

# Techno-advantages of acoustic televiewer logging on shaft boreholes

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## ABSTRACT

Geophysical borehole logging of two shaft boreholes separated by 300m was used to complement geological logging of un-oriented borehole core in a geotechnical investigation aimed at mapping rock strengths and stability in advance of shaft-sinking operators. High-angle (>60°) dip magnitude fracture systems interpreted from acoustic televiewer imagery were ubiquitous throughout both holes and showed large variations around a mean strike orientation of NW-SE, in line with borehole “breakout” events also mapped from the televiewer. Fracture depths correlates well with those mapped from geological core logging. A unique, 150m wide zone of anomalously high fracture frequency density in borehole A has been confirmed from ongoing shaft-sinking as reflecting “disturbed” ground, and points to the presence of a sub-vertical structural feature intersecting the borehole. Fracture orientations over the “disturbed” ground differ considerably from those above and below this zone. Ancillary geophysical data (density) does not uniquely define the extent of the highly fractured zone. Elsewhere, shallow temperature anomalies in both boreholes possibly reflect intersections of the same aquifer

## 1. INTRODUCTION

This report addresses acoustic televiewer and ancillary borehole geophysical logging results from two 1000m to 2000m deep shaft boreholes separated by 300m at a location on the Western Limb of the Bushveld Complex. Project requirements were to map the depth distribution and true geometry of fracture-zone sets intersected by both boreholes. We have compared results over the top 1000m of each borehole.

The (acoustic) televiewer uses high resolution acoustic scanning of borehole wall-rocks to generate digital depth images mapping litho- structural features from which true dip and strike estimates are obtained for low to high angle fractures and faults. As such this tool has largely replaced the resistivity-pad based “dipmeter” tool with its limited ability to measure moderate to high dip angles. A rotating acoustic transponder measures two parameters:

- The ratio of incident to reflected acoustic energy at the wallrock. Smooth, unfractured rocks are good reflectors while rugose, fractured rocks are poor reflectors.
- The travel time for the reflected signal, which is a measure of borehole radius

Data is recorded at ~2mm intervals up the borehole Fluxgate and accelerometer navigation devices built into the televiewer tool generate information which allows for the orientation of the tool to be known at all times, and allow for the correct orientation of

televiewer digital data (e.g. with respect to magnetic north).

Primary interpretation phases involve identification of fracture location and orientation, fracture width, fracture filling and also borehole break-outs. Follow-up interpretation phases focus on the use of comprehensive digital database summarising fracture orientations and other classification parameters, and generating a variety of structural display products

- Rock Quality Designation (RQD) or Fracture Frequency: traditionally it is an estimate of rock mass quality from borehole core logs. Core broken due to drilling-induced fractures or natural failures (faults) are measured and used to estimate the RQD. Fracture frequency (per metre) estimates from the televiewer can be used to refine core-based RQD estimates and in zones of total core loss provide proxy values.
- Contoured polar plots: summary of the structural information obtained from televiewer data interpretation.
- Break-out analysis: yields a good indication of the orientation of major principal stress which is normally perpendicular to the break-out direction. The latter refers to the longest axis of the nominally circular borehole.

This paper focuses on the information content of televiewer products based on *a priori* acquisition of

orientated data and digital nature of this data obtained from two closely-spaced platinum boreholes.

## 2. BACKGROUND

The requirement for high quality geotechnical data in the planning of shaft-sinking operations has long focussed on core from vertical “shaft boreholes” collared over or around the proposed shaft position. High among priorities in geological logging of this core are fracture mapping and determination of fracture dip and strike directions. In the recent past, for reasons which relate both to technical virtuosity and cost-savings, core data has been complemented and sometimes superceded by data interpreted from geophysical borehole logging surveys using the high resolution, fracture-mapping capabilities of the acoustic televiewer. (Prensky S.E., 1999).

This has come about because of the over-arching requirements for measurement of *true* dip and strike for fracture systems which are met by a cost-effective televiewer product. Consider the numbers. This paper looks at moderately deep Bushveld boreholes whose drilling costs must be greater than R500.00 per metre. Such operations generate core which is not oriented and thus apart from some local knowledge, can only be mapped to provide fracture depths and *relative* fracture geometry. An oriented-core operation can be run at an acquisition premium of around R75.00 per metre, plus an additional R15.00 per metre in the core yard. Exploration anecdotes advise that core orientation integrity is overly reliant on driller input, and that strike estimates have large error variances. By way of contrast, the acoustic televiewer tool with its on-board accelerometer/fluxgate navigation system inputs allows for system georeferencing and ex-post interpretation of fracture geometry at a cost of around R100.00 per metre. While providing Excel spreadsheet results far away from core-yard confines.

At roughly equivalent costs levels, the digital imagery and digital data delivery products from the televiewer system outstrip those available from traditional core logging operations with respect to simple fracture geometry. And there is an additional rider. We are advised that oriented core cannot be acquired from vertical boreholes: in which case televiewer data is not a complement but a primary provider of information.

## 3. METHODS AND DATA PROCESSING

Two closely-spaced boreholes about 300m apart with depths of 1 750m and 1 350m were logged using televiewer, gamma-gamma density and borehole fluid temperature plus conductivity tools. The televiewer image of the borehole wall rocks is presented as a grey scale image in which smooth wall rocks appear as very light background and, fractured/faulted sections as dark grey to black features. Linear structural features

accordingly appear as black curvilinear traces. Other tool data is simply presented in profile format after “depth-levelling” corrections.

Upon importation of the raw televiewer data the images can be automatically orientated to magnetic north. The digital image is then “cut” along the northern meridian and “unrolled”. On this flattened image, any planar feature intersecting the borehole will appear as a sinusoidal wave (Figure 1). The amplitude of this sine wave is a function of dip magnitude and the respective maxima and minima indicate the dip direction. The interpreter traces out sine wave with a cursor across the screen image and fracture dip plus direction are directly computed by software. Several standard classification systems are in place (dip i.e. 0°-30°, 30°-60°, 60°-90°, expressions etc) and export classifications can be applied. Interpreted fracture geometry and depth data is output as an Excel spreadsheet and used for the generation of various depth profiles and statistical plots.

## 4. RESULTS AND ANALYSIS

Fracture information from the top 1000 m of both boreholes were used to generate Schmidt-LH Type polar plots (stereographic projection). A distinct population with a NE-SW strike which is inline with stress directions is observed within every 100m intervals throughout the boreholes (Figure 2). The population group is often over shadowed by more prominent populations in instances where large amounts of fractures are experienced. There is no obvious borehole-to-borehole correlation of fractures or fracture.

Fractures are ubiquitous down the length of each borehole but their frequencies (per metre) vary greatly between the two boreholes (Figure 5). BH1 and BH2 are characterized by low levels of background fracturing which have mean values of 1.4/m and 3.3/m respectively. BH2 shows anomalously high fracture frequency levels (3 to 5 times background) over an ~150m wide zone extending from 301m to 445m depth (Figure 4). There is no indication of such a prominent zone in BH1, and at first blush it appears that BH2 phenomena must reflect a steeply dipping structural feature close to or intersecting BH2, but distant from BH1. Ongoing shaft sinking at the sites of BH1 and BH2 supports this conclusion, in that progress is much slower at BH2.

Borehole breakouts are evidenced from televiewer data as ovoid deformation of the borehole plan outline, with the elongated axis being perpendicular to the major horizontal stress direction. Breakout events are sparsely distributed down the boreholes (@ intervals of ~1 per 100m) but much more numerous (~1 per 10m) in the 150m wide anomalous zone of BH2. Borehole

breakouts are small, with maximum eccentricity long-to-short-axis ratios of only 1.06. Azimuth directions average 67° for the anomalous zone and 65° for the remainder of this borehole, supporting a major horizontal stress direction of NW-SE for this locality.

The 150m zone showed a strong population group sub parallel to the borehole axis (striking E-W) which overshadowed the already identified minor population striking SE-NW. Fracture orientation within this highly fractured zone was found to be considerably different from zones above and below it.

Wide, open fractures observed on the televiewer were inline with kicks picked up on the caliper. An open fracture detected at 260m for BH2 looked similar to the one observed at 289m for BH1. Televiewer image complemented with calculated differential temperature log showed a corresponding inflection in both boreholes. For BH2, the inflection on the calculated differential temperature anomaly appears just above the fracture, and below the fracture in BH1, this demonstrates the intersection by the same aquifer and narrowing towards BH1. See both Figure 6 and Figure 7.

## **5. CONCLUSIONS**

While here and elsewhere there is up to a 98% correlation between fracture depths mapped from the core and those mapped from televiewer data, the outstanding advantage of the latter is the ready and reliable extraction of true dip and strike estimates.

Although no more correlations of fracture orientation and fracture frequency are apparent over the top 1000m of both boreholes between the two boreholes over the top 1000m, there is a minor population group found within each 100 m interval in both boreholes.

The televiewer provide a continuous log over badly-broken ground where core loss can and does occur.

Televiewer data illustrates the ubiquity of background jointing over competent ground, and fracture frequency

density levels of 3 to 5 times this figure over “disturbed ground”. Subsequently confirmed from shaft sinking.

## **6. ACKNOWLEDGMENTS**

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## **7. REFERENCE**

Prensky, SE, Advances in borehole imaging technology and applications, Geological Society, London, Special Publications; 1999; v. 159; p. 1-43

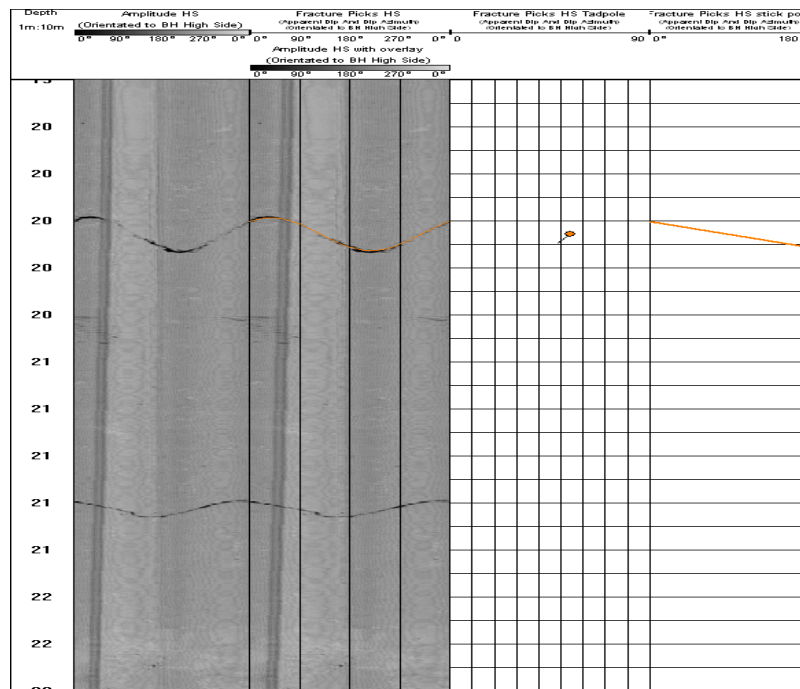


Figure 1. Televiwer image showing unwrapped borehole wall image with picked fracture in projection, tadpole and stick pole modes

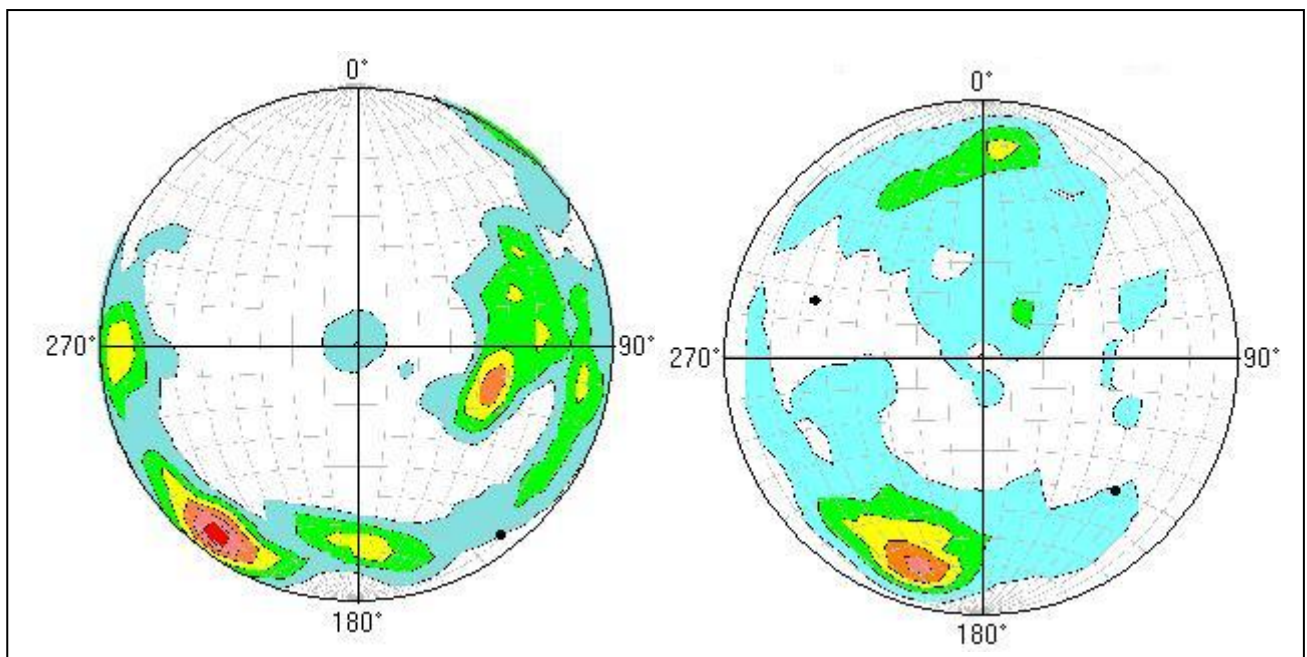
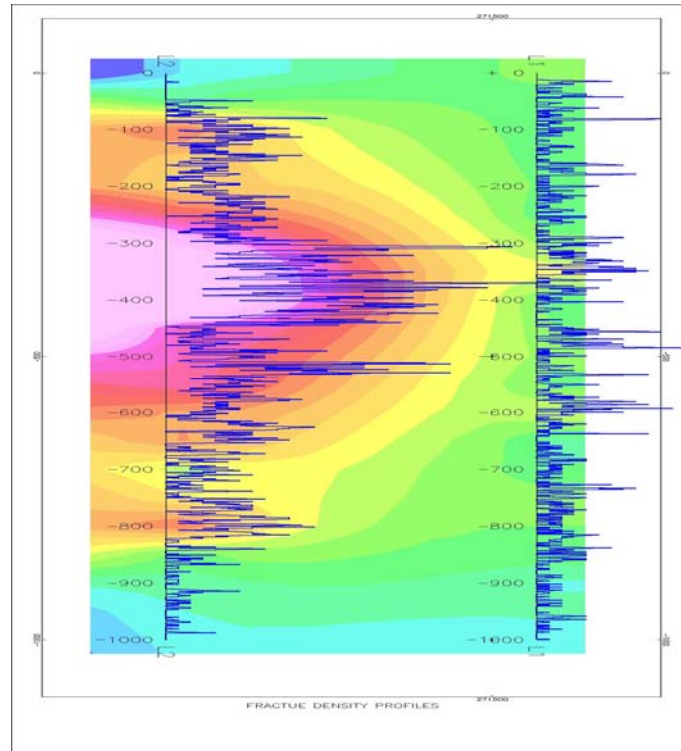


Figure 2. BH1 (left) and BH 2 (right) Schmidt LH-Type ( Area-equal) Contoured polar density plots for equal and more than 50% expressions fractures over 200 m- 300 m interval showing minor population group striking SE-NW



**Figure 4. Anomalously high fractured zone in BH2 (left) as compared to fracture frequency in BH1 (right).**

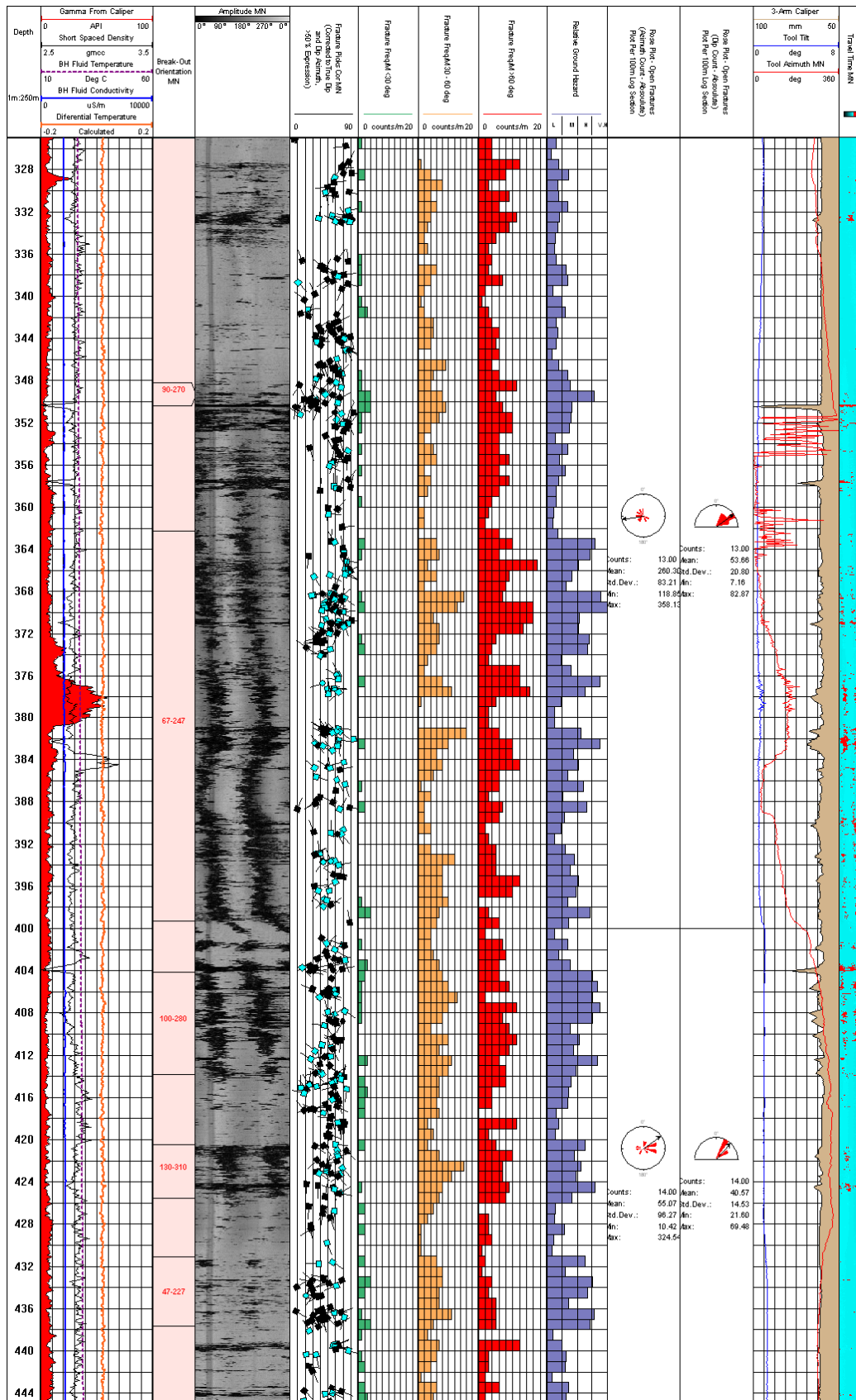
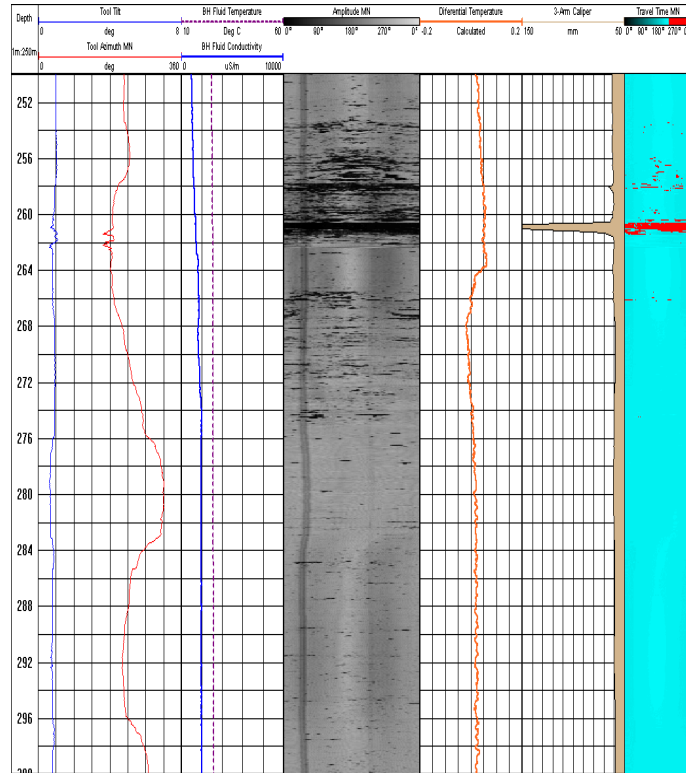
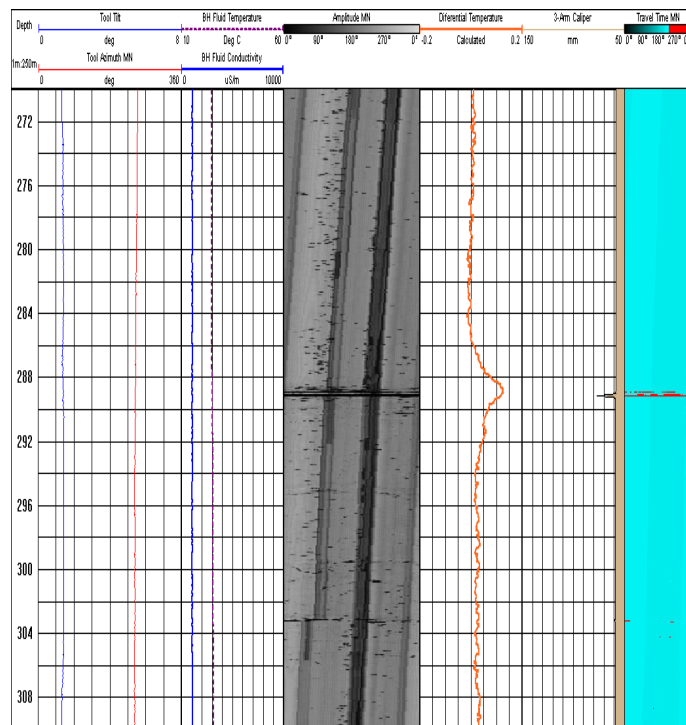


Figure 5. Televiwer image characterised by more intense open fractures and breakouts corresponds well with kicks picked on caliper log.



**Figure 6. BH2 image showing fracture (red in travel time) with corresponding inflection in differential temperature log just beneath the fracture.**



**Figure 7. BH1 image showing fracture (red in travel time) with corresponding inflection in differential temperature log just above the fracture.**