Neutron - and X-ray diffraction analysis of residual stress in rocks of the KTB

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X-Ray diffraction:

X-ray and neutron diffraction analysis of residual stress is based on the measurement of the interplanar spacings of familiar planes (hkl) of rock forming minerals which have been deformed.

The strains, caused by the stress, is given by Bragg's law (Maeder et al., 1980),

$$\varepsilon = \frac{1}{2} \cdot \cot g\Theta \cdot 2\Delta\Theta$$

where Θ_0 is the Bragg angle in a deformed lattice and $\Delta\Theta$ is the shift of a diffraction line of the (hkl) family caused by stress.

Fig. 1 shows the result of the lattice-deformation for specimen KTB-607A1a resulting from the position of the quartz 311-reflection. A Bragg-diffraction angle shift of $\Delta 2\Theta = 0.06°$ can be recognised.

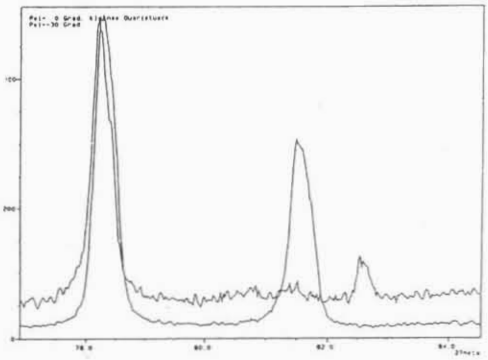

Fig. 1: Diffraction angle and reflection profile for the Bragg-reflection (311) of quartz at various stress levels ($\Delta 2\Theta = 0.06$)

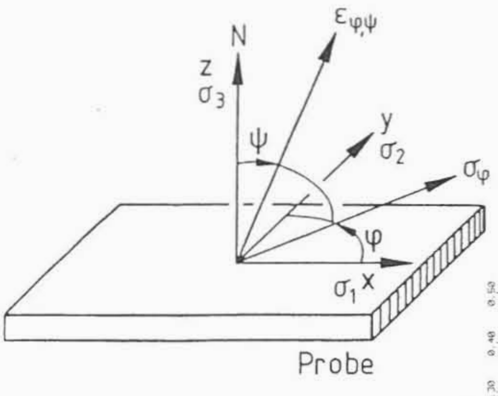

Fig. 2: Coordinate system for fixing a triaxial stress condition

For the stress analysis a polycrystalline plane specimen is assigned to an orthogonal coordination lattice with the orientation of ε_i-axes, as shown in Figure 2.

These mentioned relations are a function of the orientation of planes (hkl) with respect to the sample surface.

This condition can be realised by adding in addition to the 2Θ circle two further independent circles, ψ and φ, to a diffractometer.
Their geometrical relation to the orientation of the strain σ_i-axes of the sample is shown in Figure 2.

For stress analysis it is postulated that the strain $\varepsilon_{\varphi,\psi}$ is uniform to the measured lattice spacing of the same direction (Glocker, 1958):

$$\varepsilon_{\varphi,\psi} = \frac{d_{\varphi,\psi} - d_0}{d_0}$$

By determination of the lattice spacings of the same family in several ψ-directions at a given azimuth φ the following regularities are established:

1. The lattice spacings $\varepsilon_{\varphi,\psi}$ are independent of the azimuth φ and linear to $\sin^2\psi$.

2. The slope of the $\sin^2\psi$ straight line

$$m\varphi = \frac{\delta\varepsilon_{\varphi,\psi}}{\sin^2\psi} = \frac{1}{2} s_2 \cdot \sigma_\varphi$$

is proportional to the stress component σ_φ at a given azimuth φ.

3. Finally, by employing the Voigt constant s_1, the intercept of the strain plot on the axis of ordinates, which is the same for all azimuths φ, gives the sum of the principal stresses according to the equation:

$$\varepsilon_{\varphi,\psi} = 0 = \varepsilon_3 = s_1(\sigma_1 + \sigma_2).$$

Using X-rays the residual elastic strain locked in quartz grains of naturally deformed rocks can be monitored.

The interatomic spacings were determined as a function of $\sin^2\psi$ on KTB cores. The X-ray diffraction datas of specimen 607A1a are documented in figure 3.

From the diagram in Fig. 3 a residual stress of

-280 MPa

could be determined.

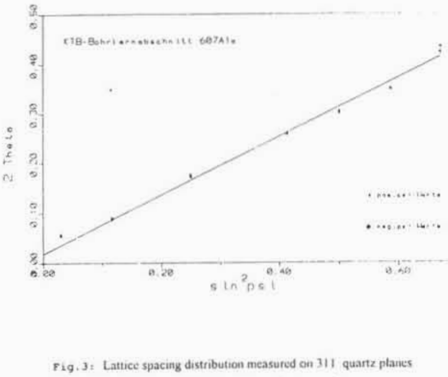

Fig. 3: Lattice spacing distribution measured on 311 quartz planes of KTB-core 607A1a versus various ψ-angles

Neutron diffraction:

In the case of silicates the penetration depth of neutron radiation has a magnitude of centimetres. Therefore, and with the aid of diaphragms and he xyz-translation device it was possible to choose any crystal of the specimen for determination of the residual stress analysis by neutron diffraction. Even stress gradients in smallest regions of a sample could be determined.
For investigating coarse grained rocks, the **single crystal diffraction technique with neutron radiation** is an indispensable tool.

These experiments were carried out at the Berlin Neutron Scattering Centre - BENSC, using a powder diffractometer which was installed at the beam tube T 2.
For the single crystal technique an Eulerian cradle with an xyz-translation device is installed in the instrument E3 (Fig.4).

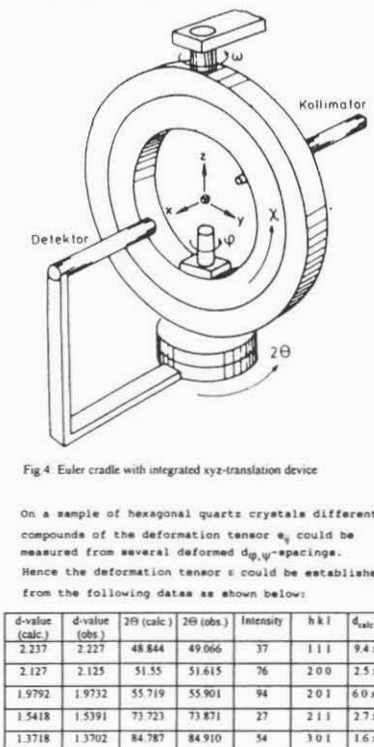

Fig 4: Euler cradle with integrated xyz-translation device

On a sample of hexagonal quartz crystals different compounds of the deformation tensor e_{ij} could be measured from several deformed $d_{\varphi,\psi}$-spacings.
Hence the deformation tensor ε could be established from the following datas as shown below:

d-value (calc.)	d-value (obs.)	2Θ (calc.)	2Θ (obs.)	Intensity	h k l	$d_{calc} - d_{obs}$
2.237	2.227	48.844	49.066	37	1 1 1	9.4×10^{-3}
2.127	2.125	51.55	51.615	76	2 0 0	2.5×10^{-3}
1.9792	1.9732	55.719	55.901	94	2 0 1	6.0×10^{-3}
1.5418	1.5391	73.723	73.871	27	2 1 1	2.7×10^{-3}
1.3718	1.3702	84.787	84.910	54	3 0 1	1.6×10^{-3}
1.2558	1.2535	94.8686	95.098	61	3 0 2	2.3×10^{-3}
1.1804	1.1799	103.173	103.233	43	3 1 0	2.3×10^{-3}
1.1405	1.1399	108.379	108.464	57	2 0 4	6.0×10^{-4}
1.1143	1.1137	112.203	112.295	61	3 0 3	6.0×10^{-4}

with

$$\varepsilon_{ij} = \begin{pmatrix} a & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & a\sqrt{3} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & c \end{pmatrix}$$

$a = 4.9098$
$a_0 = 4.9133$
$c = 5.3972$
$c_0 = 5.4053$

The experiments were carried out on KTB-sample H027.

It must be mentioned that the direction of the principal stresses do not directly ensue out of the principle deformation direction.

Our investigation are being continued.

References

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