Case studies of high resolution acoustic televiewer for geotechnical exploration and core sample correction

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ABSTRACT: This paper presents a high resolution acoustic televiewer for borehole imaging, fracture investigation, and core sample correction from several case studies in central and south Taiwan. The acoustic televiewer uses a fixed transducer and rotating mirror system to acquire the reflected acoustic amplitude and travel-time. Based on the amplitude and travel-time, geologic features including fractures, gouges, and veins could be identified, and the strikes and dips of geologic features could also be obtained. Further fracture analysis aims to identify geometric sets of fractures, and then estimate variations in mean-dip and frequency within the sets and lines of intersection among the sets. One of the useful functions of the acoustic televiewer is the output of breakout log which predicts the possible deformation and collapse of borehole walls. In addition, imaging of the borehole wall provides useful information for the collection and interpretation of core samples, for example, corresponding position of core sample, drilling-induced weakness. Preliminary results obtained showed that abundant geologic information can be acquired from the borehole imaging using the high resolution acoustic televiewer.

1 INTRODUCTION

Taiwan is located at an active mountain belt created by the oblique collision between the northern Luzon arc and the Asian continental margin in which fissures, joints, beddings, and even faults prevail in most of mountainous areas. While existing joints and fractures provide ideal conduits for water to flow, large volumes of groundwater are stored in aquifers in which water inflows are often encountered during tunneling. Recently, several case studies of tunneling in Taiwan demonstrate that the water inflow is the major cause for the failure. As a consequence of groundwater loss, the problem of environmental arguments may also arise (Yang et al., 2007). Therefore, the early detection of environmental impacts on water resource is of great importance to the planning, design and construction of tunnel projects because it can be expected to minimize accidents and project delay during construction.

The use of geophysical prospecting methods in hydrogeology is increasing and is widely being applied to the evaluation of aquifer geometry and the determination of the subsurface hydraulic parameters (Singhal et al., 1999). For instance, borehole televiewers can be used to identify lithologic and fractures in open boreholes instead of visual logging of core samples. The image data not only indicate the exact depths of fractures, but also bring information to arrange test sections of hydraulic tests. The borehole televiewer results were used as valuable information during the design of the hydraulic tests by providing more accurate positions of geological structures and fractures compared to traditional rock core interpretations (Hsu et al., 2007).

This paper presents a high resolution acoustic televiewer for borehole imaging, fracture investigation, and core sample correction from several case studies in Kaohsiung, Taiwan.

2 GEOPHYSICAL PROSPECTING METHOD

A high resolution acoustic televiewer was used during the study. High resolution acoustic televiewers are the most commonly used tools for borehole imaging in geotechnical exploration. The borehole televiewer probe uses a fixed acoustic transducer and rotating acoustic mirror to scan the borehole walls with a focused ultrasound beam. Imaging with acoustic televiewer results in continuous and oriented 360° views of the borehole wall from which the character, relation, and orientation of lithologic and structural planar features can be defined (Fig. 1).

The amplitude and travel time of the reflected acoustic signal are recorded simultaneously as separate image logs. According to the results, geologic features such as fractures, voids, foliation, and layering can be identified. The type of prospecting method is competitive with traditional borehole exploration in interpretation of rock samples because these investigated data are not affected by the subjectivity and human errors. In order to gain accurate geological data of the borehole wall without human errors, the research group selected the tool in this case.

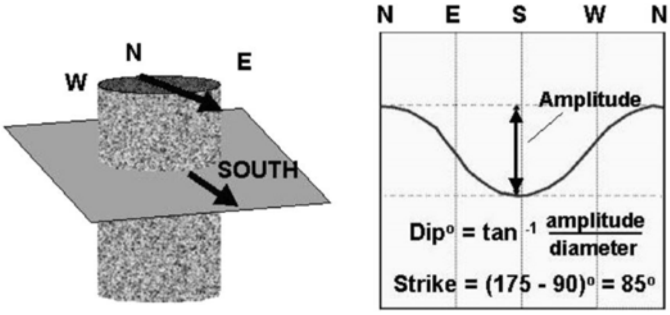


Figure 1. Oriented, 360° image of the borehole wall and calculation of strike and dip plane. (Williams & Johnson, 2004)

3 CASE STUDY

3.1 *Case background*

The study area is located at Shang-Ming, Kaohsiung County, south of Taiwan. According to the watershed division of the Water Resource Agency, Ministry of Economic Affairs, three watersheds of Lao-Nong Creek, Chi-Shan Creek and Tsao-Lan Creek watersheds were involved in study area. The water diversion tunnel is divided into the east and the west sections. The east section is 9.6 km long crossing Lao-Nong Creek and Chih-San Creek watersheds while the west section is 4.3 km long crossing Chi-Shan Creek and Tsao-Lan Creek watersheds. Both sections have 1/700 slope to divert the water by gravity flow (Sinotech Engineering Consultant, Ltd., 2006).

3.2 *Geological structure and borehole position*

The dominant rock strata that the tunnel passes through include the Miocene sedimentary rock with layers of sandstone or shale or their alternation. Among the many geological structures that the tunnel crosses, the major ones consist of a series of parallel easterly inclined thrust faults and folds; they often form local fractured zones including the geological structures such as Lao-Nong Fault, Gao-Jhong Fault, Lao-Ren Creek Anticline, Lao-Ren Creek Syncline, Chi-Shan Facult, Xiao-Lin Syncline, Ping-Xi Fault and Biao-Hu Fault. The cross-sectional diagram of geological structure along the axis of the tunnel is shown in Fig. 3.

Boreholes HB-95-01 and HB-95-02 were newly drilled boreholes in the west tunnel section. They superseded two previous groundwater monitoring wells that malfunctioned in September 2005. The lengths of boreholes HB-95-01 and HB-95-02 are 250m and 350m, respectively. The principle lithologic units for HB-95-01 borehole are comprised of sandstone, argillaceous sandstone, and sandy mudstone. The principle lithologic units for HB-95-02 borehole are comprised of sandstone, argillaceous sandstone, and sandstone mixed with some mudstone. Boreholes HB-95-01 and HB-95-02 are close to the Biauhu fault and Pingshi fault, respectively. Rock core data indicated soft and cohesive gouges are intensive for both boreholes. This is a good opportunity to study hydraulic property of fault-related rocks as well.

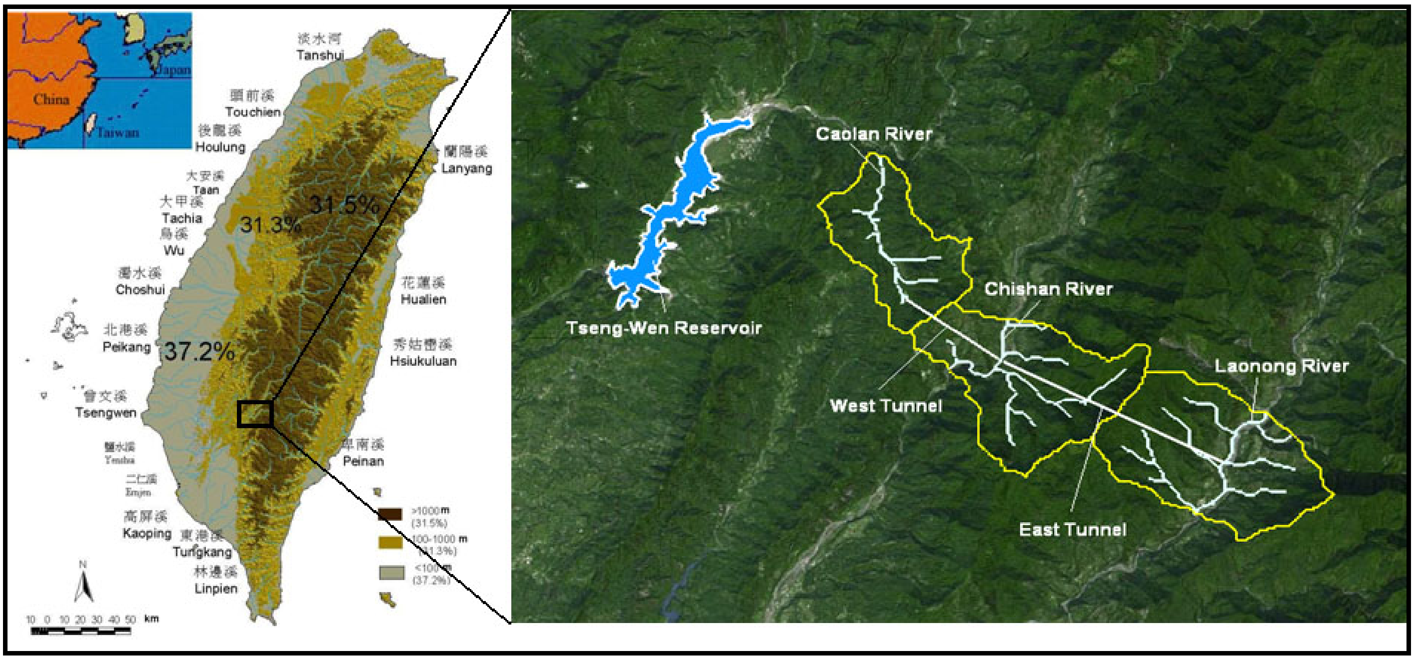


Figure 2. Locations of the study area and Tseng-Wen transbasin diversion tunnel.

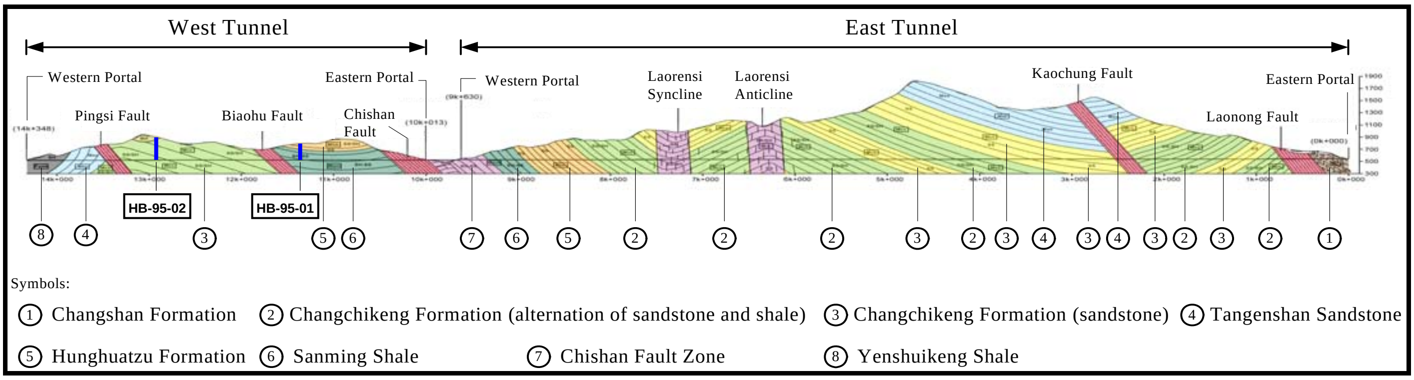


Figure 3. Cross-section diagram of the geology along the tunnel axis.

3.3 *Feature picking and core sample correction*

3.3.1 *Feature picking*

Planar geologic features intersecting a circular borehole obliquely leave fixed period, sinusoidal traces on the unrolled borehole wall image (Fig. 1). On the borehole wall image, a fracture trace satisfies an equation on the form

$$z = \rho \sin(x - \phi) + z_0 \tag{1}$$

where ρ is amplitude; ϕ is original phase and z_0 is depth of the fracture.

Based on above theory, we can do the next step: feature picking. We use RGLDIP to pick and analyze features in the study. The program provides three feature picking methods, included automatic, semi-automatic, and manual feature picking. User can set the type, form, state and remark attributes for each feature. Figure 4 is the typical interpreted BHTV log. It includes the core orientation, amplitude, arrow plot, and comments.

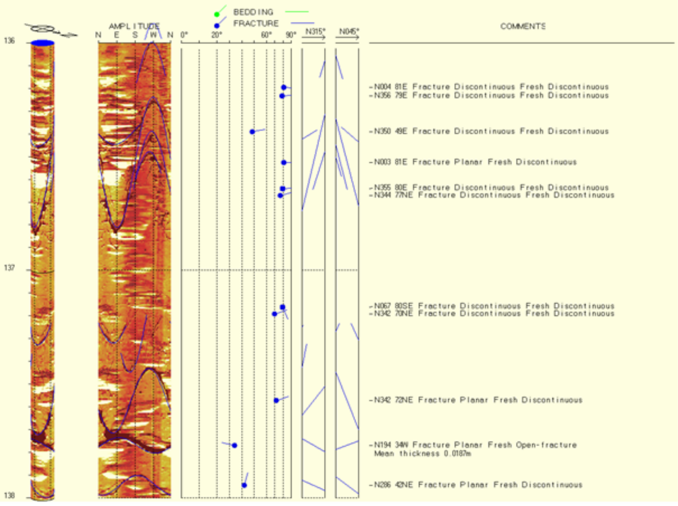


Figure 4. The results of feature picking in borehole HB-95-01 at the depth of 136-138m.

3.3.2 *Core sample correction*

Imaging of the borehole wall provides useful information for the collection and interpretation of core samples, for example, corresponding position of core sample, drilling-induced weakness.

Figure 5 and Figure 6 show that the position of rock core was misplaced by drillers from its original place. The difference between the original place and modified place are 0.85 m and 0.75 m, respectively. Figure 7 shows that the fractures of rock core were belong to drilling-induced weakness.

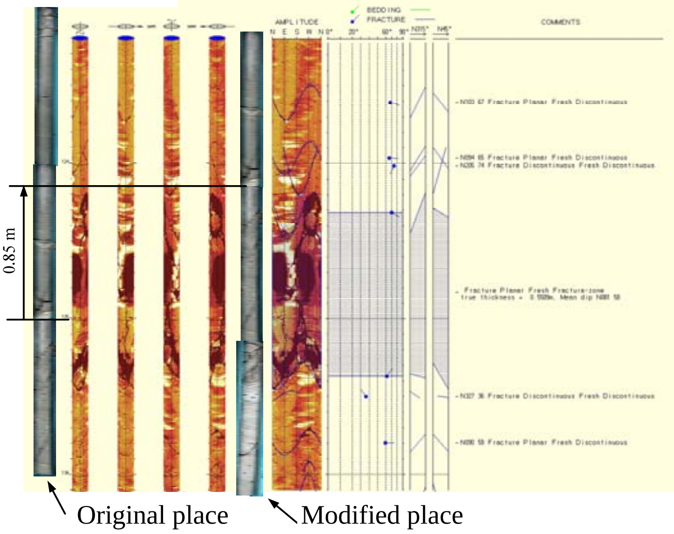


Figure 5. Comparison of acoustic image data and traditional rock core in borehole HB-95-01 at the depth of 133.2-136.1 m.

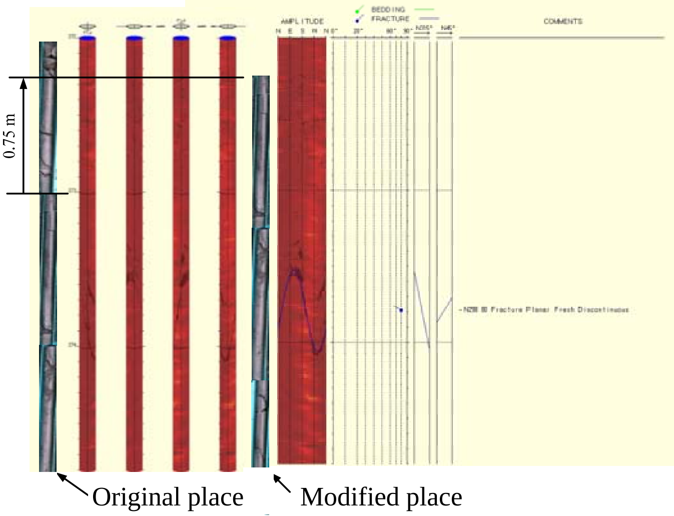


Figure 6. Comparison of acoustic image data and traditional rock core in borehole HB-95-02 at the depth of 272.0-274.8 m.

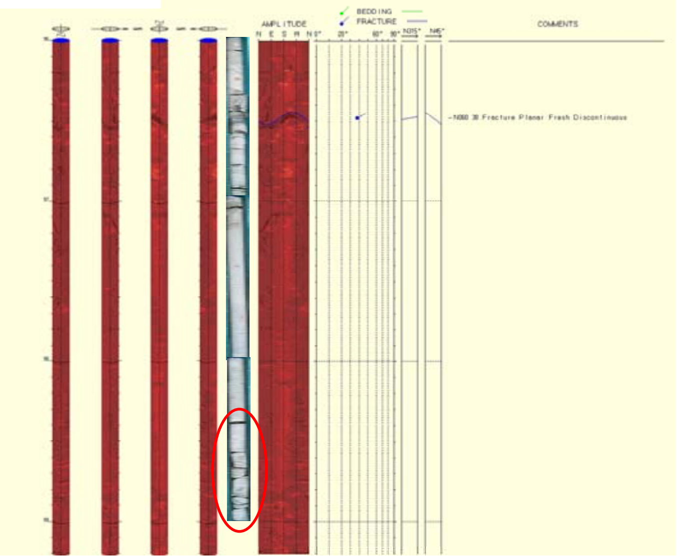


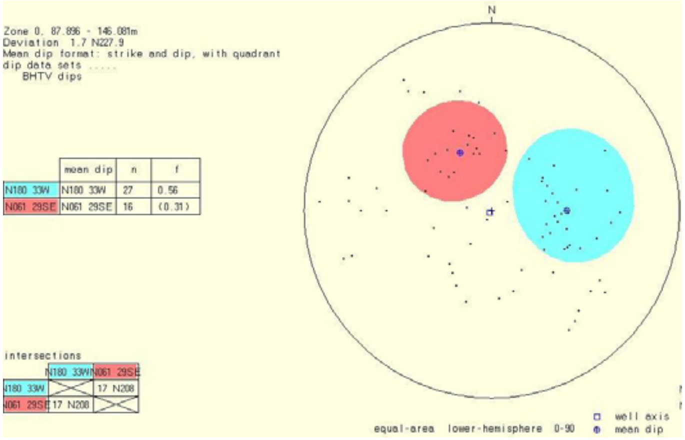
Figure 7. Comparison of acoustic image data and traditional rock core in borehole HB-95-02 at the depth of 96.0-99.2 m.

3.4 *Fracture analysis*

Fracture analysis of the dips resulting from processing aims to identify geometric sets of fractures, then estimate variations in mean dip and frequency within the sets and lines of intersection among the sets, with depth.

3.4.1 *Identification of geometric sets*

Poles to all features for the whole log are shown on an equal-area, lower-hemisphere stereogram and contoured according to pole density. Areas of high pole-density can be enclosed in up to 7 small-circles, drawn by trial and error on the stereogram. These are taken to define the natural geometric sets represented in the borehole. Mean dips and mean frequencies for the sets and lines of intersection among the sets are calculated and tabulated. Fig. 8 and Fig. 9 are the fracture analysis stereogram of HB-95-01 and HB-95-02, respectively. Mean dips, written as dip-azimuth and dip, for the fracture sets are used as labels, the small circles are colour coded. The labels and colour coding persist throughout the depth-zonation procedure.

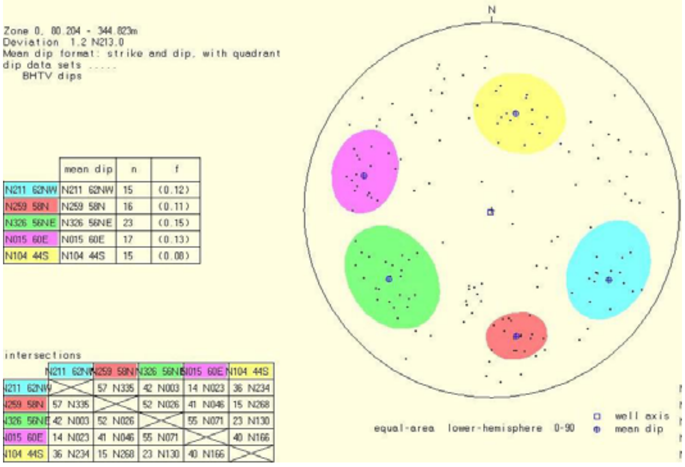

Zone 0, 87.896 - 146.081m
Deviation 1.7 N227.9
Mean dip format: strike and dip, with quadrant
dip data sets .....
BHTV dips

	mean dip	n	f
N180 33W	N180 33W	27	0.56
N061 29SE	N061 29SE	16	(0.31)

intersections

	N180 33W	N061 29SE
N180 33W		17 N208
N061 29SE	17 N208	

Figure 8. Fracture analysis stereogram for all dips in borehole HB-95-01.


Zone 0, 80.204 - 344.823m
Deviation 1.2 N213.0
Mean dip format: strike and dip, with quadrant
dip data sets .....
BHTV dips

	mean dip	n	f
N211 62NW	N211 62NW	15	(0.12)
N259 58N	N259 58N	16	(0.11)
N326 56NE	N326 56NE	23	(0.15)
N015 60E	N015 60E	17	(0.13)
N104 44S	N104 44S	15	(0.08)

intersections

	N211 62NW	N259 58N	N326 56NE	N015 60E	N104 44S
N211 62NW		57 N335	42 N003	14 N023	36 N234
N259 58N	57 N335		52 N026	41 N046	15 N268
N326 56NE	42 N003	52 N026		55 N071	23 N130
N015 60E	14 N023	41 N046	55 N071		40 N166
N104 44S	36 N234	15 N268	23 N130	40 N166	

Figure 9. Fracture analysis stereogram for all dips in borehole HB-95-02.

3.4.2 *Depth zonation procedure*

Dips are shown on an arrow plot, colour coded according to geometric set. Histograms of frequency with depth, for each of the sets, are shown alongside the arrow plot. Depth zones are defined downwards, by selecting a series of depth lines that separate different patterns of frequencies with depth. When a new depth line is selected, poles to features for the new depth zone are shown on a stereogram and mean dips and frequencies for the sets are calculated and displayed. Figure 10 is the fracture analysis log for all dips in borehole HB-95-01.

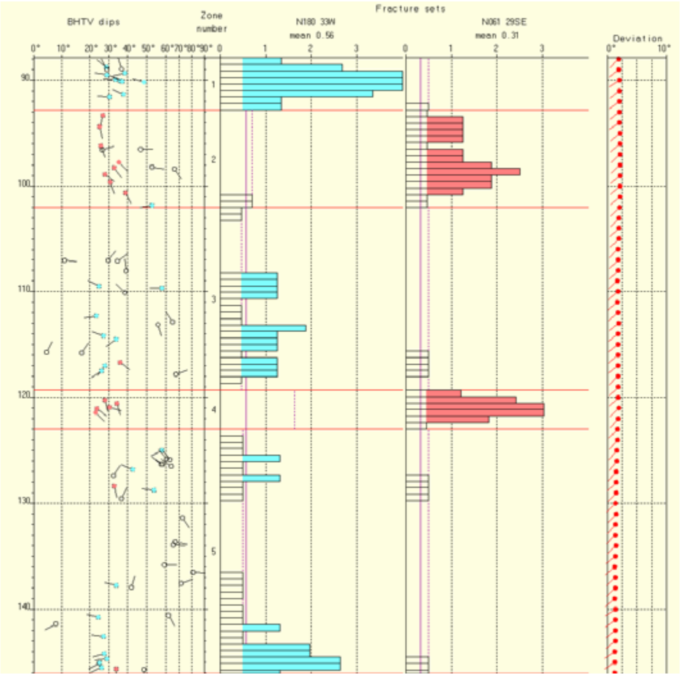
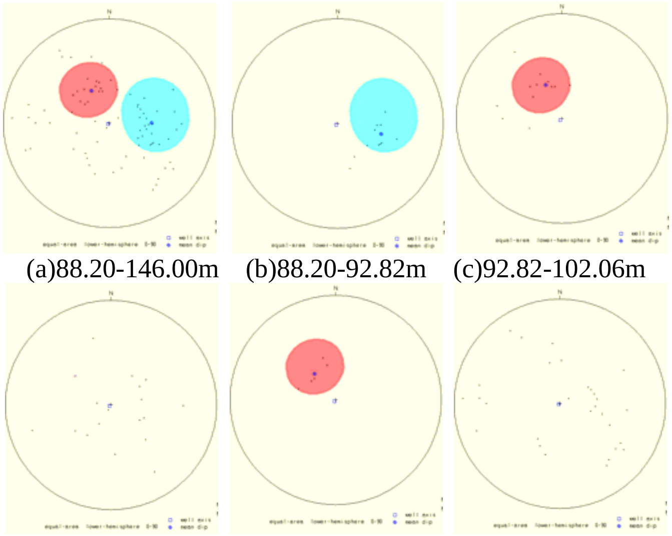


Figure 10. Fracture analysis log for all dips in borehole HB-95-01.

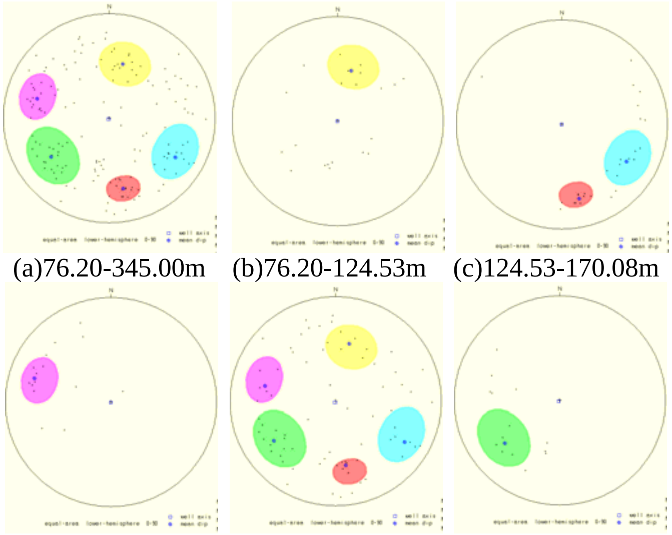
When we finished the depth zonation procedure, RGLDIP will output the fracture analysis of each fracture set. Fig. 8 and Fig. 9 are the fracture analysis stereogram of HB-95-01 and HB-95-02, respectively.



(a)88.20-146.00m (b)88.20-92.82m (c)92.82-102.06m

(d)102.06-119.29m (e)119.29-122.99m (f)122.99-146.00m

Figure 11. Fracture analysis of each fracture set in borehole HB-95-01.



(a)76.20-345.00m (b)76.20-124.53m (c)124.53-170.08m

(d)170.08-194.09m (e)194.09-330.14m (f)330.14-345.00m

Figure 12. Fracture analysis of each fracture set in borehole HB-95-02.

3.4.3 *Brief summary*

In the case of borehole HB-95-01 2 geometric sets of fractures have been defined on the whole-well stereogram showing all 150 dips (Fig. 8), then divided into 5 depth zones. The steeper N180° 33°W and N061° 29°SE sets are dominant, both in terms of numbers and frequencies. HB-95-02 5 geometric sets of fractures have been defined on the whole-well stereogram showing all 261 dips (Fig. 9), then divided into 5 depth zones. The steeper N211° 62°NW, N259° 58°N, N326° 56°NE, N015° 60°E, and N104° 44°S sets are dominant, both in terms of numbers and frequencies.

4 CONCLUSIONS

Rock cores from boreholes HB-95-01 and HB-95-02 can indicate the depth of fractures and distribution of lithology with depth. However, these data may be affected by the subjectivity and human errors. This paper introduces a high resolution acoustic televiewer for borehole exploration. This tool allows for quantitative and statistical measurements of the depth, thickness, and orientation of fractures. Since data from the equipment can quickly provide the exact depth of fractures without human errors, this can bring information to arrange test sections of hydraulic tests.

The borehole-geophysical logging from the borehole acoustic televiewer was proven to be a highly efficient way to obtain useful information for hydraulic testing, such as the location, strike, and dip of fractures, as well as the lithologic contacts. The image data not only indicate the exact depths of fractures, but also bring information to arrange test sections of hydraulic tests. BHTV logs in combination with a double packer system can be integrated as a prospecting method to determine hydraulic parameters. Thus, the BHTV preliminary information can assist in not only the proper design of the test but also the choice of a conceptual model for analyzing hydraulic test data.

In addition, from the application this study concludes fracture connectivity and infillings cannot be identified using the borehole acoustic televiewer technique. This problem can be solved from aids of rock core samples.

ACKNOWLEDGEMENTS

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