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# TEXTURE INVESTIGATIONS OF NATURAL ROCK SALT USING NEUTRON DIFFRACTION

*(Figs. 8, Tabs. 3)*

Abstract: Plastic deformation of rocks occurs mainly by slip of the rock-forming minerals and is commonly restricted to certain slip systems. The shape change is generally accompanied by an orientation change of the crystal lattice in the minerals. This is one cause of texture formation during plastic deformation in polycrystalline materials and rocks. Texture investigations contain important information on the temperature-pressure-strain rate conditions existing during the deformation process. Therefore, precise and complete description of the texture is the essential subposition to petrofabric analysis.

A lot of elements shows favourable transmission properties for thermal neutrons. Thus, neutron diffraction is a suitable method for studying preferred orientations in natural rocks. The results of a texture analysis of natural rock salt using neutron diffraction will be presented. The initial material for our investigations is rock salt from mines of Zielitz, Bleicherode and the Werra region. Pole figures were measured for the NaCl (200), (220) and (222) reflections.

All samples of the Zielitz and Bleicherode mines show a (100)-fibre texture, for the stronger plastically deformed samples of the Werra region we found a (110)-fibre texture.

Резюме: Пластическая деформация пород появляется главным образом сбросом породообразующих минералов и она обычно ограничена на определенные системы сброса. Изменение формы обычно сопровождается изменением ориентировки кристаллической решетки минералов. Это является одной причиной образования текстуры во время пластической деформации поликристаллических материалов и пород.

Исследования текстуры содержат важные информации об условиях температуры, давления и напряжения, существующих во время процесса деформации. Поэтому точное и полное описание текстуры является существенной предпосылкой структурно-петрографического анализа.

Много элементов показывает свойства, благоприятные для переноса термальных нейтронов. Таким образом нейтронная диффакция является подходящим методом для исследования преимущественных ориентаций в естественных породах.

Приводятся результаты текстурного анализа естественной каменной соли, полученные нейтронной диффакцией. Исходным материалом для наших исследований каменная соль из рудников Цилиц, Блайхероде и района Верра. Полюсные фигуры были измерены для отражений NaCl (200), (220) и (222).

Все пробы из рудников Цилиц и Блайхероде показывают текстуру волокна (100), для сильнее пластически деформированных проб района Верра была определена текстура волокна (110).

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## *Introduction*

The properties of polycrystalline materials and rocks depend, among others, on a number of parameters characterizing the size, shape and crystallographic orientation of grains of which the rock is built up. Because of the statistical nature of the grain structure the three quantities are described by statistical distribution functions, i. e. the grain size distribution, the shape distribution and the orientation distribution. Whereas the size and shape distribution are usually determined by optical microscopy the orientation distribution - also called the texture of the material- is frequently determined by diffraction methods.

Most of the physical properties of crystlline materials are anisotropic, i. e. they depend on the crystallographic directions in which they are measured. The macroscopic properties of polycrystalline rocks are certain mean values of the properties of the constituent crystallites depending on the texture of the minerals. In the case of random orientation the macroscopic properties are the same in all directions. The material is said to be quasi-isotropic. In the case of preferred orientation, however, a macroscopic anisotropy may result, the kind and magnitude of which depends on the orientation distribution or texture.

Texture studies have been used in metal-science since the discovery of X-ray diffraction. They play, however, also an important role in geological sciences where texture investigations are used in order to obtain information about rock forming processes which have occurred millions of years ago. The study of textures in deformed rocks is the subject of petrofabric analysis. Its goal is to use the pattern of preferred orientations to get information on the stress--strain temperature history of rocks and use it to understand deformation of the earth's crust. In contrast to metal-science, where textures are used to control mechanical properties, they serve in geology as a historical record. Relationships are very complex and the pattern of preferred orientation is the accumulated and product of a long and often variable path through time. On the other hand, information about possible textures in rocks is necessary for understanding and calculating of anisotropic physical properties in rocks, such as plasticity, elasticity, thermal conductivity, magnetic properties, ultrasonic and seismic wave propagation.

Up to now, experimental values for plasticity of polycrystalline rocks are considerably inaccurate and differ in a wide range from one mineral aggregate to another, and often in the same mineral deposit, too. About the influence of texture upon this disadvantage is only rarely reported. There is a very large literature about natural mineral fabrics and about experimental rock deformation. References are found in textbooks and compilations of Sander (1950), Turner — Weiss (1963), Paulitsch (1970) and Wenk (1985). Thus, it is not surprising that even though numerous scientists have spent large parts of their lives in this field, and thousands of fabric diagrams have been measured over the last fifty years, progress has not been very satisfactory, and with the exception of a few simple cases no textures can be interpreted quantitatively.

Two recent developments had most significant impact and sparked new interest in the study of textures. Firstly, through experiments at high pressure and temperature the mechanical properties of most minerals have been determined and through analysis with the transmission electron microscope deformation mechanisms have been established for various conditions. Secondly, geologists have been stimulated by material scientists to use three dimensional representations of textures instead of ambiguous pole figures, allowing for a quantitative and complete description which is the basis for a satisfactory interpretation. The result is, we have today quantitative data on deformation mechanisms, including glide systems and critical shear stresses. We are able to produce preferred orientations in rocks in the laboratory and are just at the beginning of interpreting these often very complicated patterns.

In this review I wish to discuss some of the background, how preferred orientation develops and how it is measured and represented. Then I vill summarize some of our observations on natural rock salt using neutron diffraction method and will outline the facilities of neutron diffraction for the study of preferred orientations in minerals and rocks.

## *Definition of the texture*

The crystallographic orientation g of an individual crystallite in a polycrystalline sample is defined by the orientation of its crystal coordinate system $K_c$ with respect to the sample coordination system $K_s$, Fig. 1. It is to be described by three orientation parameters. The orientation of a specific crystal direction [uvw] may be determined by two angular coordinates $\alpha$, $\beta$. The crystal may then still rotate about a third direction. In oder to fix its orientation completely this thir parameter $\gamma$ is needed. The texture of the material is thus described by an orientation distribution (ODF), which depends on three angular variables and which describes the volume fraction of crystals having the orientation $g = f(\alpha, \beta, \gamma)$

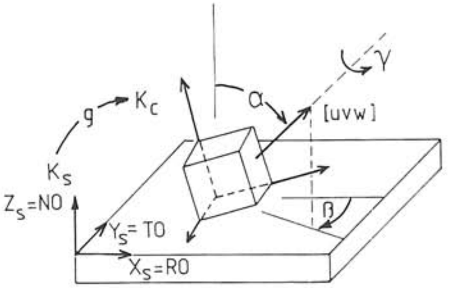

Fig. 1. The sample coordinate system $K_s$ and the crystal coordinate system $K_c$. The orientation g of $K_c$ with respect to $K_s$ can be described by the angles $\alpha$, $\beta$ of a direction [uvw] and the rotation angle $\gamma$ about [uvw].

$$dV/V = f(\alpha, \beta, \gamma)\, d\alpha\, d\beta\, d\gamma \qquad (1)$$

Textures are mostly measured by diffraction methods. If the direction [uvw] in Fig. 1 is the normal to the reflecting lattice plane (hkl) then the reflected intensity is independent of a rotation of the crystal through the angle $\gamma$. Polycrystal diffraction experiments thus yield the orientation distribution of the crystal direction [uvw] as a function of $\alpha$ and $\beta$ (Fig. 2).

$$dV/V = P_{hkl}\,(\alpha,\,\beta)\,\sin\alpha\,d\alpha\,d\beta \tag{2}$$

The $P_{hkl}$ pole figure is thus only a two-dimensional projection along the coordinate $\gamma$ of the three-dimensional orientation distribution function (ODF).

It has been shown, however, that the complete ODF can be calculated if several pole figures with different reflecting lattice planes (hkl) have been determined. This procedure has been called pole figure inversion or ODF-analysis and is described mathematically by Bunge. Texture analysis may thus be divided into two main steps: the pole figure measurement and the ODF-analysis. In the further discussion I want to deal with the first step, pole figure measurement, only.

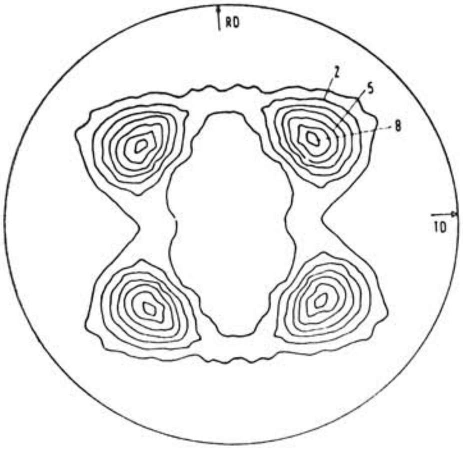

Fig. 2. The pole figure $P_{hkl}$ ($\alpha$, $\beta$) is the orientation distribution of crystal direction [uvw] normal to the planes (hkl) with respect to the sample coordinate system (as example a (111) pole figure).

## *Determination and representation of preferred orientations in rocks*

A prerequisite for any quantitative approach to textures are accurate measuremets. In contrast to metallurgists who used frequently diffraction methods, geologists and mineralogists relied maily on the petrographic microscope equiped with a universal stage (see Berek). Most minerals, when ground to about 30 $\mu$m become transparent to light and allowing one to measure optical directions such as axes of the indikatrix and morphologic markers like cleavage planes, twins, and deformation bands or etch pits of individual crystals. These measurements are represented in a crystallographic projection. Schmidt (1932) has discussed the advantages of equal area projection because it allows contour regions with equal pole-density graphically.

Densities can be normalized and expressed as multiples of a random distribution. A contoured and normalized fabric diegram is equivalent to a pole figure. Fabric diagrams are usually based on 500—1000 measurements. If only a few crystals are measured, and the fabric shows weak preferred orientation, the method of contouring and the question of statistical significance of point clusters become important.

The main advantage of the U-stage technique is that it permits keeping track of the orientation of individual crystals. This can be used to study the local distribution of orientations in the sample. Disadvantages are that the technique is rather time consuming (measurement of one c-axis of quartz for example takes about 1 minute and a complete determination of a single grain may easily take one hour). Some minerals such as quartz lack morphological markers and are optically uniaxial, allowing only measurement of a single crystallographic direction. In the case of optical isotropic crystals (halite, flourite, magnetite, garnet, e. t. c.) the application of polarized light is not possible and one can use only the interpretation of cleavage planes for orientation measurements.

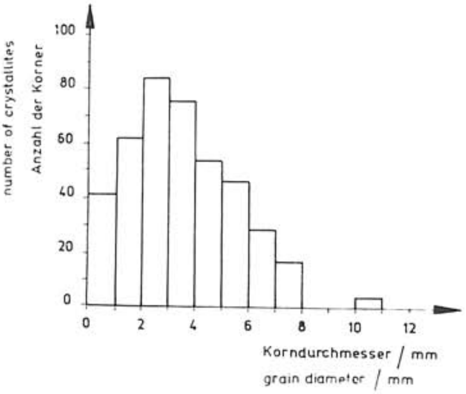

Fig. 3. Grain size distribution of coarse grained natural rock salt specimen used in this investigation.

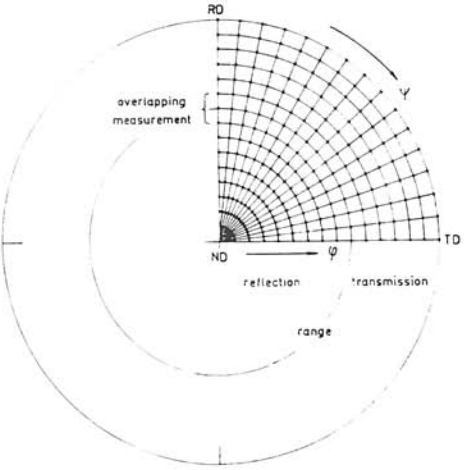

Fig. 4. In the applied circular scanning mode the angles φ and Ψ are varied independently. The back-reflection and the transmission range of a pole figure are shown. The overlapping range is common to both ranges.

X-ray diffraction techniques have only recently become popular in the analysis of mineral fabrics but have been applied succesfully in various topics of metal reasearch. The textre goniometers for pole figure measurements, used by metallurgists had to be modified for the special requirements of rock fabrics. In contrast to metals, minerals are generally coarse grained with a grain size of over 1 mm. Thus, in a scan which covers the pole figure, only a relative small quantity of crystallites is in reflection position. With a rapid oscillation technique the investigated sample area can be extended and improving grain statistics considerably.

But even so X-ray measurements remain restricted to fine grained fabrics, furthermore silicates and oxides are low scatterers, producing only weak X-ray

Table 1

Comparison of neutron and X-ray scattering factors and absorption coefficients for some elements

| element | scattering factor in $10^{-12}$ cm (a) | | mass absorption coefficient (b) in $\mathrm{cm^2g^{-1}}$ | |
|---|---|---|---|---|
| | neutron | X-ray (sin = 0) | neutron (= 0 . 108 nm) | X-ray (= 0 . 155 nm) |
| Na | 0.36 | 3.09 | .007 | 30.6 |
| Cl | 0.96 | 4.80 | .33 | 107 |
| K | 0.37 | 5.30 | .08 | 145 |
| S | 0.28 | 4.50 | .0055 | 90.5 |
| O | 0.58 | 2.25 | .00001 | 11.7 |
| Ca | 0.49 | 5.60 | .0037 | 164 |
| Mg | 0.52 | 3.38 | .001 | 39.2 |

(a) Bacon, G. E.: Neutron Diffraction; Clarendon Press, Oxford (1975).
(b) International Tables for X-ray Crystallography (1962).

peaks which — due to low crystal symmetry and large lattice constants — are often close and only well separated at low diffraction angles. At these low angles intensity corrections are most critical in reflection geometry which is the principal mehod applied. Most of the pole figure measurements with X-rays are done on flat slabs in reflection geometry and yield incomplete pole figures (see also Fig. 4).

Because of these limitations in X-ray diffraction, which are due mainly to the high absorption of X-rays by materials, neutron diffraction method is more appropriate for studying preferred orientations in natural rocks. Some of the limitations which exist in X-ray diffraction do not occure for neutrons and the experimental equipment is comparable. Thermal neutrons have similar energies as X-rays [a Zn (002) monochromator provides a wavelength of $\lambda = 0.1458$ nm] but their scattering factor is about one order of magnitude smaller (Tab. 1) and required long measurements. On the other hand, absorption coefficients for most chemical elements are very small (Tab. 1), which enables to use large samples of roughly spherical shape with a diameter up to 30 mm and slabs with a thickness up to 10 mm, too (Tab. 2).

The number of pole figures for rock fabrics is increasing. Diffraction methods are generally not less laborious than the U-stage technique, but they allow determination of pole figures of many different crystallographic directions. After rock fabrics were measured with diffraction techniques it became clear that the classical optical axis fabric diagram only gives a very incomplete description of preferred orientation making an interpretation often ambiguous. Fortunately, the theory of the three dimensional representation was already fully developed for metals by Bunge (1969) largely unnoticed by structural geologists.

The traditional way to describe preferred orientation is with pole figures (fabric diagrams), representing one crystallographic direction relative to spe-

Table 2

Comparison of neutron and X-ray penetration depth $d_{1/2}$ for 50 % absorption

| mineral | formula | X-rays ($\lambda = 0.154$ nm) $d_{1/2}$ cm | neutrons ($\lambda = 0.145$ nm) $d_{1/2}$ cm |
|---|---|---|---|
| halite | $NaCl$ | $0.42 \,.\, 10^{-2}$ | 0.82 |
| sylvin | $KCl$ | $0.34 \,.\, 10^{-2}$ | 1.07 |
| polyhalite | $K_2MgCa_2(SO_4)_4 \,.\, 2\,H_2O$ | $0.38 \,.\, 10^{-2}$ | 0.60 |
| kieserite | $MgSO_4 \,.\, H_2O$ | $0.79 \,.\, 10^{-2}$ | 0.32 |
| anhydrite | $CaSO_4$ | $0.32 \,.\, 10^{-2}$ | 2.39 |
| hematite | $Fe_2O_3$ | $0.06 \,.\, 10^{-2}$ | 0.89 |

cimen coordinates. This is an incomplete way to relate two coordinate systems, that of the specimen with that of the crystal. For instance, it is not possible to predict from two or three pole figures the pole figure for another crystallographic direction without applying mathematical methods. The orientation of two coordinate systems is specified by the three Eulerian angles and a texture is the statistical distribution in the three-dimensional space of this Euler angles, called orientation distribution function (ODF). If the crystal orientation cannot be measured, then it is necessary to calculate ODF from pole figure data (from X-ray or neutron diffraction experiments) of many other reflections (hkl) using spherical harmonic analysis. For cubic crystal and triclinic specimen symmetry 3 or 4 complete pole figures, for trigonal crystal (quartz) and triclinic specimen symmetry 10 to 12 complete pole figures must be used. The application of the ODF representation contain so much more information and we hope that this method will gradually replace the fabric diagram. Figures can then be restricted to illustrate only the most important features of the ODF.

## *Development of preferred orientations in rocks*

There are many different causes for oriented mineral fabrics. Crystals which nucleate and grow on a substrate have orientation which are controlled by orientation of the surface or in annealing recrystallization fabrics by the orientation of the host crystal. Settling and sedimentation of anisotropic crystals suspended in liquids produce oriented fabrics in sediments and igneous rocks.

Geologically most important, though, are those mechanism which produce preferred orientation during deformation either due to

(1) reorientation of crystals with anisotropic grain shape during straining;
(2) nucleation and growth of preferred orientation in a stress field; or
(3) plastic deformation by slip or twinning.

In the further treatment I want to deal only with the last topic because the progress in the field of dislocation theory is not to overlooked.

Under application of stress dislocations within the crystal are moving, generally within a plane, the glide plane, and with atomic displacements described by the Burgers vector $\vec{b}$ in the glide direction. These movements are on a submicroscopic scale and dislocations are visible with the transmission electron microscope. Dislocation movements are evidenced as deformation lamellae, kink bands and twins on the light microscope and lead to crystal rotations producing preferred orientation. A review of these processes is given by Kocks (1969) and Reid (1973).

Schmid proposed that single crystal yield on a particular glide system if the resolved shear stress on a plane and glide direction reaches a critical glide value $\tau_c$

$$\tau_c \geq m_{ij}\,\sigma_{ij} \qquad (i, j = 1, 2, 3) \tag{3}$$

The stress state is defined by the tensor $\sigma_{ij}$ and $m_{ij}$ is the tensor transformation matrix. The left side of this equation (3) is a material property and the right side the applied stress. For a single glide system and pure compression $m_{ij}$ degenerates to:

$$m = \cos\psi \,\sin\lambda \tag{4}$$

where $\psi$ and $\lambda$ are angles between the compression axis and the slip plane normal and glide direction. m is called the Schmid factor. The total strain $d\varepsilon_{ij}$ is given by:

$$d\varepsilon_{ji} = {}^1/_2\,(m_{ij} + m_{ji})\,d\gamma \tag{5}$$

where

$$d\gamma = 2\,.\,(d\varepsilon_{12})$$

It is customary to use differential strains because stress-strain relations often follow a rather complicated path determined by the development of the dislocation microstructure. If equality (3) is inverted and $\sigma_{ij}$ multiplited with $d\varepsilon_{ij}$ it becomes evident that the work done by external forces equals the work done in the slip systems.

$$\sigma_{ij}\,d\varepsilon_{ij} = \tau_c \tag{6}$$

If the crystal is not constrained by neighbours then rotations will occur until stress axes are parallel to corresponding strain axes. In uniaxial compression the applied stress direction moves towards the pole of the operative slip system. In extension of the glide direction is rotated the applied stress direction. The situation is complicated by the fact that there may be more than active glide system operating.

In a crystal aggregate activation of glide systems is constrained by neighboured grains. To avoid opening of cavities at grain boundaries the strain has to be the same at all points throughout the material. This requires activation of at least five independent glide systems. Taylor (1938) suggested that this combination of glide systems will be active which has the minimum sum of glide shears (eq. 6). The active combination of five glide systems can than be calculated for each crystal orientation with respect to the stress system.

Table 3

Glide systems and critical resolved shear stress (in MPa) of halite reported by Carter and Heard

| P kbar | T/°C | deformation rate / sec$^{-1}$ | critical shear stress in the glide system / MPa | | |
|---|---|---|---|---|---|
| | | | $\{100\}$<br>$\langle 011\rangle$ | $\{110\}$<br>$\langle 1\bar{1}0\rangle$ | $\{111\}$<br>$\langle 1\bar{1}0\rangle$ |
| 2 | 25 | $2.3 . 10^{-6}$ | $\sim$19.5 | $\sim$4.5 | $\sim$13.5 |
| 2 | 250 | $1.5 . 10^{-6}$ | $\sim$6.0 | $\sim$2.0 | $\sim$6.0 |

The sum of glide shears — the Taylor factor — is a measure of the energy required to deform a crystal of a given orientation.

Siemes (1974) used this method to predict preferred orientation of experimentally deformed cubic minerals in a first approximation. He tooked only the {111} glide system into consideration, but the other glide systems with different critical resolved shear stresses are to consider too. The result of this first approximation is a (110) fibre texture for cubic minerals during uniaxial compression. Lister (1978) applied the Taylor theory as modified by Bishop—Hill (1951) to explain natural quartz fabrics as a result of dislocation gliding. He could show that he fabric type changes abruptly as different glide systems become active.

As in metals predicted patterns of preferred orientations are always weaker than those observed and the model needs further refinement. At low temperature the restriction of homogeneous strain is not very satisfactory for mineral fabrics with plenty of evidence for microcracking and grain boundary sliding.

Also, application of Taylor theory requires information about glide systems and their respective critical shear stresses. These have mainly been inferred from single crystal deformation experiments analyzing the dislocation microstructure by TEM methods. Over the last years there has been progress in this field but quantitative data for the many important rock-forming minerals are still incomplete both as far as glide systems an critical shear stresses are concerned. Some new information about halite are summarized in Tab. 3. A general relationship between fabric type, glide mechanism, temperature and strain rate can be established by applying of the Taylor theory. An extrapolation of experimental data in deformation experiments in laboratories to strain rates of $10^{-15}$ sec$^{-1}$ which are encountered in tectonic deformations is absolutely necessary.

## *Observed patterns of preferred orientation in halite using neutron diffraction*

Due to diverse recrystallization processes rock salt is frequently found to be rather coarse-grained. This together with the optical isotropy limits the applicability of most well-known texture determination methods in geology. Therefore only a few investigations of preferred orientations in natural rock salt have been reported by Schwerdtner, Goemann and Brockmeier. Up to now, however, there has been no clear understanding of the influence of texture on the physical properties and of the existence of a texture in natural rock salt.

For the first time the texture was studied using neutron diffraction to get information about the global texture in coarse-grained rock salt and to determine experimental parameter for texture measurements.

Samples used in this investigation are naturally deformed rock salt from the Zielitz mine near Magdeburg (G.D.R.), the Bleicherode mine (G.D.R.) and the Werra region (G.D.R.). Samples were orientedly cut in a reproducible geographical and also in a geological coordinate system to give information about a global texture and their inhomogeneities over a geological folding and perturbation zone. The initial material for our studies is the hanging wall salt of the stratigraphic layer Na $3\beta$ (650 m depth in Zielitz) in a Zechstein salt deposit (aged 240 mill. years) of the unit of Calvörde and the same stratigraphic horizonte in the other rock salt deposites of Bleicherode and the Werra region.

Slabs ($90 \times 90 \times 8$ mm$^3$) and cubes ($20 \times 20 \times 20$ mm$^3$) for the neutron texture experiments and polished sections for reflection optical microscopy studies were prepared. The average grain diameter of the coarse-grained halite determined by microscopic studies is about 2 to 4 mm shown in Fig. 3, representative for all samples investigated. Chemical analysis and X-ray powder diffraction patterns show halite to be the dominant phase (more than 92 mass $^0\!/\!_0$ NaCl) and they indicate that superpositions of Bragg reflections by other minerals (sylvin, anhydrite and hematite in a small concentration up to 5 mass $^0\!/\!_0$) can be neglected.

Neutron diffraction experiments were done at he water moderated research reactor of the CINR Rossendorf, G.D.R. It provides a flux of monochromatic thermal neutrons at the sample position of about $10^8$n cm$^{2-}$ s$^{-1}$. The beam size is 40 mm in diameter. Neutrons are collimated by Soller slits of variable divergence. Diffracted intensities were measured for a preset monitor count rate to compensate changes in neutron flux by a He$^3$-detector. The detector slit was 38 mm and 90 mm respectively. The complete pole figure was scanned in a equal-angular scan of $\Delta\psi = 6°$ and $\Delta\varphi = 6°$ in transmission and reflection as shown in Fig. 4 giving a total of 1020 data points on the hemisphere. For geological material the complete pole figure is needed because no sample symmetry can ad hoc be expected. Measurement of one pole figure tooks about 17 h.

In the angle-dispersive method the number of counts corrected for background is proportional to pole density. In the further numerical treatment we corrected the experimental data for absorption after Kleinstück. A special extinction correction has not been applied because extinction influence was not investigated separately.

The integral measurement of diffracted neutrons in diffraction angle $2\Theta_{(hkl)}$ and the increased incoming neutron beam up to 40 mm make demands for increasing of detector slit. The experimental (200) pole figures of halite in the same sample B.4 (Bleicherode) are shown in Figs. 5a and 5b respectively. Obviously an increase of detector slit leads to averageing of intensity. The result is a more clear picture of preferred orientations in he pole figure, more connected pole-density areas can be recognized and the pole figure can be better interpreted. In the Bleicherode mine we found only this type of a (100) fibre texture of halite. In the stronger plastically deformed Werra region we found an other type of preferred orientation of halite. In Fig. 6 the (110) pole figure is shown and one can see a significant girdle in 60° distance from pole figure centre. This is a typical pattern for a (110) fibre texture.

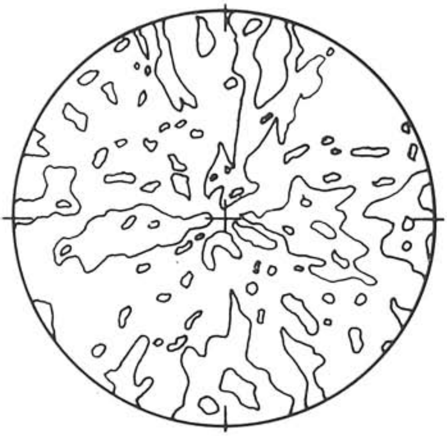

Fig. 5a. Sample B 4 (Bleicherode), detector slit 38 mm, counter level: 1.0; 1.5; invest. No.: 583391152 (200) pole figure, NaCl.

Fig. 5b. Sample B 4 (Bleicherode), detector slit 90 mm, counter level: 1.0; 1.5; 2.0; invest. No.: 584191152, (200) pole figure, NaCl.

Fig. 6. Sample W 6 (Werra region), counter level: 1.0; 1.5; invest. No.: 584161153. (220) pole figure, NaCl.

More improvements in pole figures (apart from increasing of detector slit) are possible by investigation of different neighboured samples with the same sample orientation and a following mathematical superposition of the single results in a summation procedure. In a so recorded "composite pole figure" more single grains are taken into consideration and the statistical significance is increased. On the other hand the single measurement may be compared to the composite pole figure in order to get information about the homogenity of the texture in a greater area. In Figs. 7a, 7b and 7c two single measurements of the NaCl (200) pole figures of neighboured samples from the Zielitz mine and the calculated composite pole figure are shown, respectively. From our calculations of composite pole figures we conclude, that a numerical superposition of 2 or 3 pole figures is sufficient for composite pole figures to be interpretable. Further mathematical summation of single measurements does not modify the picture of a composite pole figure significantly.

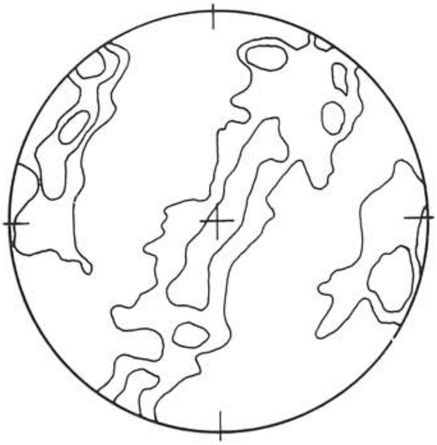

Fig. 7a. Sample 1.2.A. (1) (Zielitz), single measurement to composite pole figure, counter level: 1.0; 1.5; 2.0; invest. No.: 585071152, (200) pole figure, NaCl.

Fig. 7b. Sample 1.2.A. (3) (Zielitz), single measurement to composite pole figure, counter level: 1.0; 1.5; 2.0; invest. No.: 585091152, (200) pole figure. NaCl.

Fig. 7c. Sample 1.2.A. (Zielitz), composite pole figure, counter level: 1.0; 1.5; 2.0; invest. No.: 585821152, (200) pole figure, NaCl.

Our hitherto existing results in neutron texture investigations of halite in natural rock salt can be summarized as follows:

— all investigated samples from different points in the salt deposits of Zielitz and Bleicherode showed a corresponding weak (100) fibre texture. This could be interpreted as due to a planar deformation process.

— The (100) fibre texture of halite does not fit the rock salt layering. Over a folded rock salt layer, shown in Fig. 8 the halite texture does not follow the geological fold geometry in the perturbation zone of the Zielitz mine.

— The (100) fibre texture we found in 27 natural samples in the Bleicherode and Zielitz was in a good agreement with that found by Brockmeier in the Asse salt dome (F.R.G.).

— Our results show that the texture of halite in the Zielitz mine is largely influenced by recrystallization processes during deformation because a $(\bar{1}10)$ fibre texture after deformation reported by Kern could not be found in the perturbation zone.

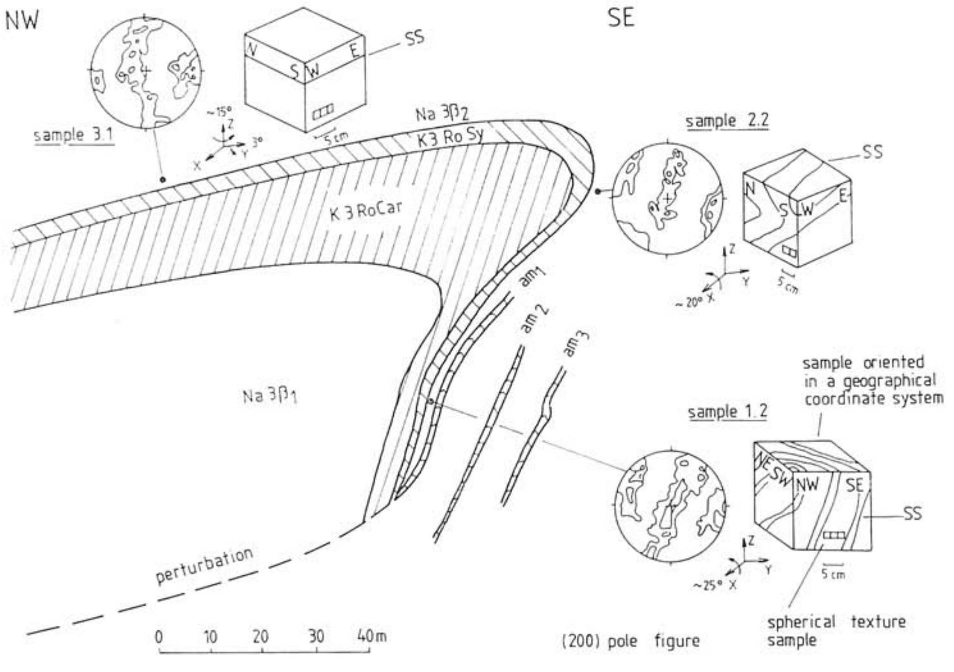

Fig. 8. Stratigraphical geological map of the perturbation zone (650 m depth) in the Zielitz mine with indication of sampling places. Only the (200) pole figures are shown with respect to the sample position in the folded rock salt layer, respectively.

— In the stronger plastical deformed samples of the Werra region we found a (110) fibre texture. This is in a good agreemet to the theoretical predicted pattern of preferred orientation in cubic minerals by Siemes using the Taylor theory.

## *Conclusion*

From our studies we can conclude that the texture of coarse grained natural rock salt can be determined using neutron diffraction. Our results on a natural folding and perturbation zone show that the halite texture is strongly influenced by recrystallization and they indicate a general texture in natural rock salt. However, more texture analysis of rock salt from other salt deposites will be required in order to generalize this results.

Preferred orientation in rocks is one of the most complex features in geology. More than any other fields its study needs collaboration of scientists with different backgrounds, geologists, physicists and material scientists. At present geology cannot supply many solutions about the development of textures but on the other hand is offers a multitude of challenging problems which are much more complex than in metals. I hope that this Symposium will promote some of the necessary interaction to help understand the processses which formed the Earth on which we live.

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