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Tectonic evaluation of borehole PTP-3 in the Krušné hory Mts. with ImaGeo mobile corescanner

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Abstract. In the winter of 2000 borehole PTP-3 in the Krušné hory Mts. was drilled. The borehole was measured with acoustic borehole televiewer and the core was scanned with the ImaGeo mobile corescanner. As a result of combining these two methods the oriented distribution of the different geological phenomena, especially the fractures cutting the core, could be determined as well as two theoretical paleostress field systems (one with a NE-SW and one with a NW-SE main stress direction). The fracture frequency in the borehole was very low (3.04 fractures per metre) so the evaluated granite body cannot be termed as a fractured one but still a remarkable fracture pattern was found in the borehole and separate "fracture zones" could be distinguished.

Key words: granite, tectonic control, fracture zones, foliation, alteration, geometry, stress, borehole, corescanning, Krušné hory Mts., Bohemian Massif

Introduction

Geological exploration based on borehole and core log evaluation produced a remarkable development in the last few years. With the help of these effective methods the geological features can be oriented after the core emerged from the hole. The ImaGeo corescanner combined with the acoustic borehole televiewer (BHTV) imaging provides a great improvement in this field.

In borehole PTP-3 drilled in granite in the Krušné hory Mts. we measured the whole rock column with BHTV and core scanned the granite in separate depth intervals: from 21 to 61 m, from 81 to 121 m and from 141 down to 348.70 m, the end of the borehole. In the following sections, we introduce the method we used and give a summary based on the results of the structural analysis.

Methods

First of all, let us write a few words about the ImaGeo Mobile Corescanning System developed in Hungary and the working methods with the corescanner. The corescanner moves the cores between two rotating cylinders while a digital camera installed above the cylinders is taking an image of the core surface line by line. We start digitising and evaluating the data immediately on the spot of the drilling with the help of the corescanner and the computers installed in the equipment van. The corescanner fills the raster image recorded in the optical range by a digital camera unit into the evaluating computer. We can analyze the 254 dpi resolution images after setting, saving and archiving them with the help of evaluating software modules. Since during scanning we digitize the surface of the whole core (maximum 80 cm in length and 20 cm in diameter), the planar elements (such as fractures, veins, etc.) appear as sinuous lines.

The images obtained by scanning are evaluated by CoreDump software. As the first stage of the evaluation, the geological features are drawn in vectorial form onto the images: fractures, rock boundaries, carbonate veins, quartz veins, microgranite veins, shear zones, foliation, limonitic infillings, argillaceous infillings, altered zones, etc. The evaluated elements will be called objects in the followings. The individual object types are collected in a database. The software gives the dip, the azimuth and the depth of the evaluated objects in relation to a chosen marker, as a local coordinate system fixed to the core. In borehole PTP-3, 836 objects have been analyzed (these are the oriented objects only).

The next stage of the evaluation is the orientation of the marker-zones into the real coordinate system. For this purpose, the acoustic borehole televiewer (BHTV) image was used (Zilahi-Sebess and Szongoth 2002). This image can be visualized in CoreDump software as well as the evaluated objects.

The BHTV method is a downhole well logging method where an ultrasonic equipment emits the acoustic waves. The borehole televiewer method is based on the measuring of travel time and amplitude of acoustic waves reflected from the wall of the borehole. This information can be converted to two kinds of images on which the rock discontinuities are visible (Zilahi-Sebess and Szongoth 2002).

Several statistical programme modules aiming at tectonic analysis can be run on the objects that became oriented, these are stereogram, rose diagram, tadpole diagram, pole distribution diagram and maximum wandering diagram (Maros and Pásztor 2001, Maros and Palotás 2000).

Since the different features are separated in a database after evaluating the images, in this way it becomes possible to analyze their distribution separately. First, the spatial differences of the phenomena are examined, that shows in the distribution of the azimuths and dips as well as in their change in depth. The different object-types cor-

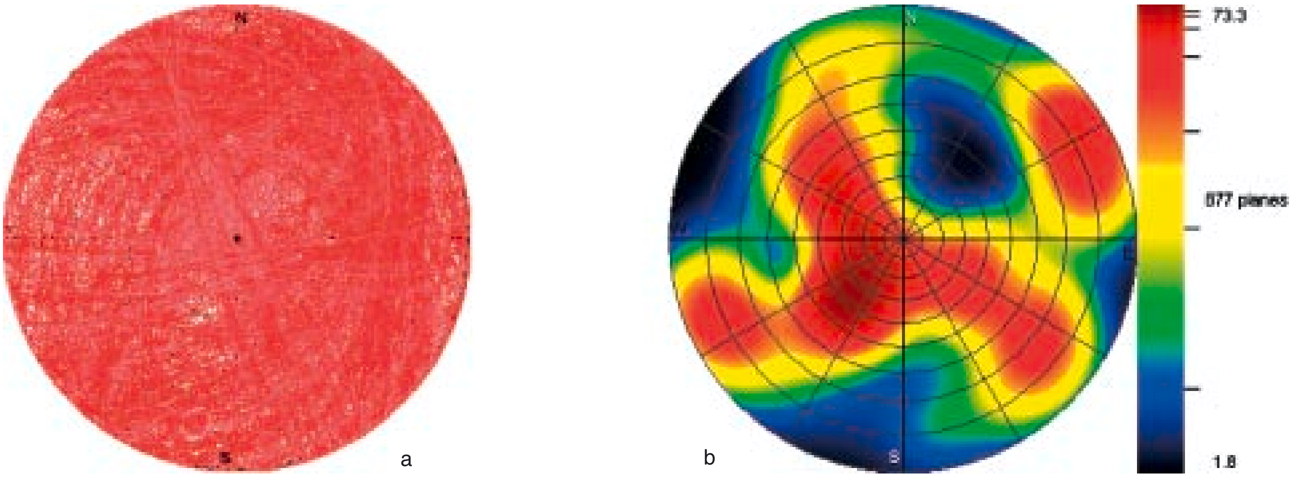
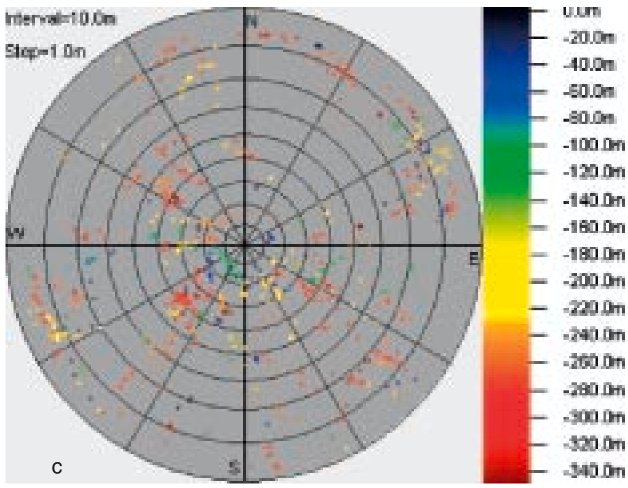


Fig. 1. Stereogram (a), pole distribution diagram (b) and maximum wandering diagram (c) of all the fractures.



respond to the properties of the rock, so their uniform or chaotic distribution is characteristic and depends on the history of the rock.

Evaluation of the observed phenomena

Due to the resolution of the scanned images, we could distinguish 23 different geological features. Concerning the petrology of the cores several granite types were distinguished. The geological description of the cores resulted in the following types (Breiter 1998): dyke granite, stock granite, old granite, aplite and some hydrothermal alterations (e.g. greisenisation, formation of hematite, limonite, etc. infillings). Concerning other phenomena, we could identify some more, mainly tectonic features (different fractures, striae, etc.). In the followings the most impressive layers are defined and shown (Table 1).

Rock boundary

Where we found some remarkable changes in the size of the minerals, in the texture or in the colour of the rock etc., we drew the planar boundary between the two different rock types. The distribution of rock boundaries is rather scattered, but it is well visible that eastward dipping rock boundaries are practically missing.

Aplite dykes

Altogether three aplite dykes were found in the sections we scanned. They contain visually much less mica and more feldspar and quartz than the “normal” granite. The boundary of this fine-grained rock type with the granite is generally rather sharp, but continuous transition into the host rock was also observed. All three have a dip of about 15–40°, but their azimuths are completely different, therefore no conclusion can be drawn from that.

Foliation

On 367 occasions, a very weakly developed foliation is visible in the granite at macroscopic scale, which was also

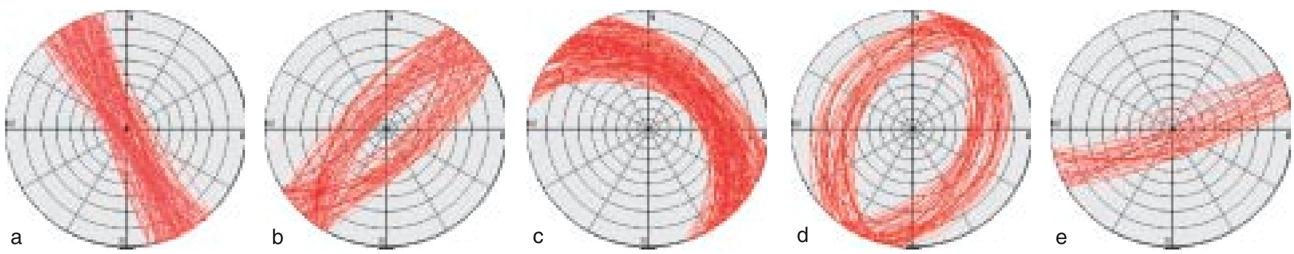


Fig. 2. Fracture sets distinguished on the basis of the stereogram of all the fractures a) to e) — see in the text.

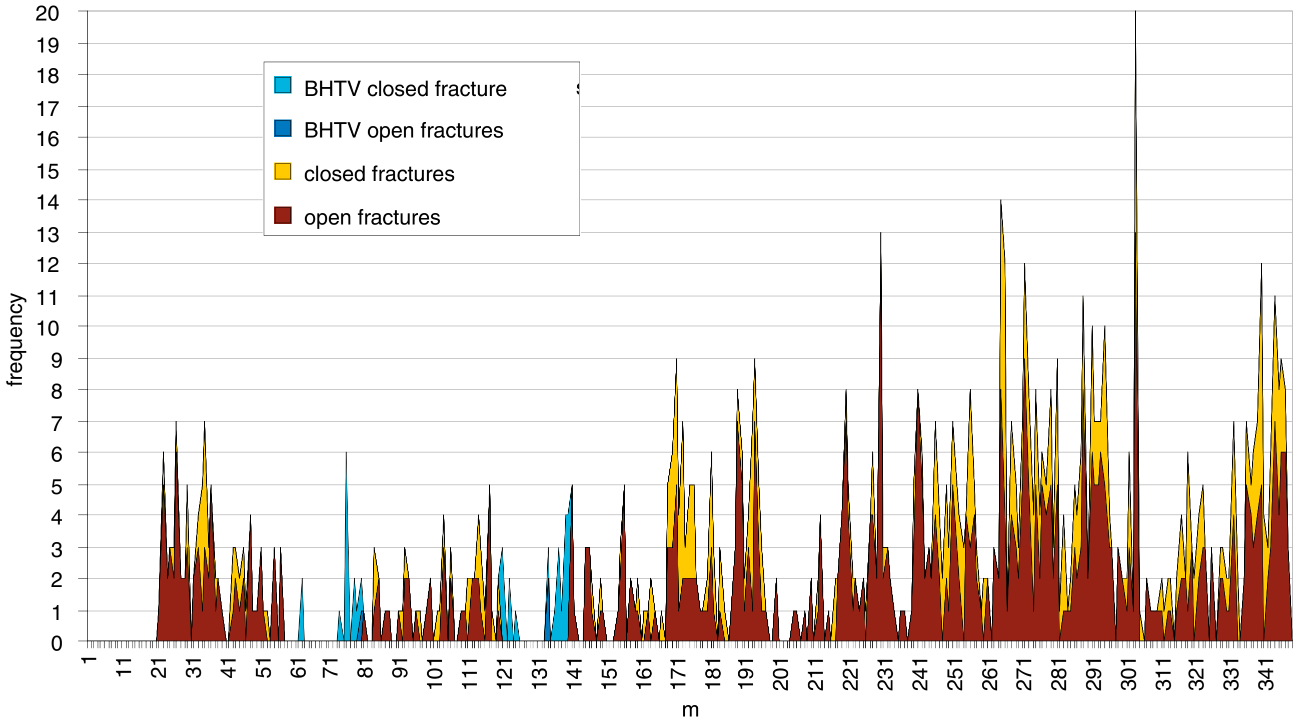


Fig. 3. Fracture frequency of open, closed and all fractures. The brownish colours refer to the corescanned intervals, the bluish colours refer to the non-scanned intervals where we used the data of the BHTV image.

marked on the images. Foliation was defined as a planar feature in the rock originating from the oriented alignment of different minerals (predominantly micas) but it is surely not a metamorphic foliation. Although its distribution is not totally chaotic, no special azimuth directions can be distinguished. Their dip varies mostly between 35° and 65°, which is a characteristic feature. However, it should be noted that the identification of the objects belonging to this category was generally rather uncertain, and further microscopic investigations will be needed to clarify this problem.

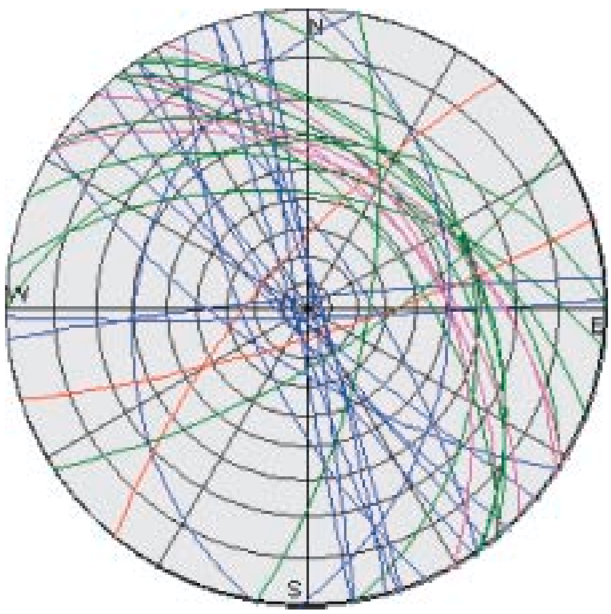


Fig. 4. Stereogram of the fractures with striae.
(red – sinistral, blue – horizontal, purple – normal, green – vertical).

Alteration

Along some fractures the granite (mostly the feldspars) alters near the fracture plane. This phenomenon appears with discolouring and whitening of the feldspars in the lower part of the borehole. This phenomenon can be important from hydrodynamic point of view if the alteration is caused by water flowing through the granite along the fractures.

This feature can be noticed in the lower part of the borehole (below 164 m) and can usually be connected with

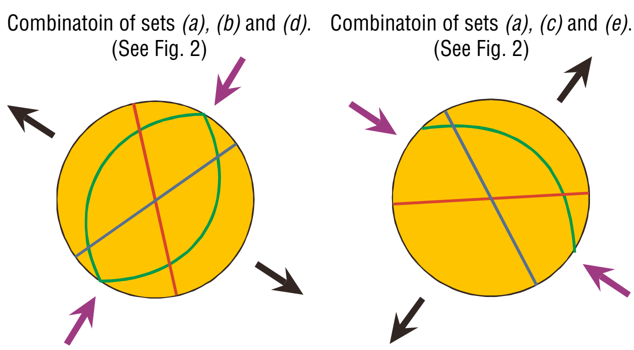


Fig. 5. Theoretical stress fields as a possible explanation for the present fracture pattern. (blue – sinistral, red – dextral, green – normal).

moderately (30–50°) NE dipping fractures as well as nearly vertical fractures striking NNW-SSE. The distribution of the altered fractures is similar to that of white argillaceous infillings.

Reddening of feldspars

In the lower part of the borehole, below 171 m, an interesting phenomenon, namely red stained feldspar crystals along planes, is visible connected to almost vertical planes of NE-SW as well as WNW-ESE strike. We think that the reddening or ferric staining of the feldspars happened along microfractures that are invisible to the naked eye.

Infillings

Five different types of infillings could be distinguished in the fractures. Limonite and hematite are dominant in the cores from 21 to 95 m, but we found hematite infilling as deep as 115.36 m. Green and white argillaceous minerals also sometimes appear. Generally, green and white argillaceous minerals can be found together below 105 m. Yellowish green infillings can be spotted in the core below 118 m. Quartz occurred only in a few occasions, so its stereogram is not worth drawing.

The distributions of the fractures with white and green argillaceous infillings are very similar to each other. The distributions of fractures filled with hematite and limonite seem to be very similar, too. It may indicate that this is a separate limonite infilling phase, while the others belong to the same event or limonite is only the weathering product of hematite.

Fractures

We distinguished two basic types of fractures, open and closed fractures. We know that these categories are rather artificial, since during the drilling process the rapid emergence and unburdening of the granite causes stress release and so falling apart of the rock but we think them worth separating because of a simple reason. If a fracture is closed after the core emerges from the hole it surely means that it was closed in the depth, too. This is the minimal number of closed fractures, which is valuable information. The fractures with motion indicators (striae) were taken into account too. These phenomena are visible only on the fracture planes, so we marked and numbered them onto the core surface before the scanning process. After the orientation of the cores the striae data became oriented too. The analysis of these data follows below.

As another classification, we separated fractures on the basis of their surface, namely smooth and rough surfaced fractures. This attribute can be important from the point of view of hydrodynamic modelling. The determination of this feature was made during the tectonic description and it was marked onto the cores.

Fracture sets

Altogether, 896 fractures were marked on the images of the core surfaces, and 877 of them were possible to orient with the help of the BHTV image. In the followings, we will talk only about the oriented fractures (Fig. 1). 574 fractures were open and 303 were closed. This does not necessarily mean the same situation in the depth, since during the drilling process a number of otherwise closed fractures became open because of technological reasons. We found that nearly vertical fractures appear to be closed more often. This may either mean that only they were closed originally or that the drilling technology opens the less steep fractures more often.

Despite of the rather chaotic nature of the stereogram of all the oriented fractures, a few groups of significant azimuths and dips can be clearly distinguished (Fig. 2). These are the followings:

a) a steep, 70–90° dipping set with azimuths of about 60° and 240°,
b) another steep, 50–90° dipping set with azimuths of about 135° and 315°,
c) a 20–55° dipping set with an azimuth between 10–70°,
d) a pair of 15–45° dipping sets with azimuths of about 95–130° and 285–320°,
e) a steep, 60–90° dipping set with a strike of about 70–250°.

On the maximum wandering diagram of all the fractures (Fig. 1) one can see that the 150–330° striking nearly vertical set (Fig. 2, set "a"), the NE dipping set "c" and fractures belonging to set "d" occur throughout the whole core column. Set "b" is almost missing in the upper part of the borehole, just like set "e", which is characteristic between 170–250 m.

Fracture frequency is a parameter for characterizing the rate of core breaking up. In this case the maximum is 20 fractures/metre and the average is 3.04, which is a very low value. The average of closed and open fractures is 1.05 and 1.99 fracture/metre respectively. On the diagram of fracture frequency (Fig. 3) we completed the corescan data with the BHTV data (Zilahi-Sebess and Szongoth 2002) in the non-scanned intervals. An increasing trend can be recognised from 81 m down to about 303 m, with a fallback at about 195 m. Below 303 m there is a sudden decrease in the number of fractures, then again an increase to the bottom of the drillhole. At the upper part of the borehole from 61 m upwards the fracture frequency increases, which is probably due to the fact that we are approaching the earth surface where the rock is more affected.

Paleostress field systems

Fortunately, 36 striae could be found on the fracture surfaces and 35 of them could be oriented. We could determine the direction of 2 sinistral and 5 normal movements for sure. The other striae were separated into groups of horizontal and vertical movements on the basis of the angle of the striae (vertical: angle of striae larger than 45°; horizontal: angle of striae smaller than 45°; Fig. 4).

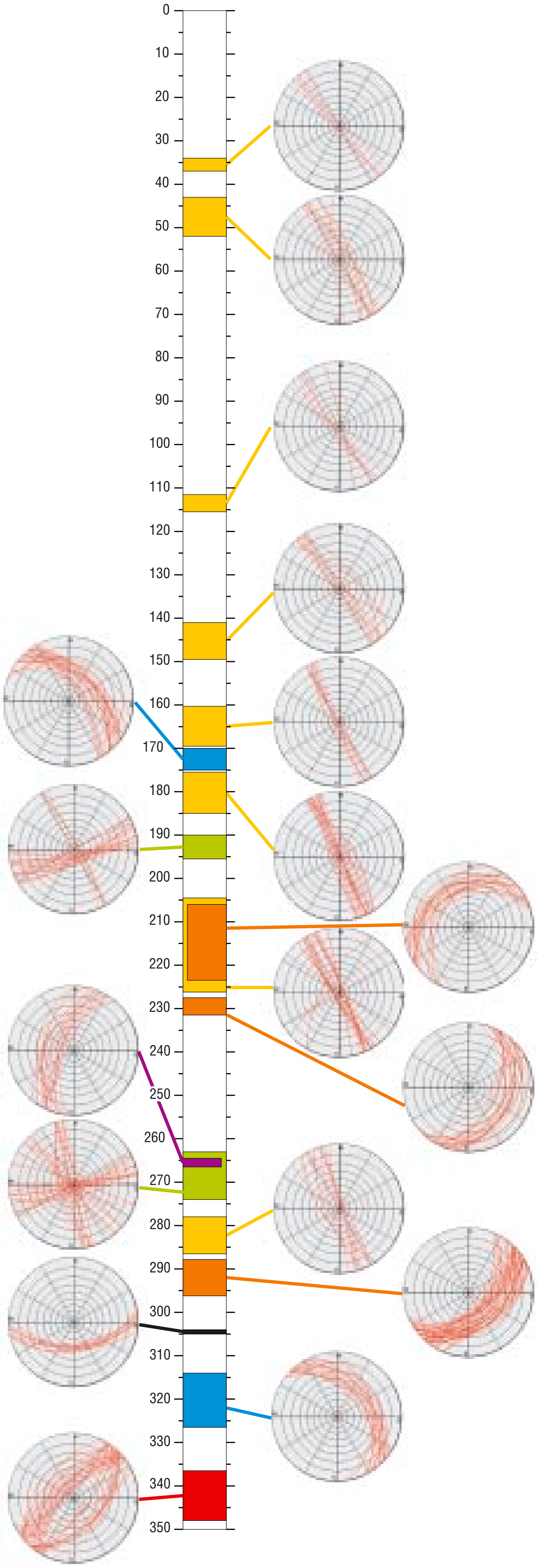
With the help of the striae and assuming that the nearly vertical fractures belong to strike slips and the less steep ones to normal faults, we could speculate about two possible paleostress field systems that might have affected the granite body (Fig. 5), but it should be emphasized that these are only possible geometric solutions based on very vague proofs. Since no overprinting relations of the fractures or striae could be observed, the relative chronology of the two systems is unknown. Both systems are characterised by horizontal σ_1 and σ_3 and vertical σ_2, creating strike-slips and normal faults.

1) The first system contains the 150–330° striking steep fracture set as a dextral strike slip system (set "a"), the 45–225° striking steep fracture set as a sinistral strike slip system (set "b") and the conjugate pair of 25–55° dipping sets with a strike of about 25–205° as a normal fault system (set "d").
2) The second system contains the 150–330° striking steep fracture set as a sinistral strike slip system (set "a"), the 70–250° striking steep fracture set as a dextral strike slip system (set "e") and the 25–55° dipping set with an azimuth of about 20–50° as a normal fault system (set "c").

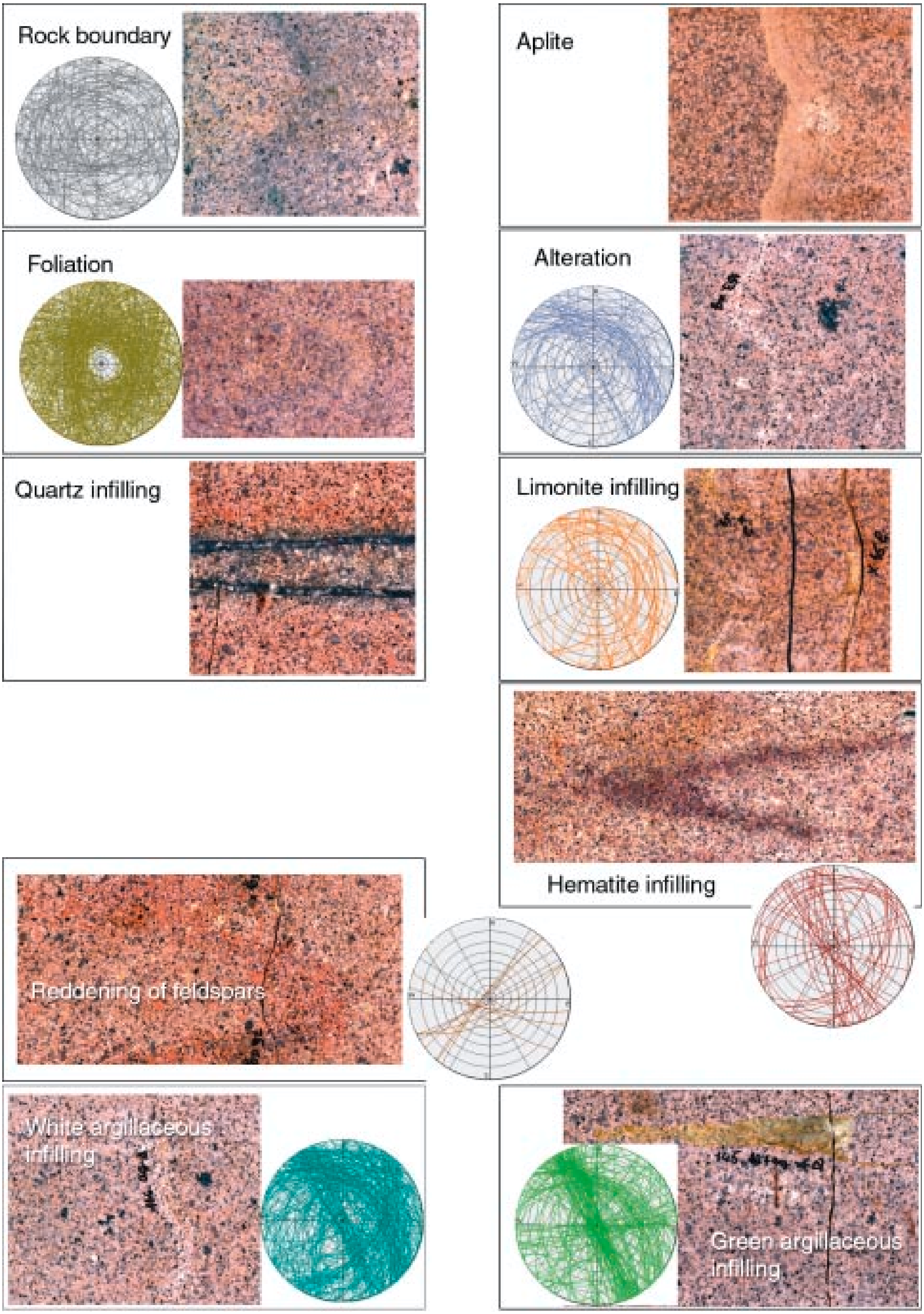
Fracture geometry

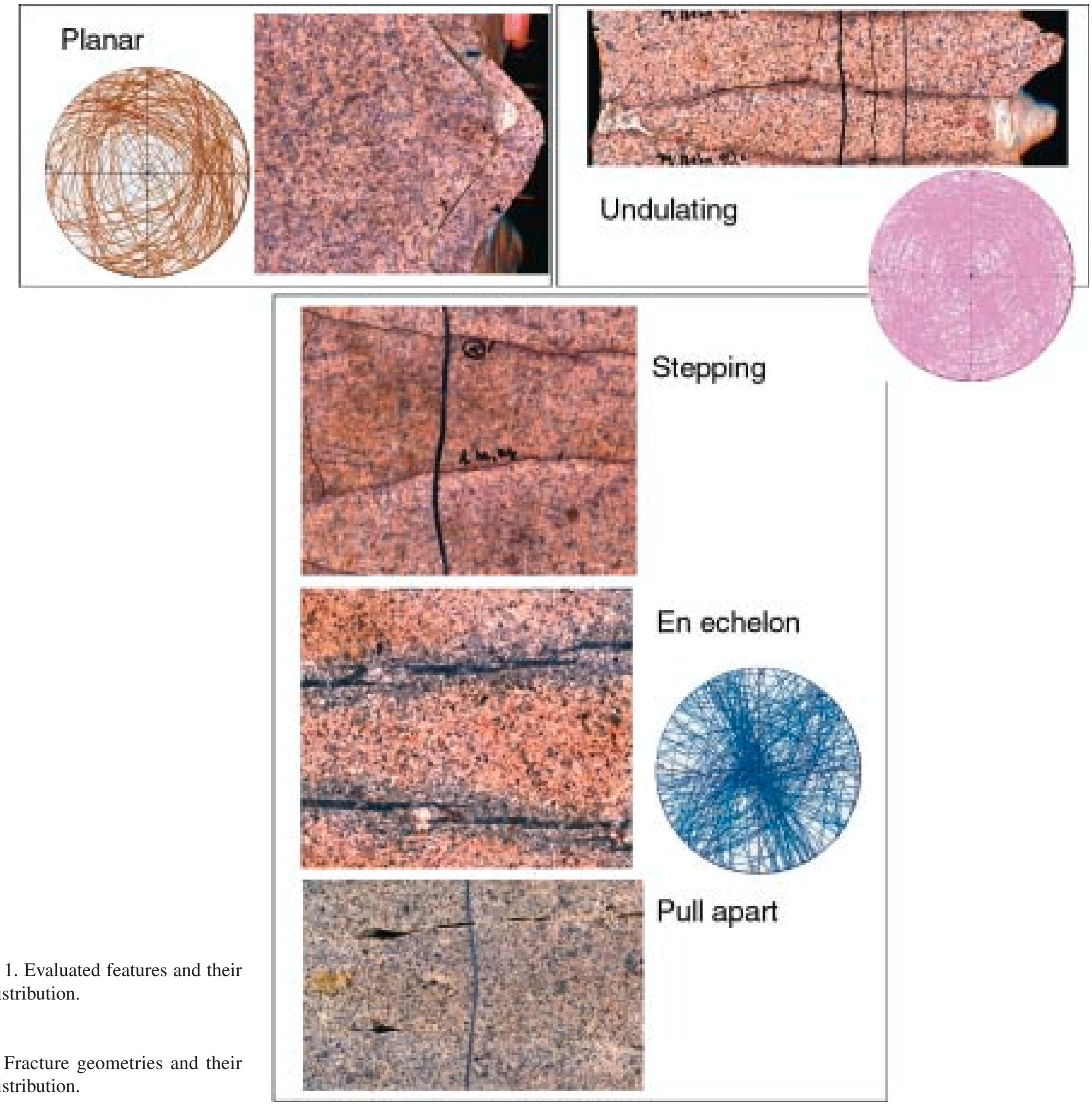
The geometric attributes of the fracture planes can also be important from the point of view of hydrodynamic modelling. Five different fracture geometries were distinguished: en echelon, stepping, pull apart, planar and undulating (Table 2). The first three types can be united as those that indicate shear. The majority of these fractures have dip values more than 45°. However, it should be taken into account that the geometry of steep fractures can be much more easily noticed on the core surface than the horizontal ones, since a longer interval of the steep fractures can be observed.

The distribution of fractures with planar and undulating geometry shows a distinct difference: the nearly vertical fractures are rather rare at the planar geometry; they appear in much larger number at the undulating geometry. Fractures with maximum 50° dip values occur at both types. It is also striking that the distribution of fractures with smooth surface is very similar to the distribution of planar fractures while the distribution of fractures with rough surface is very similar to the distribution of undulating fractures.



→ Fig. 6. Orientation of fractured zones in the borehole column. The colouring indicates fracture zones belonging to the same fracture set.


Rock boundary
Aplite
Foliation
Alteration
Quartz infilling
Limonite infilling
Hematite infilling
Reddening of feldspars
White argillaceous infilling
Green argillaceous infilling



← Table 1. Evaluated features and their spatial distribution.

Table 2. Fracture geometries and their spatial distribution.

Orientation of fractured zones

The granite in borehole PTP-3 cannot be considered as a fractured rock. However, at some sections of the drilling some azimuths and dips appear to be more frequent and more uniform than the others. In Fig. 6 we define them as fracture zones and mark these zones with different colours. We show the stereograms of the characteristic fractures of each zone beside them. Please note that in the stereograms we indicate only the most characteristic directions and dips. Zones consisting of fractures of similar azimuths and dips are indicated with the same colour.

Conclusions

Altogether we can conclude that the granite of borehole PTP-3 was fairly easy to scan for the reason that it was very little fractured, with a fracture frequency of 3.04. Five main fracture sets could be determined; 1. steep, 70–90° dipping set with azimuths of about 60° and 240°; 2. steep, 50–90° dipping set with azimuths of about 135° and 315°; 3. 20–55° dipping set with azimuth of 10–70°; 4. a pair of 15–45° dipping sets with azimuths of about 95–130° and 285–320°; 5. steep, 60–90° dipping set with a strike of about 70–250° and the nearly vertical fractures dominated in the distribution. Two theoretical paleostress fields were determined, one with a NE-SW σ_1 and one with a NW-SE σ_1 direction. Both are connected with strike slips and normal faults. We defined and separated fracture zones. Most of them that were possible to determine belonged to the nearly vertical sets, actually they occur all along the drilling hole, while the other fracture zones characterized by another type of fracture sets occur in only several depth intervals.

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