Measurements of Rock Pressure and Pillar Loads in Deep Potash Mines

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ABSTRACT

Failures in German potash mines (rock bursts, water inflows, gas outbursts) induced intensive efforts for better knowledge of salt rock reactions in mining.

Measurements in potash mines have been carried out using the following techniques: Deformation measurements in bore holes relative to wall, roof, and floors; measurements of absolute subsidences/uplifts after working a panel; bolt loading measurements; measurements of hydrauli pressures in bore hole sections filled with oil and sealed.

The measurement results represented by graphs and tables enable the following statements:

1. *Any new opening in rocks subject to a high triaxial stress removes one direction of stress. The surrounding salt rock reacts immediately by plastic deformation into the opening. Deformations measured shortly after working do not indicate loading, but relaxation of the involved salt rock.*

2. *Plastic deformation of salt rocks depends on time; moreover, the zone of flow extending is controlled by mechanical properties of the involved rocks and their original stress.*

3. *As soon as the time required for sufficient flow has passed, the very low yield points of salt rocks allow only quasi-hydrostatic local stresses running from approximately zero a the boundaries of the openings to the original stress behind the zone of flow.*

4. *In spite of the great transverse extension, small, high pillars do not take any load until the strata of the main roof subside at a sufficient rate. Thus the uplift of the strata belo a panel is not efficiently impeded, if competent roof strata delay subsidence.*

5. *Sudden recovery of delayed subsidence may load pillars too fast; first of all, carnallite pillars are subject to brittle fracture by sudden loading due to rock bursts in competent roof strata. Similar release fracture is caused by sudden removal of one stress direction from salt rocks which include gasses under high pressure.*

INTRODUCTION

During the past century, since the first potash was mined at Stassfurt, more than 250 potas shafts have been sunk in various districts of Germany. More than 100 of these shafts are now flooded, in a great many cases because of insufficient roof support by pillars. Many other German potash mines have suffered rock bursts or gas inflows, the record of the 1950's shows:

1951, gas explosions or partial collapses in four potash mines, South Harz district.

1953, rock burst caused partial collapse in a potash mine, Werra district.

1954, water influx from the floor into a potash mine, South Harz district.

1955, nearly all workings of a potash mine collapsed, Stassfurt district.

1957, all workings of a potash mine flooded from the floor, South Harz district.

1958, largest rock burst ever known in world mining destroyed several square miles of a potash mine, Werra district.

1959, partial collapse of a potash mine, Stassfurt district.

Considering a loss rate of one shaft per year, a great many investigations have been carried out during the past 15 years in order to determine the causes of such failures and to eliminate them in further operations.

However, conclusions drawn from measurements in mines and from experiments in laboratories differ greatly; in particular, false conclusions have been drawn from pillar deformation measurements because some authors believe that pillar deformations are exclusively caused by loading comparable to sample loading in a laboratory.

Figure 1, a typical example, was first published in 1958 (Hoefer, 1958 a, b), but demonstrated as incorrect by several discussions at the International Strata Control Conference, Leipzig, 1958 (Baar, 1959; Wilkening, 1959). Nevertheless, this figure and consequently false conclusions drawn from it were stressed in various later publications and finally, again emphasized at the IV International Conference on Strata Control and Rock Mechanics, New York City, 1964 (Hoefer, 1964).

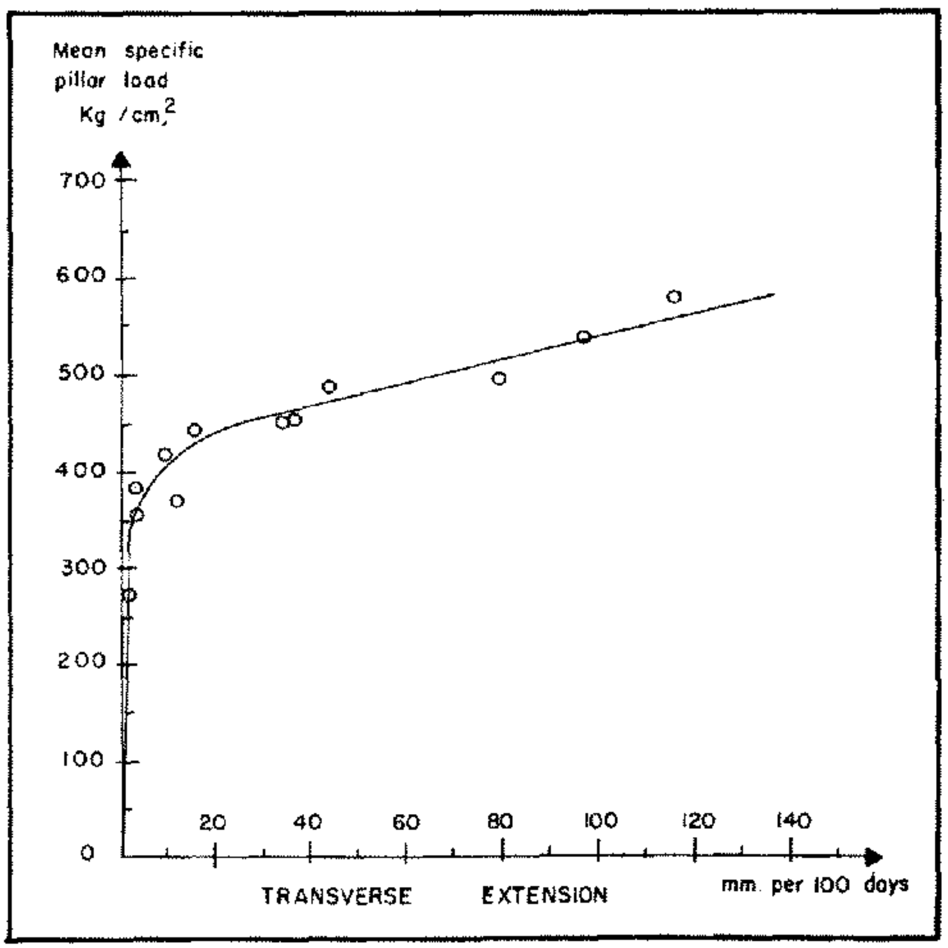

Figure 1. Rate of transverse extension in pillars as a function of the mean specific load on the pillars (after Hoefer, 1964).

Following this figure, pillar transverse extensions measured in South Harz potash mine caused by loading with the full weight of the overburden. A correction to this conclusion will given by various measurement results dealt with in this paper. However, it is not the purpos this paper to discuss incorrect conclusions, but to present measurement results.

Although the main conclusions drawn from these measurements are believed to be inevit anyone may accept or refuse them; objections from any point of view will gladly be considere should a real argument occur. The matter of rock mechanics in deep potash mines is extrem important since every mine represents a value of many millions of dollars, in particular, if t depth is more than 3,000 feet as is the case in Saskatchewan.

MEASUREMENT CONDITIONS AND TECHNIQUES

The measurements, some representative results of which will be given, were carried o a potash mine in the South Harz district. In 1938, this mine suffered a water inflow from the and had to be abandoned. Efforts in sealing the flooded workings succeeded later on and new ings were opened using the main shafts and the shafts 1 and 2 as shown in Fig. 2. This unusu situation enabled roof strata subsidence to be compared to pillar transverse extensions.

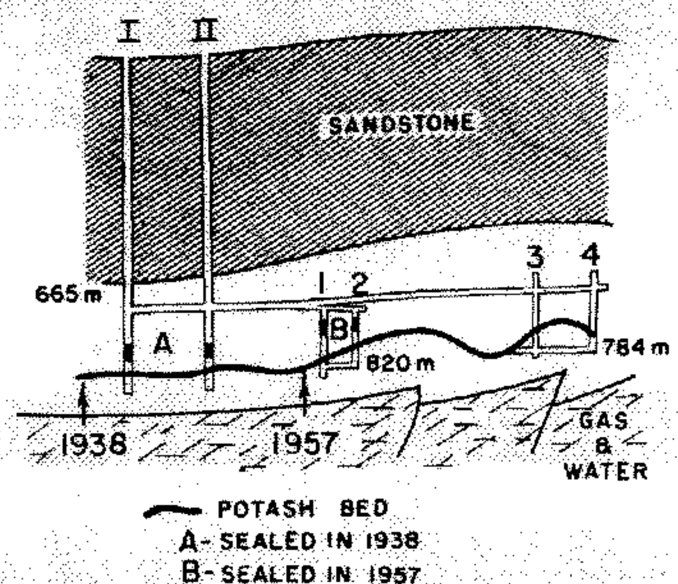

Figure 2. Scheme of a potash mine, South Harz district, Germany. White: Rock salt sequence.

In 1957, the measured deformations resulted in another water inflow from the strata bel the salt sequence. Again, sealing the flooded workings succeeded, and production was resum workings outside of the flooded areas using the shafts 3 and 4 as shown in Fig. 2.

During the past decades, similar water inflows from the strata below the salt sequence caused the total loss of several mines in this district, and gas inflows also occurred from the strata. For this reason, extensive measurements, surface subsidence measurements as wel pillar deformation measurements, have been carried out in this potash mining district.

The normal geological succession above and below the worked potash bed is shown in Fi The rock salt between the potash horizon and the gas and water bearing floor strata varies in mal thickness from 30 to 75 meters (100-250 feet). As far as this rock salt bed is not affecte mining operations, it is absolutely impervious and provides for a safe sealing of gasses and b in their reservoirs below the mine workings.

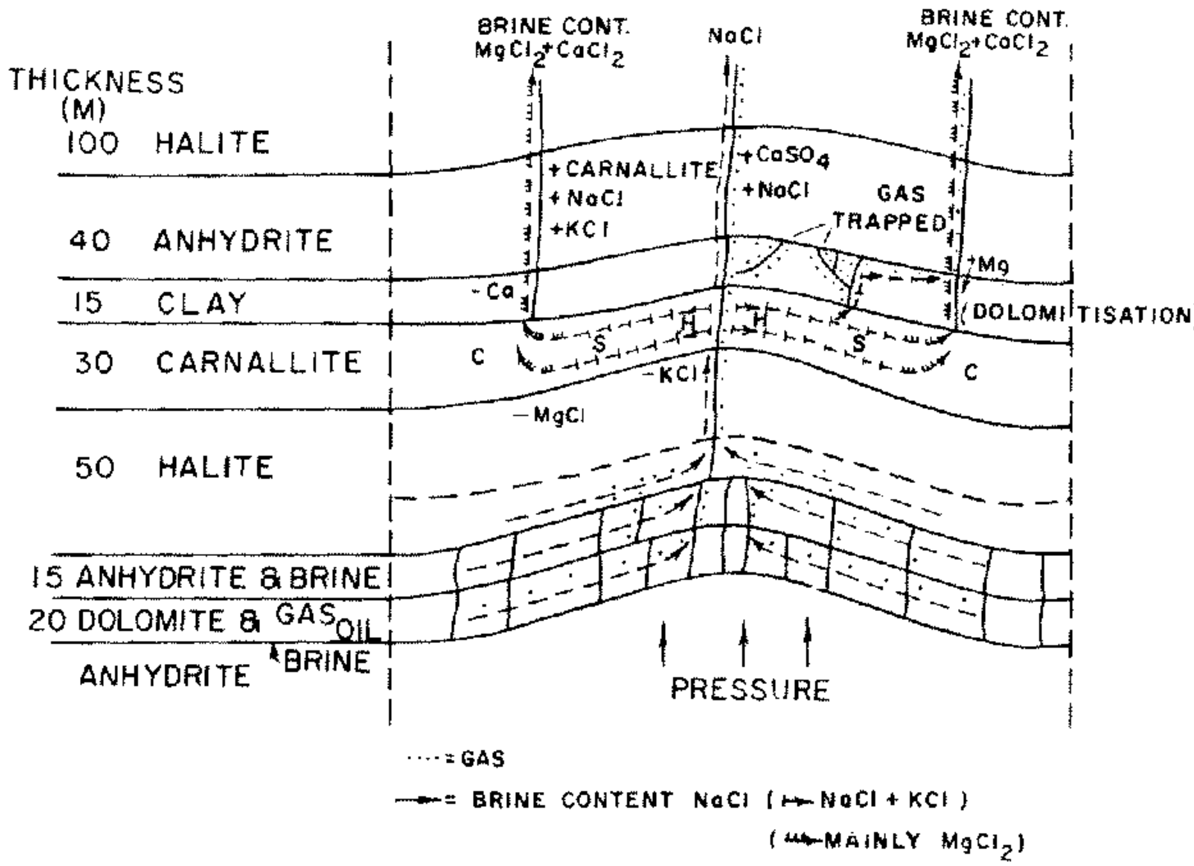

Figure 3. Stratigraphic column of the salt succession and scheme of alterations of the potash bed by ascending brines in the geological past, South Harz district.

C -- Carnallite Precipitation: +

S -- Sylvite

H -- Halite Dissolution: -

Due to tectonic movements in the geological past, gasses and brines ascended in fissure zones and resulted in alterations of the potash bed as shown in Fig. 3. Small areas of workable sylvite ore were formed near unworkable carnallite or halite rock areas. For this reason, the normal panels are small in this mining district. The sylvite ore is worked in rooms up to 250 m. long, pillars of the same length being left between the rooms.

From the geological situation, it is obvious that the remaining pillars have a very important role to fulfill in a panel. It is not only indispensable that they support the immediate roof in order to prevent collapses, but far more important is the prevention of floor deformation, which would permit the infiltration of water or gasses from the reservoirs below the salt.

As far as pillar extension measurements are concerned, the main question is: do pillar extensions indicate pillar loading sufficient both for roof support and prevention of floor deformation? Figure 1 indicates yes, but the measurements to be presented here contradict this conclusion.

In the above mentioned mine, measurements were carried out for several years before the mine was flooded for the second time in 1957, the main level being 820 meters below the surface at that time. Measurements were carried out by two other authors (Kampf-Emden, 1956; Wilkening, 1957) as well as by the author of this paper, using the following techniques:

1. Measuring the extension of the rock surrounding an opening using boreholes relative to the surface. Figure 4 demonstrates a scheme applied especially in connection with pressure measurements in boreholes (item 4). Measuring the alterations of depths of boreholes of

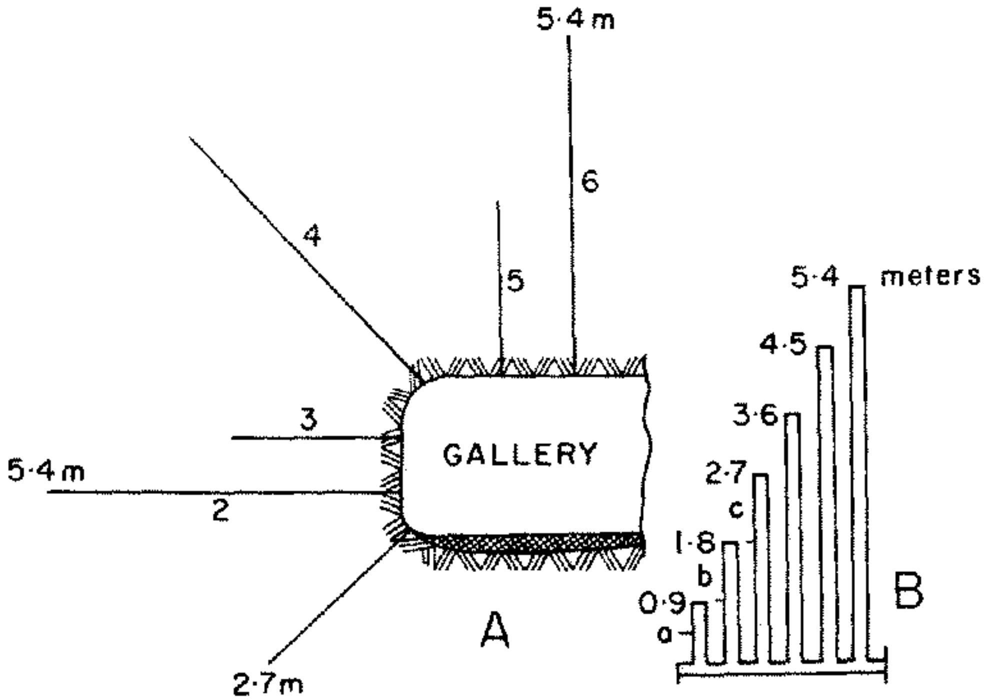

Figure 4. Extension measuring scheme, each numbered line representing a series of boreholes up to the indicated depth as shown by the separate scheme B.

different initial depths indicates deformations of rock sections at various distances from the opening surface.

Diverse measuring methods were used, the following was apparently the most convenient one: to attach wires at the borehole bases, stretch them by weights, and conduct them over a tube fastened to the wall, a hand fixed at every wire indicating the alteration in length on millimeter paper glued to a plate below the tube. Employing writing indicators and moving the millimeter paper by a clock work, the alterations in length of boreholes may be recorded easily.

2. Measurements of loads on steel rods in boreholes through pillars, the rods being attached to both pillar sides.
3. Measuring absolute subsidences or uplifts above and below workings (Wilkening, 1957).
4. Measurements of pressure in borehole sections filled with oil and sealed. Inclined boreholes were drilled up to various distances from an opening, the deepest sections of approximately one foot were filled with oil. The holes were sealed using a special cement mixture, the oil-filled section being connected to the opening by a high pressure steel tube. Closing the tube, the pressure in the deepest part of the borehole was indicated or recorded. Using a pump, any pressure could be produced in the measuring section; opening the tube, the pressure decreased immediately due to oil outflow.

MEASUREMENT RESULTS AND IMMEDIATE CONCLUSIONS

Deformations Around Openings

Figure 5 shows typical transverse extension curves measured in Fig. 4 stations.

Curves 1-3 represent measurements in a gallery surrounded by rock salt. Measuring began one year after working the gallery, except curve 3 measurements for which began three months after working. During measuring time, no mining was carried out in the neighborhood. Accurate data is compiled in Table 1. Average data of section extension in a Fig. 4 type station is compiled in Table 2. Measuring conditions equal those of curves 1 and 2, Fig. 5.

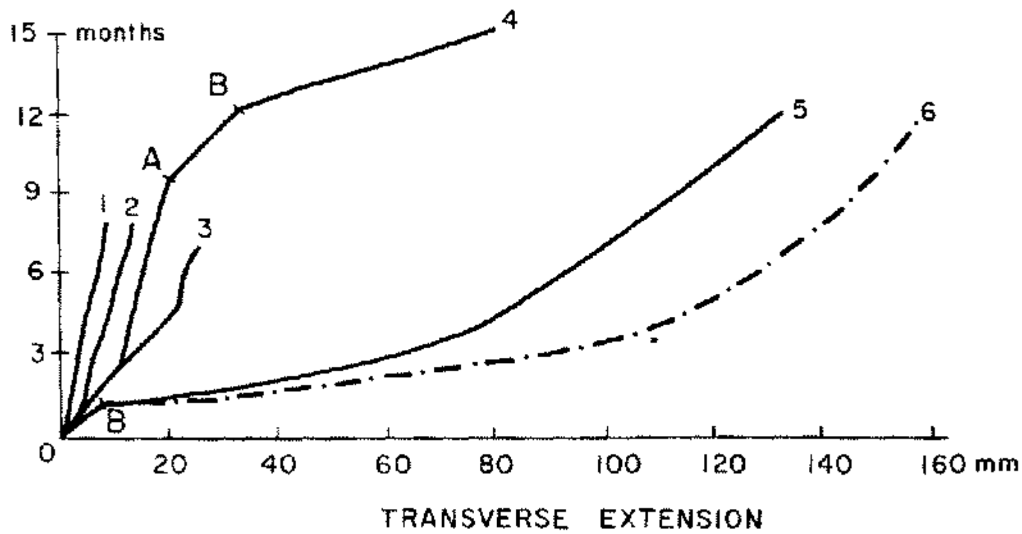

Figure 5. Transverse extensions measured in Figure 4 type station.

TABLE 1

Data Concerning Figure 5, Curves 1-3

Curve --	1	2	3
Height of wall (meters)	2.6	2.6	2.2
Height of borehole above floor (meters) and inclination (if not horizontal)	2.5/45°	1.7	1.4
Initial length of measured section (meters)	2.83	2.80	2.70
Extension (millimeters) and measuring time (months)	8/8	13/8	25/7
Extension per month (millimeters)	1.0	1.6	3.6

TABLE 2

Average Transverse Extensions,
Measuring Conditions Equaling Figure 5, Curves 1 and 2

Average extension of 2.7 meters sections in 20 months		21.9 millimeters	
Extension achieved in the first 10 months measuring time		14.9 millimeters	
Extension achieved in the following 10 months measuring time		7.0 millimeters	
Percentage of average extension in sections a, b, c (see Figure 4)	a. 52%	b. 28%	c. 20%
Same percentage in the first 10 months measuring time	54	26	20
Same percentage achieved during the following 10 months	49	33	18

Curves 4-6, Fig. 5, show typical pillar transverse extensions. The pillar rock is made up of anhydrite (20%), sylvite (30%), and halite (50%). At the measuring side of the pillar, its height was 6 meters, which was also the width of the pillar. Since the room at the measuring side had been excavated more than one year previous, the transverse extension into this room had died away as shown by curve 4 up to point A. At that time, a new room was worked, the initial height of which was 2.5 meters. At time B, the initial height was increased to 6 meters, which is also true for points B in curves 5 and 6. More interesting data is compiled in Table 3.

TABLE 3

Data Concerning Figure 5, Curves 4-6

Curve --	4	5	6
Height of measured borehole above floor (meters)	3.65	1.6	1.5
Initial length of measured pillar section (meters)	3.0	3.0	5.0
Transverse extension (millimeters)	80	134	160
Measuring time (months)	15	12	12
Average extension per month (millimeters)	5.3	11.2	13.3

Immediate Conclusions

1. Even more than one year after working an opening, the surrounding salt rock deforms into the excavation from all directions.
2. Initial high deformation rates decrease, but deformation continues for months and may still not be completely finished even after several years.
3. The centre of deformation is gradually removed from the surface into the surrounding rock.
4. The height of an opening is extremely important; the higher a wall, the easier and more extensively the rock deforms into an excavation.
5. Measuring pillar extensions and comparing extensions per time unit, regard must be paid to the time passed since an opening was excavated. Deformation rates during the first weeks after working differ greatly from deformation rates calculated from periods of months or even of years. In Fig. 1, the transverse extension rates were calculated from measurements over various periods from 103 to 1,245 days (Hoefer, 1958 a). Comparing such transverse extension rates, no correct conclusions can be drawn with respect to pillar loads.
6. At points B in Fig. 5, pillar and room width were the same before and after working. The theoretical "mean specific pillar load" has not been altered since only the pillar height increased. Nevertheless, large extensions occurred. Such pillar deformations, shortly after working, are not caused by higher pillar loads, but by pillar height increase as stated under item 4.

Remarks

Similar transverse extension development has been measured by both Kampf-Emden, 1956, and Hoefer, 1958 a, in the South Harz district, and at IMC Esterhazy, Saskatchewan mine by Zahary, 1965, who also believes in "consistency of loading and deformation."

Further conclusions from other observations and measurements should be mentioned: among salt rocks, ease of deformation increases in the following order: anhydrite, saliferous clay, anhydritic or kieseritic sylvite-halite, halite, sylvite, carnallite (Baar, 1953; Borchert and Muir, 1964).

Measurements of Loads on Rods Through Pillars

In order to detect the nature of deformation and the amount of force involved in pillar transverse extensions, steel rods in boreholes through pillars were attached to both pillar sides by steel plates. Pillar transverse extension was prevented until the rod was loaded sufficiently to deform. Compressive force could be applied to the pillar walls by tightening the nuts at the rod ends.

Figure 6A shows load measurement results immediately after working the second pillar side. Rod loads increased rapidly in agreement with the high deformation rates shown by Fig. 5, curves 4-6, after points B. Consequently, the rods were torn apart, breaking at the threads after some days. More than one month after working the second opening, the rods could bear the transverse extension; obviously, the rods then were increasing in length at the same rate as the pillar was extending.

Figure 6B shows the results of similar measurements on a pillar several months after working the second pillar side. The rod was loaded to 40 metric tons by tightening the nuts at the rod ends. This compressive load applied to the pillar obviously shortened the pillar width, since the indicated load decreased for some days; then, however, increased corresponding to further pillar transverse extension.

Immediate Conclusions

1. By applying compressive pressure against a pillar which has extended for some months, pillar transverse extension may be reduced at a certain rate.
2. Since observed deformations imply pillar relaxation and release fractures arise along pillar walls, rod load decrease as shown by Fig. 6B is apparently caused by recompression of the outer pillar parts by applying high initial compressive load to the pillar. Continuing transverse extension of the inner pillar equalizes this shortening within a limited time and then causes increasing rod loads.
3. Pillar transverse extensions shortly after working are not caused by loading, but by relaxation following the removal of one direction of stress from the pillar surface.

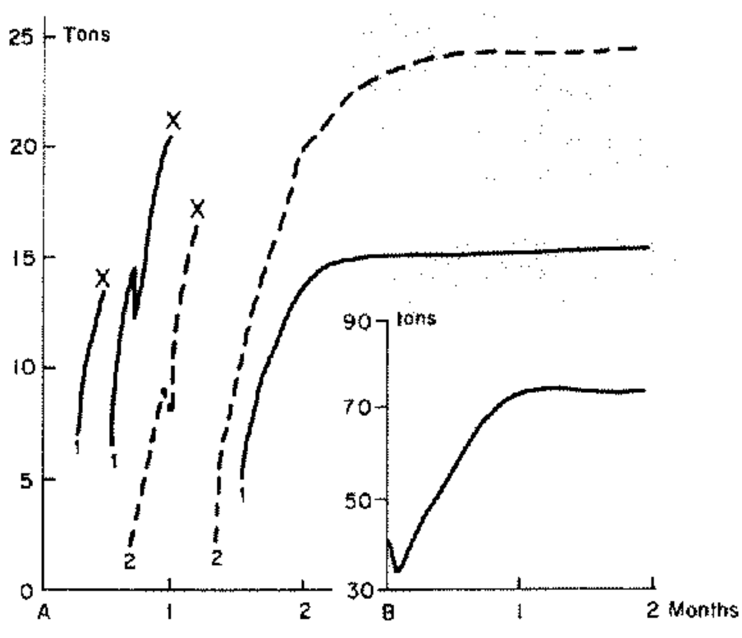

Figure 6. Loads on rods through pillars.

A Measurements, shortly after working the second pillar side.
X Rods torn apart.
B Measurements, several months after working, initial rod load first decreasing.

Subsidence Measurements Compared With Pillar Extension Measurements

Comparing subsidences measured in a roof gallery across a panel with pillar transverse e tensions measured in that panel, the nature of pillar deformations shortly after mining was definitely revealed.

The general situation is demonstrated by Fig. 2, the 665 m. level being the reference hori zon of subsidences measured as indicated by Fig. 7, which also shows the panel development at 820 m. level. Subsidences caused by working that panel were measured at 18 points in the roof gallery some of which are indicated along the reference lines in Fig. 7. The subsidence curves refer to measurements carried out one-half, one, two, and three years after working of the pane had begun. Various intermediate measurements confirm the subsidence development as shown b Fig. 7. Obviously, subsidence development corresponds to panel extension development.

Two years after working, the first four pillars in the panel centre collapsed without any ef fect on roof gallery subsidences.

Subsidences extended some 100 m. beyond the panel boundaries indicating compression of the nonextracted zone along the boundary, i.e., a zone of increased stress surrounding the pane as concluded from other observations in areas suffering gas or water inflows from the floor (Baa 1953, 1954 a, b).

Transverse extensions of the first pillars in the panel centre are listed in Table 4. Measu ing began one month after mining the first room had started, pillar width being 6 m., room widt 12 m., final pillar height 6-8 m., pillar rock consisting of 20% anhydrite, 30% sylvite, 50% halite. Measuring time zero is the moment in which the pillar side opposite to the measuring side was increased from 2.5 m. to the final pillar height.

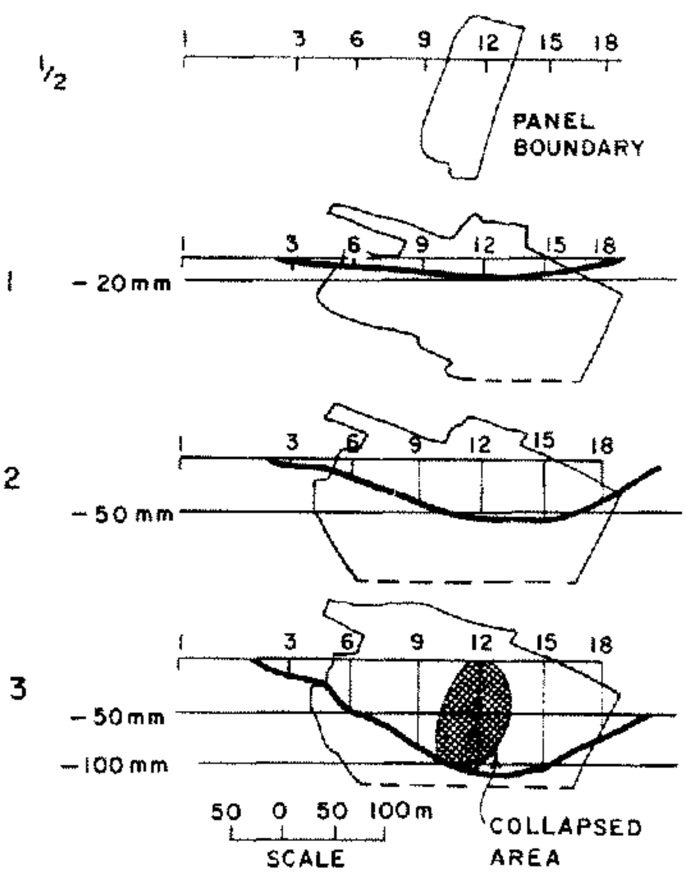

Figure 7. Subsidences above a panel and panel extension development (after Wilkening, 1967). One-half, one, two and three years passed since working of the panel began.

TABLE 4

Pillar Extensions in Millimeters
1, 2, 3: 3 m. Pillar Sections
4, 5: 5 m. Pillar Sections

Time since zero (months)	1	2	3	4	5
1	34.1	24.0	24.2	29.5	36.8
2	57.3	43.4	45.4	64.	66.6
4	97.2	72.6	79.8	106.3	105.6
8	177.4	112.2	117.0	160.1	146.8
10	201.9	123.9	130.9	180.9	157.6

Further measuring had to be ceased since heavy bed separation took place caused by release fissures along the pillar surface, rock scales up to one foot thick scaling off the pillars. After one more year, the pillar width in middle height was 2-3 m. instead of 6 m. original width.

Immediate Conclusions

1. Since rapid pillar transverse extensions, as listed in Table 4, took place before any subsidence was registered in the roof gallery, loading by the weight of main roof stata could not be the reason for pillar extensions; relaxation alone must have been the reason until a certain amount of reloading may have taken place by subsidence.
2. Because of pillar relaxation, the rock salt below this panel was not efficiently restrained against deformation by upheaval, which could result in water influx from the well-known reservoirs below the rock salt (thickness, 60 m.).

In 1956, these conclusions were not acknowledged, nevertheless, they were proved true some months later when the mine was flooded by a water influx precisely from the centre of that panel where the first pillars had collapsed without any effect on subsidence.

Pressure Measurements in Sealed Borehole Sections

Conclusions drawn from deformation measurements lead to the attempt of measuring hydraulic pressures in borehole sections filled with oil and sealed. Obviously, plastic deformation took place around openings. Since the yield points of salt rocks are known to be very low, pressures arising in sealed borehole sections should represent the local stress of the surrounding rock.

Questions to be clarified were: does plastic deformation strengthen (harden) salt rocks raising their yield points? How much time is required for the removal of strain hardening possibly introduced by plastic deformation (see Borchert and Muir, 1964, pp. 259-261)?

The answers have been ascertained by measurement results, some representative examples of which will be given as follows.

Figure 8 compiles daily readings of two borehole pressure measuring systems as described above, borehole depths being respectively 4.0 m. and 5.5 m. The measurements correspond to deformation measuring results shown by Fig. 5, curves 1-2. The pressure alterations indicated by dotted lines have been undertaken intentionally in order to observe the reaction of the measuring systems.

After a few months, the readings were remarkably uniform indicating pressures of 85 kg./cm.^{2} at 4 m. and 125 kg./cm.^{2} at 5.5 m. distance from the opening.

The original stress before working the opening was approximately 200 kg./cm.^{2}, calculated from a depth of 820 m. and an average overburden density of 2.5. Since deformation measurements had revealed rock flowage into the opening from all directions, the measured pressures were believed to indicate local stresses within the zone of flow surrounding the opening.

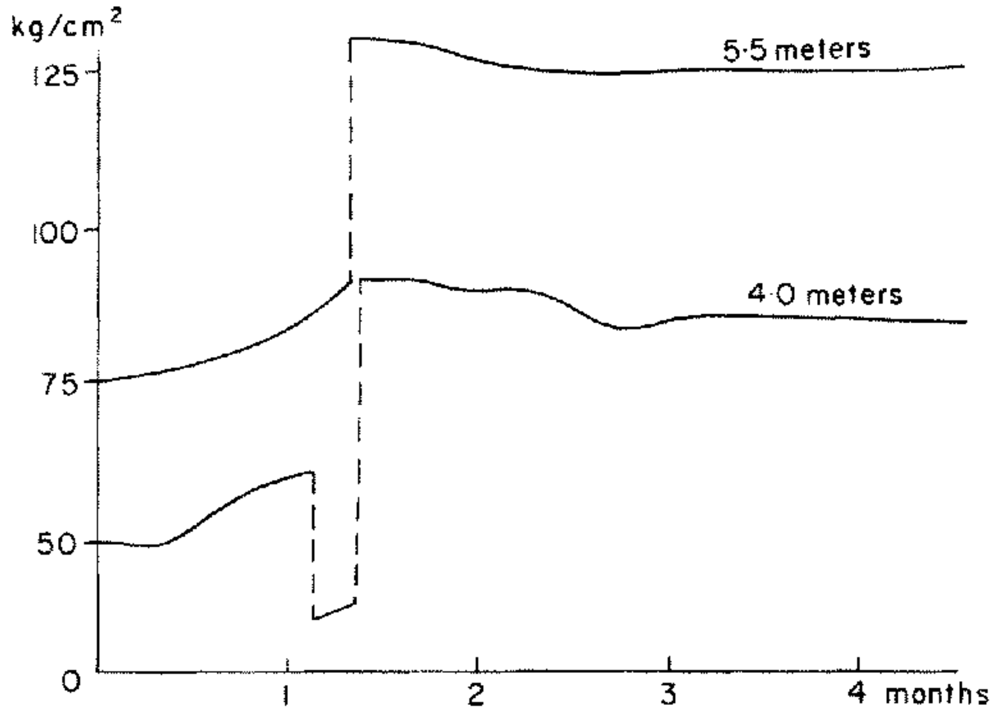

Figure 8. Pressures measured in borehole sections filled with oil and sealed. Borehole depth is 4. 0 m, and 5. 5 m. Dotted lines indicate intentional alterations.

Although this conclusion certainly agrees both with the low yield points of rock salt and theoretical calculations on plastic deformation around an opening, the result was not accepted. In order to make sure of the nature of indicated pressures, some measuring systems have been subjected to examinations as shown in Fig. 9.

Recording pressure gauges were joined to measuring systems. Alternately, every few days the pressure in a measuring system was lowered to zero or increased to nearly 200 kg. /cm. ^{2} as shown in Fig. 9, upper part. The pressure record indicates a remarkable short-term adjustment of varied pressures to the original pressure of 85 kg. /cm. ^{2} which had been indicated for several months before.

The lower part of Fig. 9 shows the reaction record of another measuring system. The original pressure was also 85 kg. /cm. ^{2} indicated for some months at 4 m. depth.

Instead of an alternating increase and decrease, the pressure has been increased several times to nearly 200 kg. /cm. ^{2} resulting in recorded pressures, somewhat higher than the original. However, the system began adjusting to the original pressure as shown by the record.

Immediate Conclusions

1. Salt rocks react immediately upon alterations even of one direction of stress deforming plastically into the direction of stress release and into the opposite direction in case of stress increase. Provided that the time required to adjust stress differences by plastic deformation has passed, the local state of stress in a salt body must be almost hydrostatic since the very low yield points of salt rock do not allow any noteworthy local stress difference to persist.
2. The quasihydrostatic local stresses in the zone of flow around an opening are indicated by the pressures in hydraulic measuring systems in sealed boreholes as described above.
3. Provided conditions similar to those prevailing during the measurements dealt with above -- a single gallery being worked approximately two years before in homogeneous

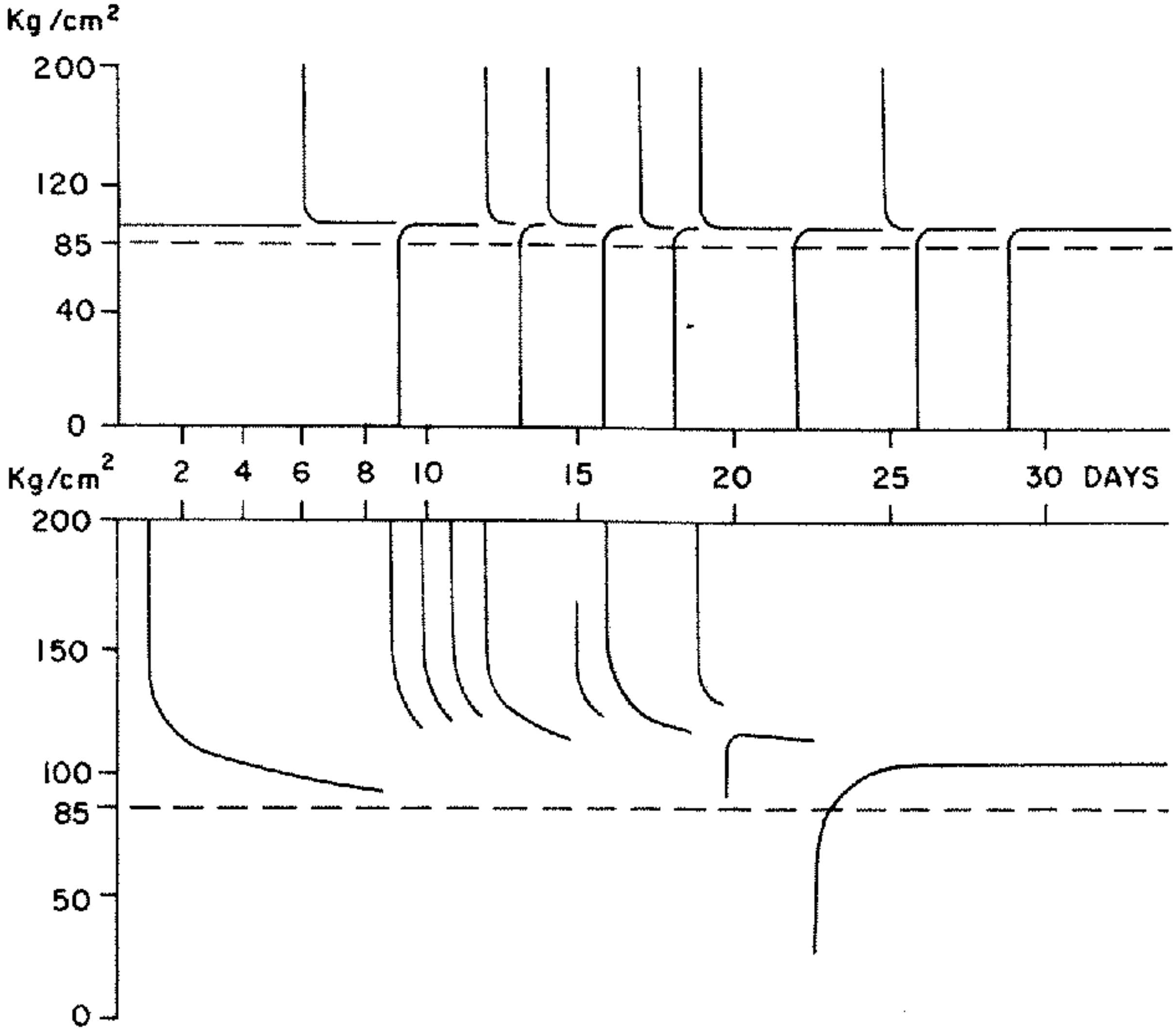

Figure 9. Recorded reactions of borehole pressure measuring systems upon repeated intentional decrease or increase of pressure.

rock salt not affected by previous mining -- Fig. 10 demonstrates the zone of flow extension, local quasihydrostatic stresses running from nearly zero at the gallery surface to the original stress of 200 kg./cm.^{2} behind the zone of flow. In that case, the horizontal extension of the zone of flow is approximately 10 m. This is a statement confirmed by additional pressure measurements as well as by many deformation measurements.

4. The zone of flow extends most rapidly immediately after working, due to great stress differences arising at the new opening surface where one stress direction is suddenly lowered to the atmospheric pressure.

5. Strengthening by plastic deformation does not play an important part under mining conditions, contrary to sample behavior under laboratory conditions, because yield points of samples subjected to uniaxial stress rise with increasing deformation (Borchert and Muir, 1964). Even repeated stress alterations as shown in Fig. 9 do not affect the plastic behavior of the involved rock. Under such conditions, comparable to conditions after working an opening, obviously no raising of yield points and no strain hardening of involved rocks takes place.

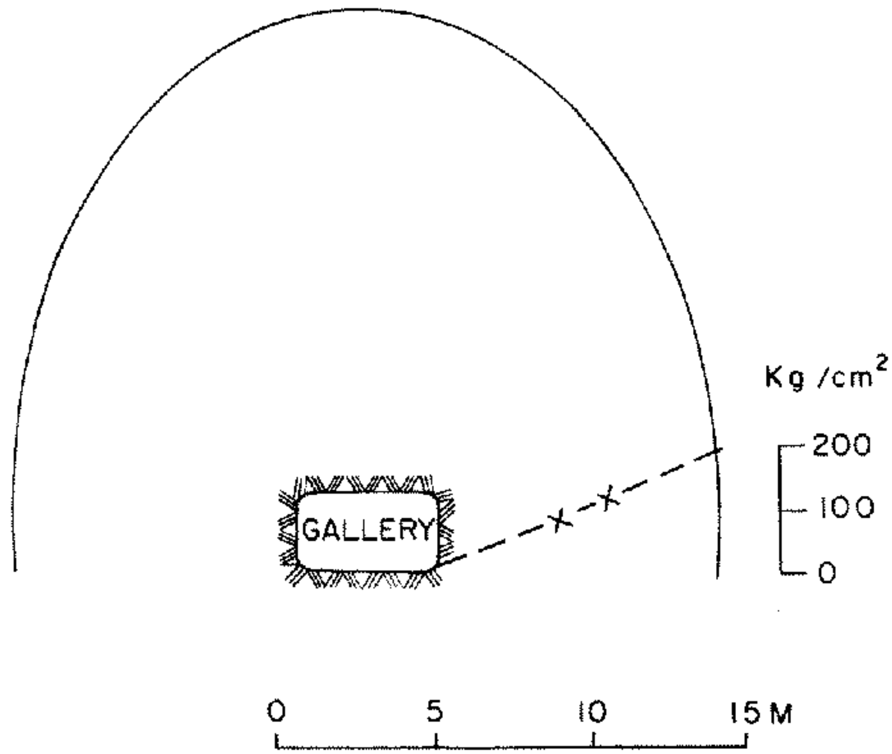

Figure 10. Quasihydrostatic stresses in the zone of flow around a gallery worked two years ago in homogeneous rock salt, depth 320 m.

GENERAL DISCUSSION AND CONCLUSIONS

Figure 11 demonstrates the usual mining method in the South Harz district and the reaction of the rock surrounding an opening upon working, a gallery like the one in which the previously mentioned measurements were carried out being preassumed as the first room in a new panel. Line A represents the surface (cross section) of the pre-existing room; curve a indicates the local quasihydrostatic stresses in its zone of flow according to Fig. 10.

In the next step, an initial opening approximately 2.5 m. high is worked parallel to room 1, the pillar being 6 m. wide. This new room is represented by line B in Fig. 11. In the following operation, the ore in roof and floor is worked as shown by line C.

According to the measurement results dealt with above, the local quasihydrostatic stresses in the pillar develop from curve a to curve b shortly after working room B. Increasing the room height as shown by line C further decreases the local pillar stresses to curve c due to rapid transverse extension as found in all measurements.

This main statement is confirmed by subsidence and pillar deformation measurements as well as by pressure measurements in boreholes in or below pillars. Due to geological conditions, all panels in the mine in question were small; so no remarkable roof subsidence was possible. Consequently, all pressures measured in boreholes in or below pillars were less than 50 kg./cm.^{2} according to Fig. 11, indicating high grade pillar relaxation.

In order to reload pillars released at such a rate, considerable main roof subsidence must occur. However, the required subsidence is impossible in generally small panels as demonstrated by Fig. 7.

Under such conditions, pillars are not able to prevent floor deformations which may cause water or gas inflow from the strata below the salt sequence.

It follows from Fig. 7, that roof subsidence depends on panel extension. However, on account of a presumed rock burst danger in that mining district, the main theoretical principle

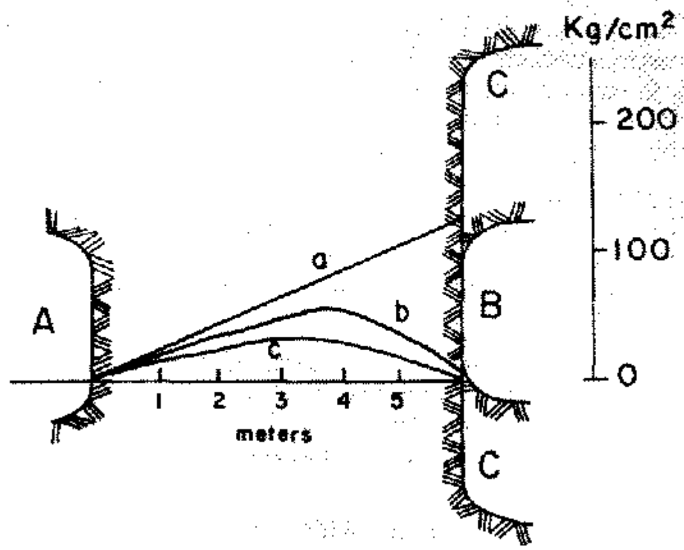

Figure 11. Scheme of stress development in a pillar, working conditions being similar to Figure 10.

A, B, C cross sections of rooms worked in the same order.
a, b, c quasihydrostatic stresses developing in the pillar.

was to retain the roof strata in its original position. For that reason, all panels were intentionally kept small by arranging large so-called safety-pillars (barrier pillars) along the roadways as well as in the panels after every tenth or twelfth small pillar. These very large pillars around a panel bore the main roof load preventing reloading of the small pillars in-between.

Since similar conditions determined all measurements compiled in Fig. 1, measured pillar transverse extensions do not relate to theoretical overburden loads calculated from pillar and room width. The measured pillar deformations rather indicate high pillar relaxation resulting in insufficient prevention of floor strata deformation. This conclusion is strongly confirmed by practical experience, since all mines listed in Fig. 1 suffered heavy gas or water inflows from the floor.

As a redress the author recommended abolishing any large so-called safety-pillars in order to make the roof strata subsidence as uniform as possible (Baar, 1954 a; 1959 a, c). This recommendation, contrary to Hoefer, 1958 a, was supported by other authors (Gimm and Pforr, 1961) and is believed to be carried out since the last five years. No further failures similar to the ones during the 1950's have been reported from that mining district.

It should be mentioned that sudden alterations of the state of stress, even sudden removal of one direction of stress may cause brittle fracture of involved salt rocks. Well-known examples are gas outbursts and rock bursts.

In cases of gas outbursts certain preliminary conditions must be fulfilled such as high content of gas inclusions in the salt rock, high original stress, etc. As soon as a sufficiently large surface is worked fast enough through the zone of flow of an opening, the gas pressure may cause initial brittle fractures, which rapidly extend into the rock as far as suitable outburst conditions exist. In this case, sudden release of one direction of stress causes fracturing similar to bed separation off pillars by release fissures along the pillar surface (Baar, 1962, 1964; Gimm and Pforr, 1964).

On the other hand, if delayed subsidence of the main roof strata is suddenly recovered due to a rock burst in the main roof, pillars may be loaded too fast, the vertical stress direction increasing in almost released pillars as shown by curve c in Fig. 11. In such cases, carnallite pillars, in particular, are subjected to fracturing, the bed separation phenomena remarkably resembling release fracturing (Baar, 1959 a, 1964; Gimm and Pforr, 1964).

Regarding the difficulties and mistakes in relating pillar deformations to either loading or relaxation or to a combination of both, the only known way to make sure what is occurring in a deep potash or rock salt mine is to measure the pillar loads employing the described technique of pressure measuring in boreholes. Two or three measuring systems in a pillar provide reliable knowledge of loads supported by that pillar at any time.

A network of measuring stations across the mine panels provides knowledge of the sum of pillar loads which should equal the calculated overburden load; if it does not, main roof strata subsidence is delayed which must be considered as dangerous. However, it is better to realize a situation and to be able to correct it by suitable operations than to be surprised by nature correcting the situation in its own way.

A special advantage of borehole pressure measuring systems is that there is no temporary restriction in using a measuring system once established. Moreover, this pillar load measuring method is very convenient. There is no difficulty in electrically transferring measuring values to any central point in the mine or even to the mine manager's office outside of the mine.

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