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LIQUIDATION OF ABANDONED MINE EXCAVATIONS BY FLOODING

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ABSTRACT

The authors elaborated the method of liquidation of unproductive mine excavations by flooding. The specificity of this problem consists in flooding abandoned mine excavations in upper parts of a mine above its active part. The method has been practically tested at the mine Vítkov in Western Bohemia. On the basis of the positive evaluation of structural, hydrogeological and mining conditions of the mining space and on the basis of the elaboration of safety measures the flooding of the old mining section was permitted.

The flooding took place from November 1979 to August 1984. The liquidation of mine excavations has been finished after the complex evaluation of the flooding course and of the proofs of its consolidated regime. The realization of this method contributed to substantial economic savings in mine operation, improvement of land ecology and it brought new methodical knowledge.

INTRODUCTION

The liquidation of abandoned mine excavations is being made for the most part by flooding. The aim of this measure is:

a/ suppression of working-technical machinery in the mine, as e.g. pumping equipment and resulting savings of energy and labour;
b/ improvement of land ecology, above all of disturbed hydrological cycle.

The authors elaborated this generally known process for the liquidation of mine excavations by flooding above the active part of a mine. The specificity of this problem consists in a reservoir of mine waters in upper parts of a mine, under which mineral resources are being mined.

The solution of this problem is divided methodically in three parts:

1/ evaluation of mining deposit -, structural and hydrogeological conditions of the mine field on the basis of all documentation and proper prospection;
2/ appointment of flooding conditions of mine excavations and of regime of observation in its course;
3/ control of flooding evolution and its final evaluation.

The flooding is generally finished, if the water levels in piezometers vacillate in dependence on natural changes of underground water level in the surrounding pillar.

This methodology has been applied at flooding the old mining section at the mine Vítkov in Western Bohemia.

MINING-HYDROGEOLOGICAL CHARACTERISTIC

The old mining section is approximately 1,5 km SW from the mine Vítkov. This section is opened from the surface by a shaft and a ventilation chute that is at a distance of about 400 m to the west. The old mining section is at a level of 200 m under surface, worked by a crosscut and by a system of drift entries. The total volume of mining operations in this section was 69 000 m^3. At the mine Vítkov there are mine excavations driven at the level of 385 m under surface that are under the region of the old mining section.

The mining space is made of metamorphosed rocks of varied series of moldanubicum and magmatic rocks of Bor massif. Metamorphic rocks are represented by medium grained biotite paragneisses and amphiboles. Magmatic rocks are formed by porphyritic coarse-grained granite and various diorite rocks and numerous veins of fine-grained aplites. In igneous rocks there are numerous xenoliths of varied series and of diorite composition. The greater part of rocks has a solid omnidirectional construction. The low cleavage degree gives presupposition of large mechanical strength.

The deposit is developed along tectonic failures in the form of lenses (1). The general direction of failure zones is N-S with mild deflection to the NNW, or SSE. The western edge of the deposit is deliminated by Vítkov failure that falls under the angle of 50-75° to the east. It represents a zone with variable thickness from 1 m to tens of metres. The failure is associated with a series of co-dipping failures of irregular development and various thicknesses. One of larger failures runs through the shaft of the old section into the space of underlying mine excavations. The eastern edge is deliminated by the 30th failure with the dip of 60-80° to the west. It reaches the thickness 10-15 m at larger variability (1). All failures are filled with crushed altered rocks including clayish minerals.

From the hydrogeological point of view in the deposit area water-bearing reservoir rocks are developed. The upper water-bearing reservoir rock is formed in overburden sediments. These rocks are noted for low permeability, order 10^{-6}m.s^{-1}. Alluvial fluvial accumulations have higher permeability, order 10^{-5}m.s^{-1}, but they fill only narrow valleys. Vítkov failure outcrops partially on surface under alluvial fluvial accumulations. The upper water-bearing reservoir rock has an important function, as it supplies the upper disturbed part of underlying rocks by underground water. The thickness of reservoir rock doesn't reach over 4-5 m. The lower water-bearing reservoir rock is attached to fracture systems of gneisses and granites. The form of reservoir rock is irregular, dependent on occurence and filling of open fractures. This has been fully verified at the drivage of mine excavations.

The sinking of shaft of the old section was influenced by water inflows from the overburden formation and from the surface disintegration of fractures in the massif. The inflow stabilized gradually at 0,5 - 0,6 m^3.min^{-1}. The construction of the crosscut took place upon the same conditions. The worked larger failures ware noted for initial high inflows that decreased gradually. Large inflows were often followed by broken grounds. After the ending of works the whole inflow of water stabilized upon 2,5 m^3.min^{-1} from both directions. According to the layout of inflow places the flowing of fracture underground water takes place from the south to the north. The mining activity in the fracture system of rock mass appeared as a drainage effect on its fracture waters. This influence worked out in accordance with failure systems. Owing to this there were water losses not only in wells near the shaft, but also in the adjacent valley.

From the hydrogeological point of view the conditions as to the composition and failure of rocks at the mine Vítkov are the same as in the old mine section. The fractures are braced owing to the depth effect, as is proved by occasional, low inflows of water along the whole length of entries. Higher inflows were noted from Vítkov failure that was affected by bore holes. The average inflow from a level was 0,25 m .min^{-1}.

At the same time the continuity of mine inflows with surface water in this part of mine was being solved. From the analysis of regular measurements of mine inflows in a longer time series the close dependence between the variation of precipitation and inflows of mine waters was not evident. By means of tritium analyses the isotopic difference of mine waters from surface waters has been proved. According to the shift of tritium activities at both types of water the delay time of infiltrated water in the fracture system was specified at least 5-6 years and more. On the whole mine inflows are controllable and don't threaten the mine operation.

The samples of main types of granite, gneiss and of xenolith of diorite type were examined in simple compression. The results of measurement proved that the rock mass from the point of view of rock mechanics is homogeneous with the same compression strength (average value 128 MPa).

The evaluation of all information resulted in favourable conditions for the liquidation of mine section by flooding. The rock mass is solid enough and inflow-resistant even at higher hydrostatic pression.

FLOODING PREPARATION

The preparation consisted in elaboration of methods for objective evaluation of the effect of flooding the old mine section on active low mine levels and on elaboration of operation- and safety measures. It is to determine the initial state, to evidence the whole course of flooding and its termination.

The registration of rates of flow of mine water from main inflow directions was ensured by a system of measuring stations. Rules and a methodology of operation measurement were elaborated. Limited space possibilities of the entry called for a certain adjustment of measuring object for the measurement of higher flows (Fig.1).

On main gate at the watched level of the mine Vítkov a system of water retaining dams as counter-waterburst measures was built up. Dams are built in the whole gate-section; At the footwall there is a pipe for free flowing-off.At the height of 2,2 m there is a free ovdrflow. (Fig.2) Dam-to-dam spacing is variable according to the incline of the gate footwall. This system enables to catch about 4000 m^3 of inflow water. The interconnection of pipe orders into lower levels with pumping stations is a part of the system of counter-waterburst measures.

A pump with output 5 $m^3.min^{-1}$ for the case of exposure to danger was installed into the shaft of the old mine section. Further on a level indicator was installed into the shaft and into a ventilation chute. Measurement of underground-water levels in selected wells near the shaft was involved into the set of observation. A uniform and independent documentation was established for measurement and observation.

The basis of operation- safety measures is the determination of critical water inflow in the given area. This va-

Fig. 1 Specific overflow

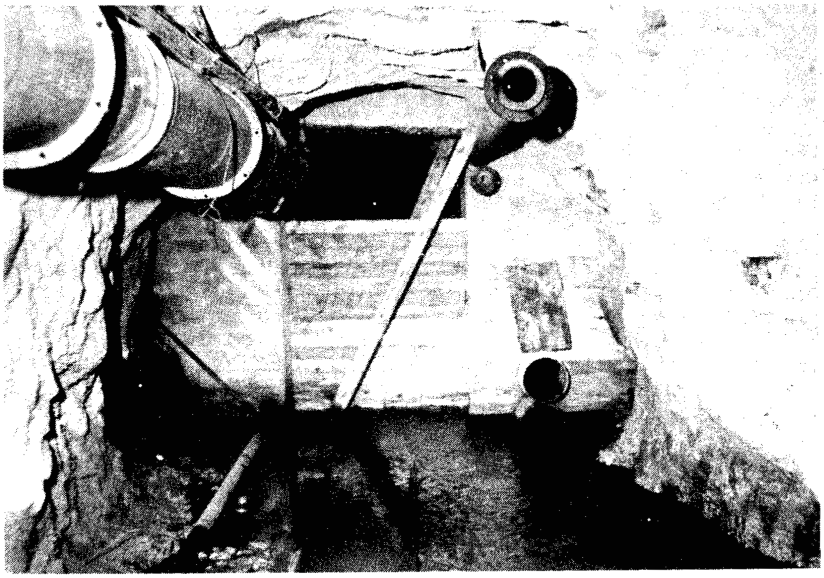

Fig. 2 Water retaining dam

lue indicates the higher water inflow that must not be surpassed. The limiting element is the mine pumping capacity. The value 2m^3.min^{-1} was the basis for the elaboration of operation rules. In these rules individual capacities of mine inflows under the flooded area and respective measures were determined, e.g. higher measurement and control rate in entries, starting the pump in the shaft etc.

COURSE OF FLOODING

After approval of all preparatory operations the flooding of an old mine section was initiated in November 1979. The course of flooding is illustrated in Fig.3. Monthly changes of water level in the shaft are in the Table 1. A part of the observation system was also the ventilation shute. The same course of changes of water level in time at both piezometers proved the connection of entries. At the same time the system of observation enabled the space control of the flooding of cavities in higher placed parts of the rock mass. The differences of water levels in piezometers balanced in short intervals.

In Fig.3 the line "h" illustrates the initial rapid increase of water level in the shaft. This increase began immediately after the stopped water pumping from the old mine section. The increments of water level in the shaft reduced during the year 1980. At the beginning of the year 1981 a mild increase of water level in the shaft could be observed, but since May till September 1981 the level sinks. Since April 1982 the trend of decrease of water level is perceptible. This total change was induced by gradual filling the drained rock mass in broader territory. The original inflow 0,25 m^3.min^{-1} from the area under the flooded section in the mine Vítkov quickly increased from the beginning of flooding,too. During 6 weeks it increased up to 0,7 m^3.min^{-1}. In May 1980 the highest flow of water 0,932 m^3.min^{-1} was measured, in August 1980 it stabilized at 0,859 m^3.m^{-1}. This value of total inflow has not practically changed up to this time.

Higher water inflows dependent on higher hydrostatic pressure in rock mass were generally presumed. This presumption was verified on the contact of the aplitic vein with porphyritic granite. This vein was already worked formerly at the drivage of vertical mine excavation in this area. The increase of total inflow was enabled by bore holes that caught the disturbance zones. These bore holes were originally plugged inconveniently,as the reducing of concentration of the rock mass in neighbourhood was not taken into account, as the entry, as the proper bore hole. Therefore there are water inflows from fractures on entry walls near the bore holes. In a short period water inflows became constant, even if the proper flooding has not yet been terminated.

Table 1

MONTHLY CHANGES OF WATER LEVEL AND PRECIPITATION TOTALS

Year	Month	Height of water column in the shaft (m)	Relative changes of water level in the shaft	Monthly total precipitation (mm)
1979	11	23,86	23,86	64,8
	12	49,92	26,06	106,3
1980	1	69,70	19,78	51,5
	2	87,86	18,16	65,0
	3	104,28	16,42	47,2
	4	115,63	11,35	61,2
	5	123,50	7,87	37,1
	6	127,25	3,75	63,9
	7	131,26	3,93	131,6
	8	134,16	3,67	23,5
	9	135,29	1,13	22,6
	10	136,77	1,48	62,2
	11	138,44	1,67	28,0
	12	139,41	0,97	32,4
1981	1	141,37	1,96	75,8
	2	144,42	3,05	29,2
	3	148,65	4,23	56,9
	4	150,86	2,21	34,2
	5	150,39	- 0,47	59,4
	6	149,50	- 0,89	24,3
	7	149,12	- 0,38	134,2
	8	148,87	- 0,25	40,5
	9	147,98	- 0,89	39,1
	10	149,62	1,64	165,9
	11	152,65	2,93	67,9
	12	156,19	3,54	88,5
1982	1	159,38	3,19	61,9
	2	160,68	1,30	10,2
	3	161,39	0,71	36,1
	4	161,58	0,19	35,1
	5	160,80	- 0,78	56,9
	6	158,89	- 1,91	52,5
	7	157,48	- 1,41	48,5
	8	155,52	- 1,96	69,9
	9	153,90	- 1,62	17,1
	10	153,92	0,02	82,5
	11	152,68	- 1,24	20,1
	12	153,06	0,38	72,7
1983	1	153,55	0,49	73,4
	2	156,42	2,87	32,0
	3	157,32	0,90	35,3
	4	158,22	0,90	83,6
	5	158,72	0,50	76,1
		158,24	- 0,38	
	6	156,92	- 1,75	49,5
	7	155,69	- 1,23	9,0
	8	153,62	- 2,07	100,4
	9	151,89	- 1,73	39,7
	10	151,40	- 0,49	23,8
		151,50	0,10	
	11	151,00	- 0,50	55,4
		151,36	0,36	
	12	150,65	- 0,71	21,4
1984	1	150,12	- 0,53	71,5
		150,62	0,50	
	2	152,46	1,84	56,7
	3	152,30	- 0,16	14,5
	4	153,72	1,42	48,1
	5	154,15	0.43	90,0
		153,94	- 0,21	
	6	154,21	0,27	64,3
		153,94	- 0,27	
	7	153,19	- 0,75	52,0

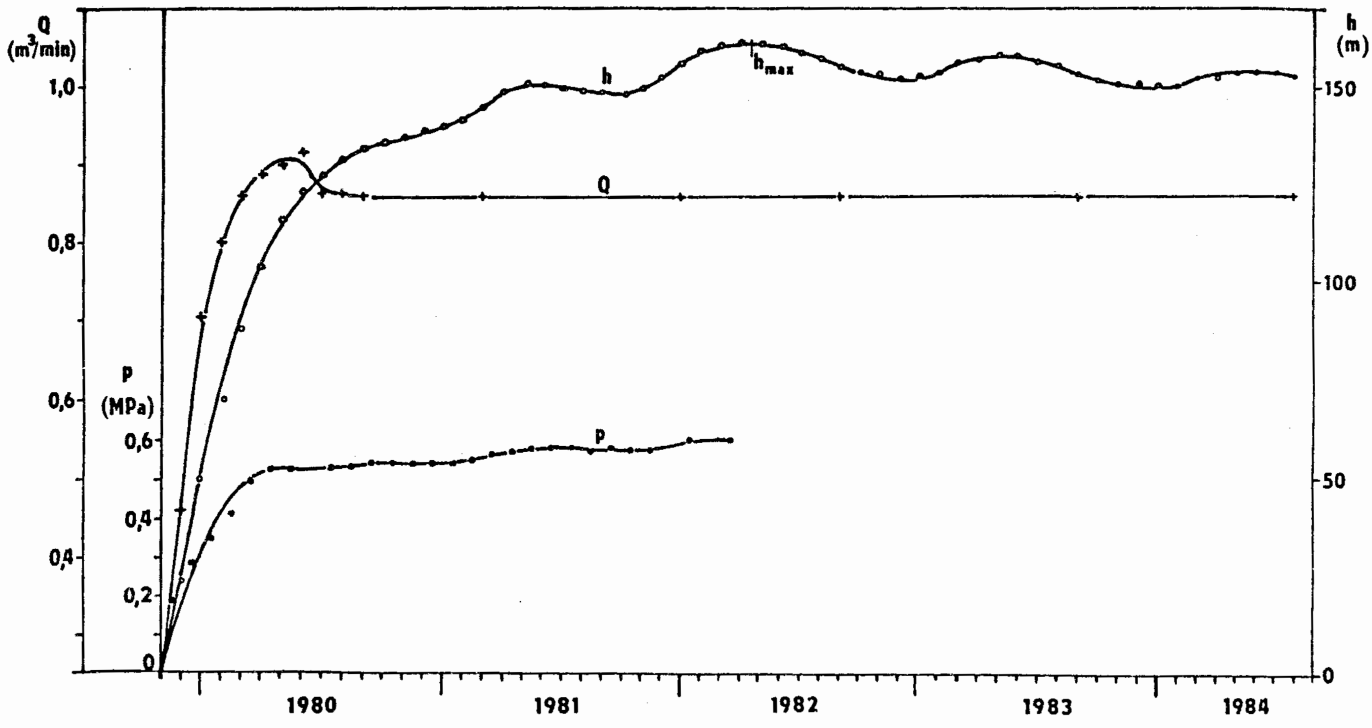

Fig. 3 Course of water level increase in the shaft (h), total inflow (Q), hydrostatic pression (p)

On the level under the flooded section the changes of pressure in rock mass were observed in the bore whole, induced by its loading. Before flooding the pressure in porphyritic granite was 0,15 MPa, in March 1980 it increased up to 0,53 MPa. Then the pressure slowly changed up to the fixed value of 0,6 MPa, i.e. in January 1982. In the neighbourhood of the bore hole new inflows into the entry were not observed. The opening of the bore hole didn't appear as higher water inflow. It testifies the constant tightness of rock mass event at increasing hydrostatic pressure. We must carefully differentiate this phenomenon from worked water-bearing disturbance structures that on the contrary are noted for higher water inflows owing to a certain washing of the fracture filling and owing to their larger regional range.

EVALUATION OF FLOODING PROCESS

Compared with original prognoses it was evident that flooding must be seen as a long-termed process. This consideration issues from the structural construction of rock mass and from the previous long-termed drainage of the fracture water-bearing reservoir rock. The course of flooding was hydrogeologically evaluated in relation to precipitation that has principal share in water infiltration into the fracture system of the rock mass.

In Table 2 monthly precipitation totals in the period of increase and decrease of water level in the shaft are compared with long-termed average precipitation.

Table 2

AVERAGE VALUES OF PRECIPITATION TO 50 YEARS AVERAGE

	Annual total of precipitation (mm)	Relative proportion to 50years total %	Relat.propor.to 50years total	
			Level increase in the shaft %	Level decrease in the shaft %
1901-1950	646			
1979	710	110,-	11/79 - 12/79	
1980	626	97,-	1/80 - 12/80	
1981	816	126,3	11/79 - 4/81 108,6	5/81 - 11/81 91
1982	563,5	87,2	10/81 - 4/82 146	5/82 - 11/82 81,6
1983	600	93,-	12/82 - 4/83 135	5/83 - 1/84 86

Periods of water-level increase are characterized by higher precipitation and the phase of decrease by lower precipitation. The differences between individual periods are outstanding. The highest water level in the shaft 161,58 m was taken in the period of the highest relative difference 146 %. The lowest water level 150,12 m shows 86 %. The period of water-level increase in the shaft was always terminated in April of the competent year. On the contrary the period of level decrease gradually extended. Close dependence between precipitation activity and flooding evolution of the mine section can be stated. The first period of the water-level increase in the shaft represents the filling of the depression cone near the shaft that lasts till April 1982. In further course of flooding the dependence of the water level height on precipitation conditions becomes evident.

The dependence of water-level changes in the shaft on precipitation was being solved by means of trend analysis. The investigated relation is being changed in time that represents a variable value for a long time. The functional dependence is expressed by a functional F, where time = t is the argument of the functional:

$$h = F/f\ (as)\ /\ (t)$$

where: h = water level height in the shaft;
as = precipitation.

Graphically expressed course of the function illustrates the time dependence of water-level changes on precipitation (Fig.4). The value of general correlation coefficient 0,75 is considered as reliable limit of the beginning of the formation of a certain stationary state at the long-termed variable time. In the period 1979-1981 the course of line of the function illustrates the filling of mine excavations and of the drained rock mass in next neighbourhood. In December 1981 the function reaches the limit 0,75. Further course of the function vacillates around the value 0,8. From the fourth quarter of the year 1982 the function shows a mild increasing tendency. The signed line decreases in principle agree with observed water-level decreases in the shaft. The retardation of the influence of precipitation on water-level changes amounts to 3 months. The mild line increase shows also the long-termed course of flooding. In principle the gradual filling of drained fracture systems of rock mass in broader neighbourhood is under discussion.

The chart in Fig.5 completes the evaluation of dependences between precipitation and water-level changes in the shaft. To the end of the year 1981 the functional F stabilizes and becomes constant. The time as a long-termed variable is not therefore the determinating element and it is therefore possible to omit this quantity. The graphic dependence

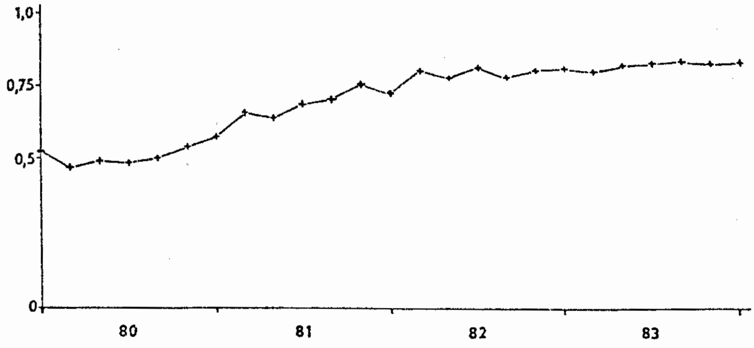

Fig. 4 Standardized general correlation coefficient

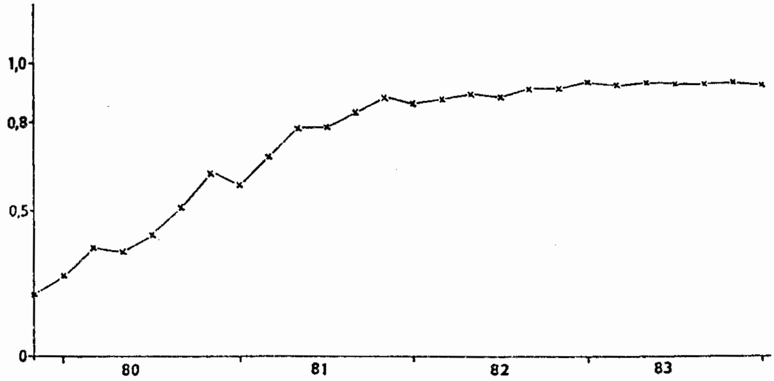

Fig. 5 Factor of regression stability

expresses only changes of functional values:

$$h = f\ (as)\ .$$

If the values of the factor of regression stability approximate to the value one, the regime stabilizes in the flooded area. If we start from the value 0,8, it is evident that in the last quarter of the year 1981 the regime of flooding began to stabilize. This process lasted practically the whole year, till October-November 1982. The constant course of the line above the value of 0,9 indicates that a quasistationary state has been formed. By means of gradual filling the broad neighbourhood of the shaft this state will slowly change into stationary.

The interval test according to Mathew is expressed graphically in Figure 6. It completes the dependence in Figure 5. The chart illustrates the variability degree of the functional F. The course of individual lines describes the rate of changes of the functional preceding dependence in one year, divided into 4 time periods. The year 1980 can be characterized as a period with the highest unsteadiness of the function, when the factor M_t reaches 0,5. In next years the stabilization of the function is evident, as the lines every year approximate to the value 0,9. From the chart the long-termed formation of the stationary state is evident.

The evaluation of all factors and information concerning the course of flooding proved the reality of its termination. The old mine section is permanently conserved since August 1984.

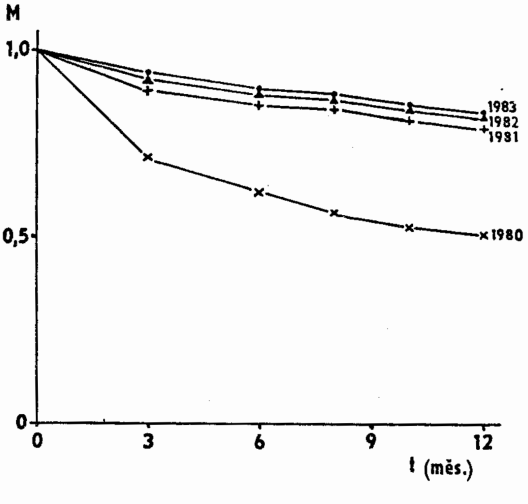

Fig. 6 Interval test according to Mathew

CONCLUSION

The liquidation of old mine excavations brought economic savings as in costs for the operation of pumping equipment, incl.energy savings and labour savings, as in costs for ncessary reconstructions of mining equipment. The finished pumping of mine waters appeared ecologically as increase of freatic water in wells. The evaluation of the course of flooding brought even new information for defining elaborated methods with more precision.

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