GEOPHYSICAL LOGGING IN TUNNEL PRE-DRILLINGS

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Introduction

A large-scale of complex geological research started in 1996 in Bátaapáti, Hungary, to locate the nuclear power plant's small- and medium activity nuclear waste deposit. During the 10 years period of surface research Geo-Log Ltd. carried out the well logging in 62 drillings, the sum total of which is more than 10.000 meters. Research has been succesfull. After that, during underground activities (heading the inclined shafts and connecting galleries, creating storage chambers) exploratory drillings and pre-borings of the galleries were carried out in a total length of approximately 10.000 m. The research has been succesful, handing over of the underground storage chambers was in September 2011.
This summerizing paper shows the Geo-Log Ltd.'s activity in supporting the researches, the tunnel driving and the development of the storage chambers.

1. The undertaken measurements

Conditions of underground measurements differ considerably from those of surface exploration. Therefore, the applied instruments were adjusted to the needs of the underground environment.

- Due to the unstable electric network of the mines, separator transformers and stable power supplies had to be used.
- The equipment had to be protected against the intensive precipitation of humidity.
- The placement of the carrier vehicle and the installment of the communication cables were successfully resolved in narrow places and under unfavorable conditions.
- Due to the small diameter of boreholes 36-40 mm diameter probes were utilized.
- In sub-horizontal boreholes centering of the probes is a serious challenge, especially for the acoustic televiewer measurements, because this method is extremely sensitive for eccentricity.
- Because the uncertain state of the boreholes and the limited time it was not possible to repeat the measurements.

Figure 1: underground logging at Bátaapáti

2. Applied methods and information obtained from water-saturated core drillings

During our measurements numerous methods were applied in order to gain the necessary information. These are summerized in the following list.

- Resistivity (10 and 40 cm potentials) prediction of the physical properties of rocks (RMR = Rock Mass Rating = classification of rock body, Q = Quality).
- Gamma ray - petrology.
- Caliper (i.e., caverns).
- Temperature, differential temperature places of water influx.
- Full acoustic waveform: longitudinal (Vp) and transversal (Vs) velocity, Poisson coefficient, Young-modulus, shear modulus, Strength-index, uniaxial compressional strength.
- Acoustic televiewer:
    - caliper log (in 72 or 144 directions), ovality.
    - dip of the drilling and its direction.
    - frequency of fractures (pcs/fm).
    - average of reflecting amplitude.
    - orientation of fractures (dip, line of dip).
    - classification of fractures (open, closed, semi-open etc.)
    - statistical processing of the above mentioned data (rose-diagram, histogram, pole-density plots).
- Optical televiewer:
    - frequency of fractures (pcs/fm).
    - identification of fractures (original, drifting).
    - quality of material (cement-boundary etc.).

3. Bp-4B complex logging interpretation

The entire series of measurements are presented in potential borehole Bp-4B [8]. The petrological, hydrogeological and geotechnical evaluation were done based on the measurements.
The petrological interpretation was done using the results of the gamma ray analysis considering the geological column provided by the Geological Institute of Hungary.
The low- and high value parts of the gamma ray section could be correlated well with the alteration zones identified in the cores.
The caliper log section from BHTV image indicates the individual open fractures and the strongly fractured zones, where materials falling-out from the fractures..
The temperature varies in a narrow range between 20-22 °C, each and every temperature anomaly, which is indicated spectacularly by the differential temperature curves, is associated with a particular water inflow.
The fracture zones (T1, T2 etc.) were marked based on the resistivity and full acoustic waveform sections and acoustic televiewer images.

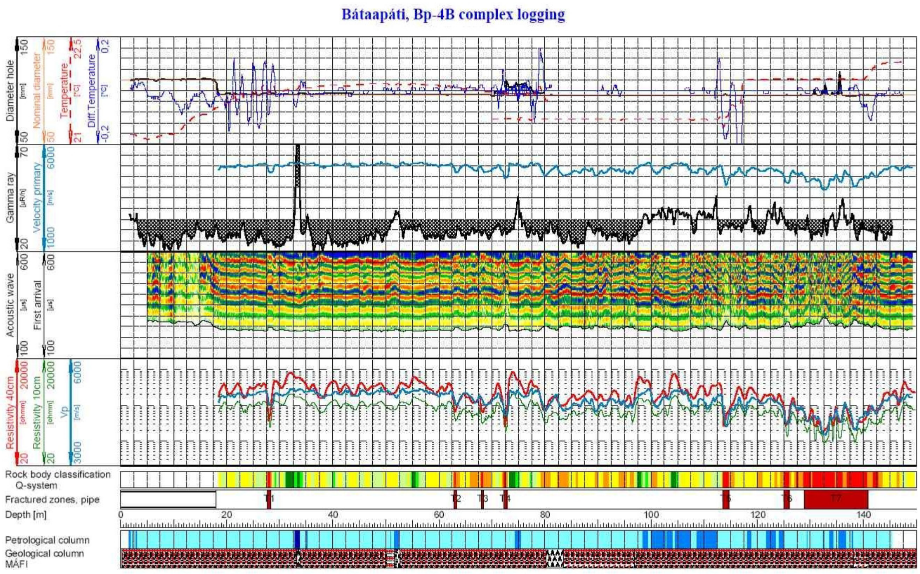

Figure 2: complex logging in Bp-4B drilling

4. Bátaapáti, Bp-4B rock mechanical parameters determination

The arrival times were determined based on the full acoustic waveform logs and then longitudinal (Vp) and transversal (Vs) velocities were calculated. We have not carried out density measurement in the underground drills, due to safety reasons. Density was determined on the basis of the relationship between resistivity and density in the surface drilling. From the two kinds of velocity logs and the density log, we determined the mechanical parameters of the rock (Young-modulus, shear modulus, strength index, Bulk modulus, Poisson coefficient).

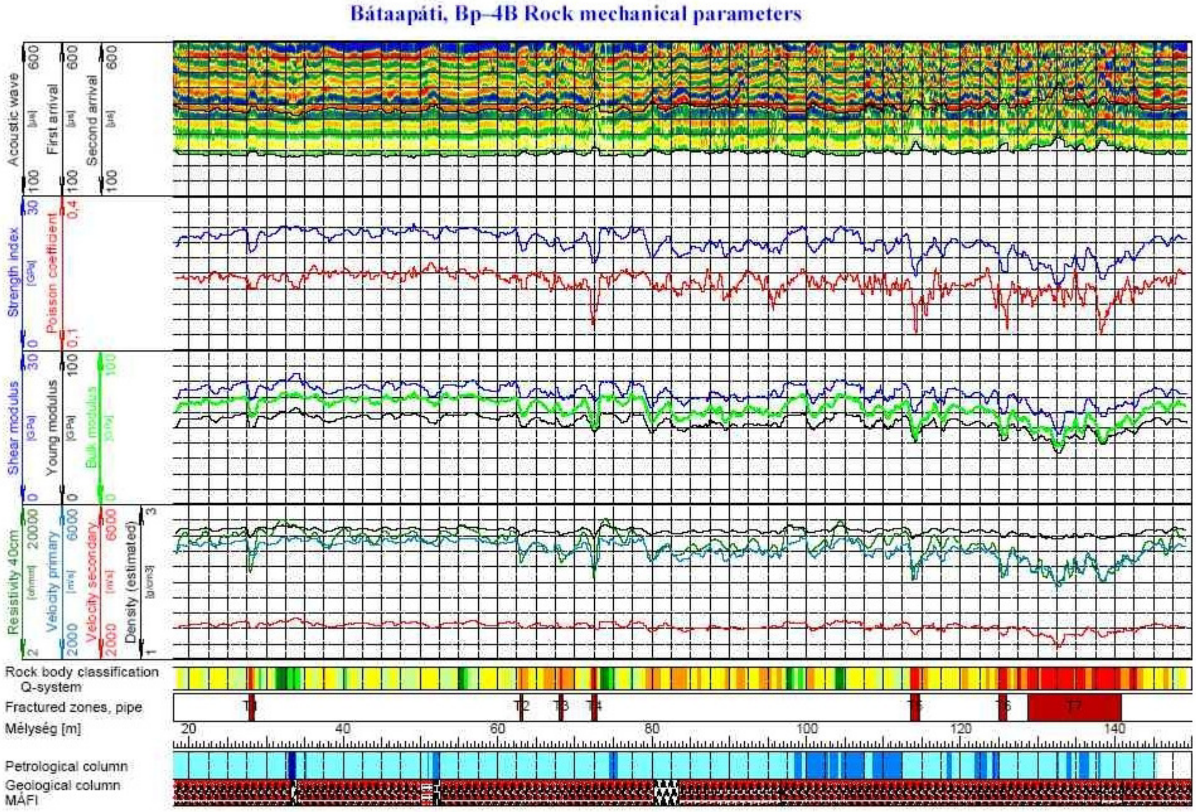

Figure 3: rock mechanical properties in Bp-4B drilling

5. Rock body classification

During the analysis and interpretation of the more than 10000 m surface drillings, within the granitoid rocks (most probably even every stiff, fractured rock) the resistivity and full acoustic waveform measurements represent extremely well the geotechnical state of the rock. After the realization of this relationship, we determined the regressive connection between some electric and acoustic methods and the state of the rock [3,6] by the comparison of geophysical well-logging and rock body classification of RMR-method in 8 different surface drillings [3,6]. Initially only with experimental intention, but later, at request we started doing the prediction of rock class in subsurface drillings based on geophysical well-logging [9].
When the number of underground measurements reached 10, we created the regression of the boreholes against the geotechnical RMR-values. Character of the curves obtained from the surface and underground measurements agree considerably well.
The slight difference between the curve's character and relationships can originate from several factors which include: the underground geophysical well-loggings are implemented under conditions differing from the surface's conditions (i.e., diameter of the borehole, cavernity, resistivity of the drilling mud, effects of sub-horizontal drillings); the descriptions of the cores were done by different firms and different experts; the conditions of drilling were changed (percentage of the core recovery, slip of the core, asymmetrical cavernity).
For the farther analysis the regressional relationship determined from underground measurements were utilized.
In the end we used the relationship between the resistvity and RMR for the evaluations, because here was the best connection, and so the rock body classification can be calculated directly from the measured resistivity log.
We show an example to the RMR and Q determination in the right figure.

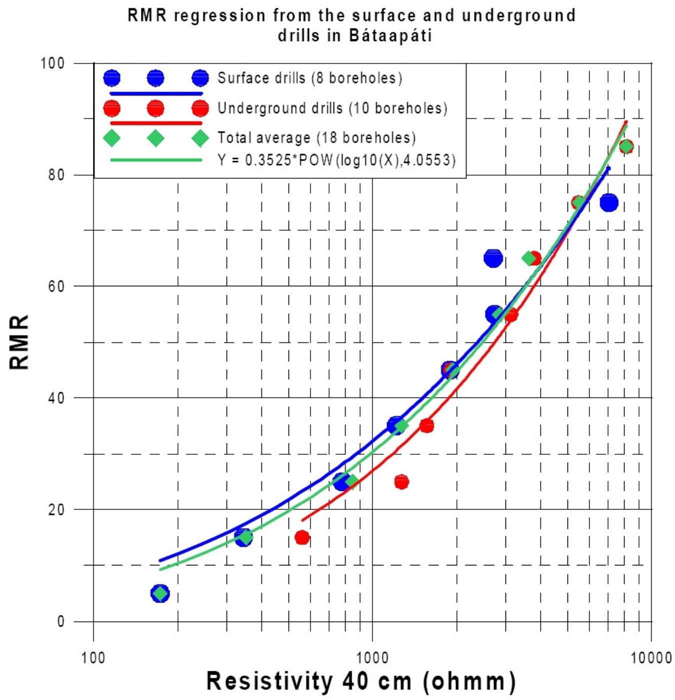

Figure 4: RMR regression from the surface and underground drills

6. Bátaapáti, Bp-4B rock body classification

In the lower track the resistivity log and the Vp rock velocity log were plot on such a scale, that the two curves would best fit each other. The reliability of the fit would also serve to check the measurements. If the level and character of the two curves, which are based on different physical methods, are close to each other then the measurements are suitable for quantitative calculations. In the middle and upper tracks Q- and RMR-type rock body classifications are plot respectively. In both of these tracks rock body classifications calculated based on core geotechnical descriptions (Kőmérő Ltd.) and resistivity logs are displayed.

Benefits of well logging-based rock body classification:

-does not require core drilling

-does not require laboratory tests

-objective

-can be prepared in situ

-cheap

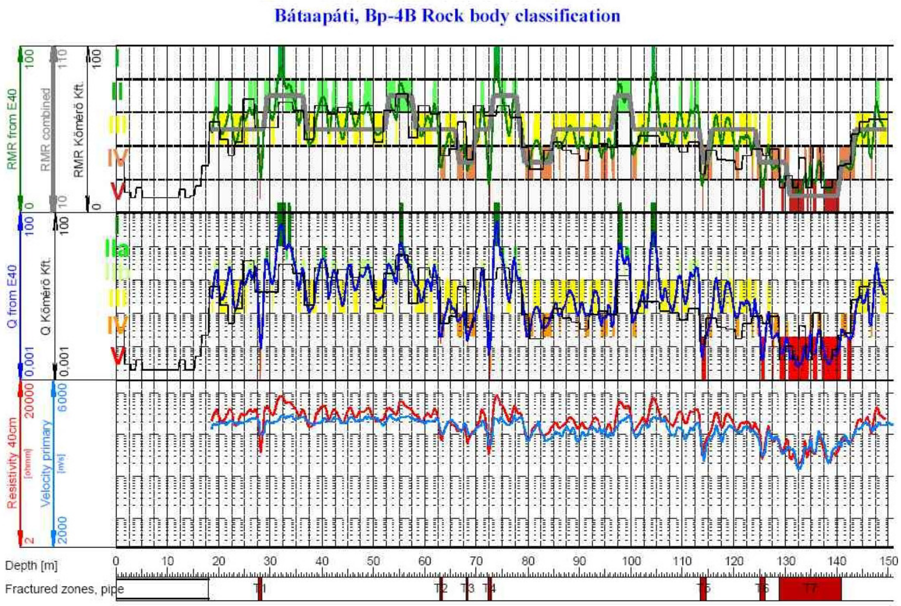

Figure 5: rock body classification in Bp-4B drilling

7. The acoustic and optical televiewers data interpretation

Acoustic and optical televiewer images were processed according to the protocol developed during the surface explorations [2,7]. The line and angle of the dip were constrained with 10 cm resolution and then we marked the position and quality of fractures. The fractures classification was very useful for hydrogeological interpretation, the effective water inflows are usually relate to open fractures.

We compiled the fracture-frequency and amplitude-average log and calculated fracture statistics [7]. The prepared fracture statistics from different aspects were used to the tectonic interpretation, which provided very important information on the fractured zones positions and help to mark out the storage rooms' exact location.

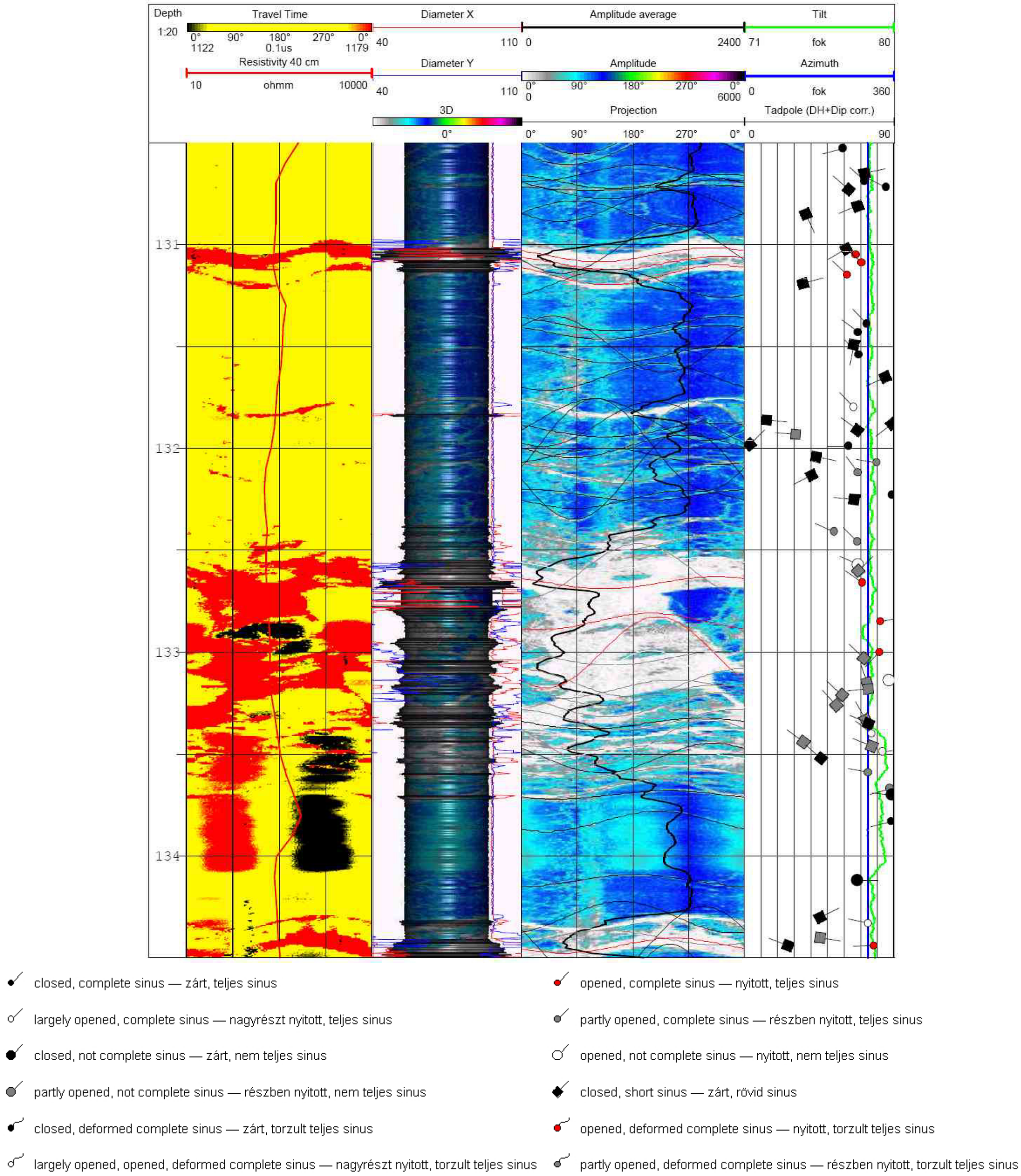

Figure 6: interpretation of acustic borehole televiewe image

8. Bp-4B deviation plots

Real direction and dip of the borehole as well as the spatial position (X,Y,Z) of individual points were constrained by the acoustic televiewer record. The variation of the X,Y, Z coordinates are plot as a function of borehole-length as well as the deviation from the measured and set direction. In this 150 m deep borehole the deviation was especially significant (4.4 m) because the drilling differs increasingly from the depth of 40 m from the original direction. The planned and the actual direction of the drillings were usually matched well, the presented example had a big difference because during the drilling the drilling machine shift slightly from its position because of the wrong supporting.

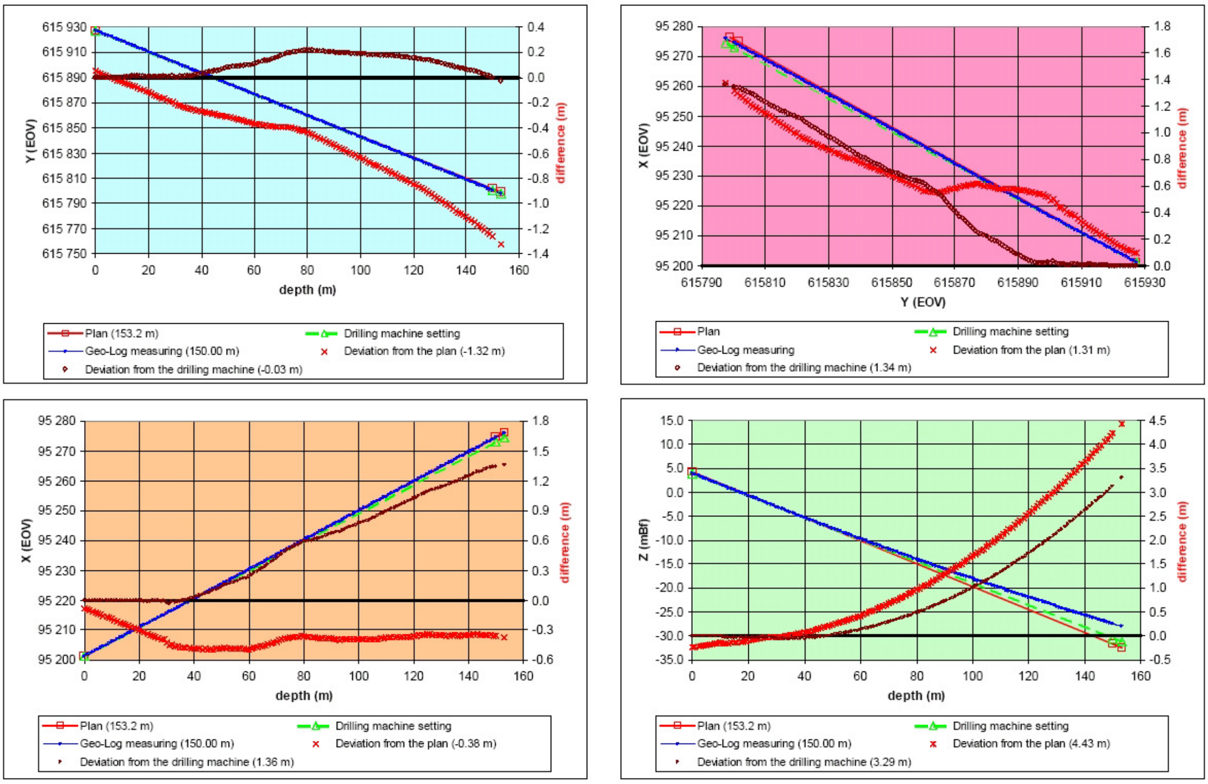

Figure 7: results of deviation surveys

Summary

The geophysical well-logging provides substantial information for surface geophysics, geology, tectonics and hydrogeology during surface geophysical exploration [1,2,4,6]. Some of the geophysical measurements (e.g. gamma ray) reveal petrological properties of the rocks, while resistivity and full acoustic waveform reflect the geotechnical conditions. In the case of a few drillings which had rock body classicfication both from the core material and geophysical measurements, a regressive correlation can be determined. Consequently a very effective and quick rock body classification can be provided for further drillings.

A very effective and prompt rock body classification can be done based on the resistivity and acoustic measurements, which complement and considerably help to evaluate the information from the core investigation and pressure tests. These methods were made suitable for the considerably changed conditions of underground measurements.

Furthermore, we developed a method of predicting the physical properties of rocks based on geophysical well-logging.

In this paper some practical examples are demonstrated, which show that resistivity and acoustic methods are suitable in hard rocks (e.g., granite) to the drilled cross regions for preliminary geotechnical layout quantitative characterization.

Rock body classification based on mainly resistivity measurements is very effective, quick, objective, and describes well the real petrophysical state of the rock in the overwhelming majority of cases.

Of course one single method cannot describe automatcally all the lithological and tectonic features, therefore we are improving our method, we are trying to integrate other methods. Exact locations of water inflows can be determined from the results of high-sensitivity flowmeters or from the sudden changes of temperature

measurements. Classification of fractures (complete sinus, open, closed, etc.) can be determined from the measerements of acoustic borehole televiewer. Moreover the width of cracks can be taken under consideration by comparing the acoustic velocity and resistivity logs.
By considering all these possibilities results of automatic rock body classification is implied to change only at few places and this change is not more than one class.

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