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HYDROGEOLOGICAL ANALYSIS FOR THE LONG-TERM SUSPENSION OF THE RECSK DEEP MINES BY FLOODING

Ph.D. Theses

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I. Objectives

Protection of environment, ranging from the subsurface to the atmosphere, has received increasing attention in Hungary in the end of the 20th century due to the political transition, increasing social awareness and due to declining heavy industry and its remnant pollution.

Before the political transition, industry was expected to be economic only, while modern society expects the industry to be environmental-conscious as well.

As a result of improving environmental legislation and long-term low market prices, subsurface mining has almost completely ceased in Hungary and information on mining can be obtained only from professional literature. Ore mining in the Mátra Mts. has a long history that had the Recsk Deep Mines as its ”big dream”. Development of the Recsk Deep caused a number of environmental problems, according to the present legislation. The long-term suspension of the Recsk Deep by groundwater flooding is unique in Hungary and abroad.

Long-term suspension is not defined by the Hungarian Mine Law, therefore its definition according to LOIS (2000a) is the following: The objective of long-term suspension is ”saving the mine for the next century and to maintain the possibility of reopening”. Flooding is a natural consequence of mine closure, however it is a means of long-term suspension in case of the Recsk Deep Mines.

The objective of this research is to support the analysis of mine flooding (1) by defining the original pre-mining groundwater levels, (2) by defining the groundwater depression during the mine suspension period, and (3) by defining the corresponding infiltration rates. Further objectives are (1) analysis of the flooding process in confined and unconfined aquifers based on groundwater data for the first 5 years of flooding, and (2) the analysis and comparison of groundwater chemistry before and during mining activities, and after mine closure.

Mine flooding has brought up numerous questions since 1990. Based on earlier prognoses, prospecting geological and hydrogeological data, and on the experience of the last 5 years of mine flooding, we may obtain knowledge of sub-surface hydrogeological and hydrogeochemical processes that could be used in similar ore mine areas as well.

Guideline of my research was provided by POLLNER (1973):

”Life demanded and still demands from the Recsk Deep Mines and from us ever: reopening!”

II. Materials and methods

My research was characterised by gradual understanding of the study area. When I joined the Recsk Ore Mines Company in 1999, my duty was related to the mine suspension activities. I had to learn about the mine activities of the past period and to prepare for the tasks of the coming period. Parallel to this, I had to study the environmental reports related to the preparation for the long-term mine suspension. I studied a great number of reports and papers on the Recsk Ore Mines and I also studied the nearby Lahócai Mines to fit it into the groundwater model of the Recsk Deep Mines.

My calculations for the mine flooding process showed that the original pre-mining groundwater flow system had to be understood so I studied all the Recsk Deep drilling reports (136 altogether) kept at the National Geological and Geophysical Archives. I designed forms for the efficient collection of hydrogeological and geochemical data. Based on this investigation I realised that mining reports deviate from the original drilling reports in some cases. Thus, I used the original drilling reports throughout my research, and all my calculations, statistics and model analyses are based on these data.

During my work, the original pre-mining flow directions, spring locations and groundwater levels in wells were graphically represented. The source of spring data was the VITUKI Water Research Institute Spring Register, while well data was taken from the VIZITERV Hydrological Design Company Well Register. Groundwater flow analysis was hindered by the lack of coordinates in the Well Register, so well coordinated had to be identified first. Coordinates of only 80 wells developed in 1974 was identified because the 2,150 wells in the Well Register did not give extra information and because these selected wells were distributed along a 500-700 m grid over the study area. A Microsoft Excel code was developed for the infiltration calculations.

Hydrogeochemical data was interpreted in the light of sampling, analytical and applied statistical methods. Analysis included hydrogeochemical data from (1) drill hole and mine shaft development reports, (2) the monitoring in the period of flooding (November 1999 - May 2004), and (3) depths-stratified water samples taken in June 2003. Statistical and data analysis techniques used univariate distributions analysis and time series analysis, and bi-variate correlation analysis between the original measured and stationary de-trended time series. Statistical analyses were performed by Statgraphics Plus Version 5 software.

III. Theses

1. THESIS In the area of the Recsk Deep Mines the original groundwater flow direction was calculated to be in the W, S, and NNE directions, that was modified to N-S and NE directions by the Lahóca Mines pumping, in accordance with the findings of KBFI (1980). Calculated surface and groundwater flow directions also confirmed the original flow directions.

Assuming unconfined conditions, stationary groundwater flow and wells, it has been shown that pumping in the Lahóca Mines between 1926-1956 affected to a distance of 650 m. This means that the original water levels in the Recsk Deep drillings was not affected by the Lahóca Mines. Water pumping was necessary in the Lahóca Mines due to precipitation infiltration, while latter in the deeper shafts (ore blocks VIII and X) pumping was necessary due to water seepage from the streams around the Lahóca Hill (Baláta-patak, Áldozó-patak, Bikk-patak).

Water pumping from the Lahóca Mines did not cause significant change of the groundwater system. Thus original water levels could be corrected for the depression conditions using hydrogeological results of GAGYI PÁLFFY (1971) and MARKÓ (1976) and the Recsk Deep drilling reports data. Data for the Mátraderecske Rm-11/a thermal well since 1967 was also considered. (The effect of the Bükkszék pumping since 1937 can be also used for more detailed investigations). The thus obtained flow is in the W, S, and NNE directions (Figure 1) that can be regarded as the original pre-mining piezometric surface. This model is confirmed by the piezometric surface constructed based on spring and well data.

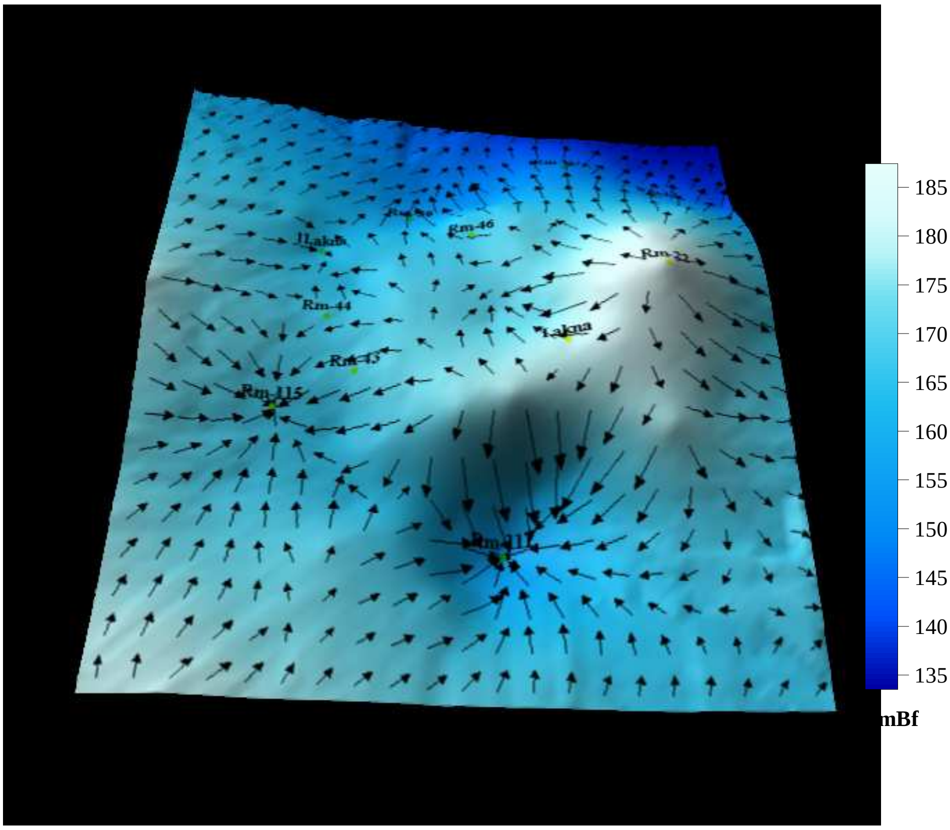

Figure 1. Original piezometric surface for the study area (SOMODY 2005).

The original piezometric surface is almost identical with the topographic surface apart from the area at the Rm-111 and Rm-115 bore holes because there are groundwater level minima at these bore holes. The probable reason for the groundwater minima is the double groundwater level observed during Recsk Deep drillings. Double groundwater level was observed in 8 bore holes but no further investigation was carried out for its analysis. Based on the geological, tectonic and ore deposit characteristics around the Rm-111 and Rm-115 bore holes it is probable that the local minima marks locations of fractures where groundwater is drained from the upper to the lower lithological units.

2. THESIS There is no need to distinguish the infiltration properties of the Paleogene strato-volcanic andesite, the diorite-porfirite intrusions, and the mineralised and hydrothermally altered versions of these rocks because there is no significant difference between their infiltration quantities that also simplifies calculations.

Infiltration analysis considered two cases:

1. Paleogene strato-volcanic andesite was considered the only infiltration area (Figure 2),
2. various rock formations within the paleogene strato-volcanic andesite and its wall-rock such as Oligocene clayey marl, sandstone and Miocene volcano-sedimentary series were also considered together with the paleogene strato-volcanic andesite having identical transmissivity.

Assuming 10 mm infiltration and $5.35 \cdot 10^{-8}$ m/s hydraulic conductivity, and having the analytical model calibrated to the Rm-39 bore hole, the total yield provided by the sectors was 1411 l/min in the first case, while it was1398 l/min in the second case. Based on these results it can be concluded that the paleogene strato-volcanic andesite and its various versions can be regarded the same in terms of infiltration properties. It is noted that due to its chemical composition (NaKCl), Eocene limestone was regarded as a part of the basin bedrocks. The calculated hydraulic conductivity of $8{,}15 \cdot 10^{-8}$ m/s is a good approximation of the average hydraulic conductivity of the strato-volcanic andesite ($8{,}30 \cdot 10^{-8}$ m/s) published by GAGYI PÁLFFY et al. (1971).

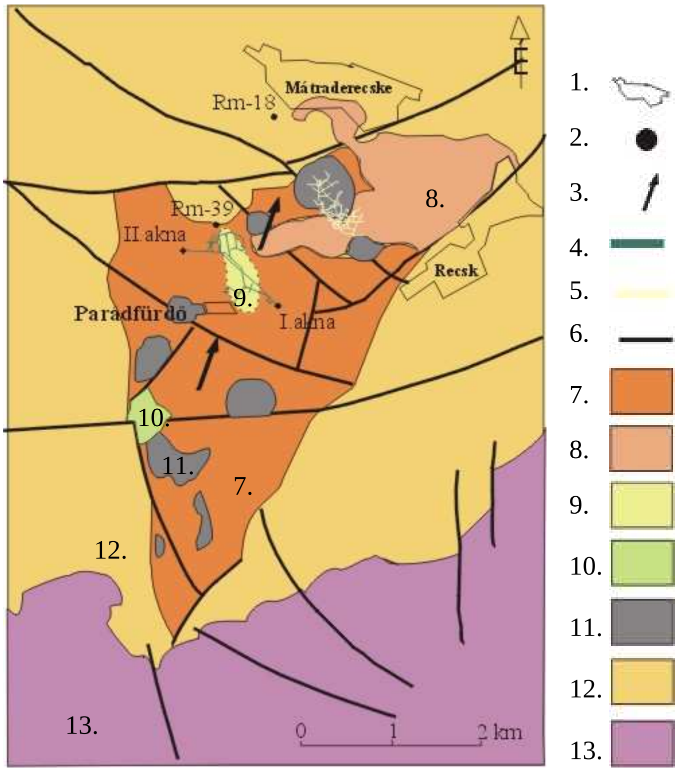

Figure 2. Geological map of study area (Földessy 1996)

(Key: 1: settlement, 2: shaft, bore hole, 3: groundwater flow direction, 4: Recsk Deep Mines adits, 5: Lahóca Mines adits, 6: fault, 7: Eocene andesite, dacite, middle strato-volcanic series, 8: Oligocene-Eocene andesite, upper strato-volcanic series, 9: Hidden diorite-porfiric intrusion 10: Mineralised Eocene diorite-porfiric ore breccia, 11: Zone of intenzive hydrothermal alteration, 12: Oligocene clayey marl, 13: Miocene volcano-sedimentary series)

3. THESIS The average recharge rate by precipitation in the strato-volcanic andesite is 1.81 mm/y, while it is 1.12 mm/y elsewhere. The radius of the depression cone calculated for 16 November 1999, for the -891 mBf groundwater level measured in Shaft II was between 8,029-24,866 m (8-25 km).

The area of the strato-volcanic andesite exposed to the surface 11,3 km^2 that is covered by Miocene and Oligocene rocks around the exposure (Figure 2). The covered part of the strato-volcanic andesite has lateral water recharge primarily. The carbon-dioxide, methane gas and oil traces known in the Recsk area come from the oil-bearing Bükkszék Formation as shown by carbon isotope studies. The present study has also shown the lateral recharge of the confined parts of the strato-volcanic andesite.

Calculations for all sectors provided a 1745 l/min yield that deviates by 3,05 % from the 1800 l/min initial value indicating an approximate value from 1993, thus the obtained recharge value is acceptable. The average precipitation recharge in the strato-volcanic andesite is 1.81 mm/y while it is 1.12 mm/y elsewhere. The depression radius is between 8,029-24,866 m (8-25 km) (in 1999) cross-cutting infiltrating rocks in all cases.

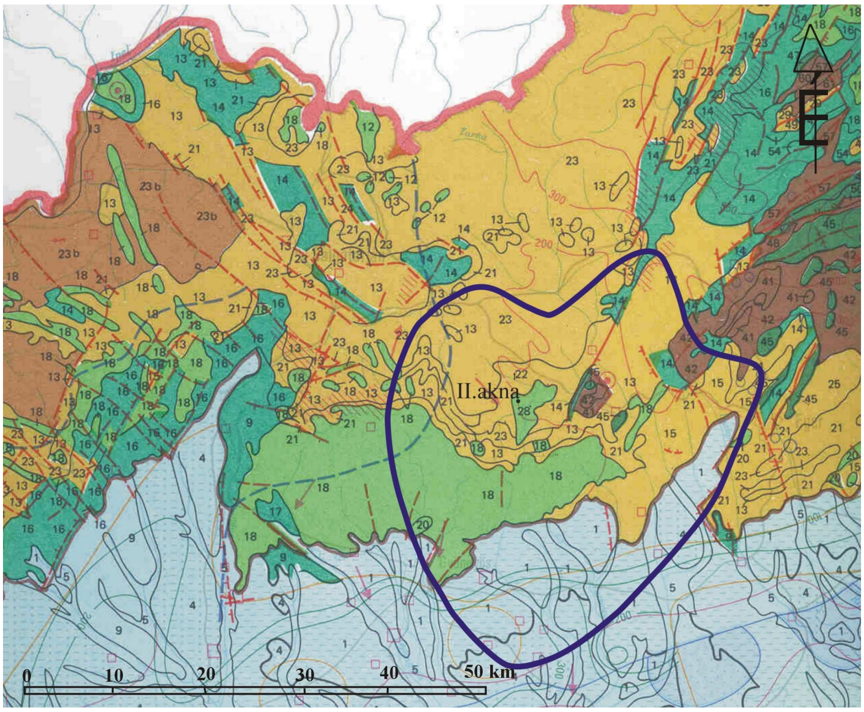

Figure 3. Depression surface developed by pumping in the Recsk Deep Mines in 1999 (SOMODY 2005., map by SIPOSS 1989)

(Key: 1: clay, 4: loess, 5: river, stream sediments, 13: sand, sandstone, 14: pebble, sand, 15: clay, clayey marl, sand, 18: Miocene andesite, 20: rhyolite, 21: rhyolite tuff, 23: clay, sand, 28: Eocene andesite, 42: clay slate)

These calculations show that hydraulic communication is more limited than assumed earlier. In such a depression the deep mines are recharged by 6.5 mm precipitation infiltration only when the infiltrating rock (strato-volcanic andesite) is close to the well (Shaft II in this case) and it is pumped. Greater amounts of infiltration occur in the N, NW sectors that might be in connection with groundwater inflow in the strato-volcanic andesite or Triassic limestone. The maximum 30 mm infiltration recharge for deep mines (depth 1200 m) seems a strong overestimation.

Precipitation infiltration occurs along fractures left open by secondary and ore minerals. Rock porosity has secondary role with respect to water conduction as pointed out by SZILÁGYI (2002).

Although mine water pumping yield is different from the 4-5 m^3/min at 5 million tons ore production as calculated in 1970, the 1.8 m^3/min yield during the period of mine maintenance fits into the depression extension predicted by GAGYI PÁLFFY et al. (1971). Permanent infiltration conditions would develop in 30 years leading to a 100 m depression extension.

Results are in concert with the report while the infiltration rate is much lower than that predicted by KBFI.

4. THESIS Values corresponding to the confined and unconfined aquifers in the flooding curve of the Recsk Deep Mines can be used to calculate the minimum and maximum values of transmissivity.

Mine flooding analysis was carried out for both confined and unconfined aquifers because the system is gravitational and partially unconfined with dissolved gases. Two sections were identified in the analysis (Figure 4). Section I corresponds to the confined aquifer. Section II has a mixed character due to fractures. Piezometric levels are higher than in the confined aquifer but lower than in the unconfined aquifers. For both sections, however, both confined and unconfined transmissivities were calculated because flooding rate has declined after section I partly due to that the system became unconfined.

Transmissivity has been calculated to be lower for the unconfined system than for the confined case. Also, transmissivity is higher in section I in Shaft I than in Shaft II. This difference is attributable to that flooding rate was higher in Shaft I than in Shaft II. The skin effect value below 6 (3.6) has proved the existence of a zone of low conductivity around the mine shafts and adits (Table 1).

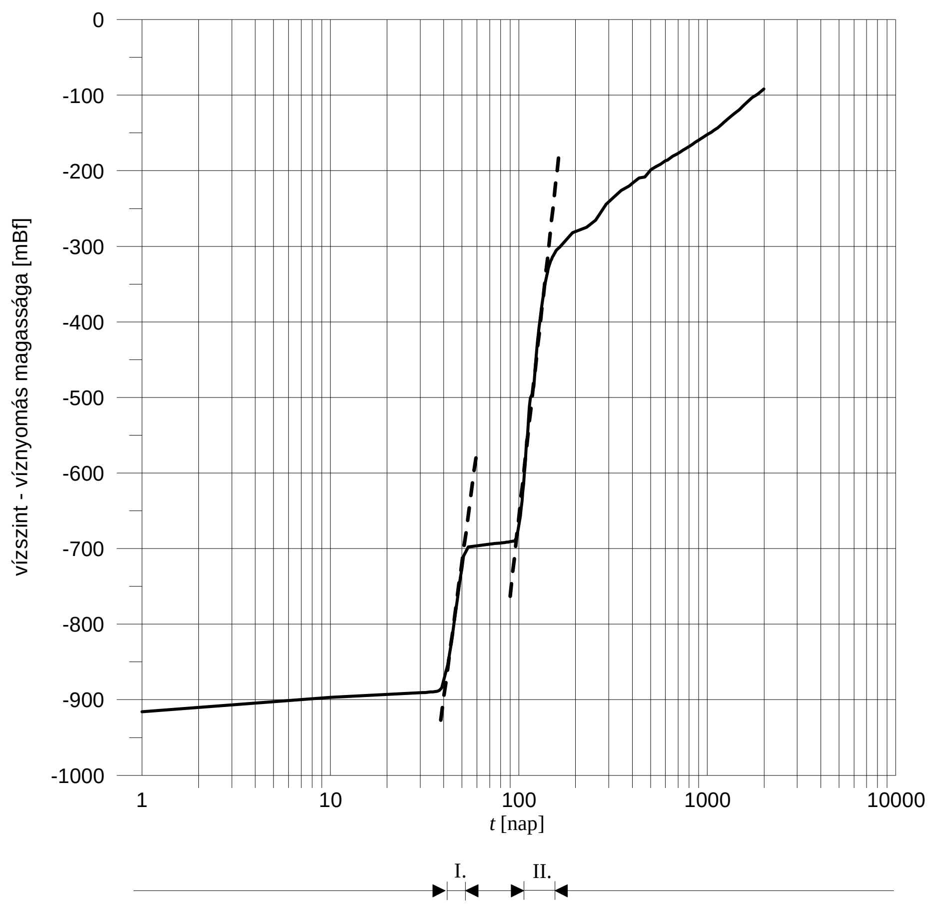

Figure 4. Flooding curve of Shaft I (Somody 2005).

Table 1. Summary of calculated parameters

type of system	Parameter	unit	Shaft I	Shaft II	sections
unconfined	*km* (*transmissivity*)	m^2/s	$1{,}83 \cdot 10^{-4}$ $1{,}07 \cdot 10^{-4}$	$2{,}06 \cdot 10^{-4}$ $1{,}01 \cdot 10^{-4}$	I. II.
confined	*k* (*hydraulic conductivity*)	*m/s*	$2{,}32 \cdot 10^{-4}$ $2{,}04 \cdot 10^{-4}$	$2{,}02 \cdot 10^{-4}$ $1{,}96 \cdot 10^{-4}$	I. II.
confined semi- confined	$\bar{t}$	-	0,11 0,28	0,03 0,08	I. II.
	S_p *(skin effect)*	-	3,6		

5. THESIS Trend analysis of hydrogeochemical time series of Shafts I and II shows disolution, precipitation and dilution processes. Analysis of time series after trend removal yielded insight into the chemical-mineralogical composition of host rocks. As flooding progresses, a uniform mixed water chemical composition develops in the shafts.

In the case of Shaft I, correlation between pH and metals, and among the metals correspond to the mineralised, primarily skarn, sections. Trend is defined here as the systematic, non-random change of measured hydrogeochemical time series. Trend removal is defined as the removal of systematic physical and chemical effects from the measured hydrogeochemical time series by statistical methods. Trend in the hydrogeochemical time series was calculated by means of 3 or 5 point moving median filters. Residuals were calculated by the subtraction of the calculated trend line from the original measured values. The thus obtained residual time series retained only two correlations: pH~Fe and pH~TDS. Results show that trend in the time series is caused by the disolution, precipitation and dilution processes caused by the flooding process.

For Shaft II it can be observed that correlation is primarily between the main water chemistry parameters and correlations after trend removal reflect the ore mineralization composition. Trend reflects here the disolution, precipitation and dilution processes, too, promoted by water flooding into the shaft at locations. Slowing of mine flooding and mixing of waters in this shaft leads to equilibrium conditions, also shown by the depth-stratified sampling.

Significant correlations were found between the main water chemistry parameters and between metals in observation bore holes Rm-18 and Rm-39. Statistical analysis of both original and de-trended time series reflected rock composition. These bore holes thus can be regarded as background observation locations with respect to mine flooding since flooding has no effect on their hydrogeochemistry through flushing or dilution.

Statistical analysis of time series has shown that effects of change of analytical laboratorories and effects of natural process cannot always be distinguished in the time series.

6. THESIS Stationer piezometric conditions are unlikely within 50 years in the Recsk Deep Mines area, thus there is no need to account for the movement of waters in the shafts during this period.

Water transmissivity values decreasing with progressing mine flooding indicates that stationer piezometric conditions are unlikely within 50 years.

Waters in the shafts do not bring contamination risk because mineralized parts of mine adits and shafts have already been flooded. Thus, heavy metal concentrations will further decrease and remain insignificant.

Shafts are main elements of the flooding process through which hydrogeological and hydrogeochemical processes can be monitored. Thus, they should play an essential role in the long-term monitoring system, in particular because their hydrochemistry is different from that of the observation bore holes.

Application of results

The fate of the Recsk Deep Mines has brought uncertainty since its opening. The covering of the shafts is useful from a mining point of view, but also for obtaining hydrogeological and hydrogeochemical information and knowledge applicable to similar ore deposits. Findings of this thesis can be used for support of decisions by the authorities.

Results of this thesis can help with answering aquifer protection problems and regional thermal water production design.

The groundwater depression cone developed by 1999 and the slowing flooding process makes it desirable to study the whole affected area in Recsk, also providing information for the analysis of the hydrogeological role of the Darnó Line and for the analysis of the hydrogeological connection of areas on either side of the Darnó Line.

The thesis results are used in the following on-going activities:

1. the interpretation of tidal phenomena registered by the Recsk and Bükk karst area monitoring system,
2. the analysis of the effect of the Recsk Mines pumping and flooding on the Bükkszék thermal water system,
3. erosion and flood modelling for the catchments of the Bikk stream and of the Parádi-Tarna stream,
4. hydrogeochemical study of the groundwater in the area affected by the depression,
5. interpretation of geothermal conditions in the Recsk Deep Mines.

IV. Publications prepared in relation to the Thesis

Book chapter:

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