PROBLEMS OF AND EXPERIENCE IN CONTROLLING KARST PHENOMENA IN THE VICINITY OF ABANDONED MINES IN THE ZECHSTEIN SUBDIVISION IN THE GERMAN DEMOCRATIC REPUBLIC

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ABSTRACT

In the German Democratic Republic, potash salts, rock salt, and copper schist are extracted exclusively from deposits in the zechstein subdivision, with underground operation being characterized by the development of large-area mine openings in the vicinity of readily soluble minerals.

Representing an extremely critical phase after the closing-down of such a mine is, from the mining safety and environmental protection point of view, the subsequent treatment of mine openings. Experience has shown that underground mine openings lying below natural ground-water horizons tend to fill with water after abandonment there of, the water reaching the mine either through channels formed already during mining or as a result of phenomena of destruction after close-down. Water flowing to, and moving within, mine openings tends to dissolve, up to the saturation limit, all those salts with which it will come in contact, thus causing considerable damage to the surrounding strata. As a result of this, there occur depressions, disturbances, and displacements of rock masses, which may involve major economic disadvantages.

Scientifically substantiated methods of controlled flooding of abandoned mines have been used in the G.D.R. since the mid-1960's, which enable adverse effects to be reduced to a tolerable minimum. Examples of controlled flooding are furnished in this paper, dealing with geological and hydrological peculiarities, territorial conditions on the earth's surface, technological aspects, and questions of measuring, control, and observation.

INTRODUCTION

The G.D.R. potash, rock salt, and copper schist mining industry, which in the past twenty years increased its output substantially through the development of new and extension of existing mines, was at the same time brought up against the problem of closing down a number of older mines, the reasons for this being exhaustion of deposit resources and increasing hydrological difficulties. In addition, there were a larger number of old potash mines which were in a poor condition. They had been closed down some fifty to sixty years ago, and it was with the object of reopening at some later date that upon abandonment they had been left more or less controlled and filled with air. Major problems in connection with safety in mines and environmental protection resulted in the concept of controlled flooding being developed.

KARST PHENOMENA IN THE VICINITY OF ABANDONED POTASH, ROCK SALT, AND COPPER SCHIST MINES

1. in the potash mine of Friedenshall near Bernburg (Fig. 1) there has since 1962 been observed, in the abandoned potash mine field, a steadily increasing influx of salt solutions [1]. After initial attempts to prolong the life of rock salt mine fields by pumping out the salt solutions and discharging them on the land surface, pumping operrations were given up because of the high pressure on the environment, the constantly increasing costs, and the considerable damage caused to the underground openings. Complete flooding of the mine resulted in the overlying rock being lowered by as much as ten meters in the vicinity of where the water and salt solutions entered the mine workings. It was in the most critical phase of flooding that three earth falls occurred one after the other, the largest of wich had a depth of some forty meters and a diameter of one hundred and thirty meters. What was characteristic of the formation of the sinkhole was that it announced itself by quick, vibratory movements of the rock mass which occurred a couple of hours or days before the actual earth fall took place, with the break forming the cave to the surface being accompanied by rather violent earth shocks that were recorded even at a relatively great distance from the site where the earth fall occurred. The total process of deformations and fractures taking place on the surface quickly subsided after complete flooding of the mine.

This was to be attributed to the rapid saturation of water with minerals in situ, the superimposition of the collapsed rock cover, and the stabilizing effect of hydrostatic back pressure upon farther removed pillar systems that were less heavily crushed. The processes that proceeded in the external zone of affected overburden made it necessary to give up for a short time about o,25 square kilometers of farmland, evacuate temporarily the farmhouse and barns, and by-pass a highway for about one kilometer.

2. A potash mine located near the city of Aschersleben and consisting of several shafts (Fig. 2), which had to be closed down in 1956 because of depletion, but which remained filled with air, had water flowing into it from shaft tubes, which in the late sixties threatened to get out of control. Because of the large area of the exhausted mine fields, noncontrolled flooding had the effect of threatening several localities, two main railroad lines, and shaft houses /which were now being used for purposes other than mining/, especially those on the Schierstedt saddle. Experience gained with the flooding of the Friedenshall potash mine and new knowledge with respect to the kinetics of dissolution of mineral salts in water led to the decision to counteract unavoidable noncontrolled flooding by controlled flooding through holes bored using surface rigs. The basic idea was to feed into the underground mine openings large and readily measurable quantities of flooding medium, with feeding taking place at a properly chosen point and within a short period of time. Suitable places were those points in the underground workings at which the flooding medium introduced would become saturated with the most essential salt components and where damage caused to the land surface would be minimal. The flooding medium thus presaturated would then be caused to flow to those areas of the field which were underneath the objects to be protected thus preventing further damage to them. Essentially, this objective has been accomplished, although a certain number of the decicions that had to be taken were forced by the water which had already entered the mine, in an uncontrolled manner, by way of the shaft tubes.

3. The copper schist deposit in the Mansfeld trough (Fig. 3), which had been opened up through a large number of shafts,was depleted in the late nineteen-sixties. The abandoned mines in this deposit left, up to the level of what was called the key galerry, a mine opening of more than forty million cubic meters, of which about twelve million cubic meters were under the zechstein salts that were locally developed in these mine fields, too. It was already since the beginning of the last century that water which had for many decades been flowing into the underground mine openings had, in the area of settlement of these mine fields, led to topside depressions and major fractures which, in turn, had caused substantial damage to buildings, transportation facilities, and various other objects, since the water,while flowing into the openings, had dissolved salites, thus greatly exceeding the level of deformations that were directly caused by mining operations. To reduce as for as possible these phenomena of chronic subrosion due to mining operations, the underground openings have since 1970 been systematically

flooded, under controlled conditions, with the inflowing mine water, with flooding being as far as the level of the key galerry, the level of discharge into the natural drainage ditch /about seventy- five meters above sea level/ [2; 3]. Flooding reached the planned final level in 1981 (Fig. 4). As expected, the phenomena of subrosion of the critical places in the area of settlement of the mine fields decreased, in the last ten years, to the natural level of deformations, so that the economic objective can be considered to have been achieved. At the same time, however, there have, since 1975, been observed new phenomena of major subrosion and deformation at several points of the land surface above the mine fields. These phenomena, which had not been expected to occur, required both residential and nonresidential /i.e., industrial/ buildings to be abandoned. They may be explained by the fact that water accumulated in the underground mine openings and in the loosened, karstified overlying beds are only partially saturated with the existing remnants of soluble salites. Because of the gravitative exchange of unsaturated solutions in underground mine openings and karst cavities, there is now taking place a process of final saturation of which the duration and location cannot be determined beforehand. This process, which is still going on, involves especially those salites at the highest points in the mine fields which have been opened up either directly or indirectly by mining.

It is because of the particular hydrological conditions prevailing in the zechstein subdivision that shaft plugging poses special problems. The exposure of soluble rocks within the shafts results in salites being dissolved by the rising flooding medium, which may lead to instability of shaft plugging materials. In so far as these particular phenomena are concerned, interesting information has been obtained which will be reported elsewhere.

PRINCIPLE OF CONTROLLED FLOODING

The dissolution of in place salt rocks cannot, in general, be prevented by controlled flooding if the flooding medium used is not saturated with these salites. Also, sufficient quantities of saturated flooding medium are not usually available in the vicinity of mines to be flooded. Accordingly, the principle of controlled flooding consists in feeding unsaturated flooding medium to one or several points of underground openings where rock mass deformations and fractures due to intensive dissolution of rock will cause only comparatively little damage to the land surface. Lendingthemselves particularly well to such operations are non-built-up and little-used areas. According to the well-known laws of the kinetics of dissolution, the process of dissolution or saturation will proceed most intensively, because of the existing difference in saturation, on initial contact of the flooding medium with the soluble rock [4; 5]. In potash and rock salt mines this process will fade as the flooding medium continues moving through the openings and as the time of residence therein goes by. In general, the rate of saturation will be dependet not only upon flow conditions which are known to be different in different mine openings, but also upon the type of saline rock involved, the difference in saturation, and the ratio between the surface area of the saliferous rock to be dissolved and the volume of the in situ flooding medium. The process of dissolution will be complete when there is a dissolution equilibrium between the flooding medium and the in place salt rocks and when there is no longer any movement of flooding medium because of the density thereof at any point of the mine. Of the various saline minerals, carnallite /$KCl.MgCl_2.6H_2O$/, a potash salt frequently occurring in the G.D.R., is characterized by the greatest intensity of dissolution. If large quantities of this saline mineral are present in the mine, then magnesium chloride /$MgCl_2$/ of this salt will readily pass into solution, even if the flooding medium already possesses a high degree of presaturation with other salt components. Compared with the above-explained laws of dissolution of salts in potash and rock salt mines, salt dissolution in copper schist mines has a number of characteristic features because of the localized exposure of salt rock. One of these is that in copper schist mining influxes from superincumbent strata are a common occurrence. Another of these is the fact that contact between the flooding medium and salt rock is determined in a large measure by jointing due to extraction and by karst cavities in the roof. It is absolutely necessary for both of these characteristics to be carefully considered in flooding concepts for copper schist mines. The basic principles outlined above are reflected in the outward form. With controlled flooding it is, therefore, essential that to protect the land surface the most suitable point of inflow be chosen with due consideration of dissolution kinetics aspects. This will only very seldom be a shaft, since mine installations are usually located in the neighborhood of residential areas or industrially utilized areas, being intensively used for other purposes subsequent to the closing-down of mines. Frequently, the composition of salites and the location of openings also are not, in the vicinity of shafts, ideal for the selection of a point of inflow. Consequently, it is neccessary that, at the most suitable point of inflow, the underground openings be connected with the ground surface through a deep hole or through pipage in shafts. It is imperative that deep holes cut through layers of rock be saced and grouted off so as to insure against uncontrolled flow of water from superjacent strata into the mine openings. Industrial waste water or other effluents may be used as media for flooding underground openings. Flow measurements and tests perfomed with a view to checking the composition of the flooding medium /which tests should preferably be conducted at the point of inflow as at different points in the mine/ provide a good basis for the controllability of flooding. Preferably, rates of inflow should be in the region of 200 to 600 cubic meters per hour depending upon the volume of the openings to be flooded. Usually, these are in the order of ten million cubic meters. It is recommended that the point of inflow be chosen so as to enable the incoming flooding medium to reside near that point for an extended period of time and find there an adaquate supply of representative saline rock for saturation thereof. Also, it is essential that the flooding medium, when entering those parts of the mine field which are located directly below topside objects to be protected, have a concentration of dissolved components that virtually rules out any further dissolution of saliferous rock. Upon the completion of flooding, the flooding medium will have reached a hydrostatic pressure which, in these particular portions of the field,will have the additional effect of stabilizing the carrier rock strata.

The response of strata to the process of dissolution proceeding below ground is checked by subsidence surveys as well as by recording and locating seismic pulses. This makes it possible to determine the time, location, and intensity of deformations and breaks expected to occur on the ground surface and ascertain the temporal and spatial trends of such processes. Negative trends of development can be checked by changing the points of inflow and varying the quantities of flooding medium fed into openings, with endangered areas on the surface being easily locatable.

CONTROLLED FLOODING OF THE NEUSTASSFURT VI AND VII, BERLEPSCH, MAYBACH, AND LUDWIG II POTASH MINE SHAFTS

With the valuable experience gained by flooding the Friedenshall potash mine and the results of latest research into the kinetics of dissolution of mineral salts, the G.D.R. potash mining industry was faced with the problem of closing down, in the early seventies, a number of depleted and hydrologically endangered mines located on the northeastern side of the Stassfurt saddle and exploited over a period of many decades and, thus, abandoning the last mines existing at the place of origin of potash mining. Some of the underground workings are located directly below the city of Stassfurt, with residential areas, industrial and transportation facilities lying in the affected zone. To save this section of the city from suffering the same fate as that which those of the city lying over the southwestern side of the Stassfurt saddle have been sustaining, as a result of mine flooding, from 1910 up through the present time, careful plans have since 1966 been made to abandon the mines on the northeastern side of the saddle and flood them under strictly controlled conditions. It was here that the principle of controlled flooding had been systematically used for the first time, being made an integral part of all planning, preparatory, and implementational operations.

The carnallitic deposits (Fig. 5) exposed by mine working were, from the beinning, suggesting a high degree of dissolution and decomposition of carnallite which is a readily soluble, kind of mineral. Employing the principle of cont rolled flooding (Fig. 6), the point of inflow of the flooding medium was chosen so as to be located on the outermost berder of the northernmost mine field. A deep hole that was bored to this particular end connected the topside point of inflow with the openings of the 620-meter level of the field of the Neustassfurt VI and VII mine shafts. In this, the place of entrance of the flooding medium into the mine had been chosen so as to minimize the phenomena of dissolution of in place rock salts in the immediate vicinity of the borehole. Also, this prevented the borehole from being adversely affected by deformations and fractures. The flooding medium, after having flowed a distance of about two hundred meters, entered large chambers in which, through prolonged residence therein, the medium was adequately saturated with individual components dissolved from in place carnallite. A connection with the neighboring Berlepsch and Maybach field in the south was made by a hole bored underground in the former boundary pillar. This borehole was sized and aligned so as to enable essentially saturated flooding medium to enter the neighboring mine openings at a predetermined rate of flow of about four hundred cubic meters hour. In addition, an underground hole was bored through the barrier pillar to connect the Ludwig II mine field in the south with the Berlepsch and Maybach field, with boring being done from the latter location. With the saturated flooding medium transferred from the Neustrassfurt VI and VII fields to the Berlepsch and Maybach mine field, the Ludwig II mine field was subsequently flooded systematically through this bore, too. This made it possible for the Neust assfurt VI and VII locations to be used, according to the flooding concept worked out with great thoroughness, for the production of saturated saline solutions required for the controlled flooding of the Ludwig II as well as Berlepsch and Maybach mines. The flooding medium was pipelined from a pumping station to the flooding borehole. In the course of flooding, a second flooding hole had to be bored in the northern section of the Neustassfurt VI and VII locations, since clogging of flow paths was occasionally observed in the mine. Flooding operations were measured and checked by means of an extensive network of topside measuring for subsidence surveys over all mine fields; by the use of seismographs and seismic detector locations; and by the provision of sampling stations in the Neustassfurt VI mine shaft /Table 1/, in an overground observation hole in the

Neustassfurt VI and VII locations near the border with the Berlepsch and Maybach mine field, and withiin the latter field, and more specifically at different levels and different distances from the shafts. The rate of inflow of flooding medium at the northern point of influx could be controlled in the range of from 0 to 600 cubic meters per hour.

Subsidence basins (Fig. 7) developed during flooding in the northern section of the Neustassfurt VI and VII fields, this being in relatively good agreement with what had been realized and calculated beforehand. The development and increase in size of these subsidence troughs was accompanied by temporary vibrations that could be located by seismic detectors and which suggested fracturing of substrata in the vicinity of openings. The only earth fall observed in this connection in the Neustassfurt VI and VII mine fields was preceded by marked seicmic pulses.

On the whole, seismic activities were restricted to the northern and central parts of the Neustassfurt VI and VII fields. The depressions observed on the surface were of the same tendency and order of magnitude. Controlled flooding, which had been finished in 1979, had as its objective to save the Ludwig II as well as Berlepsch and Maybach mine fields, which are located in the region of the city of Stassfurt, from depressions. This objective has been accomplished. All of the measures taken under the prevailing circumstances allowed the severity and tendency of phenomena of deformation and fracturing of overlying rock to be assessed and dangers to the ground surface to be recognized and warded off on time.

CONCLUSIONS

The present results of flooding large mine fields in zechstein deposits in the G.D.R., the details of which will be reported in additional papers, allow to make the following initial conclusions:

1. Abandoned mines,by which readily soluble rocks were exposed, are potentially endangered by unsystematic and uncontrolled flooding and consequent damage to the surface /"industrial karst"/.

2. Controlled flooding, by means of unsaturated flooding media, of abandoned mines in readily soluble rocks enables damage to the vicinity of openings to be minimized. Potential danger can be predetermined as to both location and time.

3. By controlled flooding of underground mine openings in soluble rocks is understood the introduction, under strictly controlled conditions, of flooding media into selected points of a mine field, the objective being

to reduce adverse effects upon the superincumbent rock and the land surface to a minimum.

4. The extent of damage to the vicinity of mine openings can be reduced through the use of presaturated flooding media.

5. For controlled flooding to be highly effective, it is essential that quantity of flooding medium introduced in unit time be many times that of the natural influx. Introduction of flooding media can be dispensed with in those cases in which the natural influx satisfies controlled flooding requirements as regards the rate of inflow, the degree of saturation, the ranges of resaturation, and the points at which water flows into underground openings.

6. The following factors can be considered critical to the determination of points of introduction of flooding media into underground mine openings:

   - Situation on the surface in the area adjacent to the point of inflow,
   - Degree of exposure, kind and quantity of soluble in place rock, and location thereof relative to the volume of the opening,
   - Paths of flow and point of retention of flooding media in underground openings.

7. Seismic observation of strata fracturing caused by the dissolution of salites enables the prediction of both earth falls and sudden large-area subsidence processes. Usually, these are preceded by the emission of marked seismic pulses. The location of earth falls can be nearly accurately determined from records of seismic pulses. However, the time at which earth falls will occur cannot generally be determined accurately.

8. Overground subsidence surveys will provide reliable information about the time course of deformations of superjacent strata under the action of saline rock dissolution. Subsidence of overlying rock strata will fade completely when controlled flooding has been completed successfully.

9. Regular determination of the composition of saline solutions in flooded mines shows that, in salt mines, a dissolution equilibrium can be obtained in a relatively short time, which is due primarily to the high degree of dissociation. In underground mine openings with a low degree of dissociation of salt, such as in the region of what is known as the Mansfeld trough, the process of dissolution caused by flooding proceeded, locally at least, over an extended period of time, with unexpected major damage being caused to limited places of the rock mass.

10. During recent years, controlled flooding of mines in zechstein deposits in the G.D.R. enabled damage and negative effects upon safety in mines and the environment to be prevented or minimized, respectively.

LITERATURE

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Table 1

Density and distribution of solution components at the point of sampling in the Neustassfurt VI mine shaft.

Depth of shaft [m]	Density $[g/cm^3]$	Concentration of solution components $[g/dm^3]$			
		KCL	$MgSO_4$	NaCl	$MgCl_2$
301	1.290	50,8	77,8	60,2	212,7
400	1.290	53,7	72,7	54,8	226,2
460	1.292	50,8	65,5	44,4	246,0
530	1.293	50,9	67,9	46,7	246,5
560	1.293	50,1	67,3	46,2	244,6

FIGURE CAPTIONS

Fig. 1. Friedenshall mine field
a/ Shafts
b/ Area where solutions entered and earth falls occurred
c/ Mine field
d/ Shoreline of petash deposit
e/ Direction of ground-water flow

Fig. 2. Mine fields near Aschersleben
a/ Shafts
b/ Boreholes for flooding
c/ Mine field
d/ Shoreline of potash deposit
e/ Contour lines of the upper limit of the potash deposit

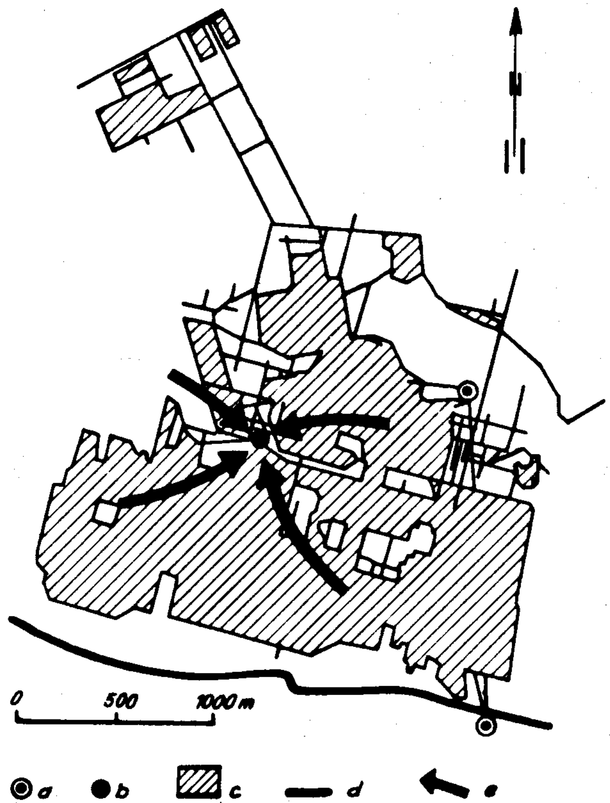
Fig. 3. Idealized section of the copper schist deposit in the Mansfeld trough
a/ Outcrop of the deposit
b/ Deposit
c/ Karst with inflowing water
d/ Mottled sandstone
e/ Zechstein strate /lime, anhydrite/
f/ Rock salt strata
g/ Salt level /rock salt subrosion area/
h/ Level of entrance of the flooding medium into the drainage ditch
i/ Center of gravity of subsidence

Fig. 4. Schematic course of a subsidence curve as a function of the flooding of subrosion horizons
a/ Amount of subsidence
b/ Time duration
c/ Period of relatively low rates of constant subsidence prior to the commencement of flooding
d/ Period of rapid rates of subsidence during the flooding of rock salt horizons
e/ Period of faded processes of subsidence subsequent to the flooding of rock salt horizons

Fig. 5. Idealized section of the northeastern side of the Stassfurt saddle
a/ Shaft
b/ Openings /chambers/
c/ Potash deposit
d/ Saliferous clay and anhydrite
e/ Older rock salt
f/ Younger rock salt
g/ Mottled sandstone
h/ cap rock /saline residue/
i/ Tertiary
k/ Pleistocene

Fig. 6. Idealized longitudinal section of the mine fields on the northeastern side of the Stassfurt saddle
a/ Neustassfurt VI and VII locations
b/ Berlepsch and Maybach locations
c/ Ludwig II mine field
d/ Residential and industrial sections of the sity of Stassfurt above the mine field
e/ and f/ Flooding boreholes 1 + 2
g/ Observation and check hole
h/ and i/ Connecting boreholes

Fig. 7. Location plan of the northern part of the Neustassfurt VI and VII fields
a/ Shaft
b/ Flooding borehole
c/ Seismic transducers
d/ Located foci of seismic disturbance
e/ Amounts of subsidence /in millimeters/ from 1973 through 1980.



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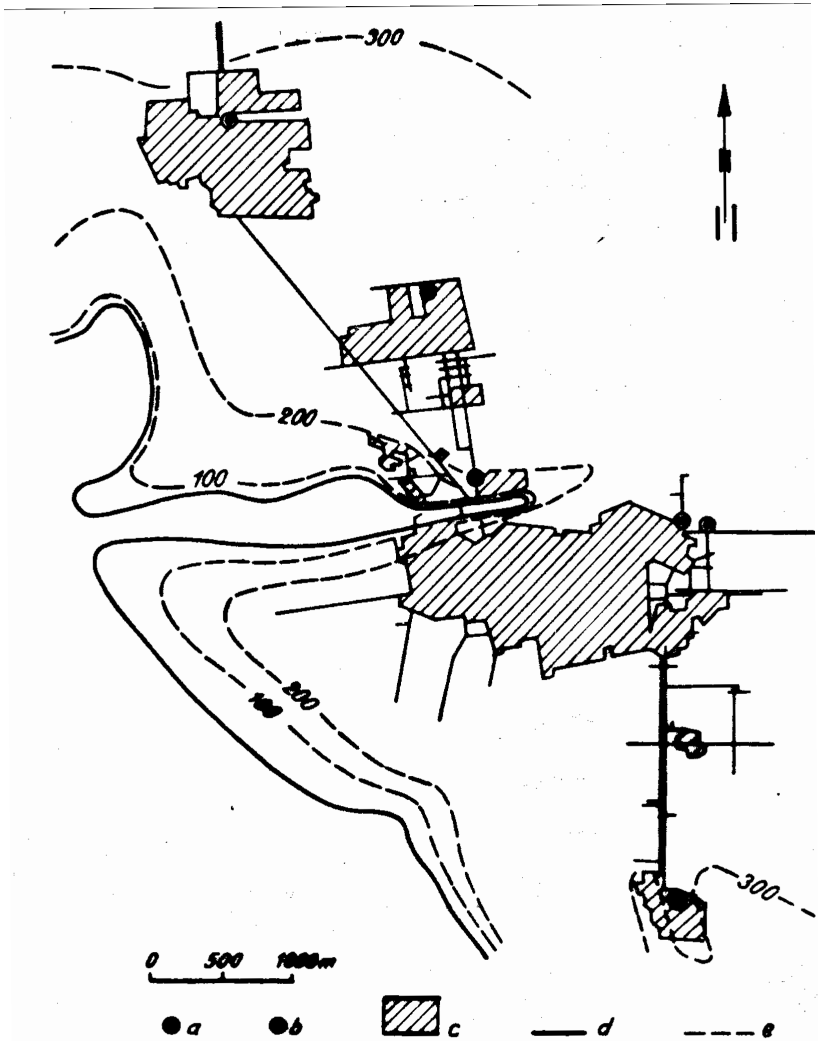

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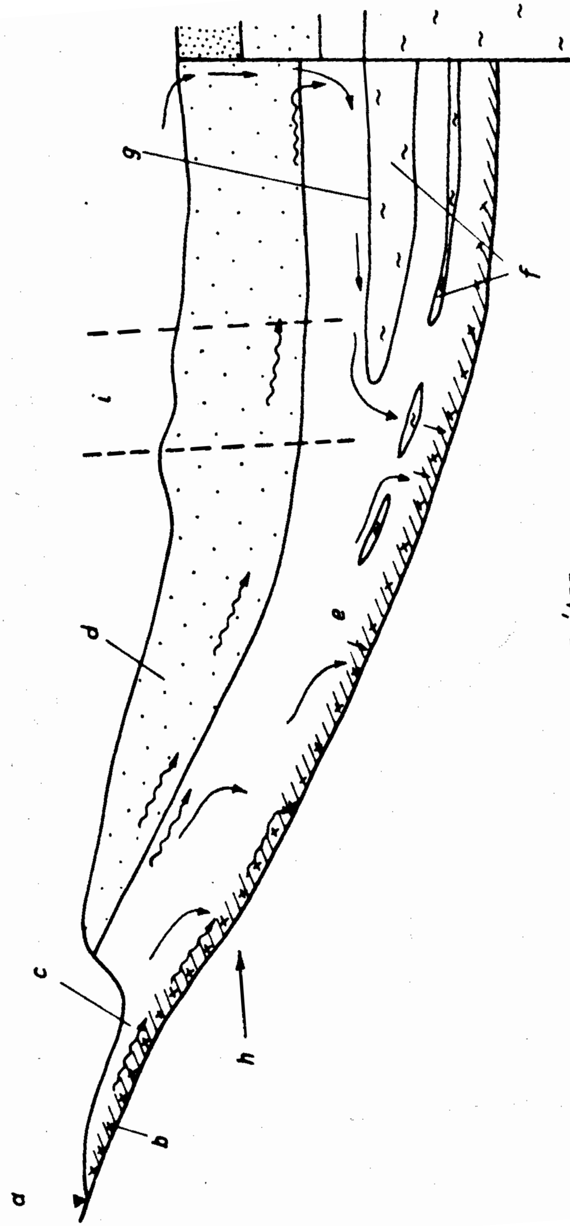

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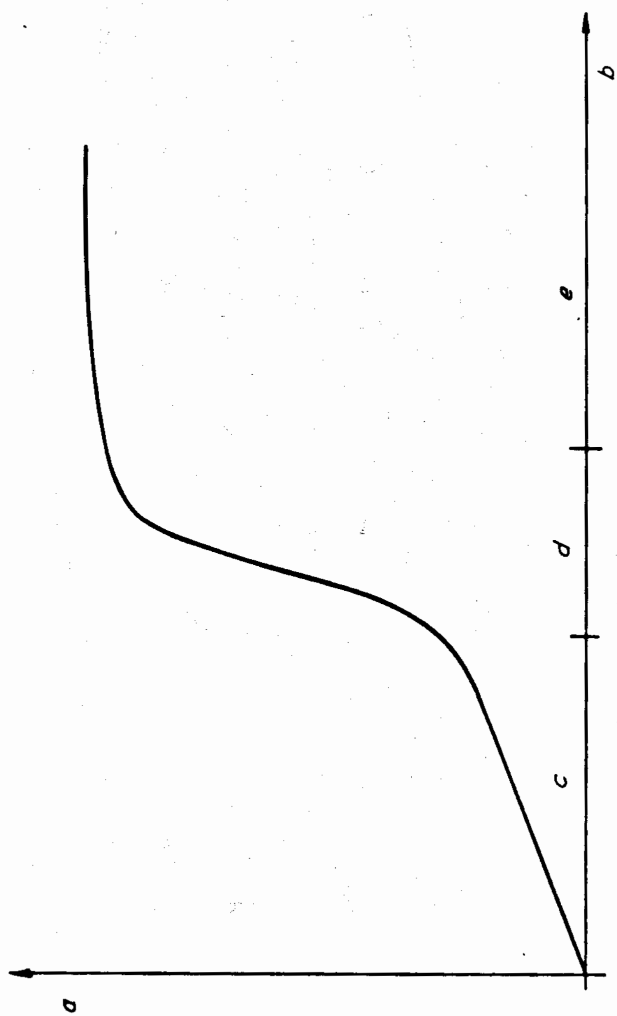

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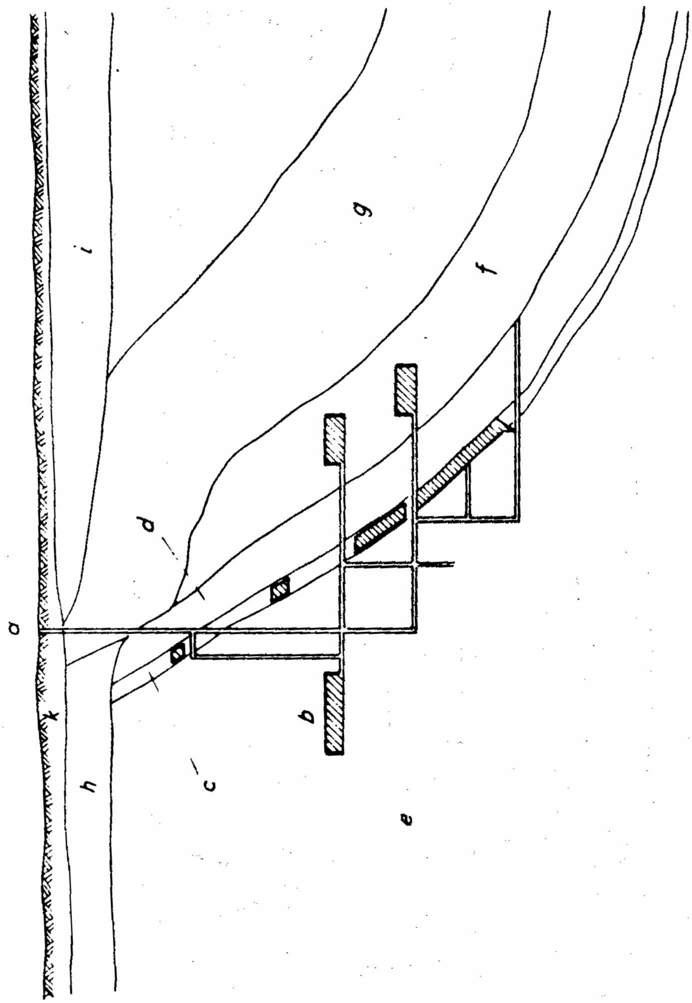

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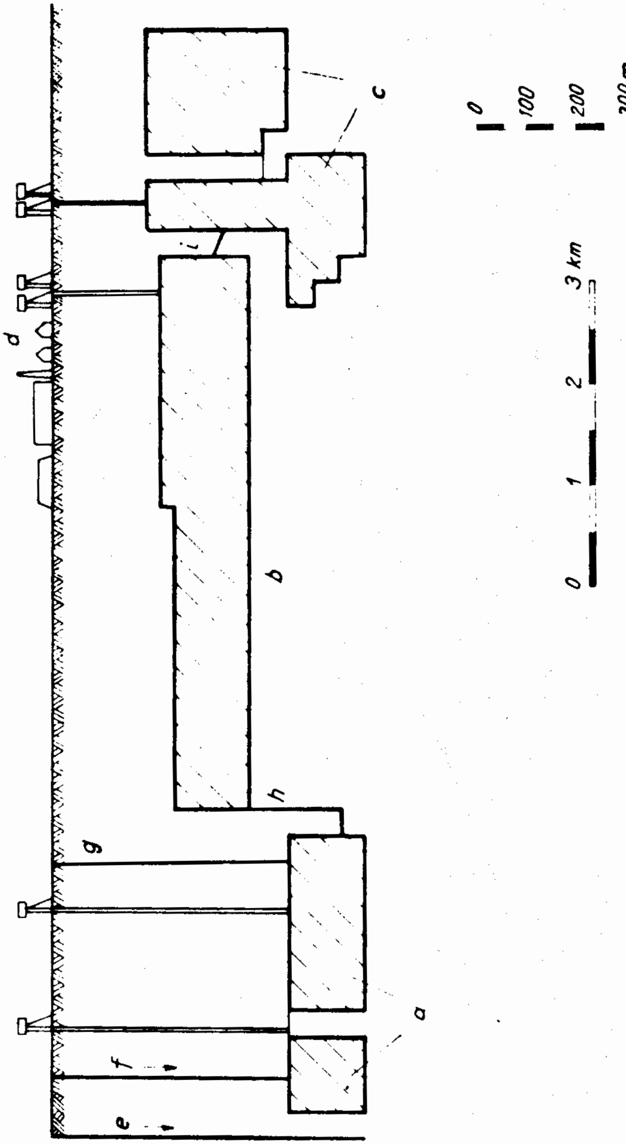

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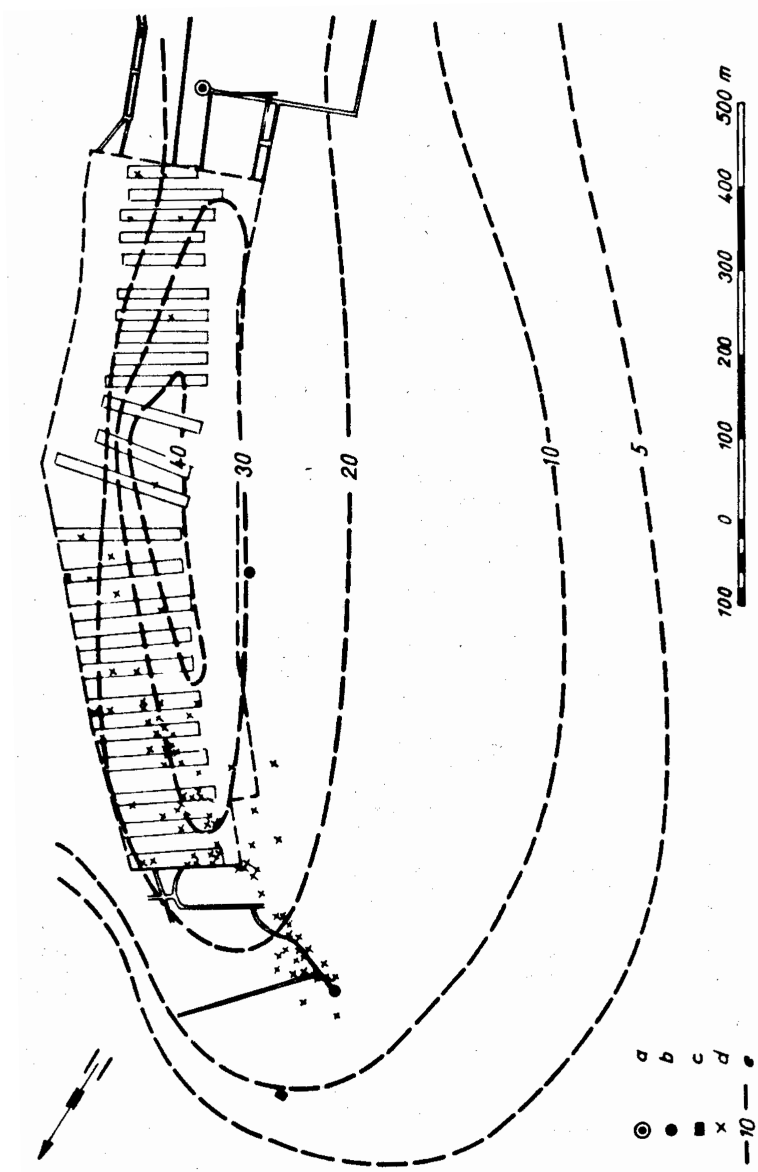

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