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DEVELOPMENT OF ABRASION ON THE BANKS OF THE BRNO RESERVOIR

P. Kubíček

Department of Geography, Faculty of Science, J. E. Purkyně University,
Kotlářská 2, Brno, Czechoslovakia

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SUMMARY

The paper deals with changes in the submerged area of the Brno reservoir. The gradual development of the banks was judged from the original isohypse plan, observation in the field and from papers describing the state of abrasion cliffs in the reservoir in the history. In the text were summarized factors evoking the modelling of the bank line; above all the connection of abrasion and slope processes was stressed.

INTRODUCTION

The construction of reservoirs considerably affects and changes the appearance of the georelief in their surroundings. Reservoirs are becoming a wide-spread element in the cultural landscape and abrasion processes in the contact zone of the water surface and the banks can differ from abrasion processes of the bank zone of lakes, because in water works there are rapid changes in the water level.

A number of authors have dealt with geomorphological changes in the submerged territory at the Brno reservoir. Linhart (1954) describes changes in the banks due to abrasion depending on the variation of the level and prevailing winds. Closely linking up with his paper these problems were also dealt with by three authors from the Faculty of Civil Engeneering in Brno, Bayer, Mencl and Pelikán (1955) who elaborated the problems of material resistance to surf with respect to the slope gradient. The territory under study was also dealt with in detail by Prof. Dr. s. Kratochvíl (1969, 1970) who elaborated above all the theory of the effect of waves on the bank.

In the time elapsed since that research the conditions have changed essentially. In the present paper I try to describe the present state and the main factors affecting the formation of abrasion wave-cut cliffs and compare my results with the data published. I start from the assumption that with the construction of the water reservoire Vír rapid variations in the water level were removed and the overall variation was changed. Owing to that fact the importance of slope processes formerly considered insignificant and inessential for the evaluation of abrasion is growing.

CHARACTERISTICS OF THE BRNO RESERVOIR

The dam on the river Svratka was completed in 1940. It can hold water on the area of 270 hectares with maximum volume of 21 milion m³, the highest elevation being 231.00 m. The length of the submerged area is about 10 km and according to its shape it can be divided into 3 sectors (Fig. 1).

1. The front part of the reservoir (about 3 km) is of a lake type with the widest water area of 800 m in the region of Kozí horka hill and beaches on both banks. The valley in that region is asymmetric, the left bank being steeper, bordering on the deepest parts the most intense changes of the bank take place.

2. In the direction of Rokle the reservoir becomes narrower and up to Veveří Castle it is confined by rocky and stony steep banks (about 4 km). When the water level sinks very much, the submerged area ends at that elevation point.

3. From that sector up to Veverská Bítýška (about 4 km, normal end of the submerged area) on either bank there alternate outcrops of the underlying rocks with milder clayey banks.

The underlying bedrock of the reservoir are constituted above all by the Brno pluton. The river Svratka cuts its valley through massive diorite rocks bordering the greater part of the left bank of the main reservoir basin. In the middle part of the reservoir diorite is alternated with biotitic granite, only the end of the inudated area reaches Permian conglomerates of the Boskovická brázda furrow, continued by a narrow stripe of upper Devonian limestones. To the southwest of the dam the depression in the Brno pluton is filled with Tertiary clay.

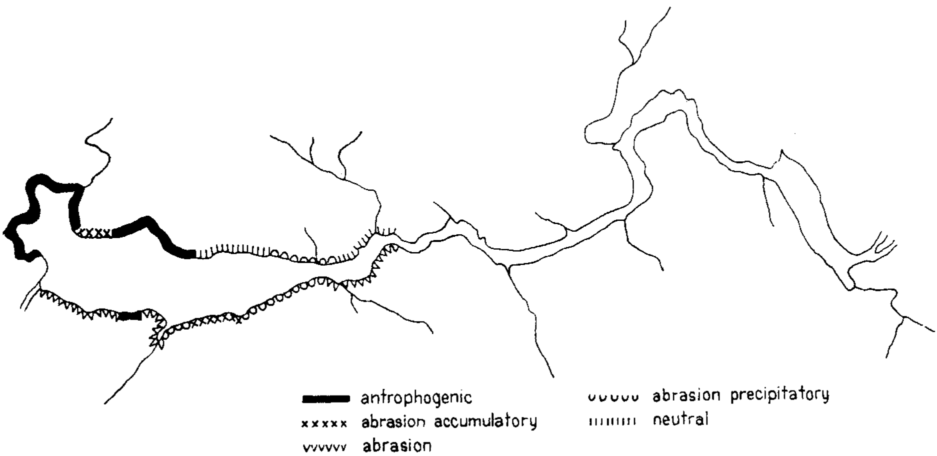


Fig. 1. Types of the banks of the Brno reservoir

METHOD OF WORK

In the course of the study in the field the development and the present state of abrasion wave-cut cliffs in the most affected region about 1 km northwest of the Sokol swimming pool near so-called Osada were studied. In that region 7 sections were measured by means of tachymetry. Other three sections were placed into close proximity of the Sokol landing bridge. The measurements were carried out in two periods of time — February 1985 and March 1986. On their comparison with the original state from the contour line plan in the scale of 1:2.880 the dynamics of abrasion processes was evaluated as well as that of their individual characteristics.

FACTORS AFFECTING ABRASION

The process of modelling the banks is the resultant of the action of a great number of factors and natural conditions. The most important of them include:

The Wave Regime

This is the active factor of wave abrasion. The greatest role is played by the energy waves which depends on the regime of the wind and the starting distance of the wave and further the motion of the sediment carried away from the region of the bank. In expressing the fundamental characteristics of abrasion in numbers, particularly its volume, the most important is the overall energy acting upon 1 m of the bank line.

Antropogenic Factors

Man can influence above all the regime of the reservoir, the variation of the level an the rate of its variation. The amplitude of this variation limits the border of abrasion. Secondary quick changes in the level of the surface result in alternating hydrodynamical tension in the bank material. Due to the fact that the Brno reservoir belongs among water works with short-term control in which the dispatcher diagram is kept, quick changes in level come into consideration in only extreme cases (spring thaws, storm spates). The action of free waves due to boat transport that can reach up to 0.5 m must also be included among anthropogenic influences.

Climatic Effects

It is necessary to take into consideration above all the wind direction and speed. Further influence is that of temperature that controls the length of ice-free periods, the action of floating ice periods and secondarily also the physical properties of bank materials (freezing and becoming musky).

Geomorphological Conditions and Processes

The extent and intensity of abrasion is affected by morphological conditions of the bank zone. This is particularly reflected in sheer slopes which, in water reservoirs, were often genetically connected with the former lateral erosion of the stream. The degree of damage and remodelling of such slopes increases if besides they are constituted by easily washed-out material. The individual geomorphological processes also operate actively, often linking up with one another. Depending on the character of the lithology of the underlying beds slope processes are activated (watering, solifluction, collapse, sliding along rotational friction areas and predetermined areas).

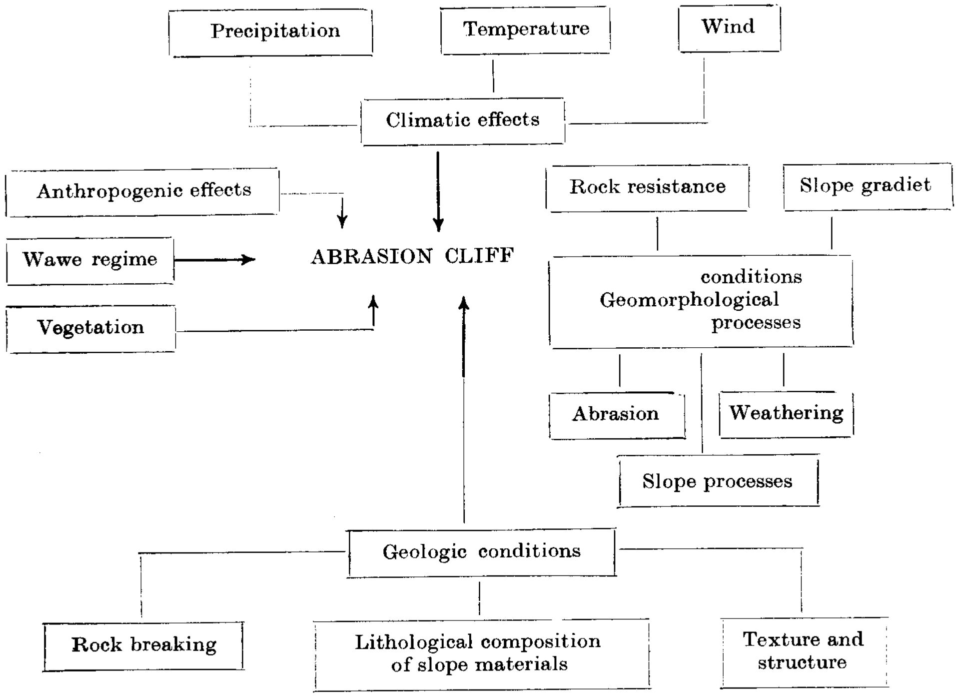
Geological Conditions

Of influence are the above lithological composition of slope materials. Near the banks constituted by outcrops of rocky underlying beds the degree of rock breaking comes into consideration (orientation of crakcs toward the prevailing wind direction) and their texture and structure.

Vegetation

Plants of the banks of the reservoir are mostly considered to be an unambigously anti-erosion factor. This thesis, howerer, does not hold absolutely (see below). Vegetation provisions can suitably be carried out on flat banks and in shallow coves where plants develop very quickly. The most suitable for that purpose are willow shrubs which form light and resilient stands with small leaf loss. The willow stand can also take the influx of water and fine detritus from the adjacent meadow zone. On steeper slopes in places threatened by sliding it is, of course, necessary to use suitable deciduous trees with deep roots and small harmless loss of leaves.

Fig. 2. Factors Constituting the Formation of Abrasion Cliff



Linhart (1969) differentiates the following types of banks of reservoirs according to the intensity and kind of remodelling of the bank zone:

— abrasion accumulatory, characterized by the cliff and abrasion platform, its height depending on the slope gradient and the kind of rock. It originates mostly in coarse-grained material, towards the water the fraction of material is diminuted.

— abrasion sliding; the raised water level causes the soaking of rocks with a great share of clay fraction, the stability of the slope is damaged and slides are formed.

— abrasion precipitatory is formed where the rock is damaged tectonically. Waves wash out fine material from the fault and on exceeding the cricital point collapse occurs. It can develop on loess deposits where due to vertical jointing whole blocks detach. Often intensified by piping.

— abrasion talus is formed at steep slopes where the water surface contacts outcrops of weathered and strongly jointed rocks. In spring and in autumn during alternating freezing and thawing of waters in the cracks the loosened material falls away and forms talus at the foot of the rock.

— abrasion has characteristic steep to vertical banks without abrasion platform, because the material is immediately washed away.

— accumulatory is formed in bays, near the mouths of streams on primarily flat banks.

— neutral is formed at low banks with the gradient of up to 3°, where waves lose their energy due to the shallow bottom. The work of waves is reflected in a mere washing of banks.

— anthropogenic has conspicuous characteristics of a direct human intervention, where a stretch of the bank is protected against the effect of waves above all with technical elements.

CHARACTERISTICS OF WAVE ABRASION

The process of the wave abrasion is a dynamical one, which can be described by characteristics acting upon 1 m of the bank line depending on time:

— the abrasion volume $Q = f(t)$ [m^3] is expressed by the amount of material remolded by waves per 1 m of the bank line.

— the retreat of the bank line $S = f(t)$ [m] expresses the total retreat in time t_i, it is given by the partial retreat above the upper limit of remolding and the retreat of the part of slope under the water which represents the horizontal distance between the points of intersection of the slope with the upper and lower limits of abrasion.

— the rate of abrasion process $v = f(t)$ [m] $year^{-1}$ characterizes the retreat of the bank zone in the course of the period of one year. The maximum is usually reached in the first year of the reservoir operation.

RESULTS OF THE WORK

The bank on the territory studied is constituted by Quaternary deposit formations. The lower part of the cliffs lies in a gravel terrace at the elevation of 230 m (Říkovský 1929). This terrace is overlain by loess passing gradually into secondary loess and slope loams. The height of cliffs varies between 390 and 540 cm. On the basis of the comparison of individual measurements characteristics of wave abrasion were evaluated.

The average value of abrasion volume has grown from 40 m^3 (Kratochvíl 1970) to 50 m^3 of abraded earth per 1m of the bank line. For determining the theoretical development of the volume of abrasion there is a variety of formulas in the literature (Pyškin and Kondratjev). Successful application of these formulas requires, howerer, a large number of sections and long-term observation.

Table 1. Characteristics of wave abrasion in the section No. 1—7

Section No.	Retreat of the bank line (m)	Rate of abrasion process (m $year^{-1}$)	Abrasion volume (m^3)
1	10	0.25	32.7
2	19	0.475	47.7
3	22	0.55	57.2
4	21	0.525	40.4
5	20	0.50	49.4
6	17	0.425	36.5
7	28	0.7	82.0
Average	19.57	0.489	49.4

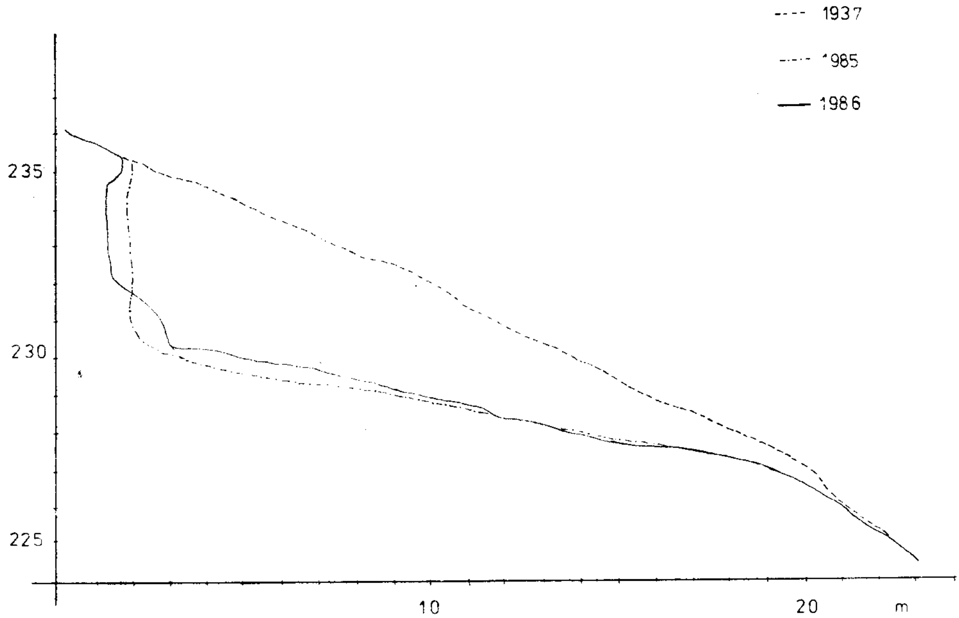


Fig. 3. Section No. 2

What can be seen well is the unbalanced character of the values of the retreat of the bank line and the rates of this retreat at the individual localities. Their overal mean value of 0.489 m $year^{-1}$ on the territory studied is less than that given by Kratochvíl (1970) who gives the mean value of 0.7—1.2 m $year^{-1}$. The value of the rate of abrasion progress is dropping in the same way as the abrasion volume depending on time. In this connection it is worth mentioning the relation of abrasion and slope processes. In steep slopes a hollow is formed in the summer season due to the action of waves. The abrasion proper, howerer, affects only a small part of the slope in this way, which is determined by the height of the highest of the wave and/or the capillary rising of the wave causing a periodic moistening of the rocks. Despite this, it is this very activity that operates as an initiator of the further development of the bank. In territory studied most of the cliffs are formed by the mural jointing of loess whose specific jointing and the overhanging section constitute favourable conditions for the activation of large areal slides and collapses. In winter months, besides, when the water level is low, the whole abrasion platform and the cliff become exposed and the bank freezes through. The cryogene texture of material becomes more expressive and soil ice is formed. In spring, with increasing temperature the frozen loess thaws and thus its cohesion is conspicuously lowered. In this very season there occur the greatest changes in the shape of the cliff. The foot is usually covered with collapsed material which forms an obstacle to the destructive activity of the waves. Its removal goes on for several ice-free seasons. Besides slides the water from the thawing snow or thunderstorm spates gives rise to deep erosion gullies and solifluction streams which transport fine material to distances of several metres from the foot. .

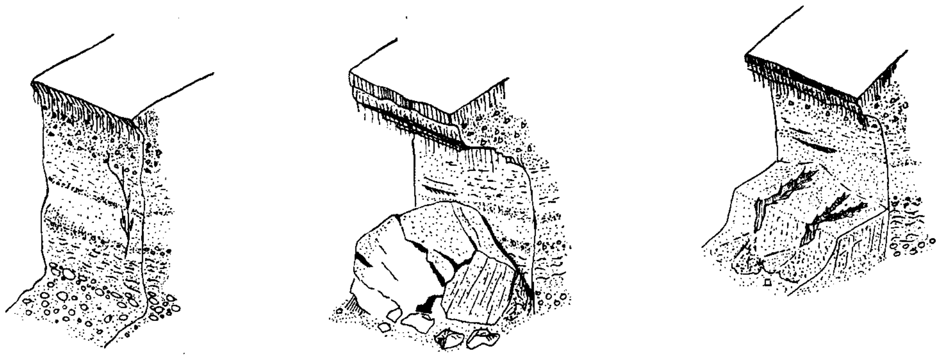


Fig. 4. Retreat of the bank line in the section No. 2

On the territory studied the development of slopes is negatively affected also by the influence of vegetation, above all stands of the forest pine which has a conspicuous column-like main root acting in loesses as an erosion agent. It destroys their vertical cohesion and aids the penetration of water and thus the origin of slides along the predetermined structural surfaces.

Table 2. Characteristics of wave abrasion in the section No. 8—10

Section No.	Retreat of the bank line (m)	Rate of abrasion process (m year^{-1})	Abrasion volume (m^3)
8	15	0.375	20.5
9	13	0.325	16.2
10	13.5	0.338	14.25
Avegare	13.8	0.346	16.98

For comparison, in the immediate vicinity of the Sokol landing bridge three section were measured in places where waves act on the cracked diorite bedrock whose character differs considerably from sections 1—7 by the overall height and material composition. The removal of diorite detritus in which an abrasion niche is formed is well perceptible. This recess is higher than the most frequent levels (about 230.5 m) The waves damage diorite only very weekly and they modelled the lower part of the cliff so that they can gradually wash away the less resistant detritus.

Among the most important tasks in connection with the activity of waves belongs the evaluation of the abrasion determinant. This term denotes the place where the retreat of the bank will stop to form a balanced section. The methods of finding that section are different (Kačugin 1955, Pyškin 1962, Rozovskij 1964) taking into

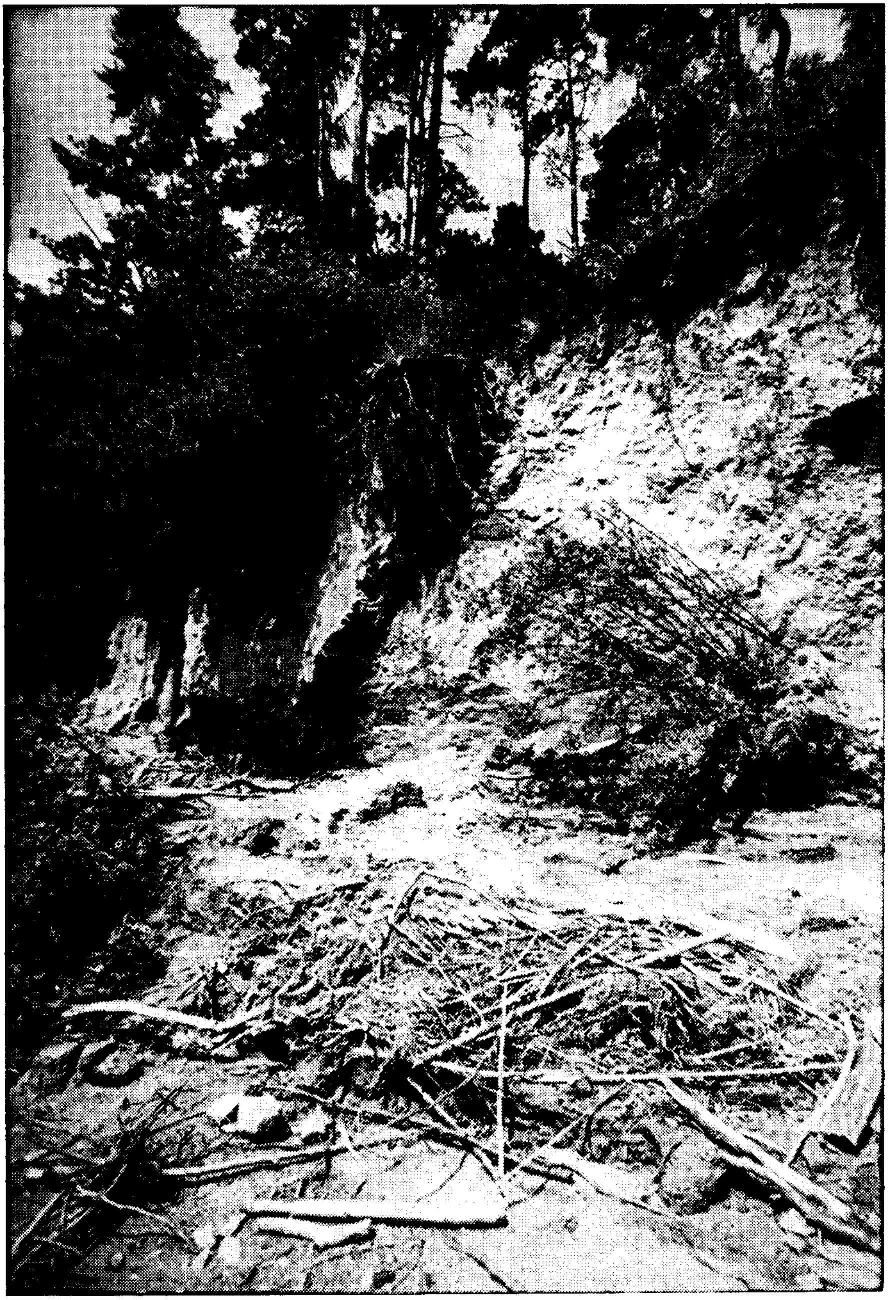


Fig. 5. Abrasion cliff near the section No. 2

consideration the length of time of reservoir operation, the homogeneity or the heterogeneity of the material, the slope gradient, the length of the shallows, the regime of waves and level variation in the reservoir. The resulting gradient of the shallows changes according to the height of the wave and the individual sorts of material. The intersection of this stabilized section with the horizontal plane determining the upper limit of abrasion is the furthermost point to which abrasion should proceed under the assumption that the present manipulation regulations of the reservoir remain unchanged. On the territory studied the situation is complicated by the heterogeneity of the slopes. The bank material closely below the level of abrasion passes from terrace gravels (stabilized gradient 13°—14°) into loesses and secondary loesses (stabilized gradient 5° to 7°). It can be assumed that the concluding sector of the bank shallows will have slightly lower gradient than the part constituted by gravels. Besides, abrasion is combined due to a considerable slope gradient and the height of the cliffs with slides and collapses.

In section No. 2 I have determined the retreat of the cliff by 9 m, in section No. 7 by 12.5 m. The values correspond with the data of Kratochvíl who gives a mean retreat by 9 m in the next 25 years (Kratochvíl 1970). The section formed would of course be ended with a perpendicular cliff constituted by loess material up to 10 m high which would further develop without action of waves only affected by slope processes. In this way further material transported by water and sedimenting in the reservoir would be loosened. To determine more exactly the time of the formation of the balanced section is possible only on the basis of a perfect knowledge of the relation between abrasion volume and rate.

CONCLUSION

The study of cliffs in the territory studied has confirmed the dynamics of abrasion processes in reservoirs. On the basis of the results obtained it is possible to state:

— The building of the Vír reservoir increased the most frequently occuring level from 227.9 to 229.7 m above sea level, thus changing the foot of abrasion cliffs as well.

— besides abrasion there operate also intense slope processes (collapse, slides) conditioned by the underwashing of slopes and the mural jointing of loesses.

— the development of abrasion cliffs goes on in certain cycles with a gradually increasing period.

— further extension of abrasion can be prevented in the most endangered places only by means of technical measures.

— the presented results of the paper further serve as a basis for making a digital model of the cliff development which would contribute to generalizing the problems of changes in the bank line of the designed reservoirs.

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