Downhole Logging in 3D Geology and Mineral Potential Modelling

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Abstract

Logging of drillholes using wireline tools is an emerging methodology in mineral exploration that adds valuable data to exploration drilling. RC drilling is relatively cheap and quick, but it comes with the price of lost sample integrity and structural coherence. Wireline logging can cover this loss, by facilitating structural interpretations based on borewall imagery. Rock property data can also be recovered below the sampling resolution, such as optical televiewer (OTV) imagery, density, magnetic properties, natural gamma radiation and acoustic properties on cm and even mm scale.

In the field, wireline logging will add just a few days to the drilling programme. A team of wireline technicians run their wireline down a recently completed drillhole using an assortment of tools depending on the requests of the client, at a cost amounting to only a few dollars per metre. The tools are oriented with magnetometers and accelerometers, enabling directional logging of geological features the drilling passed through. Combined with on-site logging of lithology and data from tools used in the field, wireline logging will enable exploration to take a significant step towards complete understanding of the prospect geology.

In this paper we show downhole logging results from Tampia Hill, Western Australia, and how this work has been used to establish a structural framework and guide the creation of 3D geological and mineral potential models.

Keywords: Optical Televiewer, borewall properties, structural logging, gold, Tampia Hill.

Introduction

Downhole logging, or wireline logging, has been used for hydrocarbon exploration for decades. Generally, downhole properties such as density, pressure, resistivity and natural gamma radiation are used to establish rock types, porosity and fluid content, as well as inform the establishment of velocity profiles for inverting seismic data. Structural orientations are gathered from televiewer logging where structural data are otherwise lost to drilling without coring.

In the mineral extraction industry, downhole logging is mostly used for geotechnical purposes for mine planning. Towards that purpose, sonic and density logs can be used to evaluate rock mechanical properties. Fractures, structures and lithological boundaries can be also be mapped from downhole optical (OTV) and acoustical (ATV) televiewer profiles, to guide interpretations of rock strength, lithology and structural trends. Other data types include
magnetic properties, which combines with density and gamma radiation data can be used to discern mineral composition and rock types.

Downhole logging in itself is not a cumbersome addition to a drilling programme. As the minimum, a ute with a winch and a small team of personnel can carry the equipment to site. Several hundred metres can be logged per day, at a rate of $2-4 per metre of hole. Diamond holes provide the best results, as the bore walls are generally smooth. The data returned are similar to what can be measured on core and samples, but can be recovered at cm and mm scale depending on need.

Where downhole OTV/ATV logging truly shines, however, is on RC holes. While the holes themselves are rougher, logging of the borewalls enables the user to recover oriented structural data, as well as to log lithology at a much finer scale than allowed by the sampling resolution. Since such data is normally lost to RC drilling, this vastly improves the variability and quality of data that can be recovered without adding much to the cost and time. It thereby allows for more sophisticated exploration tools to be added to a drilling programme without resorting to diamond drilling. It also greatly enhances what can be undertaken in areas with poor or limited access.

**Methods**

**Tools and Properties Measured**

Downhole logging involves inserting a selection of tools into a given borehole after drilling has finished and the rods have been pulled out (Figure 1). The tools are run from a winch on a cable and will scan either up or down the borehole. The data are either transmitted through the cable to the surface, or stored in the tool itself to be recovered upon tool retrieval.

![Figure 1. SURTECH downhole logging vehicle at Tamps Hill.](image-url)
**Formation Density**

This two-meter long tool estimates density using an active gamma-ray source, combined with a calliper tool to accurately measure borehole dimensions. Density is generally measured with two probes (dual probe system), with the final estimate calculated based on the difference between the short- and long-space density measurements.

**Natural Gamma Radiation**

This tool is generally < 1 m long. It uses a NaI detector and calculates gamma radiation from scintillation of the crystal.

**Magnetic Susceptibility**

This tool is ca. 1 m long and measures the degree of deformation of a projected magnetic field.

**Optical Televiewer**

This 1.5 m long tool measures 360° oriented borewall imagery, presented in oriented, unwrapped format. It can run in clear or fluid-filled holes and can be run at 2.5 m/minute at 1mm vertical resolution.

**Acoustic Televiewer**

This tool sonically images the borehole walls. It can be run in clear or turbid liquids. Similar to the OTV tool, it is up to 2 m long and uses a magnetometer subsystem to establish borehole deviation. The azimuth and inclination data can to some degree substitute for downhole surveying, although with uncertainties of +/- 2.5° on azimuth and +/- 0.4° on tilt and 1 mm resolution it will result in imprecise and complex drill traces.

**Magnetic Field Intensity**

This property is measured as part of the orienting of the OTV and ATV tools. Resolution is the same as the image resolution, up to 1 mm vertical resolution.
Other Tools

A wide array of tools can be used to characterise the borehole and the hosting formation. This includes resistivity, IP, temperature/conductivity, neutron probe, VSP probes, fluid samples and water quality probes.

Data Processing

Downhole logging can produce a vast amount of data, especially if OTV and/or ATV is involved. A workspace containing one or more downhole images can quickly grow to 0.5 – 1 or more Gb of digital storage. The data itself are delivered in industry standard formats such as LAS and bitmap files, which can be viewed and manipulated in software packages such as WellCAD (Figure 2).

While the actual logging of the holes is relatively fast and cheap, the added data will extend the post-processing time. How much depends on the amount of data logged and the detail needed. Interpreting 100 m of borewall for a medium level of lithological and structural detail will take an hour. For extensive drilling programmes, and where high level of detail is needed, this can greatly add to the time it takes to process and interpret the data.
The end result will be worth the added effort where structural trends are important for guiding exploration, and especially where these trends are not readily apparent from surface geological mapping.

**Tampia Hill**

Tampia Hill is located 12 km southwest of Narembeen, 300 km east of Perth, Western Australia. It is located with the Lake Grace section of the Western Gneiss Terrane. The belt comprises greenstone belt remnants metamorphosed to granulite facies. As described by BHP (1988) there are three main lithologies, all in the granulite facies: A felsic granulite gneiss, within which is contained bands of mafic granulite gneiss. These have been intruded by granite plutons. Mineralisation is mainly seen in the mafic gneiss, disseminated and in pods. It was noted that due to often very dark feldspars, the felsic and mafic gneisses could be very difficult to tell apart in hand specimen.

When the programme begun, the structural history was poorly understood, mainly due to lack of outcrop and only one producing mine in the area (Griffins Find). Four deformation phases have been indicated for the area, creating dome-and-basin type structures. BHPs (1988) interpreted Tampia as an almost vertical, possibly north-east plunging synform folding earlier layer-parallel foliation and recumbent folds (Figure 3). In this model, the structure is closed to the east and west by bounding felsic gneiss and granites.

![Figure 3](image-url). BHP (1988) structural interpretation of the Gault Prospect (Tampia Hill).
Auzex Exploration Ltd., now Explaurum Ltd., picked up the Tampie prospect in 2014, beginning their exploration with a series of diamond drill holes to confirm previous findings. 4 holes were drilled in 2014, followed by another 7 holes in 2015 (Figure 4). The results confirmed the previously observed mineralisation (Figure 5).

In 2015 and 2016, a series of RC holes were drilled over targets confirmed by the diamond drilling. New lithological codes were developed, reflecting the more detailed investigation of Tampie Hill: Besides defining felsic migmatite (leucosome) veining, a garnetiferous mafic gneiss code was added, as well as a leucocratic granite subtype.

Figure 4. Tampie Hill diamond holes drilled by Auzex (Kenex, 2016).
Five of the diamond holes drilled in 2015 was trialled for televiewer data acquisition. The holes were logged using OTV at 4 mm resolution for orientation and types of fractures, foliation, boundaries, and veins. Lithology was also logged. The trial was deemed successful in capturing details also seen on the drilled core, and the exercise extended to the 45 RC holes drilled in 2015.

The OTV interpretations enable the updating of the structural model for the Tampia prospect based on orientations of features observed in the OTV imagery (Figure 6). The programme expanded to over 300 RC holes in 2017, and it became apparent that parts of the prospect showed NE oriented dip directions in the southern portion (Figure 7). With more than 150 holes in the structural model, a picture is forming of a bowl-like structure plunging roughly towards the east, with dips towards the centre of the structure (Figure 8).
**Figure 7.** Orientation of banding features in the southern model region, mainly from mafic gneiss lithologies.

The updated structural data change the originally near upright syncline (Figure 3) to a SW-NE trending syncline with a much shallower dip of the fold hinge towards the west, which greatly opens up the potential for mineralisation in the easterb region of the study area.

**Figure 8.** Structural streamlines calculated for dip and plunge of foliation in Tampia mafic gneiss.

The geological model, based on borewall image interpretation from OTV, confirms this overall synclinal shape as a mafic gneiss body (high density) nested in a felsic gneiss (variable intermediate density, distinct foliation), and intersected by sheets of granite (high gamma radiation, low density) (Figure 9. The granite sheets can be thinner than the 1 m resolution of the RC sampling and can therefore be missed by chip tray logging. The downhole logging also shows the relatively undisturbed rock column, which has been homogenised in the 1 m intervals in the RC samples. Thus, the downhole logs can complement the chip tray logging with additional detailed information including structural data.
Detailed mineralogy may not be achievable from OTV imagery. But where good imagery is available, interpretations can be verified, and stratigraphic relations as well as spatial orientation can be added.

Figure 9. Block model, with lithology derived from OTV logging and guided by structural orientations observed in RC borehole walls.

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References

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