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In Situ Stress Measurements in the Copper Mine at Mitterberg, Austria

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With 6 Figures

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Summary — Zusammenfassung — Résumé

In-Situ Stress Measurements in the Copper Mine at Mitterberg, Austria. In-situ stress measurements were carried out in the copper mine at Mitterberg at a height of 664 m above sea level under a vertical overburden of 750 m. The "doorstopper"-method was applied. The measurements were made on 12 cores from one borehole which was directed towards the East. Except for the first three measurements which lay in a small depth range of the borehole behind a zone where retrieval of the cores was impossible, the scattering of the measurement values was rather small. Thus, a computation of mean values was significant. The determination of the E-modulus was carried out by means of a Goodman jack. These determinations gave additional information about the fracture zone around the borehole. The extent of the fracture zone was in agreement with the theoretical expectations regarding the direction of the maximum normal stress determined by the "doorstopper" measurements. The closure of an adjacent drive can be explained either by the development of a fracture zone in accordance with the stresses that were measured or because of an anisotropy in the foliated rock.

In-situ-Spannungsmessungen im Kupferbergbau Mitterberg. Im Kupferbergbau Mitterberg wurden in einer Seehöhe von 664 m und bei einer Überlagerung von 750 m In-situ-Spannungsmessungen mit Hilfe der Doorstopper-Methode durchgeführt. Es wurden dabei an zwölf Kernen innerhalb eines nach Osten orientierten Bohrloches Messungen durchgeführt. Mit Ausnahme der ersten drei Messungen behält die Achse der größten Dehnung ihre Richtung annähernd bei, so daß eine Mittelung sinnvoll erscheint. Zur Ermittlung des E-Moduls wurden Messungen mit der Goodman-Sonde vorgenommen. Diese Messungen erbrachten als weiteres Ergebnis auch Aufschlüsse über die Auflockerungszone um das Bohrloch. Die Ausdehnung der Auflockerungszone stand in Übereinstimmung mit der aus den Doorstopper-Messungen bestimmten größten Druckrichtung. Die Konvergenz der Verformungen einer benachbarten Strecke kann entweder durch die Ausbildung der Auflockerungszone entsprechend dem gemessenen Spannungsfeld oder durch die Anisotropie des geschieferten Gebirges erklärt werden.

Déterminations des contraintes en place dans la mine de cuivre à Mitterberg, Autriche. Des déterminations des contraintes furent faites sur place dans la mine de cuivre à Mitterberg à une élevation de 664 m s. m., ce qui est 750 m en dessous de la surface. La méthode "doorstopper" fut utilisée; les déterminations furent faites avec 12 carottes prises dans un seul trou orienté vers l'Est. Si l'on élimine les 3 premières déterminations dans la zone près de la bouche du trou, les directions trouvées de la plus grande dilatation sont à peu près constantes; on peut alors former une moyenne. Le module *E* fut déterminé par une sonde de Goodman, ce qui permettait de calculer les contraintes. Comme resultat gratuit, les observations donnèrent aussi une indication de l'ampleur de la zone affaiblie autour du trou, dont la plus grande épaisseur fut trouvée dans la même direction que celle de la plus grande contrainte déterminée par la méthode "doorstopper". La convergence des déformations d'une galerie dans le voisinage du point où les contraintes étaient determinées, peut être expliquée par la formation d'une zone affaiblie en correspondance avec le champ des contraintes déterminées ou par l'anisotropie causée par la foliation dans les roches.

1. Introduction

The *in situ* stress measurements which were carried out in the copper mine at Mitterberg, were part of a research program which is a contribution to the International Geodynamics Project. In this paper we report the first results of these measurements and try to find a connection between the effect of the stress field and the stresses that were measured.

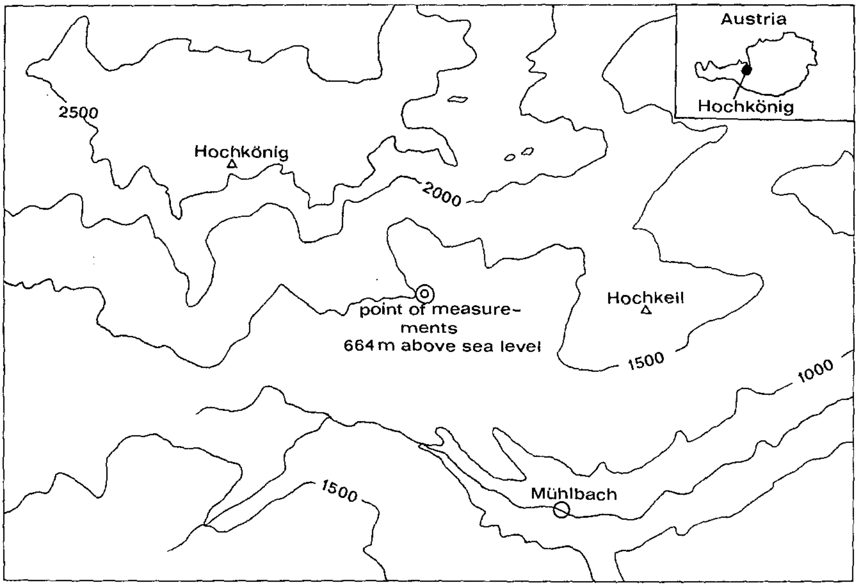

Fig. 1. Location of the point of measurements
Lage der Spannungsmeßstelle
Situation du point de mesure des contraintes

2. Location

The *in situ* stress measurements were carried out on the ninth level of the copper mine at Mitterberg at a height of 664 m above sea level. The overburden amounted to approximately 750 m. The borehole was drilled to a length of about 12 m; it was oriented toward the East and it had an inclination of 7^0. The Gauss-Krüger coordinates (M 31) of the beginning of the borehole were $x = +5\,251\,760$ m and $y = -17\,720$ m. The location of the place of the measurements is shown in Fig. 1.

3. Geology

The place of the measurements is situated within the Purple Series of Mitterberg. These strata are underlain by the Grey Series of Mitterberg and underlie the Green Series of Mitterberg. These series are greywackes belonging to the paleozoic epoch; sediments corresponding to the complete Triassic sequence (to Lias) lie upon them. At the place of the measurements, the Purple Series of Mitterberg is composed of clayey phyllites and argillaceous quartzites. Coarse-grained quartz dykes frequently cross the rock masses.

The following discontinuities influence the properties of the rock:

(a) Bedding Planes.

The sedimentary stratification is clearly visible in the sequence of phyllites and quartzites. The stratification joints are tight. The thickness of the bedding is less than 40 cm.

(b) Foliation Planes.

The foliation forms a widely spaced system of planes which is not very clearly developed. The distance between the foliation planes is about 1.5—2.0 m.

(c) Joint Systems.

Two joint systems can be seen, an older one which dips toward the East and a younger one which dips toward the West. In the domain where the measurements were carried out, the eastward-dipping system is better developed than the westward-dipping one. Fig. 2 shows an equal-area projection of the discontinuities found at the place of the measurements.

4. Measurements by Means of the "Doorstopper" Strain Cells

The stress measurements were performed by the use of the "Doorstopper Method". This method is based on a determination of the stress relief on cores during overcoring. The measurements were carried out during the time from February 14 to February 27, 1973. Strain readings were taken on 12 cores at a range of the borehole head from 6.68 m to 11.86 m. The elastic strains were superposed upon creep strains of variable intensity. For an elimination of the creep effect on the result of the stress determination, we observed the creep rate and reduced the strain readings by a linear rela-

Table 1. Principal Strains, Found by Means of the "Doorstopper-Method"
Ergebnisse der Doorstoppermessungen
Dilatations principales trouvées par la méthode "doorstopper"

Depth of the borehole T (m)	Principal strains and direction of the axis of the greater principal strain ε_1 (10^{-6})	ε_2 (10^{-6})	(ϑ)
6.68	1428	432	15
6.84	295	160	20
7.26	1122	178	61
7.54	324	56	114
7.84	984	306	95
8.93	1094	-14	121
9.45	1084	-104	94
9.70	1298	182	128
10.03	800	-180	141
11.41	1144	196	138
11.64	996	4	139
11.86	906	-106	122

tion to a time 5 minutes after the beginning of the overcoring procedure. We assumed complete elastic stress relief at that instant. Table 1 shows the strains transformed to principal strain axes. The major principal strain is denoted by ε_1, the minor principal strain by ε_2 and the angle between the axis of the major principal strain and the horizontal direction (measured anticlockwise) by ϑ.

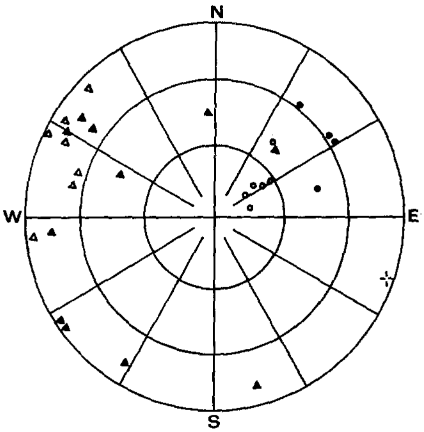

Fig. 2. Equal-area projection of the discontinuities at the point of measurements (courtesy Dr. F. Pausweg)

○ stratification, ● foliation, △ older joint system, + younger joint system, ▲ small joints

Gefügediagramm der Spannungsmeßstelle (mit der Freundlichkeit von Dr. F. Pausweg)

○ Schichtung, ● Schieferung, △ älteres Kluftsystem, + jüngeres Kluftsystem, ▲ Kleinklüfte

Diagramme du clivage dans le voisinage du point de mesure des constraintes

○ stratification, ● foliation, △ ancien système du clivage, + nouveau système du clivage, ▲ clivage miniature

From a borehole depth of 7.5 m onward the principal axes maintain an approximately constant direction. Thus the computation of mean values is significant from this borehole depth onward. One obtains

$$\varepsilon_1 = (959 \pm 93) \cdot 10^{-6}$$
$$\varepsilon_2 = (38 \pm 54) \cdot 10^{-6}$$
$$\vartheta = 121^0 \pm 6^0$$

The first three measurements lay in a small depth range of the borehole behind a zone where retrieval of cores was impossible.

5. Measurements by Means of a Goodman Jack

Measurements with a Goodman jack were carried out during the period from March 19 to March 21, 1973 for a determination of the *E*-modulus. The Goodman jack is a borehole probe with movable rigid bearing plates for the measurement of wall deformations as a function of applied load.

Table 2. Results of the Measurements by Means of the Goodman Jack
Ergebnisse der Goodmansondenmessungen
Résultats des observations faites par la sonde de Goodman

Depth of the borehole	Orientation	Moduli			Ratio
T (m)	α (^{0})	V (10^3 kp/cm^2)	E_1 (10^3 kp/cm^2)	E_2 (10^3 kp/cm^2)	E_1/E_2
7.80	0	12	16	26	0.62
7.89	90	10	21	18	1.17
9.00	0	20	27	46	0.59
9.00	90	11	43	56	0.77
9.70	35	15	20	65	0.31
9.70	125	20	50	61	0.82
10.00	35	15	35	56	0.62
10.00	125	23	70	67	1.04
10.70	35	14	38	65	0.58
10.70	125	24	55	49	1.12
11.40	35	11	19	21	0.90
11.40	125	17	24	34	0.71
11.85	0	10	18	21	0.86
11.85	90	11	17	30	0.57

Data obtained from the load-deformation measurements permit one to calculate the *E*-modulus of the rock in the direction in which the load is applied. The *E*-modulus is given by the following formula:

$$E = K \frac{\Delta p}{\Delta d/d} \tag{1}$$

In this formula, Δp is the variation of the pressure applied by the borehole probe to the borehole perimeter. The ratio $\Delta d/d$ is the relative widening of the borehole diameter, K is a constant which is determined by the Poisson ratio ν and the geometry of the loading plates. Theoretical calculations lead one to expect that $K = 1.25$, but, *in practice*, this value appeared to be too low by a factor of 2 to 3 (personal communication by Dr. R. Goodman). For our computations of the E-modulus we assumed therefore $K = 1.25 \cdot 2.5$.

At each point of measurement, three load-deformation-cycles were observed. From the resulting data three different E-moduli were evaluated.

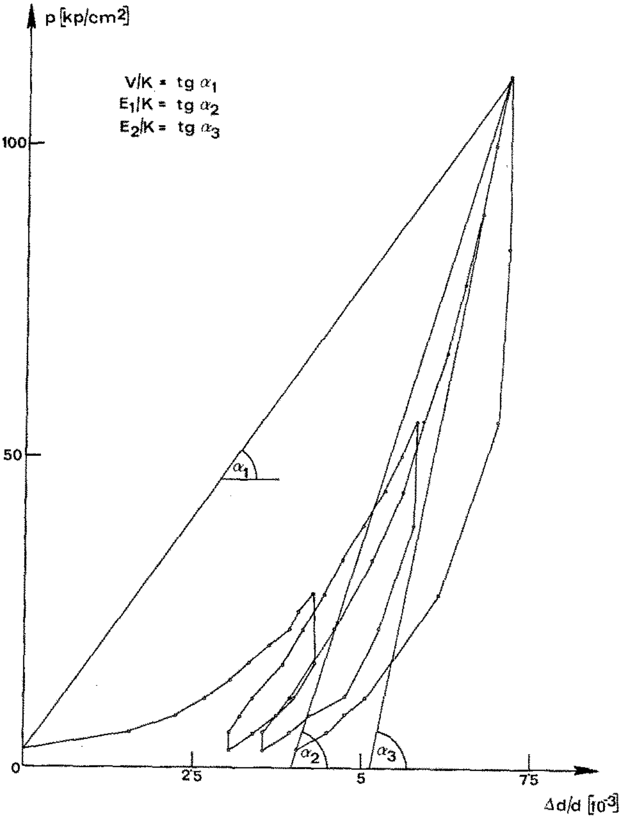

Fig. 3. Procedure for the determination of the moduli V, E_1 and E_2
p ... plate pressure; $\Delta d/d$ ... relative dilatations of borehole

Auswertung der Goodmansondenmessung für die Moduln V, E_1 und E_2
p ... Anpreßdruck, $\Delta d/d$ ... relative Bohrlochaufweitung

Utilization des observations faites avec la sonde de Goodman pour la déterminations de V, E_1 et E_2
p ... pression dans la sonde, $\Delta d/d$ ... dilatation relative du trou

These are denoted by V, E_1, E_2; their definition and significance is shown in Fig. 3; the results are collated in Table 2.

For a calculation of the stresses from the "doorstopper" strain readings, it is the modulus E_2 determined by the maximum slope of the ascending branch of the load-deformation curve which is significant. From seismic measurements, Poisson's ratio was determined to equal $\nu = 0.34$.

The measurements by means of the Goodman jack were carried out in two orthogonal directions at each point of measurement, viz. at 0^0 and 90^0 or 35^0 and 125^0.

No significant difference could be found between the E_2-modulus in two orthogonal directions. Therefore, we assume the rock to be isotropic with regard to E_2.

The frequency distribution of the E_2 modulus shows two maxima, one at $135 \cdot 10^3$ kp/cm^2 and the other at $200 \cdot 10^3$ kp/cm^2. The smaller value corresponds probably to the argillaceous strata whereas the higher value corresponds to the quartzities. As we were able to obtain only quartzitic cores, we chose $E_2 = 200 \cdot 10^3$ kp/cm^2 for the computation of the stresses from the "doorstopper" strain readings.

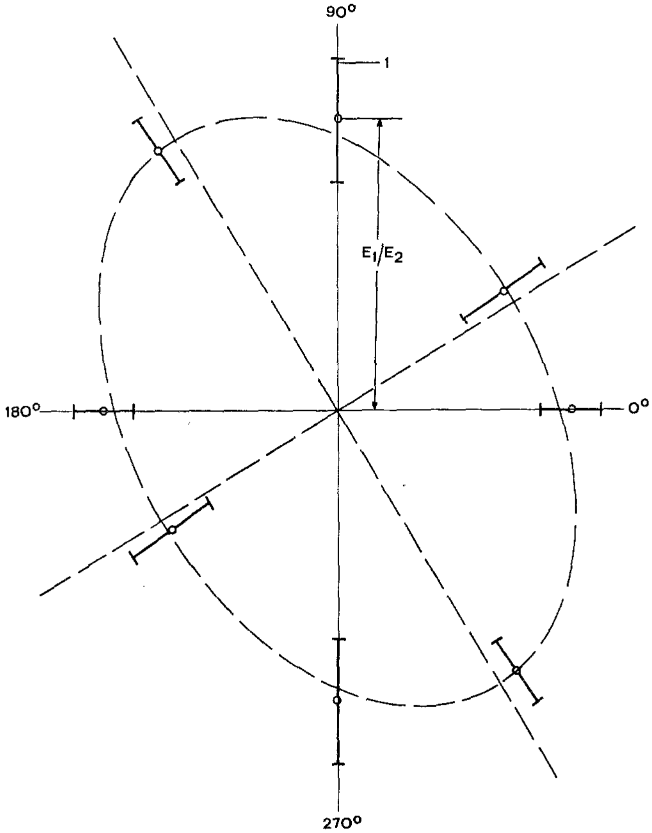

Fig. 4. Mean values and standard deviation of the ratio E_1/E_2 as a function of the direction in which the load was applied

Richtungsabhängigkeit des Verhältnisses E_1/E_2

Variation de la proportion E_1/E_2 en fonction de la direction

A further result of the measurements by means of the Goodman jack is shown in Fig. 4. In this figure the mean values and the standard deviations of the ratio E_1/E_2 are plotted as a function of the direction in which the load was applied. A significantly eccentric distribution was found. Fitting the mean values of E_1/E_2 obtained for the different directions to an ellipse, we find a good agreement of the long axis of this ellipse with the direction of the maximum stress found by the "doorstopper" measurements.

An explanation of this fact can be attempted as follows. The modulus E_1 is determined purely by the elastic properties of the rock whereas the modulus E_2 is affected by the whole deformation path and therefore by the extent of the plastic zone around the borehole. As the thickness of the plastic zone around a circular hole in a homogeneous and isotropic condition is greatest in the direction of the minor principal stress axis, we obtain an explanation for our observations from this fact (Isaacson, 1962, p. 69). The measurements by means of the Goodman jack yield therefore a confirmation for the orientation of the principal stress axis.

6. Computation of the Stresses

As the rock is isotropic with respect to E_2, the principal axes of the stress and strain tensors coincide. Therefore, the direction of the maximum pressure forms an angle of $\vartheta = 121^0$ (measured anticlockwise) with the horizontal. The principal stresses σ_1' and σ_2' in the plane perpendicular to the borehole axis are given by the following formulae (Leeman, 1969):

$$\sigma_1' = \frac{E}{2}\left(\frac{\varepsilon_1+\varepsilon_2}{1-\nu} + \frac{\varepsilon_1-\varepsilon_2}{1+\nu}\right) \tag{2}$$

$$\sigma_2' = \frac{E}{1}\left(\frac{\varepsilon_1+\varepsilon_2}{1+\nu} - \frac{\varepsilon_1-\varepsilon_2}{1+\nu}\right) \tag{3}$$

Inserting $E_2 = 200$ kp/cm², $\nu = 0.34$, $\varepsilon_1 = 959 \cdot 10^{-6}$ and $\varepsilon_2 = 38 \cdot 10^{-6}$ in the Eqs. (2) and (3), we obtain

$$\sigma_1' = 220 \text{ kp/cm}^2$$
$$\sigma_2' = 82 \text{ kp/cm}^2$$

As a consequence of the stress concentration at the end of the borehole, the stresses σ_1' and σ_2' are different from the stresses in the undisturbed rock. For the computation of the real stresses σ_1 and σ_2 the following relations were used (Leeman, 1969):

$$\sigma'_{1/2} = 1.25\,\sigma_{1/2} - 0.75\,(0.645 + \nu)\,\sigma_z \tag{4}$$

Here, σ_z denotes the normal stress in the direction of the borehole axis.

Calculating the vertical pressure from the height of the overburden which amounts 750 m and from the mean density of the rock of about 2.7 g/cm³, we obtain 200 kp/cm²; using this value we obtain an estimate of the principal stresses in the plane normal to the borehole axis. They are:

$$\sigma_1 = 230 \text{ kp/cm}^2$$
$$\sigma_2 = 120 \text{ kp/cm}^2$$

Fig. 5 shows a cross section through the Hochkönig, indicating the point of the measurements and the principal stresses in the plane normal to the borehole.

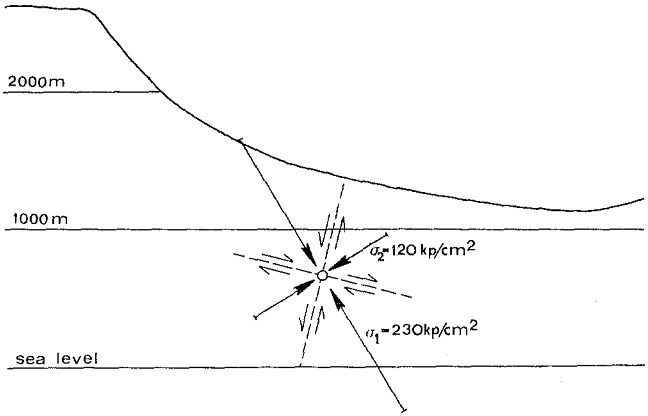

Fig. 5. Cross section through the Hochkönig and principal stresses

Spannungshauptachsen in einem ausgeglichenen N—S-Schnitt durch den Hochkönig in der Ebene der Spannungsmeßstelle

Directions principales des contraintes dans un profil généralizé du Hochkönig, dans le plan oú les contraintes furent déterminées

7. Example of the Effects of the Ambient Stress Field

Fig. 6 shows the effect of the ambient stress field on a drive which was made 12 years ago and which is situated on the ninth floor within the Grey Series of Mitterberg. On the right hand side of the figure, the geomechanical conditions prevailing before the deformations occurred, are schematically shown. As the drive strikes approximately E—W and as it is situated in the vicinity of the stress-measurement point, we assume that the same stresses prevail in a cross section through the drive as those measured by the "doorstoppers". The foliation is well developed within the Grey Series, it is nearly parallel to the strike of the drive; its dip coincides with the major principal stress axis in the plane normal to the borehole. The rock masses close in mainly from the upper part of the south wall. As an explanation of this observation, one may refer to the varying thickness of the plastic zone around the drive. As the greatest extent of the plastic zone in an isotropic rock lies in the direction of the minor principal axis, we may expect the closure of the drive to proceed mainly from this direction. The rock mass will close in on the drive more from the upper part of the south wall than from the lower part of the north wall because of the action of gravitational forces. This explanation of the observed closure of the drive agrees with the stresses measured by means of the "doorstoppers".

However, one must also admit that one has a case of anisotropy because of the well-developed foliation within the Grey Series. This anisotropy could suffice for an explanation of the closure observed even in the case where only hydrostatic stresses were present. Because of the small tensional and shearing strength in the plane of foliation, laminations will be created.

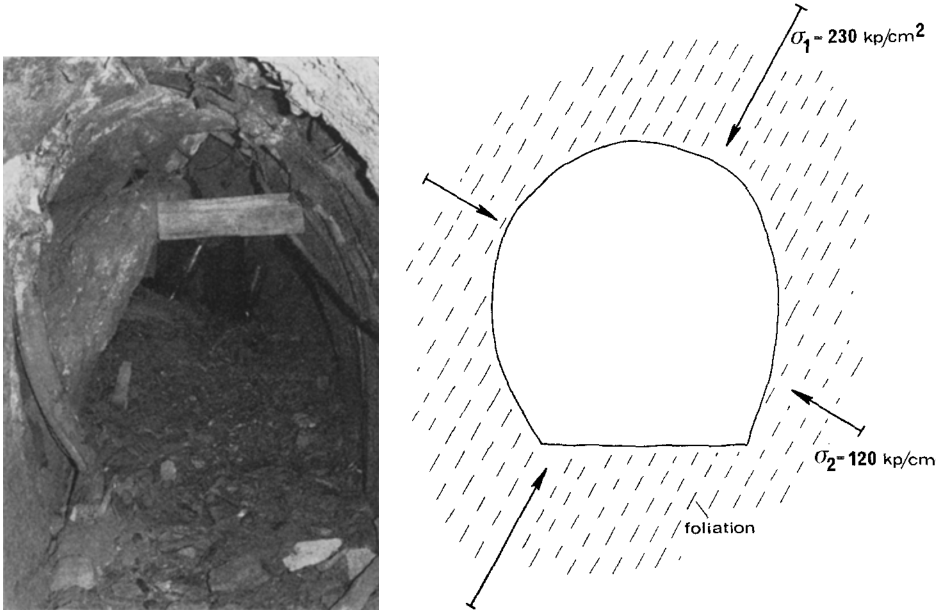

Fig. 6. Effect of the stress field on a drive

Konvergierender Stollen und Schema der geomechanischen Gegebenheiten

Effet du champs de contrainte observé sur les déformations d'une galerie

The lamellae will behave according to the beam theory (Isaacson, 1962, p. 79). Fracture will occur due to tension caused by the bending of the lamellae.

8. Acknowledgements

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