dolerite. These fractures are also indicated on the spontaneous potential log as changes in potential, suggesting streaming potentials to exist and hence confirming the fractures to be permeable, with the major contributing fracture to be at 27 metres.

Although the absolute values of the point resistance log are subject to considerable corrections they can still be used qualitatively to give formation boundaries, or, in certain circumstances, delineate fractures where the fracture is sufficiently large for detection by this method. The boundary between the regolith and the dolerite is clearly observed on the PR log as a change to a lower value of resistance in the regolith, where conduction by the clay minerals dominates.

The magnetic susceptibility log indicates clearly the fracture at 33 metres where mineralisation has occurred and also shows a diffuse zone of mineralisation to exist over the junction between the regolith and the competent basement formation.

EEC 301C

This borehole, penetrating gneiss regolith and gneiss, revealed from the geophysical logging that the boundary between these two formation was encountered at 17.2 metres. Inspection of the spectral gamma logs indicated that there was no evidence of fissures/ fractures within the profile, with the only major excursion within these logs being that of a low gamma content formation type between 31 and 32 metres, suggesting that the formation type at this horizon may have been of a high quartz content.

Generally the formation resistance was high (c. 900-1100 ohms) with more conductive material being noted at 14.5 and 20.0 metres (650 and 570 ohms respectively). The spontaneous potential log basically mirrored that of the PR log, indicating formation changes within the profile associated with changes in formation genesis. Due to the high resistance of the formation no significant changes in the induction was observed within the competent bedrock; the change to a higher conductance (lower resistivity) formation being observed within the regolith. This change in formation conductance was gradual, showing the most conductive horizon to be at 12 - 13 metres. This change would be associated with the higher levels of clay minerals.

The magnetic susceptibility log generally indicated the formation to contain very little paramagnetic minerals. Within the lower section of the borehole, from 27 to 36 metres, the magnetic susceptibility log mirrored the response of that of the gamma log, showing higher magnetic susceptibility associated with the higher gamma content formations.

The fluid column logs did not exhibit much change within their profiles. Following surface effects the temperature log showed a gradual cooling of the water to the base of the borehole, whereas the fluid conductivity log, showed an improvement in water quality with depth. The absence of any variations in these logs indicates that within the regolith, the yield from the formationwas fairly homogenous with no one horizon being the major contributor.

GEMS 3095

As with all non EEC wells, casing and screen was not emplaced to the total depth of the borehole, thus enabling a caliper log to be run. Inspection of this log, not only showed completion details but would also investigate the presence of any fracture intersecting the borehole.

Plain casing was emplaced to 25 metres, into the competent gneiss (the boundary between regolith and gneiss being encountered at 20.6 metres) and, as is normal, showed an increase in hole diameter to 8.4 inches at the base of this casing. Apart from minor rugosity, probably associated with drilling operations, no fracture system was encountered within the profile. This observation was further verified by the spectral gamma logs where there was no significant increase in the uranium content, with only a minor trough being delineated at 27 metres. The boundary between regolith and bedrock was well marked with an increase in gamma radiation levels being noted at 20.6 metres.

This boundary was also delineated on the SP/PR logs where there was an increase in resistivity within the bedrock. The competent formation showed considerable varaitions in its homogeneity with the higherst resistance be noted from 29 to 35 metres. No significant flow zones were measured by the spontaneous potential log, with the developmenet of streaming potentials, and this log mirrored that of the PR log, mainly showing formation chemistry effects to dominate.

As noted above, the most competent section of the formation occurred between 29 and 35 metres, and the magnetic susceptibility log indicated this zone to have the lowest values of susceptibility. The susceptibility of the formation increased within the regolith where the level of mineralisation was greater. Similar indications to that of the PR log were indicated by the induction log showing the more competent formation to be less conductive, with higher conduction within the regolith.

Temperature and fluid conductivity logs both indicated very little variation with the borehole fluid column, with the cooler and slightly worse electrical conductivity water (640 microSiemen) being measured in the lower section of the borehole.

AREA F

Borehole sites investigated	Formation type
EEC 69	Gneiss
EEC 70	Granite
EEC 72	Gneiss
EEC 264	Granite
EEC 269B	Granite
JP 5849	Granite

<u>EEC 69</u>

This borehole, penetrating a sequence of gneiss regolith, weathered gneiss and massive gneiss exhibited clearly the formation boundaries on the spectral gammma logs, with the formation boundaries being delineated at 14.8 metres and 20.8 metres. Within the upper sequence of the gneiss regolith there was a major peak in the gamma response between 4 and 5 metres, across the entire spectrum that indicated an increase in the uranium level and a decrease in the 100 keV/ U+Th ratio. This discontinuity, at the same horizon as the water table may indicate the existance of a paleo water table where the uranium oxide has been absorbed by the clay minerals. The delineation between regolith and weathered formation is marked by a slight increase in gamma response, showing a higher count rate within the weathered formation. Several horizons within the profile show that there has been a uranium holdup, with the only indication of a fracture within the bedrock being noted at 22 metres. From the spectral gamma response it would appear that most of the contributions to this well yield are developed within the regolith and weathered bedrock.

The SP/PR log is heavily influenced by the presence of the gravel pack, giving a point resistance log response that is that of a fairly uniform gravel pack emplacement. The majority of the spontaneous potential is poorly developed with the only indication of a potentially permeable zone being indicated at 34 metres. This change in potential is associated with a gamma log increased count rate indicating that mineralisation has occurred across a fracture within the basement rock and has resulted in an increased clay content combined with uranium capture.

Inspection of the output from the Romulus probe showed that the formation conductance was over scale for most of the profile with only the regolith being differentiated. However, the magnetic susceptibility clearly showed formation changes, that corresponded with the other logging techniques, indicating the weathered formation to have a lower magnetic content than that of the massive basement. The previously noted flow horizon at 34 metres is shown to be of low susceptibility suggesting that this horizon is fairly extensive with its width exceeded that of the bed boundary definition of the tool (in excess of 0.8 metre).

The temperature log of the fluid column did not indicated any of the formation characteristics and apart from the surface diffusion effects gave a constant temperature profile of 22.1 degrees Celsius from 21 metres.

EEC 70

Extensive weathering to 19.9 metres overlay a fissured granite. Within the regolith, a quartz band between 4.6 and 6.1 metres, had been impervious to the weathering processes and was manifest on the gamma logs as a horizon of low radiation activity. The base of the regolith was delineated by an increased uranium level and showed that the infiltrating water was subject to lateral movement on encountering the low permeability basement formation. The massive granite was shown to be heavily fissured with wide variations in the natural gamma radiation of the formation, however as this fissuring was not accompanied by wide variation in the uranium level these fissures were noted to be of very low permeability. Also, where water movement of any significant quantity had occurred the would have been the attendent weathering around these fissures resulting in the development of clay minerals. Where weathering had occurred within micro fissures, the development of clays may have subsequently blocked the fissure, resulting in indications of fissures by the spectral log, but without the uranium levels associated with significant permeability.

Formation boundaries were well delineated by the SP/PR log, with the fissured granite being entered at 19.9 metres. This boundary resulted in an increased resistance, from 200 ohms within the regolith to 400-500 ohms in the fissured granite, with no significant variations be noted within the lower formation. The only minor reduction in resistance was noted at 32 metres and this may be accounted for by a slightly increased weathering within the granite or the development of clay minerals around a fissure that is not productive. The spontaneous potential log mirrored the resistance log and indicated no steaming potentials associated with flow.

Temperature within the fluid column did not indicate any major variations, with the temperature changing constantly down the profile, from 21.3 degrees Celsius at 10 metres to a bottom hole temperature of 22.1 degrees at 47.5 metres. The fluid conductivity log however did show some variation with three distinct layers being observed. The upper layer from 10 to 25 metres (1020 to 1055 micro Siemen); the intermediate horizon from 25 to 37.5 metres (1055 to 1080 micro Siemen) and the lowest section from 37.5 to 47 metres (1080 to 1085 micro Siemen). These layers did not reflect the previously noted formations and it is postulated that the recent removal of the hand pump had resulted in a fluid column chemistry that was not in equilibrium.

EEC 72

The high variability of the gamma response in the gneiss bedrock indicated the formation to heavily fissured/fractured and where these fissures occorred there was indications from the 100 keV/U+Th ratio that the fissures were permeable. The regolith/ fissured gneiss boundary, at 16.3 metres, was easily delineated, with the fissured gneiss being immediately entered at 18 metres with the first of the fissures. A section of competent gneiss, between 19 and 23 metres, preceeded considerable fissuring throughout the rest of the profile. Of these fissures many were shown to be permeable with uranium capture being observed.

The effective bed boundary definition of the point resistance log was incapable of delineating these fissures as they were smaller than 0.6 metre. The change from regolith was indicated as a change in resistance from 250 ohms to 400 ohms in the upper section of the fissured gneiss; with the less weathered upper section of the gneiss being delineated at 21 metres. Prior to this boundary the point resistance log indicated some fissuring and weathering to be present, before a massive gneiss with small fissures was entered (formation resistance 550 ohms). The spontaneous potential exhibited an oscillation superimposed over the the formation response of this log, and it is postulated that these oscillations may either result from considerable flow horizons, resulting in streaming potentials, or the log response was influenced by external noise from telluric currents.

Compared to observations in other boreholes the temperature log of EEC 72 showed an elevated temperature profile. A surface temperature of 24.4 degrees Celsius gradually reduced with depth to a bottom hole temperature of 23.4 degrees Celsius being observed at 36 metres. This temperature profile showed a constant gradient decrease in temperature with depth with none of the fissures in the gneiss resulting in small changes in temperature. The thermal mass of the measuring thermistor may have resulted in very minor variations being integrated within the response time of the thermistor, and hence not indicating these small transitory changes.

EEC 264

Boreholes within unfractured basement formations generally indicate a lower specific capacity than those penetrating fissured or fractured formations. In the case of EEC 264 the specific capacity of this borehole was tested at 0.002 l/s/m and inspection of the spectral gamma logging showed no evidence of any horizon to exhibit fractures or fissures.

Formation changes are clearly delineated by all of the spectral gamma logs with a soil to 1.1 metres, regolith to 10.8 metres, then a higher gamma content formation (weathered granite) to 28.2 metres, entering the massive granite bedrock. The transition from regolith to the weathered granite indicated a low radiation activity horizon from 10.8 to 13.4 metres, suggesting that the formation had undergone rugous leaching with none of the origonal structure being present, with high water throughput, where the clay minerals had been completely leached. The other hypothesis would refer to the mechanical aspects of the formation, where a weakly cemented formation had resulted in a considerable washout during drilling operations, with the resultant void being infilled with gravel pack of low gamma radiation activity. Analysis of the spectral ratios, in particular that of the 100 keV/U+Th ratio, favours the second hypothesis as this ratiois extremely high indicating that the highly mobile uranium oxide had not been deposited within this horizon.

Inspection of other logging techniques, in particular the SP/PR and induction/ magnetic susceptibility, shows this horizon to be of very low resistance (30 ohms) and approximating to the resistance of the formation water. As the magnetic susceptibility log also shows this horizon to have the lowest susceptibility of any part of this profile, it further supports the existance of a considerable void to exist behind the casing. The previously noted formation breaks are also delineated by these logs with the weathered granite (200 ohms) leading into a massive granite (350-400 ohms) at 28.2 metres. These formations are indicated to have a low susceptibility within the regolith with an increased level of magnetic minerals within the weathered granite and a slight reduction in level within the massive granite.

The fluid logs, temperature and electrical conductivity, indicate that the majority of the water is produced within the upper horizons of this borehole, with both the logs showing a break point at 23-24 metres; the lower section of the profiles measuring a more saline water (680 micro Siemen) at an increased temperature.

<u>EEC 269B</u>

Comparison to the Hydrotechnica analysis shows some agreement on lithology, with the formation changes being noted at the following horizons:

0 - 12 metres	Granite regolith
12 - 26.6 metres	Weathered granite
26.6- 39 metres	Granite
39 - 44 metres	Fissured granite

The above lithological units were delineated from inspectionof all of the spectral logs with the two lower units being differentiated by significant changes in radiation level. As had been previously noted fissuring of a formation does not define its permeability and only by observing the uranium mobilisation can contributing horizons be defined. Analysis of the 100 keV/U+Th ratio profile indicated the permeable horizons to be at 17, 29 and 35 metres.

The magnetic susceptibility and formation conductivity logs agreed with the formation boundaries noted above with the bottom hole formation showing a zone of lower susceptibility. The massive granite was fairly homogenous and was overlain by a horizon, at 23.5 metres, showing high mineralisation, with the weathered granite exhibiting a similar level of mineralisation to that of the lowest formation type. It is postulated that various bands of weathering exist to depth with these horizons being interspersed by competent formation. This preferential weathering is probably associated with different crystal size of the formation with the coarse grained formations being weathered to a greater degree.

The low water table at 26 metres only enabled a fairly small portion of the borehole to be logged. Inspection of the temperature log showed a minor inflection to exist at c.37 metres. This inflection would be associated with an inflow/ producing horizon; with the lower portion of the profile not indicating any contribution to the yield of this borehole.

<u>JP 5849</u>

Although the caliper log showed borehole rugosity effects associated with fractures/ fissures intersecting this borehole, the spectral gamma logs only indicated two horizons to have some permeability, these being located at 13-14 metres and at 25 metres. The caliper log confirmed the horizon at 13 to 14 metres, with the presence of two fractures one metre apart being noted, however the 25 metre horizon was only indicated as a minor enlargement that, in normal circumstances, could be associated with drilling operations. A number of intersecting fractures were also noted at the following horizons: 7.4, 18.2, 21.5, 30 and 32.2 metres, and these showed no mineralisation to be associated with them. It is postulated that these fractures are highly localised and do not join up with any other fractures of areal extent, thus indicating a very low or nil permeability.

The SP/PR log confirms the major horizon at 13-14 metres, with a reduction in resistance to 90 ohms from the formation resistance of 130 ohms. The other minor fractures are however not indicated on the log, as either their size is below the bed boundary definition of this method. The only major excursion in the spontaneous potential log was associated with the horizon at 13-14 metres where streaming potentials had been developed.

AREA G

Borehole sites investigated	Formation type
EEC 53B	Granite
EEC 55B	Dolerite
EEC 56	Dolerite
EEC 303	Granite
EEC 304	Granite
JP 5584	Granite

<u>EEC 53B</u>

Following a cover of 1.20 metres of soil, this borehole penetrated fissures granite to the total depth of the borehole. Spectral gamma logs showes considerable varaition in radiation throughout the profile with an overall increase in radiation with depth. The granite was heavily fissured throughout its penetration with more massive fissures being encountered from 20 metres, where the highest level of uranium oxide was measured.

The SP/PR logs indicated the fissured granite formation to basically be differentiated into three dictinct levels with formation boundaries being delineated at 17 and 31 metres, these horizons being shown to be more conductive, with resistance values of 127 and 280 ohms respectively. The three formation types within the fissured granite gave values of resistance increasing with depth with the strata to 17 metres being measured at 175 ohms; the intermediate formation 290 ohms and the deepest formation with a resistance of 330 ohms. These variations would reflect the degree of fissuring with the overburden pressure reducing the frequency fo the fissuring. The spontaneous potential log showed the formation boundary horizons to be permeable with large increases in potential being associated with each horizon.

Formation magnetic susceptibility increased with depth, indicating the upper levels of the fissured granite to be about 4×10^{-3} SI, the middle formation at 5×10^{-3} SI and the lowest being 5.5×10^{-3} SI. The formation boundaries at 17 and 31 metres were indicated to be of low magnetic susceptibility. Overall, the log exhibited large susceptibility changes with depth and confirmed the large degree of fissuring to be present within the formation.

Apart from a minor increase in temperature at 31 metres, the temperature log did not indicate any other variations from that of its constant profile.

EEC 55B

Encountering fissured dolerite from 4.6 metres the formation showed two horizons of high clay content, with high gamma responses being associated with conductive formation types. These formations, at 8 and 23 metres, differentiated between changes in dolerite with 4.6 to 8 metres indicating a low gamma response and high resistance (1100-1450 ohms); overlying the intermediate formation of resistance 700-800 ohms, this exhibiting a similar level of radiation to that of the lower formation type. The resistance of this lower formation unit was 1100-1400 ohms.

Inspection of the spectral gamma ratios showed two horizons of low uranium within the fissured dolerite, where the formation was more competent, at 10 and 40 metres, with the remainder of the profile exhibiting the effects of fissuring. There were no strong indications of permeable horizons being associated with uranium mobilisation.

The temperature profile gave no strong indications of flow within the borehole but did exhibit a very minor inflection at 23 metres with water in the lower section increasing in temperature with depth.

EEC 56

Inspection of the suite of spectral gamma logs indicated the following lithology within EEC 56.

0 - 5.9 metres	Dolerite regolith
5.9- 10.0 metres	Weathered dolerite
10.0- 22.5 metres	Fissured dolerite

In comparison to the Hydrotechnica lithology the horizon between 5.9 and 10.0 metres appears not to have been differentiated despite strong indications to the contrary from the BGS geophysical logging. The dolerite regolith exhibited considerable variations in radiation with the lowest radiation level being noted in the homogenous formation between 5.9 and 10.0 metres. Within the fissured dolerite discrete fissured existed indicating that the development of clay minerals had resulted in higher radiation levels. These discrete fissures were marked, in some circumstances, by increases in uranium levels, and where these levels were pronounced it was postulated that they were associated with permeable horizons. The 100 keV/U+Th ratio indicated the following horizons to exhibit significantly higher uranium levels: 10 metres, the boundary between weathered and fissured dolerite, and a number of deeper levels where it was suggested that the more permeability horizons were in the lower section of the borehole.

The above lithology was confirmed by the point resistance log, with the 5.9 to 10 metre formation being fairly conductive (150-200 ohms), overlying the fissured dolerite of formation resistance 750-820 ohms, with the major fissures from 19 to 22.2 metres being measured at 570 to 590 ohms. These fissures are the measurement of a compound resistance where the formation value and the bed boundary resolution of the sonde has resulted in a value of resistance that does not reflect the true value for the fissure. The induction log gives similar formation delineation to the other logging methods, indicating the least conductive formations to be within the fissured dolerite, and the weathered dolerite to mirror the gamma log, where high rediation was associated with the more conductive formations.

Minor variations in electrical conductivity within the fluid column reflected formation changes with the formations containing the higher levels of clay minerology indicating higher fluid conductivities.

EEC 303

As had been previously noted the basement formation genesis can result in numerous layers of weathered formation, interspersed by competent formation, being encountered to significant depth. this borehole ideally represents this condition with at least six distinct formation types being differentiated, alternating from weathered to competent granite.

Analysis of the different logging techniques has resulted in the delineation of the following formation boundaries:

0 - 0.9 metres	Soil
0.9- 4.0 metres	Weathered granite
4.0- 9.5 metres	Granite
9.5- 13.4 metres	Fissured granite
13.4- 17.6 metres	Granite
17.6- 21.0 metres	Weathered granite
21.0- 27.0 metres	Fissured granite
27.0- 31.0 metres	Granite

This lithology does not correspond to that delineated by Hydrotechnica, showing two additional formations, where the Hydrotechnica sampling technique may not have been able to differentiate between fissured and weathered granite. These lithological changes were based on different spectral ratios and the different levels of mineralisation noted in the different formation types.

Having established the lithology the investigation of the existance of permeable horizons was investigated by means of spectral gamma ratios, the development of streaming potentials and changes in temperature and electrical conductivity within the fluid column. The major uranium retention level was noted at 13.4 metres, at the base of the junction between the fissured and competent granite, and was confirmed by a significant reduction in water quality. Below this level there was a diffusion zone to 18.4 metres, below which a fairly constant background EC reflected only the formation changes. This confirmed that the lower section of the borehole had reached equilibrium conditions with that of the formation and had not been disturbed by the flow of water up the profile. Below 13.4 metres, the temperature log indicated a costant gradient increase in temperature to a bottom hole temperature of 19.9 degrees Celsius form the 19.7 degrees observed at 13.4 metres.

The SP/PR log, due to the low EC of the fluid column water, was unuseable and reflected screen construction details.

EEC 304

Interpretation of the geophysical logs from their different responses to formations has resulted in a reinterpreted lithology, showing more detail than that of the Hydrotechnica lithology.

0- 1.1 metres	Soil
1.1- 4.0 metres	Granite regolith
4.0- 7.6 metres	Fissured granite
7.6- 10.6 metres	Weathered granite
10.6- 16.5 metres	Fissured granite
16.5- 34.4 metres	Granite
34.4- 39.5 metres	Weathered granite
39.5- 45.0 metres	Fissured granite

The massive granite from 16.5 to 34.4 metres was indicated to be fairly homogenous with very few variations within its structure, the only anomaly being noted between 28 and 29 metres, where a lower resistance value (1000 to 1100 ohms) was associated with the development of a streaming potential. The boundary between the weathered and fissured granite was delineated by a large change in both resistance and SP with a reduction in resistance from 1100 to 750 ohms, and the development of a 50 mV potential change at this horizon. The 100 keV/U+Th ratio at this level exhibited a considerable low showing that there was a high retention of uranium oxide, thus indicating a permeable horizon.

Other indications of permeability on a reduced level were also noted at 34.5 and 36.5 metres, within the weathered granite, where reductions in resistance were observed in conjunction with indications of streaming potential. The movement of fluid past the logging sonde results in the development of potentials whose magnitude is proportional to the fluid velocity and hece the relative permeability of that horizon.

JP 5584

Borehole geophysical logging has resulted in the following interpretation of lithology:

0 - 2.1 metres	Dolerite regolith
2.1 -19.6 metres	Weathered dolerite
19.6 -31.3 metres	Fissured dolerite
31.3 -48.0 metres	Dolerite

The above lithology was determined from the analysis of the spectral gamma logging, point resistance and magnetic susceptibility values as recorded for each of the formation types.

A considerable proportion of the weathered and fissured dolerite indicated high values of uranium, resulting in a low 100keV/U+Th ratio, and it si deduced that the horizons between 10 and 39 metres are the most permeable of the producing zones within this borehole. The dolerite regolith and upper section of the weathered dolerite were indicated to be of low permeability with a similar condition to exist in the bottom section of the borehole.

Borehole rugosity, as measured by the caliper log, was fairly high with the greatest rugosity being recorded between 20.4 and 35 metres. The horizon of high indicated permeability was associated with this high level of rugosity and was further verified by the low resistance (50 ohms) and spontaneous potential measurements.

The temperature log indicated a constant temperature profile to 35 metres with a gradual increase in temperature from this level to the bottom of the borehole.

AREA J

Borehole sites investigated	Formation type
EEC 229	Gneiss
EEC 240	Gneiss
JP 6260	Gneiss
V 546	Gneiss

EEC 229

The interpreted lithology from the geophysical logs was as follows:

0 - 19.0 metres	Gneiss regolith
19.0- 29.4 metres	Gneiss
29.4- 44.0 metres	Fissured gneiss

Analysis of the above lithological units showed the gneiss regolith to be fairly variable in nature with large variations in the gamma activity of the formations. Between 10 and 12 metres the formation appeared to indicate a return to a more competent gneiss formation with radiation levels approaching that of the competent gneiss. No values of resistance for the regolith were available due to the low water table at 20.71 metres. A distinct break point at 19.0 metres differentiated the regolith from the massive gneiss in levels of magnetic susceptibility, with the regolith being of higher susceptibilty.

The massive gneiss, between 19.0 and 29.4 metres, was indicated to be fairly homogenous with very few varaitions in radiation levels being noted. The uranium profile showed that the nature of the gneiss could be subdivided into two distinct formation types with the upper horizon to 22.9 metres exhibiting a slightly higher value of radiation. This subdivision of the competent gneiss would be accounted for by a slightly different genesis of the formation, resulting in a different formation crystal size and also the mechanical properties of the gneiss.

The SP/PR log showed the formation resistance to vary from 150 to 520 ohms and a low spontaneous potential to be developed. The resistance of the competent gneiss was lower than that of the regolith and fissured gneiss and indicated less variabiltiy than that of the fissured gneiss.

The fissured gneiss showed large variations in resistance with values in the range of 300 to 700 ohms being measured, and exhibited a profile indicative of that of a fissured formation. These varaitions were confirmed by inspection of the 100 keV/U+Th profile, where there were indications of low ratios associated with increases in uranium level. Generally the uranium retention increased with depth indicating the existance of more productive fissures in the lower section of the borehole.

The fluid conductivity log measured an EC of 500 micro Siemen to 24.5 metres with the section between 24.5 and 29.4 metres indicating a slightly lower conductivity before entering the fissured gneiss of conductivity 530 micro Siemen. The EC profile in the lower section of the borehole was fairly constant with more saline water existing within the bottom 0.5 metres of the borehole. The horizon at 30.0 metres showed a discrete fracture producing more conductive water, with a peak EC value of 540 micro Siemen. No significant varaitions in temperature were noted with a constant gradiant across the profile beingmeasured, a surface temperature of 22.3 degrees Celsius increased to 22.8 degrees Celsius at 44 metres.

<u>EEC 240</u>

Reference to the different logging techniques has resulted in the following lithology being interpreted:

0 - 28.1 metres	Gneiss regolith
28.1- 45.8 metres	Gneiss
45.8- 51.2 metres	Fissured gneiss
51.2- 59.0 metres	Gneiss

The gneiss regolith, following 1.5 metres of soil gave a gamma profile indicative of the response typical of regolith with a high 100 keV radiation level associated with the weathering. At 19.0 metres there was a high level of potassium, not associated with any other major increases in radiation and this significant increase is correlated with the development of a high clay content formation. The regolith exhibited a low formation resistance of 100 to 250 ohms and developed negative spontaneous potentials, indicating a relatively permeable formation type.

The gneiss was clearly demarked with a step increase in resistance to a fairly uniform formation resistance of 425 to 500 ohms. This formation was also noted to produce significant SPs in excess of 100 mV, with negative spontaneous potentials being recorded at 33.3 metres, corresponding to a reduction in the point resistance to 350 ohms. This excursion correlated with an increase in the uranium content of the formation at this horizon and would indicate that a minor zone of the gneiss was productive, with the development of mineralisation and the attendent retention of uranium oxide.

The gneiss overlays a fissured gneiss, which in turn was above an other competent gneiss. The fissuring of the gneiss resulted in an indicated formation resistance of 300 to 350 ohms, whose value was reduced, by the fissures, to this measured value. The bed boundary resolution of the PR sonde is in excess of the fissures being delineated and measures a composite resistance of the formation and the fissure.

This horizon showed the development of significant spontaneous potentials and the production of streaming potentials, hence this horizon to be permeable. The magnetic susceptibility of the fissured gneiss was indicated to be at an intermediate value between that of the regolith and the competent gneiss, with the regolith displaying the higher degree of mineralisation.

The fluid column logs showed no significant variations, with both the logs indicating profiles of increasing temperature and fluid conductivity with depth.

JP 6260

The lithology as abstracted from the logs is indicated below:

0 -	17.9 metres	Gneiss regolith
17.9-	26.7 metres	Fissured gneiss
26.7-	44.0 metres	Gneiss

Following the development of a regolith of different structure to that observed lower in the profile, at 4.1 metres. shows weathering on an increased basis up to 17.9 metres, with increasing radiation levels indicating the development of clay minerals to depth within the profile and being associated with higher levels of magnetic suscceptibility. The caliper log indicated a block of formation between 13.2 and 15.6 metres to show some enlargement with this horizon also indicating a small step change in radiation levels. This formation appears to have undergone a slightly higher degree of weathering with the competence of the formation being reduced.

The development of a mineralised horizon at 19.5 to 20.0 metres, at the top of the fissurede gneiss, is reflected as a diffuse fissure with a hole enlargement up to a diameter of 7.2 metres. Other minor indications of fissuring, as delineated by the spectral gamma logs, were too small for resolution by the mechanical caliper sonde. This formation was shown to have a susceptibility that increased with depth across the sequence and a formation conductivity of decreasing value. The fissured gneiss indicated a number of fissures to be present with major mineralisation being observed at 25.9 metres. A significant uranium peak delineated this horizon and indicated uranium retention with the development of clay minerals. Other minor fissures were indicated at the following horizons within the fissured gneiss: 17.9, 20.2, 21.6, 24.4, and 25.1 metres; these all being delineated by increases in uranium level.

The gneiss, between 26.7 and 44.0 metres, exhibited one major fissure at 29.8 metres, and two minor fissures (not recorded on the caliper log) at 34.5 and 39.4 metres. These minor fissures were recorded by the spectral gamma log as horizons of increased uranium. The major fissure at 29.8 metres showed a very large decrease in the formation resistance with a reduction from 700 ohms (the bulk formation resistance) to 240 ohms (the fissure/formation resistance). This reduction in resistance was also reflected as a change in the SP with a major negative excursion of 150 mV. No changes in the magnetic susceptibility were noted at this horizon, suggesting that no weathering had occurred within the fissure.

The temperature profile was constant with no changes in temperature, however, the fluid conductivity underwent invertion with the fluid at 25 metres increasing in quality to a minimum of 510 micro Siemen at 34 metres to 37 metres and then decreased in quality to a value of 750 micro Siemen at 44 metres. This indicated that the majority of the water was produced from the upper horizons of the borehole, with the largest permeabilty being noted at 29.8 metres.

V 546

The following lithology was deduced from the geophysical logs:

0 - 1.2 metres	Soil
1.2- 32.2 metres	Gneiss regolith
32.2- 41.0 metres	Fissured gneiss
41.0- 46.8 metres	Gneiss
46.8- 53.5 metres	Fissured gneiss

The regolith within this borehole exhibited two levels of weathering with the boundary between the different weathering being delineated between 16.5 and 20.3 metres by the development of two minor strata of indicated high clay content. These strata were not demarked by an increase in the uranium content and were thus associated with a rugous weathering process. Enlargements in the borehole were noted at 25 metres and corresponded with a minor increase in radiation levels. The potassium content of this horizon was marked with a slight increase in level, whereas the was not the corresponding increase in uranium. This zone was postulated to exhibit a different amount of weathering within the formation and resulted in a higher clay indication.

The transition to fissured gneiss was well marked with large excursions in radiation levels being recorded across the whole of this unit. The caliper log recorded on major fissure of 0.7 metre width at 33.6 metres and a zone of general enlargement in borehole diameter from 36 to 40.9 metres. Spectral radiation measurements exhibited an overall increase in all levels of radiation with
the K^{40} log showing significant variations in level, with a less well defined change in uranium levels, although these changes were still noteable in exhibiting the existance of formation permeability. General levels of magnetic susceptibility were high throughout this horizon and the formation conductivity showed an extremely conductive horizon between 37 and 42 metres, corresponding to the base of the fissured gneiss.

The gneiss, between 41.0 and 46.8 metres, recorded very little variation throughout the profile, with all of the spectral radiation logs recording a quiet section of profile with normal statistical variations. Formation conductivity was high and exceeded the range of resolution for this sonde. The point resistance log indicated a formation resistance of 400 ohms for this formation type. Due to the very low water level within the borehole SP/PR logging could not be run until 41.39 metres, the static water level.

The lower unit of fissured gneiss was again clearly marked with wide variations in all of the logging technique responses. The radiation logs all exhibited a general increase in level and there were wide variations to a more conductive formation on the output from the induction sonde. The responses of all the logging methods were typical of a heavily fissured formation, with this formation indicating a greater degree of micro fissuring than the upper fissured gneiss.

AREA M

Borehole site investigated	Formation type
CHI-JA06	Granite

CHI-JA06

The following lithology was determined from analysis of the geophysical logs:

0 - 8.0 metres	Granite regolith
8.0 - 53.3 metres	Fractured granite

The above lithology delineated only two formation units with the lower formation being classified as fractured granite. Although this unit has been classified as fractured, the fractures are distributed throughout the formation, with some zones of competent formation interspersed by high proportions or ''swarms'' of fractures. The zones of high fracture intensity were noted at the following horizons: 16 to 25 metres and 42 to 53.3 metres. These horizons were interlain by a granite in which the fracture density was considerably reduced, but still of a significantly noteable quantity for the overall classification of fractured granite.

The SP/PR log indicated the major fracture horizons as broad zones of lower resistance, departing from the background resistance of the granite (700 ohms) and showing the diffuse fracture zones with a resistance of 450 ohms. The development of streaming potentials in the spontaneous potential log indicated the formation permeability at these horizons to be significant.

As would be expected with the existance of a fractured rock, the induction sonde responded with wide variations in both the susceptibility and formation conductivity, with the massive granite establishing a very uniform background in both logs and exhibiting low susceptibility and conductivity at the fractured horizons. Both logging techniques exhibited a double peak response indicating that the fractures were smaller than the bed boundary resolution of the the sonde.

The fluid column logs both showed a constant profile (temperature and EC) with an overall decrease in temperature, after the surface diffusion zone, with depth. The water quality increased with depth and showed the bottom hole fracturing to produce a better quality water.

CONCLUSIONS

The geophysical logging of some 25 boreholes in a variety of different formations has enabled the classification of the logging technique response to these formation units. Inspection of these responses has enabled the following observations to be made and to give overall guidelines in the interpretation and analysis of these log responses.

1. Formation types may be delineated by the overall values of radiation measured by a natural gamma radiation sonde. This response has resulted in the windowing of these values to specific basement formations and for the specific sonde has resulted in the following classification:

Gneiss	150-200 cps at 100 keV
Dolerite	300-400 cps at 100 keV
Granite	600-800 cps at 100 keV

The above classification has been deduced from observation of the logging response in the competent/massive or unaltered basement formations for a specific set of equipment and is a guideline to the relative levels of radiation i.e. the natural gamma response and increase in level from gneiss throgh dolerite to granite, where the highest levels of radiation were recorded. Weathering processes and fissuring may significantly alter these levels and care should be exercised in the overall classification of formation type by just the overall levels of radiation without external control from either drilling or other geophysical techniques.

2. In the case of most of the boreholes, no direct contact or measuring technique could be utilised and where open hole conditions were present this enabled the direct correlation of the existance of fractures and permeable horizons. The development of analysis by the inspection of spectral gamma radiation ratios has enabled potentially permeable horizons to be delineated. By far the most important measurement was that of the profile of uranium levels. By considering the ratio of 100 keV

(total natural gamma radiation) against the U+Th value, an abstracted profile was obtained that indicated low values of this ratio to be indicative of permeable horizons. The weathering of a basement formation results in the mobilisation of uranium, which is subsequently oxidised to UO_2 and this uranium is absorbed on clay minerals within horizons that have undergone hydrothermal or weathering processes, associated with the movement of water. Having been absorbed within the clay minerals the uranium is then available as an indicator of the movement of water, hence permeability.

3. The development of mineralisation within formations results in an accumulation of para or ferro magnetic minerals and the profile of magnetic susceptibility clearly indicates these horizons. The relative size of this zone may be differentiated by the magnetic susceptibility sonde, with significant horizons being recorded as changes in the level of susceptibility. Where the horizon is smaller than the bed boundary resolution of this technique, the tool responds by displaying a double peak and thus the degree of change in susceptibility of the formation can be evaluated by the classification of its response i.e. formation changes associated with different formation susceptibilities and thin strata, less than 0.8 metre, exhibiting a double peak response.

4. The use of the spontaneous potential and point resistance log was linited with the screen and casing, as encountered in all EEC boreholes, reducing the effectiveness of this geophysical technique.

5. Inspection of the Hydrotechnica geophysical logging showed that this data was somewhat limited, with only a very minor suite of techniques being utilised. Where this logging was run the logs were on a point reading basis and hence the overall resolution of the logging to formation changes was reduced. Geophysical logging was only run in a very few boreholes and where logging was undertaken there were very few instances of a complete suite of logging techniques. No interpretation of the log profiles was undertaken and the data just appended to the

lithology. Calibration of the laterolog was suspect with values of resistance being measured that far exceeded the normal range of resistivities for these formations.