Open Microcracks: Indicators for In situ Stress Directions

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Introduction

The rocks from the KTB Drill hole and the surrounding area contain in general a complex crack pattern, that was formed in many phases under different conbditions. Paleo-stress directions derived from the older crack generations can with the aid of mineralisation and fluid inclusions be associated with definite crustal levels, which in part also renders as possible an estimation of their age (VOLLBRECHT et al. 1991; VOLLBRECHT & WEBER 1992). The younger opened cracks, for which such information necessarily fails, are often used as indicators for (sub-) recent in situ stress directions. The present study discusses the problems in the fabric-anisotropic KTB-samples, particularly in the spontaneous pressure relieved drill cores on the basis that an especially complex crack pattern can appear. The consideration restricts itself on the maximum (S_H) and minimum horizontal normal stress direction (S_h). According to BAUMGÄRTNER et al. (1990) al least to the depth of 3000m is $S_H > S_V > S_h$ (S_V = vertical stress).

Analyses in the Surrounding area

Microcrack analyses on quasi-isotropic granites in the KTB surrounding area have shown that next to subhorizontal cracks, a set of steep open cracks dominate. These cracks show a good correlation with the measured in situ horizontal stress directions (tensile cracks normal to S_h and parallel to S_H, respectively). In this case, the local scattering of the crack orientations perhaps display a rotation of the subrecent stress directions.

Analyses on KTB Drill Cores

In contrast to the above situation, one has to reckon with a complex crack pattern in the KTB drill cores, where the open in situ cracks (normal to S_h, in additional older generations) are overprinted by cracks that originate by spontaneous drill core relaxation (relaxation cracks are predominately normal to S_H and S_V, Fig. 1a). In the distinctly textured gneisses, one needs to take into account an additionally preferential opening of the (001)-cleavage planes oriented parallel to the foliation, which results from the extrem anisotropy of compressibility of mica (cleavage cracks parallel to the foliation; Fig. 1b).

The amount of opening parallel to the foliation varies with the directional relationship between the foliation and the stress configuration. The complexity of these crack formations makes the determination of the stress directions problematic, especially with indirect measuring methods (e.g. ZANG et al. 1989; relaxation measurements, assumption: maximum extension (e_1) in S_H, Vp_{min}-Method, assumption: lowest Vp-velocities in S_H, caused by relaxation cracks). The e_1-direction can for example, be controlled mainly by the opening of the mica cleavage planes. The Vp_{min}-Method

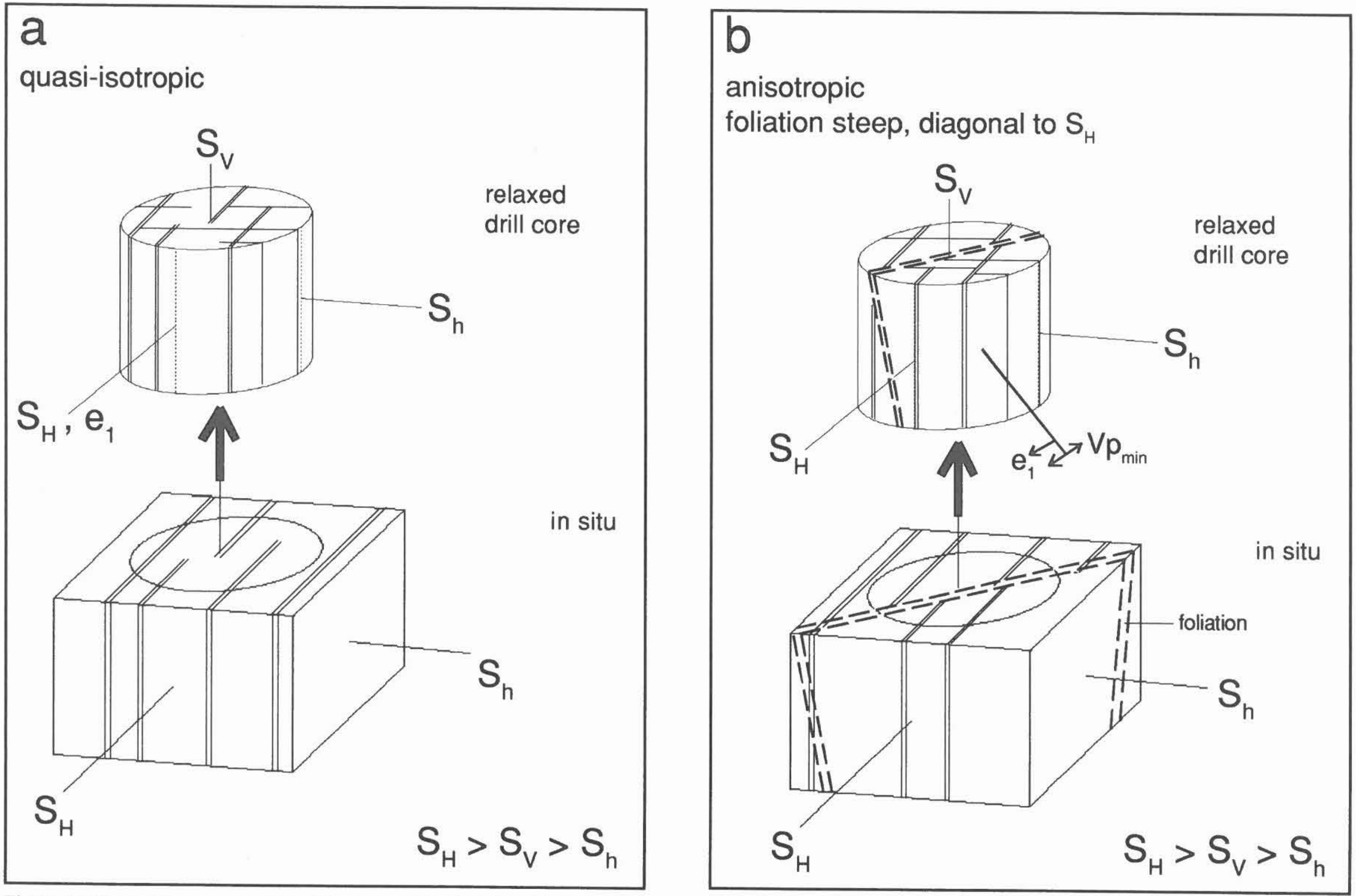
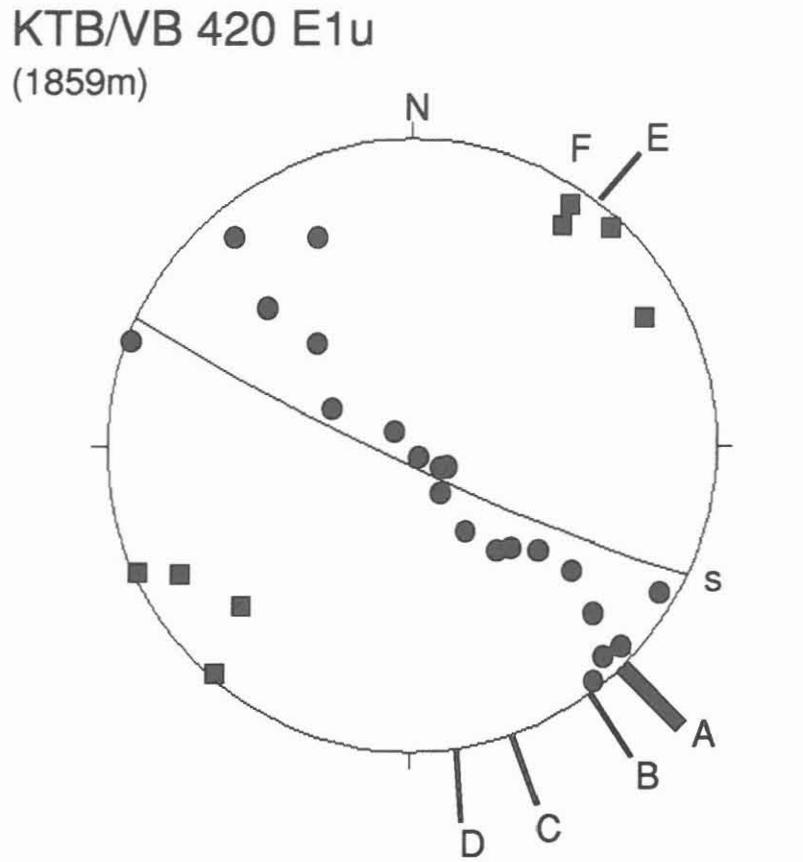


Figure 1: Schematic representation of the geometrical relationship betwen the stress directions, opened in situ cracks, and opened relaxation cracks in drill cores; a: quasi-isotropic rock, b: ansiotropic foliated rock. Further explanations in the text.



A	135º ± 12º	Own analyses of microcracks: ■ opened in situ cracks (n=8) ● opened relaxation cracks (n=21)
B	143º ± 16º	maximum horizontal normal stress direction in Central Europe (MÜLLER et al., 1992)
C	161º ± 14º	maximum horizontal normal stress direction in the KTB/VB (medium value), (MASTIN et al., 1991)
D	172º ± 15º	Lamprophyr, relaxation (KTB/VB 468 G1r, 2051,0m)
E	038º ± 10º	Bio-Sil-Gneis, relaxation (KTB/VB 422 G1w, 1870,9m)
F	030º ± 15º	estimated Vp-min direction for this sample
s	115º - 295º	strike direction of the foliation

Figure 2: Relationship between the measured opened cracks in quartz and plagioclase (sample KTB/VB 420 E1u; DÜRRAST, 1993) and stress measurements. Further explanations in the text.

not only records the relaxation cracks, but also the total population of the opened cracks. According to the relative influence of the various factors, the results of the indirect measurements can considerably deviate from the actual stress directions (schematically represented on the sample cylinders in Fig. 1). This leads to the question whether clear statements can be made through direct observations, i.e., from microcrack analysis.

Microcrack Analyses

The general observation is that in the KTB samples apart from mica cracks additional open intragranular cracks appear in an orthogonal pattern. This confirms the model of overlapping in situ cracks and relaxation cracks as shown in figure 1. Figure 2 shows how the observed crack pattern can be arranged relative to the in situ stress directions (sample 420 E1u, 1859m depth; DÜRRAST, 1993). As reference directions different S_H-determinations are shown, which were measured in the KTB drill hole and the surrounding area, and which can be considered relatively reliable. Consequently, the poles to the relaxation cracks are preferentially arranged on a girdle in the S_H/S_V-plane. The poles which are oriented normal to this girdle can be associated with the opened in situ cracks. The measured main direction of the relaxation (e_1) is mostly normal to the strike of the foliation, and merely reflects an opening of the mica cleavage planes. A probable direction for Vp_{min} is also indicated, which may result from the sum of open cracks. According to this geometrical relationship between microcrack patterns and the stress directions a girdle-like pattern of the relaxation crack poles along the periphery of the stereographic projection would be expected for $S_H>S_h>S_V$.

Conclusions

The present study indicates that in contrast to indirect (geophysical) measurements, a detailed analysis of special crack types can supply reliable informations about in situ stress directions, even in foliated rocks. In comparison to other methods, the expenditure is relatively low.

References

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