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The effect of fracturing on electrical resistivity and sonic wave propagation

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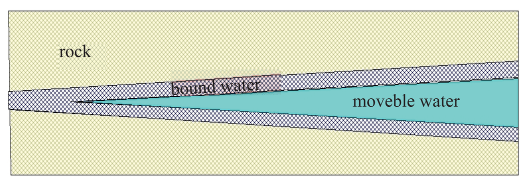
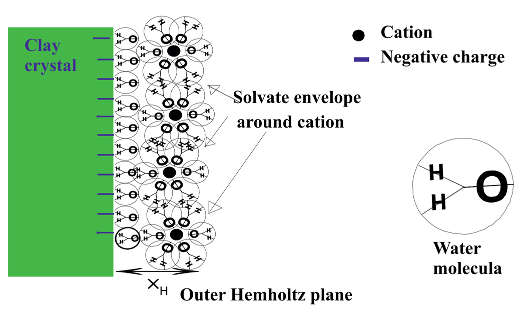
Coupled phenomenon to the presence of adsorption double layer:

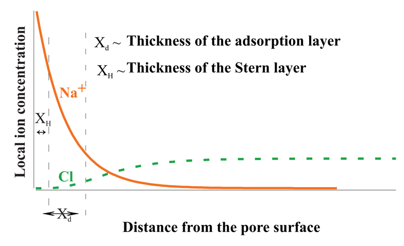
Counter ions are dissolved in adsorption water lead to the **excess surface conductivity.** It is important to mention the increment of conductivity much lower than it would be expected from the cation concentration in the adsorption double layer. This phenomenon resulted by the relative low mobiliy of ions within the adsorption bound layer (Gouy-Chapmann layer).

Induced polarisation

consequence on hydraulic properties: depending on the temperature stop permeability under a certain fissure aperture Influence on the mechanical properties: Without presence of the movable water (including subcapillary water there is a relatively small effect on the sonic wave propagation.







Surface phenomenon

Helmholtz double layer

adsorption double layer

Nernst and Gouy Chapman layer

excess cation versus distance

Coupled phenomenon

excess conductivity

Induced polarisation

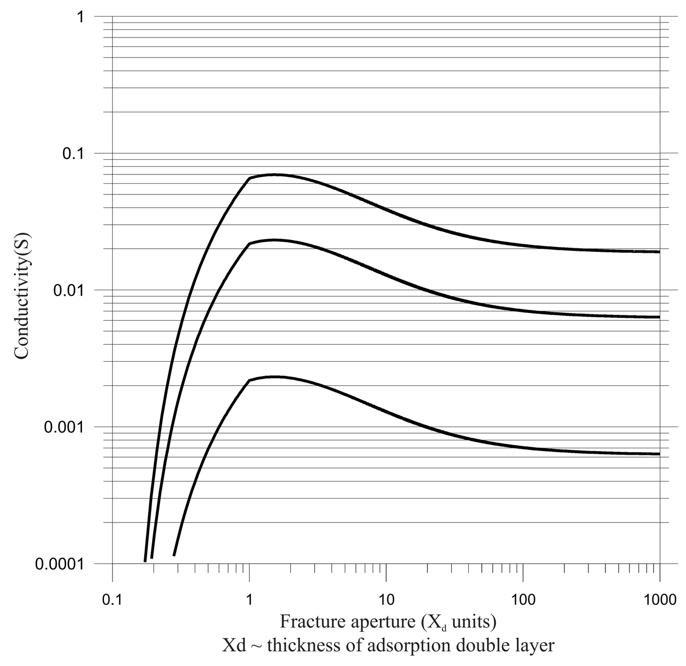
Consequence on hydraulic properties

Introduction

During the geological research for low and medium-level radioactive waste disposal, carried out in Bátaapáti area within the framework of the National Project, launched in 1992, large number of well loggings, geophysical measurements and rock sample studies provided a unique oppotunity to develop a methodology for the interpretation of crystalline basement rocks. The poster shows a part of the methodological background of he fractured rock evaluation based on well logs.

Abstract

The most important feature of the chrystalline seismically hard rocks is fracturedness which directly affects both the hydrogeological and geomechanical properties of the rock. The accumulated knowledge on the fractured rock with secondary porosity is less than that of the porosity and permeability of sedimentary rocks with primary porosity.
Because of the geological investigation on Disposing of Low-and intermediate level of radioactive waste, a better understanding of the fracture system and more effective characterisation of the rock, has significant importance in environmental protection.
The influence of properties of fractured rock on the physical parameters –mainly specific electrical resistivity and sonic wave propagation- and the connection between the two modells, are discussed. The main features of the fracture system and geomechanical properties were obtained from BHTV measurements, full acoustic waveform and coresample.
In this study, unlike the general practice, the importance of the relationship between the methods and the conclusions drawn by these methods on the fracture system are in focus. In other words, it means investigation of the impact of the fracturing itself on certain physical parameters. This study is mainly empirical, as it is based on well logging and rocksample data, but does not lack theoretical considerations.



Conductivity vs. Fracture aperture with constant porosity and effect of tortuosity
The parameter of curves is the porosity (V/V)

The conductivity under constant porosity:

$$\sigma = \Phi\left[\left(\frac{f_a - 2d_a}{f_a}\right)\sigma_1 + \left(1 - \left(\frac{f_a - 2d_a}{f_a}\right)\right)\sigma_2\right] / f(t)$$

where f_a~ thickness of the cracks

d_a~ the adsorption layer thickness,

σ_1~ free fluid conductivity,

σ_2~ bound fluid conductivity,

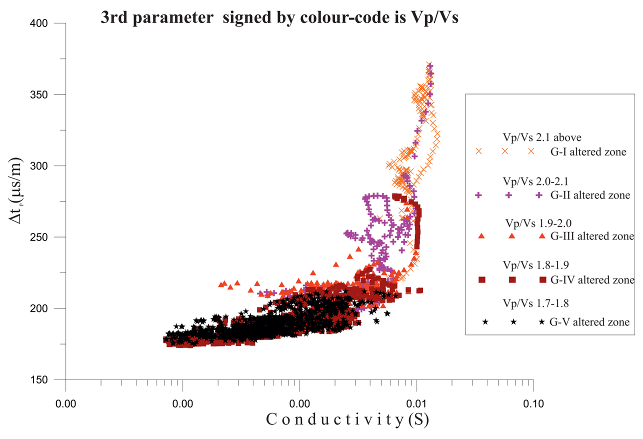
f (t) ~ quantity which is proportional to the tortuosity

$f(t) \sim (\,(f_a + 1)/f_a)^n \quad n=2$

As first approximation f (t) is consered to be proportial to the following term f(t) ~fa/(fa-2 da) i.e. the crack-opening angle increases with decreasing the tortuosity. In case of cracks smaller than the thickness of the adsorption layer, we can state that the smaller the crack-opening angle is the larger is the tortuosity, at the same time also higher electrical resistance can be expected.

Conductivity-Δt crossplot in granite

3rd parameter signed by colour-code is Vp/Vs



In the range of small Δt (high velocity) of the neutron-porosity-Δt crossplot, the straight line drawn at the lower limit of the range of cluster of points (boundary line) could be regarded as a kind of a matrix line which, in a definite case, is described by the following equation.
Δt (microseconds) = 172.5 (μs) +0.8 * Φ_N (%)
This boundary line contains the points, where acoustic Δt is minimal at a given neutron value . This physically means that, in the case of the points of boundary line, the increase in Δt is solely related the growth of neutron-porosity of the rock matrix, and in principle has nothing to do with the true porosity.
For a different type of crystalline rock, also with two-component matrix, the crossplot would be similar, but the equation would be different. The Δt of the"chlorite" component could be obtained by substituting the theoretical neutron porosity (47.5%) of the chlorite in to the equation of the boundary line. We can conclude that the presence of clay significantly affects the acoustic propagation velocity only if it contains subcapillary and capillary water, that can be removed by drying.. So far the conclusion is that, while the theoretical neutron porosity is a fixed value which is related to the stoichiometric formula, for Δt there is no such relation material quality only if the rock is free of cracking and the rock matrix effect is dominant on Δt. The general equation of evaluation curves, which is henceforward called the amended Raymer equation, is the following:

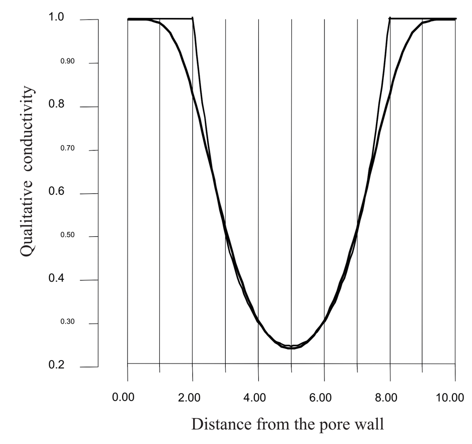
A) $\Delta t(\mu s/m) = 1/(V_m(100-(\Phi+\Phi_m)/(100-\Phi_m))^{2,75} + V_f((\Phi-\Phi_m)/(100-\Phi_m))^{2,75})$

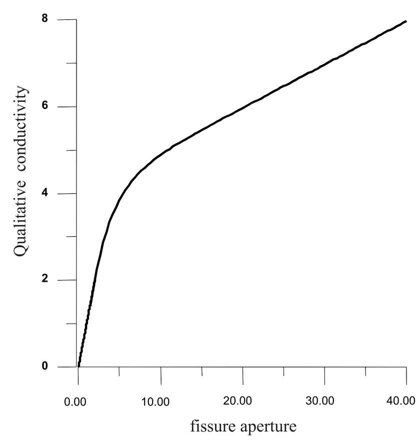
Where Fm ~ the matrix neutron porosity.

The "Φ_m = 0%" the equation expresses the relationship between total porosity (Φ_t) and Δt Because porosity expressed as a function of Δt is a bivalent function, instead of A) the exponential approximation of it should be used:

$\Delta t = 172(\mu s/m)e^{0,03378\Phi t}$ r^2 = 0,998 is the regression coefficient

Rearranged of it: $\Phi_t(\%) = 29{,}6\,(\mu s/m) \times \ln(\Delta t)(\mu s/m) - 152{,}35$

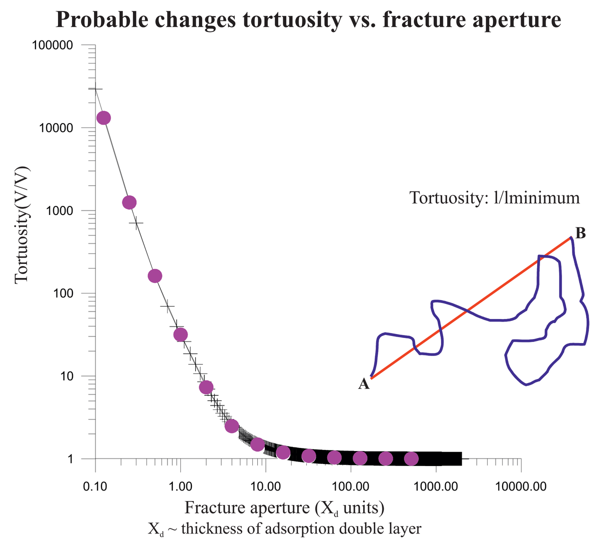




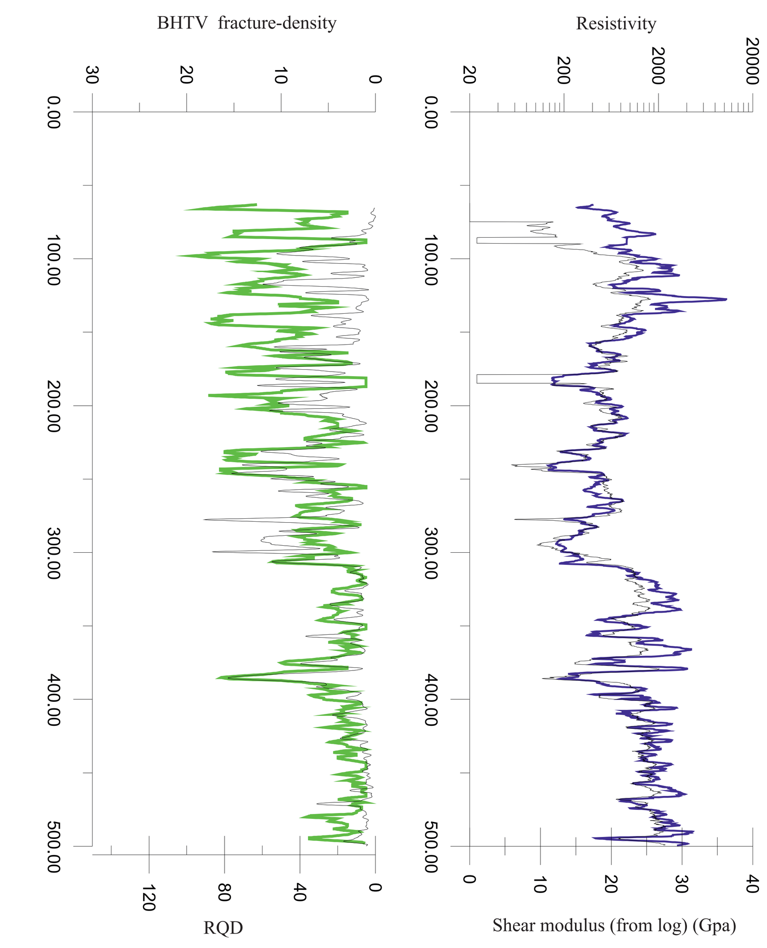
Conductivity vs porosity with constant fracture density is that the equivalent porosity proportional with fissure aperture.At thin fissures under 5 unit the fissure filled ion rich and highly conductive bound water only. Above fissure aperture 5 conductivity increase slower rate because of the effect of the less coductive free-water.

Legend: 1 relative unit on X-axis 0,005-0,1 μm (the thickness of the adsorption layer is under 0,01μm

Probable changes tortuosity vs. fracture aperture



Tortuosity assumed to be inversely proportional with fracture aperture. It follows from this, at the thin fissures the conductivity changes within wide range while the sonic wave propagation time (Δt) changes in relatively narrow interwall only. Otherwise at small Δt (thin fissures) the two parameter seems to be strictly proportional each other, what is the basis for the calculation of geomechanical parameters.

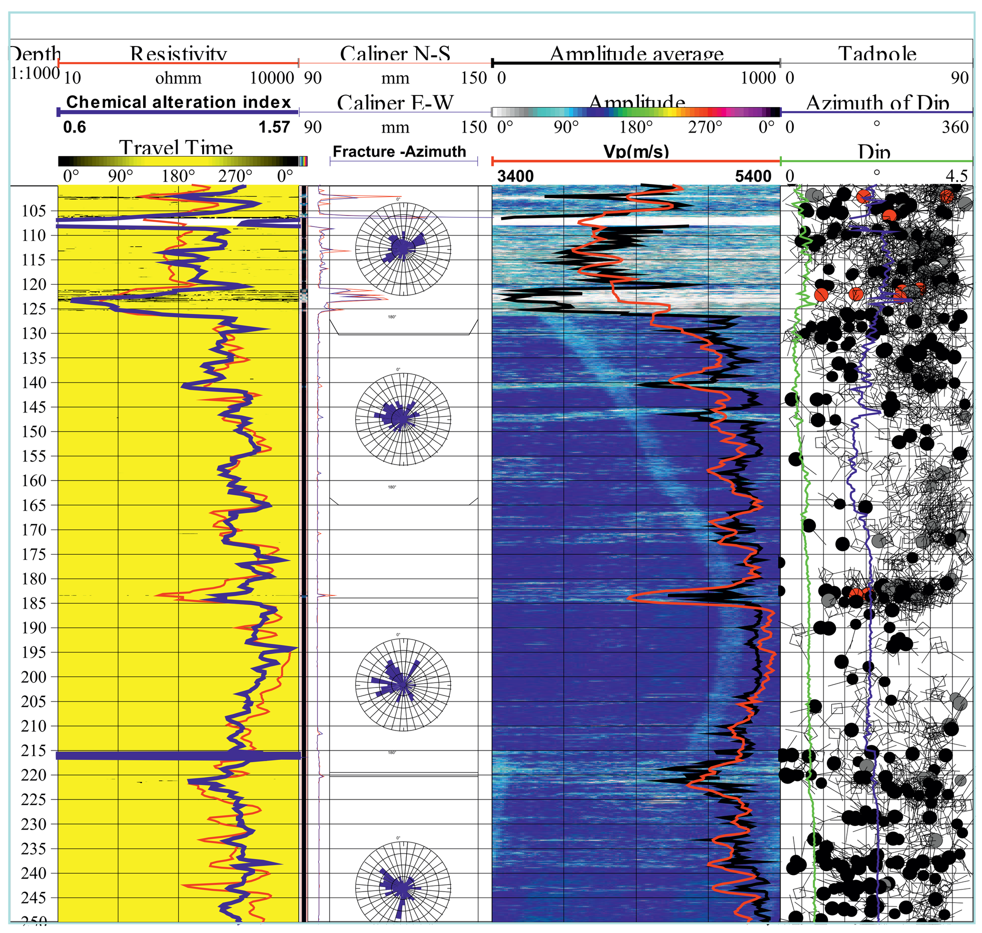


Electric resistivity and geomechanical parameters

The resistivity correlates well with shear modulus because the fracture aperture and tortuosity having influence on both parameters very similar way.. .

In the case of thin fissures, representing only a small overall porosity, fissure aperture assumed to be independent of the fissure density (geometrical parameters of the individual cracks are considered equivalent), which follows that the conductivity at fixed fissure aperture depends only linearly on fissure density.

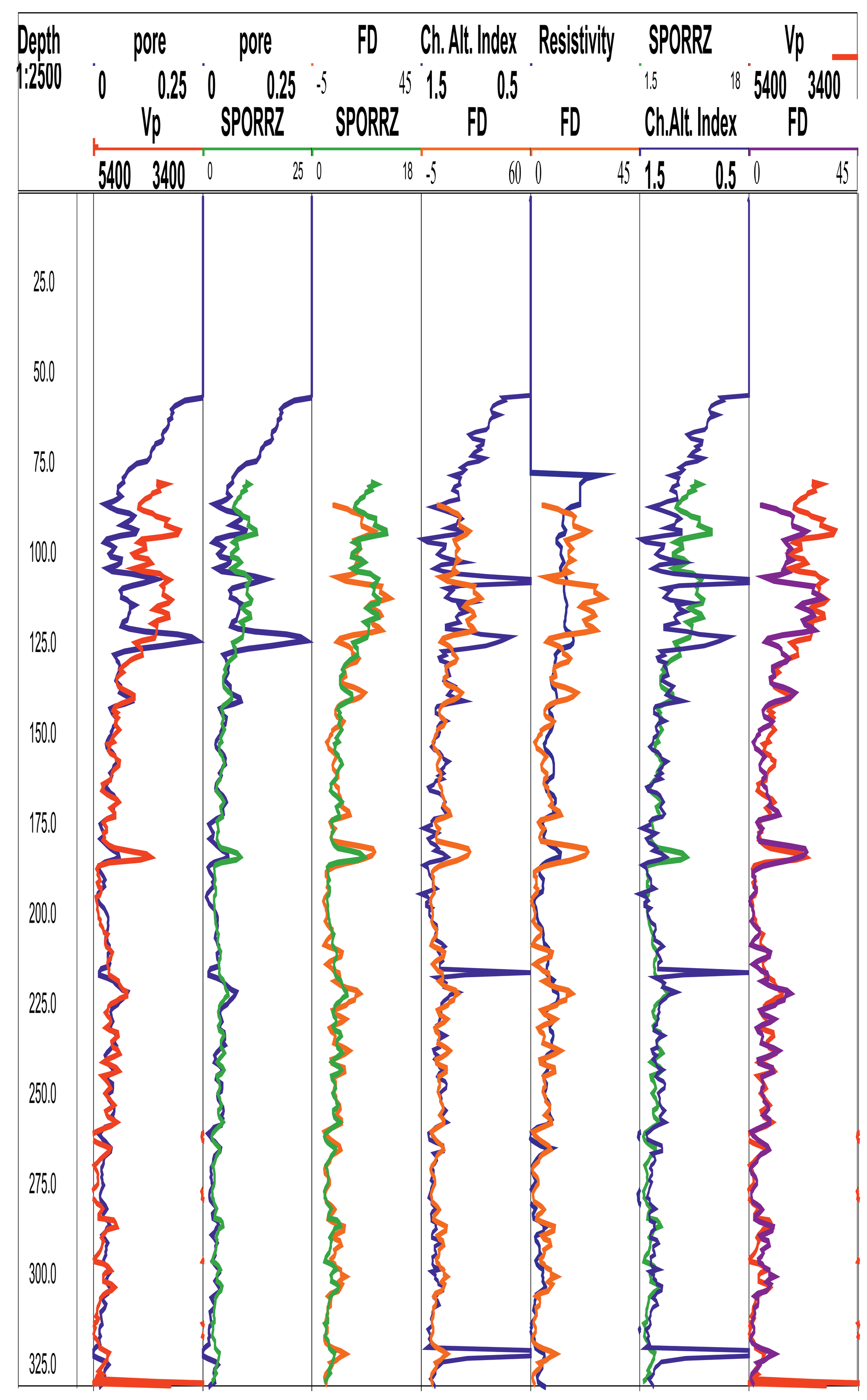
Linear dependence of the conductivity on the fissure density is consistent with the expected conductivity, both in case of the tube's bundle model of conductivity, and both the expected conductivity of cracks with similar thickness, electrically switched in parallel.



Comparison of BHTV image with other parameters in a fractured magmatic rock.

The scale of chemical alteration index is reverse.

There is good correlation between electrical resistivity acoustic compressional velocity, chemical alteration index and BHTV amplitude average. Around 123m Vp relatively high in comparison to the expected level, because the fissures are probably closed and filled with clay without movable water. The general good correlation between chemical alteration index and the other logs is a result of clay mineralisation around the fissures. It gives a proper explanation for detectability of the fissures with thickness under the resolution of the tool. Deducting from the 1Mhz requency it would be 1mm and really this is the resolution of travel time image, but for the amplitude image it is not a resolution limit because of the crushed and altered zone around each fissure.

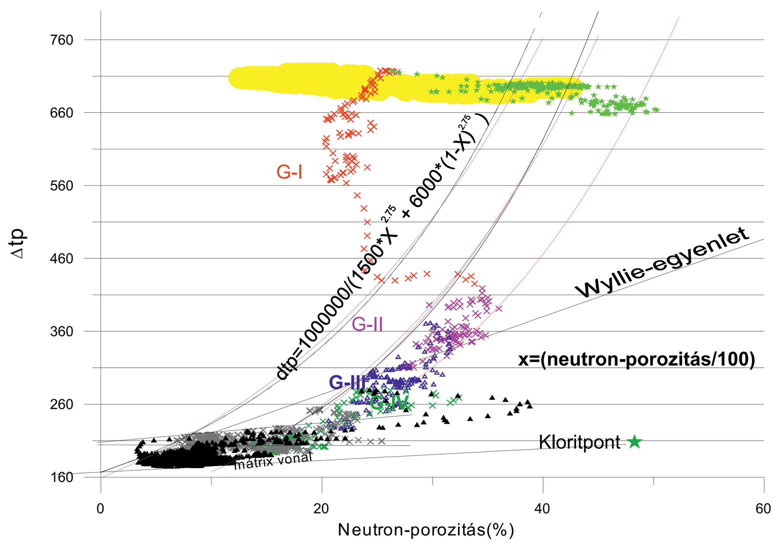


Legend: pore ~ porosity from density - neutron-neutron plott, Vp ~ compressional velocity, Fiss. Den. ~ fissure density (fissure/m), Ch.Alt Index, ~ chemical alteration index (arctg(GR/Npor), N-por ~ Neutron-porosity, SPORRZ ~ sonic porosity according to neutron-porosity-acoustic Δt crossplott

Correlation of fracture density with some measured and calculated porosity follower logs

Taking into account that the actual fissure volume in the fresh, unaltered, macroscopically porosity-free granite should be negligible (1%), hence the calculated porosity based on the crossplot of nuclear porosity tracking methods is too large, often over 10%. Nevertheless, the fissure density derived from BHTV measurements and the porosity from nuclear measurements (the porosity, from neutron-porosity and density) in the fresh granite, free of surface alteration effects, correlate well. Taking into account that the correlation of the neutron with density refers to a real pore volume ie, to the low fissure volume, relatively significant increasing effect on matrix porosity must be assumed. It follows that where there is a good fit between the curves, only a pore volume somehow connected to the fracture system exists, that is filled with.

This pore-space together with the real fissure porosity is considered as the full or total porosity, which includes both the bound and free pore water. Prevalent part of the resulting porosity, in case of the narrow cracks, is likely filled with bound water, since this mainly belongs to clayey alteration related to the cracks, the real fissure volume is only a small fraction of the total pore volume. In essence, the significant decrease in velocity observed in the degraded zones is linked to the increase of total pore space, the mikrocracks and the clayey alterations.



Neutron-porosity-dtp crossplot with the exponencial fitting on the modified Raymer equation: $\Delta t_p(\mu s/m) = 1E6(1500*x^{2.75} + 6000*(1-x)^{2.75})$
$X = \Phi_N/100$ = neutron-porosity/100

In the range of small Δt (high velocity) of the neutron-porosity-Δt crossplot, the straight line drawn at the lower limit of the range of cluster of points (boundary line) could be regarded as a kind of a matrix line which, in a definite case, is described by the following equation.
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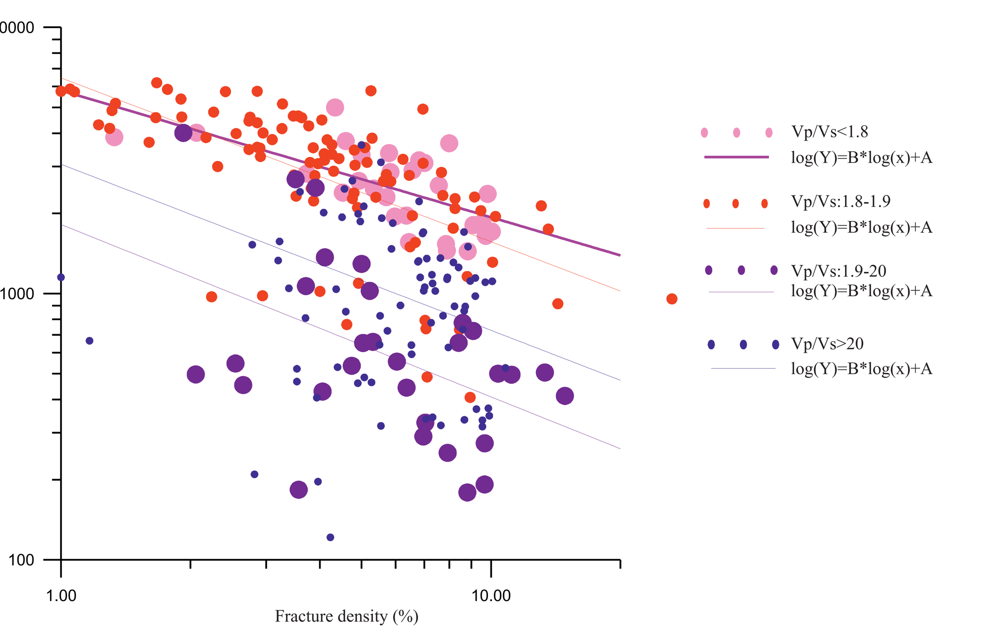
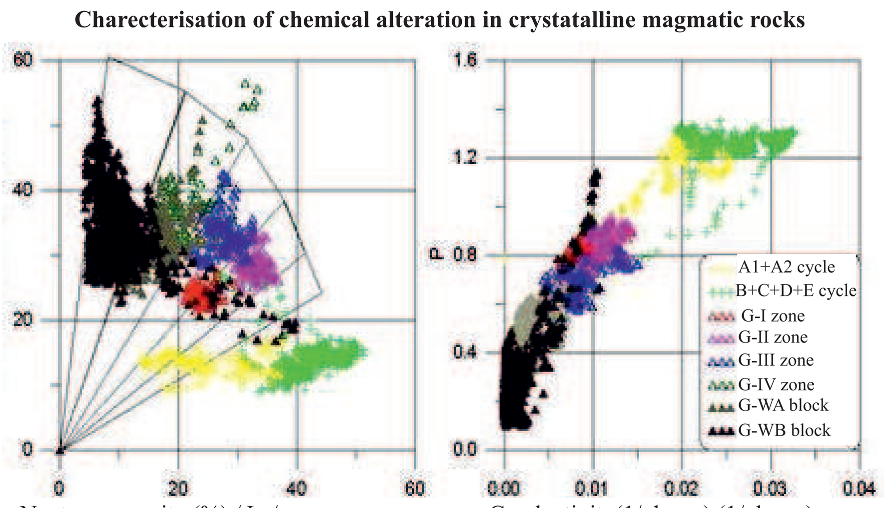


Resistivity - fracture density crossplot

In the case of constant fissure density and thin cracks, shearwave velocity should be reduced with the increase of fissure aperture, which results in an increase in the Vp/Vs ratio, as well as the electrical conductivity. These conclusions arising from theoretical models, are directly supported by the BHTV measurements, with the example of the practical measurements, and crossplot, respectively.

In the crossplot the electrical resistivity was plotted against fracture density function coming from BHTV, respectively. The third parameter of the crosplots is Vp / Vs ratio, which is plotted with color-code.

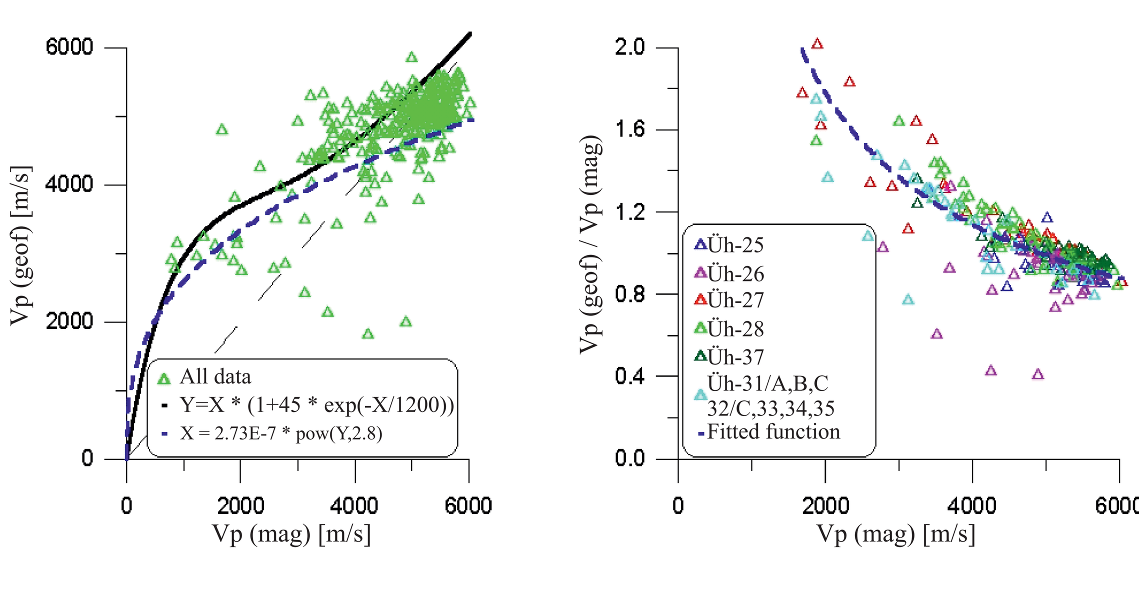
Charecterisation of chemical alteration in crystatalline magmatic rocks



Neutron-porosity (%) /Φ_N/ Conductivity(1/ohmm) (1/ohmm)
P~ chemical alteration index (arctg(Φ_N/GR))

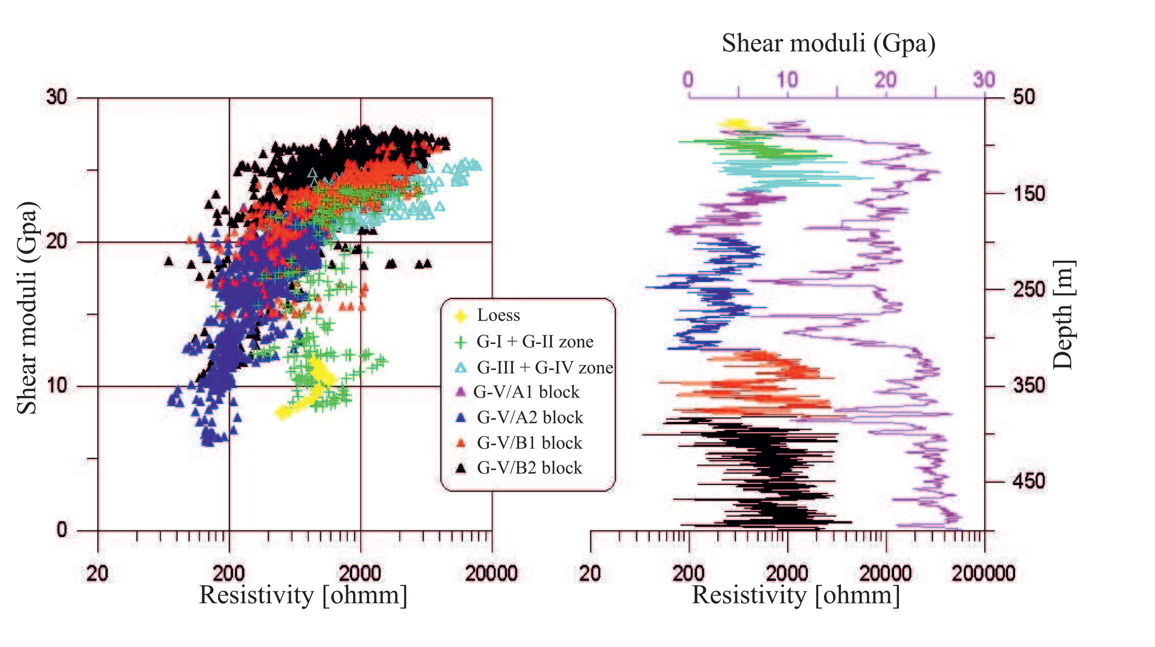
During the clayey alteration of granite, loss of the radioactivity, and the increase neutron-porosity are inter-related processes, therefore the ratio of these parameters is charecteristic to the alteration. Thus, for the characterization of alteration coefficient, P=arctg (natural gamma/neutron) guantity should be used. The P function means that, all points on the neutron - gamma crossplot can be characterized by a directional vector, avoiding to give variety with various gamma ray. of different incides to unalterd rock with various gamma ray. Neutron porosity of unaltered rock is small (lee than 5%), so all the points on the crossplott representing such a rock fall in the same direction. The alteration rate is charecterized by the and angle revolution from gamma ray axis.

Difference between physical parameters, measured on core samples, and well logs



The difference between measurable geomechanical parameters and well logging parameters increases with the increasing fracturing and alteration

Resistivity and shear modulus



At high resistivity a small change of shear modulus cause large change of resistivity, while at low resistivity the big change of shear modulus means only small change in resistivity. The colours sign the levels of the altered zone.