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Confinia et Horizontes

THE ENVIRONMENTAL HISTORY OF THE PREHISTORIC SÁRKÖZ REGION IN SOUTHERN HUNGARY

ESZTER BÁNFFY (ED.)

RGK

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CONFINIA ET HORIZONTES VOL. 1

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Inhalt

Lectori salutem!

The launching of a new monograph series is a matter of courage and confidence. Courage that it is worthwhile to publish new books in this digital age of ours, and confidence in readers that they will be willing to take yet newer thick volumes in their hand and use them for their academic work or read them out of pure interest in prehistoric archaeology. The host institute, the Romano-Germanic Commission (RGK) of the German Archaeological Institute, has established, edited, and published several monograph series during its long life since it was founded in 1902: suffice it here to refer to the *Römisch-Germanische Forschun*gen, the *Kolloquien zur Vor- und Frühgeschichte*, the series *Die Ausgrabungen in Manching*, and to the *Limesforschungen*. So, one may rightly ask, wherefore yet another one?

During the past few years, research in the RGK has been organised around two major themes and two logistically separate work teams, which are nevertheless bound by many strands scientifically. Under the umbrella of *Forschungsfeld* 2, the research topics related to the Iron Age and the Roman provincial period, research on the Roman *limes* and on the Barbaricum, i. e. the regions not occupied by the Romans, as well as research on the Late Antique period are addressed through related overarching questions such as "border studies". *Forschungsfeld* 1, established at a later date, brings together fields of research and grand themes that had commanded scholarly interest during the first half of the 20th century and were revived during the past decade as part of the RGK research agenda. These cover the Late Mesolithic and the transition to the Neolithic, alongside themes from the Neolithic to the Bronze Age. Currently, there are several RGK and collaborative projects with various institutions and colleagues based in different countries within the framework of this research group. Similarly to the work group focusing on later prehistoric and early historic periods, the basic research questions in Neolithic and Bronze Age studies are few, but they are closely related to each of the running projects and those in plan.

While members of the *Forschungsfeld* 2 work team have had several options for publishing their findings in the traditional RGK monographs, the early periods could not be fitted into any of the already existing series. Hence the idea of establishing *Confinia et horizontes.* The title of the new series matches the major theme of *Forschungsfeld* 1, "Marginal zones, contact zones". The choice of one Latin and one Greek word was wholly intentional: marginal, liminal zones would be ideal settings for potential interactions between different groups initially separate from each other, which then established contacts through exchanges and trade, and later expanded the contacts to a mutual sharing and transferring of innovations and knowledge. And, as is usually the case, these contacts can be traced in the genetic make-up of the once separate population groups. Our goal is to publish cutting-edge new research: principally the projects of the RGK community, but since the time of individual research and authorship has since long passed, these publications, as a rule, will present the findings of dynamic collaboration with other institutions. The monographs will be grouped according to the various collaborative projects. Although it is not our intention to break up *Confinia et horizontes* into subseries, we shall quite clearly indicate if a major project is published in more than one volume that these volumes are closely related. Even more importantly, individual volumes will never be publications released solely by the RGK, but will be equally owned by our partner institutes. This can also be seen as a symbolic gesture: these days, archaeological research generally involves the joint effort of specialists of fieldwork, environmental and non-invasive landscape research, geo- and bioarchaeology, all brainstorming together. The evaluation will then be based on data coming from each field of investigation. It needs to be repeatedly stressed that there is no difference between the two *Forschungsfelder*, between the different periods and phases of archaeological periodisation. Prehistory and history are equally important chapters of the human past. The ultimate goal of *Confinia et horizontes* is to integrate the data provided by various disciplines and interpret them jointly, in the hope that the result will contribute to a reconstruction and better understanding of the various dimensions of past societies. In other words, we truly hope that our prehistoric data will ultimately lead to history writing.

Eszter Bánffy

Gábor Serlegi

Groundwater under scrutiny: A hydrological aspect of human settlement strategy in the vicinity of the southern shoreline of Lake Balaton

Keywords: settlement, groundwater table fluctuations, optimal hydrological zone, static groundwater model, prehistoric periods, settlement zones

Schlagwörter: Besiedlung, Schwankungen im Grundwasserstand, optimale hydrologische Zone, statisches Grundwassermodell, prähistorische Zeitabschnitte, Siedlungszonen

Kulcsszavak: megtelepedési térfelszín, talajvíztükör-ingadozás, optimális hidrológiai zóna, statikus talajvízszint modell, régészeti korszakok, megtelepedési zónák

Introduction

The anthropogenic transformation of the physical and natural environment of the Carpathian Basin during the past two or two and a half centuries has profoundly changed natural conditions. In most cases, there is no direct relation between the geomorphologic conditions of a given archaeological site and the elements of the modern landscape. This phenomenon is particularly relevant for the formation of the hydrography of the Carpathian Basin. Following initial small-scale local water system transformations, the planned, sweeping river regulation measures launched in the late 18th century completely reshaped the hydrographic conditions of this geographic area. The extent of surface waters completely changed in the wake of the drainage of the periodically or permanently flooded areas, as well as due to meander cut-offs and the creation of new artificial channels connecting the closest sections of river bends. This drastic intervention in the regulation of the surface water system had also a significant impact on groundwater conditions.

A handful of earlier studies have dealt with the reconstruction of ancient conditions through the analysis of archaeological sites, archaeological phenomena, and river discharge, as well as the landscape forming potential of watercourses (Horváth 2004, 49–63; Székely et al. 2009, 71–93).

However, there exists a much broader range of scientific literature on the relationship between water level and the extent of water bodies, and the formation of archaeological sites. Among them, many research projects and studies covered Lake Balaton, alongside the identification of the lake's historic water level fluctuations. The results of the first phase of research with an archaeological perspective on the water level fluctuations of Lake Balaton and the past extent of the lake were published in the 1960s and 1970s by Károly Sági and László Bendefy. The relation between the depth of the archaeological features, the groundwater level, and the lake's water level was a regularly addressed issue in their publications. However, their primary goal was to estimate the past extreme water level conditions of the lake, while the associated climatic characteristics of the archaeological periods were based on the depth of the excavated archaeological features and the modern groundwater level conditions observed in them.

Due to the technological level of the geodetic measurements and the uncertainty of levelling at the time, these studies include a number of controversial issues. Research work was further complicated by the limited number of available data on this subject and the fact that these records were gained through the examination of individual archaeological sites located far from each other in different geomorphologic settings. Nevertheless, the most significant result of this early research was the growing awareness of the fact that both the surface water and groundwater conditions of the Lake Balaton area played a significant role in influencing the occupation strategies and spatial possibilities of past communities (Bendefy 1968, 257–263; 1970, 365–368; 1972, 335–358; Bendefy / Nagy 1969; Füzes / Horváth 1971, 491–497; Sági 1968a, 15–46; 1968b, 441–462; 1970, 200–207; 1971, 485–490; Sági / Füzes 1973, 247–260).

In the first decade of the 21st century, the large-scale excavations undertaken along the planned track of the M7 motorway catalysed research focusing on the relationship between the historical water level changes of Lake Balaton and the data from archaeological sites. The overwhelming majority of these studies, offering a complex assessment of possible correlations, is linked to the work of Pál Sümegi and his colleagues. As part of the interdisciplinary environmental historical and geoarchaeological analyses, the data provided by satellite imagery, aerial photographs, historic maps, and topographic surveys, as well as the evaluation of sediment samples obtained from the cores of the sedimentary basins were used to reconstruct ancient environmental conditions. The significance of these complex studies is that the reconstruction of the palaeovegetation of a particular environment was based on palynological, macrofossil, and malacological analyses. Moreover, the results gained through the corings and the observations of the groundwater fluctuations in numerous archaeological features were also considered when reconstructing the water level of Lake Balaton during different archaeological periods (Sümegi et al. 2004, 399–420; 2007, 241–253).

It is clearly visible even from this brief review of previous research that researchers were aware of the relationship between the depth of the archaeological features and that of the groundwater level already at an early stage. However, the isolated point-wise data did not allow the detailed examination of the characteristics of groundwater movements at previously excavated archaeological sites. Due to the extensive excavation work ahead of the motorway construction, the data of thousands of archaeological features across many hectares of contiguous area, the spatial data provided by modern geodetic instruments, as well as the GIS analysis of the excavations offered the possibility of analysing the changing strategies of environmental utilisation and landscape occupation during different archaeological periods around Lake Balaton. The spatial distribution of the archaeological features of a given period determines the nature of how space was used on the former settlement, which can be used to identify the occupation strategies of ancient communities. Based on my research, I have come to the conclusion that the depth and the fluctuation of the groundwater level of the occupation area are among the most decisive environmental factors in this regard. This study focuses on the detailed examination of this issue. It is based on the comparison of the spatial analysis of the archaeological features of a multi-period archaeological site located along the M7 motorway with the static groundwater model generated for the area of the site.

The broader environment

In order to understand the details of the environmental model to be described at greater length below and its results, a brief introduction to the broader geographic and geomorphologic environment of the archaeological site as well as the determining landscape elements seems in order *(Fig. 1)*.

Marcali Ridge

This ridge area divides the Inner Somogy alluvial cone. Its northern territory borders on the shoreline of Lake Balaton, whilst its southern territory flattens towards the alluvial fan. The geomorphology of this micro-region is characterised by smaller alluvial fans that developed along fault lines and by the ridges formed in-between incised valleys running from Lake Balaton toward the Inner Somogy area. The slopes of the micro-region are moderately steep; only the northern territories have steeper inclinations (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475). The geology of the Marcali Ridge is characterised by Pannonian sand, clay, and Pliocene cross-bedded sand. These sediments are covered by fluvial gravel and thick loess sediments (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475).

The area has a significant water surplus: the watercourses only seldom dry up, and a larger water discharge only occurs in spring or early summer. The groundwater level can be found within a 4 to 6 m relative depth, whilst in the deeper valleys, it occurs within 2 m. In contrast, the depth of the groundwater table can reach 10 m on higher reliefs (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475).

Nagyberek

The northern section of the eastern slope of the Marcali Ridge extends to the Nagyberek, once the biggest embayment of the Balaton Basin. The former embayment extends south into the Inner Somogy alluvial cone, lying at a distance of approximately 30 km from the present

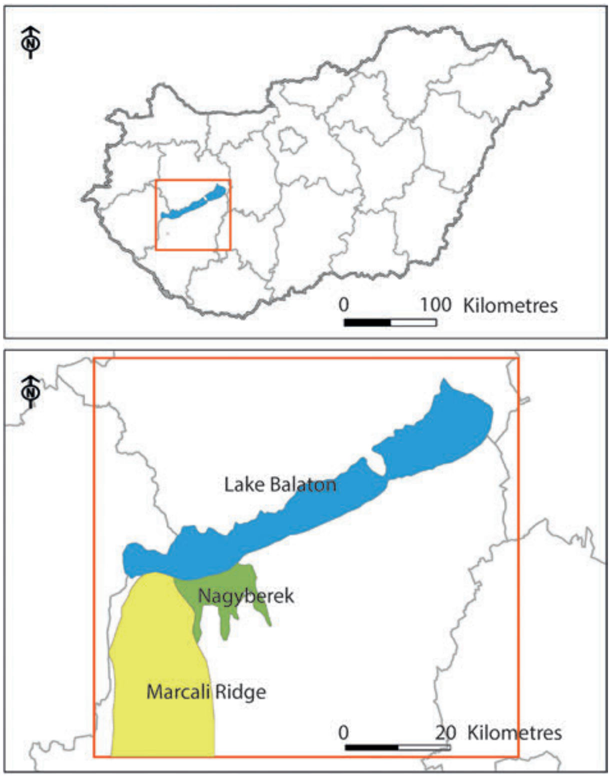

Fig. 1. The broader environment of the investigated area with the landscape zones Marcali Ridge and Nagyberek in present-day Hungary.

shoreline. The territory of the embayment is flat, with higher ridges only appearing at its margins. Its surface is plain, only lower bay barrier bars vary together with oval marshland basins (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439). Its area was once filled with the water of Lake Balaton and, as a result, not only the gritty, sandy alluvial cone material of the "pre-Balaton phase" occurs here, but younger silty, clayey, and sandy lacustrine sediments were also deposited throughout the Holocene. The bay barrier bars were formed from these latter sediment types. They slowly isolated the embayment from the lake body, resulting in the appearance of dead water. Under these conditions, significant amounts of peat, lime mud, as well as meadow and peat soils developed (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439). In fact, the entire area can be considered as a flood basin, which is underlined by the fact that at present only an extended irrigation channel system can regulate the territory's water balance. The discharge of the incoming watercourses is low, and a significant increase can only be experienced in spring or early summer. This area also acts as a buffer zone. The groundwater level is within a 2 m relative depth (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439).

Lake Balaton

At present, Lake Balaton is a south-west to north-east oriented, 77 km long elongated lake. Its shape and shoreline were formed in the wake of the afore-mentioned drastic anthropogenic effects. From the later 18th century onward, the demand for additional agricultural land in the Transdanubia region increased significantly. Permanent forest clearings resulted in significant soil erosion, which accelerated the eutrophication of the bays of Lake Balaton. In order to gain more arable land in the proximity of Lake Balaton, the hydrological interventions were intended to reduce the lake's water level. From the early 1820s, the water level was reduced in successive phases. In the wake of these interventions, the construction of the Budapest–Zagreb–Fiume railway began in 1858 on the bay barrier bars along the new shoreline. Due to the more humid and cooler years after the railway construction, the lake's water level began to rise. The storms of the drifting ice during the winter of 1860/61 caused serious damage to the railway track under construction. Therefore, following the effective intervention of the South Railway Company, a detailed regulation plan for Lake Balaton was adopted in the summer of 1862. The floodgate on the Sió Channel was built according to this regulation plan in 1863. The current state of Lake Balaton, its present extent, and its shoreline, which hardly resembles the one-time natural conditions, developed according to those measures, which were principally driven by modern economic interests.

Geology of Lake Balaton

Several studies have covered the geological evolution of the lake. Already at the turn of the 19th and 20th centuries, scholars like Lajos Lóczy (Lóczy 1913, 617), Gábor László (László 1913, 567), and Jenő Cholnoky (Cholnoky 1918, 11–22) noted that the water level and the water extent of Lake Balaton periodically exceeded its modern conditions. Their assertions were supported by the examination of the shoreline bay barrier bars, the emerged shoreline platforms, and the thickness of the peat sediment layers. One of the key findings of these geological surveys is that even a slight rise in the water level results in the flooding of the meridional valleys located south of the lake, similarly to the territory of the Nagyberek. In their publications they emphasised that in case of a water level increase, these areas become the natural embayments of the lake *(Fig. 2)*.

Later geological research noted that Lake Balaton lies on the boundary of two neo-tectonically active geological units. These active geological areas imply the gradually uplifting Transdanubian Mountains to the north and

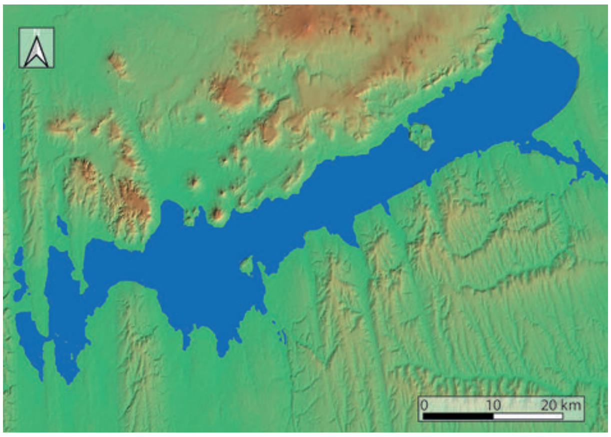

Fig. 2. The reconstructed natural watercover of the lake basin at 105 m a.B.s.l. (cf. Tímár et al. 2006).

the gradually subsiding Pannonian Basin to the south. Geological surveys conducted for clarifying the geological evolution of the lake found that the Pannonian Sea was present in this area well before the formation of the lake basin. The geological cores penetrated Upper Pannonian sediment layers within the relative depth of 8 to 10 m. However, this water body cannot be identified as the progenitor of Lake Balaton (Nagy-Bodor / Cserny 1998, 360).

Lake Balaton can be divided into four distinct sub-basins: the Keszthely Basin, the Szigliget Basin, the Szemes Basin, and the Siófok Basin, and as an additional geomorphologic depression, the Little Balaton is attached to the lake. Although the Little Balaton seems to be genetically part of the lake, it differs from the other four sub-basins of Lake Balaton in terms of its geological evolution and formation time (Lóczy 1913; Tullner / Cserny 2003, 216).

Silurian, Permian, Triassic, Miocene, Pliocene, and Quaternary geological formations can be found north of Lake Balaton, whilst Pliocene and Quaternary sediments dominate on the southern shore. The most extensive geological formations are the Upper Pannonian sediments (limestone, sand, clay) together with Quaternary sediments such as Pleistocene loess, diluvial, alluvial, and fluvial sediments. The formation process of the lake basin was determined by the interaction of several environmental factors and began around the end of the Würm glaciation period, around 15 000–16 000 cal BC (Sümegi et al. 2007, 242). Current research has shown that the basin of Lake Balaton was formed on the boundary of the afore-mentioned neo-tectonic fault during the Upper Pleistocene and was further deepened by subsequent deflation and erosion effects (Nagy-Bodor / Cserny 1998, 360; Tullner / Cserny 2003, 219). The inundation of the sub-basins did not occur simultaneously, but gradually, starting in the west and progressing towards the east due to the increased precipitation and surface water drainage. The Siófok Basin was only filled up with water at the end of the Pleistocene. The gradual process can most probably be ascribed to the fact that the larger part of the water catchment area is linked to the lake's western sub-basins. With time, and in the wake of lacustrine abrasion, the ridges that separated the sub-basin were gradually eroded. This process formed the seemingly uniform basin of Lake Balaton. Early research assumed that the merging of the sub-basins occurred already during the Pleistocene (Lóczy 1913; Marosi / Szilárd 1981, 22–27). In contrast, current palaeolimnological research contends that the process of sub-basin union occurred continuously during the Holocene (Nagy-Bodor / Cserny 1998, 361; Tullner / Cserny 2003, 219; Jakab et al. 2005, 407). The most recent complex surveys have proven that this occurred at the very beginning of the Holocene (Sümegi et al. 2014, 76).

Hydrography and sedimentology of Lake Balaton

Currently, the lake's water surface has an extent of 600 km^2 and a volume of 2 km^3 of water. The average depth of the lake is 3.35 m. The water catchment area of the lake, together with the river Zala, is approximately 5200 km^2 (Tullner / Cserny 2003, 216–218). In addition to the rainfall that falls on the surface of the lake, it is fed by 30 permanent and 20 periodic watercourses, the largest of which is the river Zala. Due to the lake's shallow water level, the wind has a significant effect on the movement of the water in the basin. The height of the waves can reach 1 m, while their length varies between 7 to 10 m. As a result of the dominant north-westerly wind, a so-called standing wave effect may occur, in which case the water level in the Siófok Basin can be 1 m higher than in the Keszthely Basin (Tullner / Cserny 2003, 218; Dövényi 2010, 445).

As a result of various factors such as the erosion of the shoreline areas and the eutrophication of the water, the sedimentation process in the lake basin is quite significant. The mean value of the lake's sedimentation rate, calculated from a 300 years long period, is 0.6–0.8 mm / a[1]. This rate can reach up to 1.5–1.7 mm / a in the western areas, especially in the Keszthely Basin, due to the alluvial effect of the river Zala. Owing to the regular wind, the redeposition of the silty sediments is also a usual process in the lake (Tullner / Cserny 2003, 216 f.). The thickness of the lacustrine sediment is the greatest along the northern shoreline. Due to the current

1 Millimetres annually.

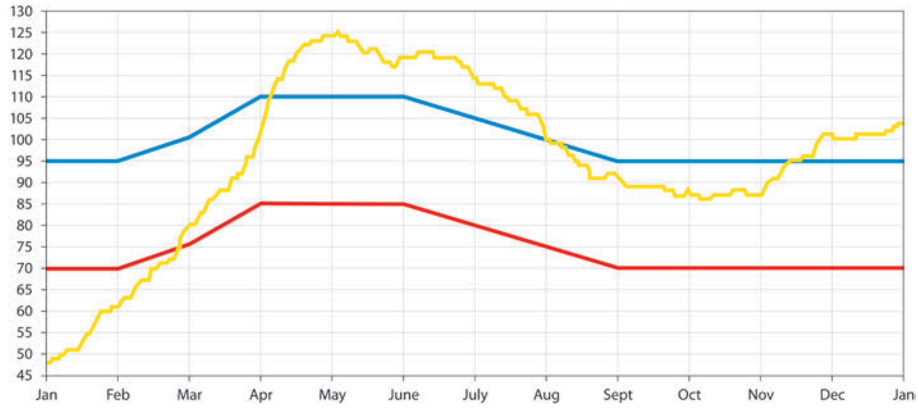

Fig. 3. Annual fluctuation of the waterlevel of Lake Balaton in 2013. Blue: maximum regulation level; red: minimum regulation level; yellow: real waterlevel.

conditions in the lake, the northern shoreline is made up of silty, whilst the southern of sandy textured sediment types. The mean sediment thickness of the lake is 5 m, but due to the extremely varied basin surface underneath the loose sediment, the actual thickness can vary between 1.5 and 8.0 m (Jakab et al. 2005, 408).

The water balance of Lake Balaton

The current water balance of Lake Balaton is essentially determined by four factors: the quantity of precipitation, evaporation, and the quantity of external water input through surface runoff and drainage (Dövényi 2010, 445). Since the rate of the water input and evaporation primarily depends on climatic conditions, the anthropogenic control over the lake's water level can only be exercised at the drainage. For this reason, a floodgate was built on the Sió Channel at Siófok, which was later rebuilt and its capacity was increased. The maintenance of the lake's water level between the required values is a significant economic, touristic, and shore protection issue, in addition to being a complex and sensitive type of hydrological intervention as well. According to the current regulation measures, the water level is determined according to the zero point of the Siófok water depth gauge (103.41 m a.B.s.l.[2]). The water level of Lake Balaton is supposed to vary between a 0.70 to 0.85 m (104.16–104.31 m a.B.s.l.) minimum and a 0.95 to 1.10 m (104.36–104.51 m a.B.s.l.) maximum value range *(Fig. 3)*.

In its natural condition, the lake's water level was determined solely by climatic factors, and we may reckon with a more significant water level fluctuation before the 19th century regulations (Jakab et al. 2005, 407).

In addition to the significant fluctuations of the water level, it is also important to note that the shape and shoreline of the lake also change due to the flooding of the southern meridional valleys and of the Nagyberek area. Thus, these areas become shallow and open embayments of the lake. These conditions change the lake's surface extent, which has an impact on evaporation too (Szesztay 1959, 193). In the lack of modern water regulation measures, this condition can occur already at a water level that is only 0.5 m higher than the maximum of the lake's currently maintained low level (104.5 m a.B.s.l.). The extent of the lake can increase to 900 km^2, which is one and a half times larger than its current surface. To increase the lake's extent by 300 km^2, to its doubled size of 1200 km^2, a water level increase of 5 m would be necessary. However, the 110 m a.B.s.l. water level would result in an extremely huge lake volume, together with an increased water amount, which can only be imagined during a long and extremely cool and moist climatic period. Based on published hydrological values (Szesztay 1959, 191–199), this 5 m interval between 105 and 110 m a.B.s.l. is the value range in which the natural water level of the lake varied during the Holocene. Its permanent water level was probably between 106 to 107 m a.B.s.l. (Sümegi et al. 2007, 251).

The lake's water level and the extent have always played a significant role in the groundwater conditions of the ridges of the shoreline areas, and therefore the water level fluctuations indirectly influenced the options of human occupation in the lake's immediate proximity. The experiences of the last decade indicate that due to the weather conditions it is a difficult task to keep the lake's artificially low water level within the previously set limits *(Fig. 3)*. Considering the values that influence the lake's water balance (e. g. precipitation: 650 mm / a; evaporation: 870 mm / a; surface water in-put: 880 mm / a; drainage: 640 mm / a), it can be assumed that even in

2 Metres above Baltic sea level.

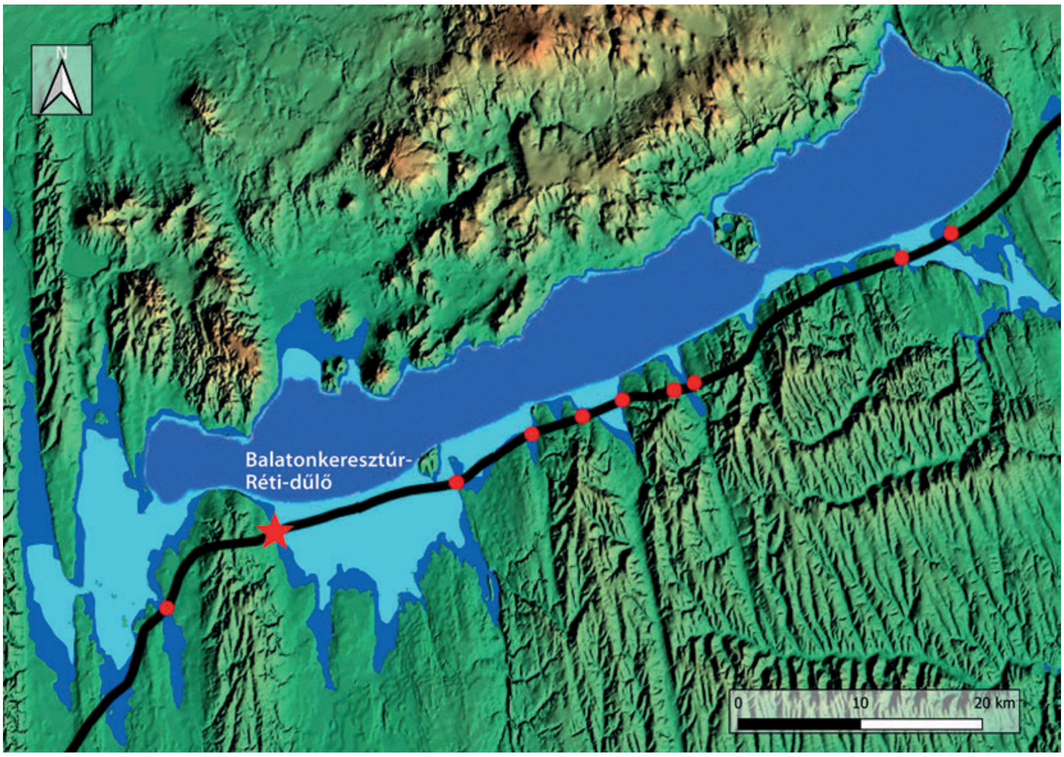

Fig. 4. Archaeological sites on the track of the highway along the southern shoreline of the former natural embayments and location of the site at Balatonkeresztúr-Réti-dűlő. Dark blue: modern shoreline of the Lake Balaton.

its natural state, the lake most likely reacted sensitively to the changing rates of these external factors. The depth of the groundwater, which was always dependent on the periodical or even seasonally raised water level and the changes in the lake's surface extent, undoubtedly influenced the conditions of human occupation. Consequently, we may posit that human communities favoured areas where environmental stability could be observed, longer or shorter changes in the previously mentioned environmental conditions notwithstanding.

Archaeological sites along the shore of Lake Balaton

At the beginning of the 21st century, numerous archaeological sites were identified and investigated during the excavations ahead of the construction of the M7 motorway running for roughly 80 km along the southern shoreline of Lake Balaton and at the eastern edge of the Little Balaton. Given the lake's recent, artificial extent and shoreline, it is difficult to assess the relation between the location of a number of archaeological sites and the lake itself as a landscape element. This can be explained by the lake's significantly different shape and extent in its natural, non-regulated condition, and its effect on the surrounding landscape. As mentioned in the above, the first geological surveys (Lóczy 1913; László 1913; Cholnoky 1918) targeting the lake's geology proved that the extent of the water surface before the regulation measures was well above the present conditions and that the shoreline along the southern shore had several smaller and larger embayments (cf. *Fig. 2*). The main reason for the discovery of numerous archaeological sites along the track of the motorway (Bondár et al. 2000, 91–114; Honti et al. 2002, 3–36; 2004, 3–70; 2007, 7–70) was that the track was designed to run parallel to the lake's current, north-east to south-west shoreline, almost perpendicular to the north to south oriented shoreline of the former natural embayments, which thus affected the area of the one-time lakeside settlements *(Fig. 4)*. These archaeological sites are located on the higher loessy slopes that lie between the former embayments. As mentioned above, the lake's water level and its extent significantly determine the groundwater level of the higher loess ridges, which outlines the extent of the areas that are suitable for human occupation and also defines their economic usefulness. Traces of human occupation from the Neolithic to the late Middle Ages were identified among the archaeological sites of the Lake Balaton area. Although they appeared in different proportions, the vast majority of the sites featured settlement sections of successive archaeological periods. The fact that the settlements were periodically concentrated in the same locations through several archaeological periods suggests that places suitable for human occupation, as well as their economic potential were very limited in the surroundings of Lake Balaton during its non-regulated, natural condition.

The hydrological conditions of human occupation

With regard to the location of the settlements of the different archaeological periods, one of the most important hydrological factors is the groundwater level of the hillsides. The groundwater depth is in close relation to the lake's water level. The extent of the water surface results in an increased groundwater level of the hillside areas around the lake. Waterfront settlements did not exist along the southern shoreline of Lake Balaton because the lake's shoreline zone graded into marshy wetlands due to the geomorphologic properties and the relatively shallow water depth.

Settlements located close to the water can only be assumed. The currently known settlements were located on the loess ridges that run in-between the embayments, meaning that hillside settlements were always located in a zone that was influenced neither by seasonal, nor by any short-term changes in the lake's water level. The communities settling in this geographic area always occupied places where the groundwater level fluctuations associated with the water level changes would not endanger their storage pits, sunken-floored houses, graves, and burials. At the same time, one important consideration in the occupation zone was that water supply features such as wells should not have to be dug too deep to fulfil their function, namely to securely and permanently reach the groundwater table. In other words, the settlements were established at an altitude where the dynamics of the groundwater level in terms of its depth and availability ensured the stable water supply of the settlements. Another important factor was a location close enough to the open water surface, since it was an important transportation route in addition to playing a significant role in subsistence strategies.

Based on the above and from a hydrological perspective, it can be surmised that the areas suitable for human occupation in any archaeological period were those locations, in a presumably narrow geographic zone, which met the criteria of the so-called hydrological optimum. The latter implies the optimal characteristics of the groundwater fluctuations and the optimal distance of the settlement from the open water surface. In addition, several other factors (e.g. geomorphology, soil type, and cultural aspects) also played a role in the selection of the settlement area, which further narrowed the extent of the places suitable for human occupation. During a longer period of drought in the settlement's lifetime, wells could dry up due to the sinking of the groundwater table and the settlement's growing distance from the open water surface. On the other hand, during a longer humid period, a rising groundwater level could reach the storage pits, while the arable lands and pastures around the settlement could become waterlogged, and therefore unsuitable for farming. In both cases, the communities most likely reacted in one way or another, which probably differed according to the robustness of these changes in their environment. This could have taken the form of the shift of the central settlement part or, as an ultimate scenario, the total abandonment of the settlement. In this sense, the analysis of the occupation patterns of the archaeological cultures of different periods within the same geomorphologic setting can reveal the level and dynamics of the groundwater table, and shed light on the hydrological regularities, which, together with other factors, determine the potential locations of human occupation in the landscape.

In order to test the above theory and to assess the impact of the depth and fluctuation of the groundwater level on the location of human occupation sites, a static groundwater model was created. This model is based on the soil mechanics survey conducted within the area of Balatonkeresztúr–Réti-dűlő. The outcome of the model was compared to the spatial distribution of the features of the site's numerous archaeological periods.

Balatonkeresztúr-Réti-dűlő

The archaeological site is located in the south-western part of Lake Balaton, relatively close to the current shoreline, 2 km south of the settlement of Balatonkeresztúr, but still in the transitional zone of the Marcali Ridge and Nagyberek micro-regions *(Figs 4–5)*. The excavation of the site was undertaken between 2003 and 2005 during the preventive and rescue excavations along the track and during the construction of the M7 motorway in county Somogy (Fábián 2004a; 2004b; 2005; 2007; Fábián et al. 2007)[3].

3 On the request of the Somogy County Museums Directorate (currently called Rippl Rónai Museum, county museum, Kaposvár), the Institute of Archaeology of the Hungarian Academy of Sciences (currently called the Institute of Archaeology, Research Centre for the Humanities, Eötvös Loránd Research Network [ELKH]) was also involved in the excavation work preceding the major motorway construction project. The excavation of the site, which is discussed in this present case study, was directed by Szilvia Fábián between 2003 and 2004. During the 2004 and 2005 seasons, the territory of the complex service area was excavated, too. I would like to thank Szilvia Fábián for kindly providing access to the archaeological data used in this case study.

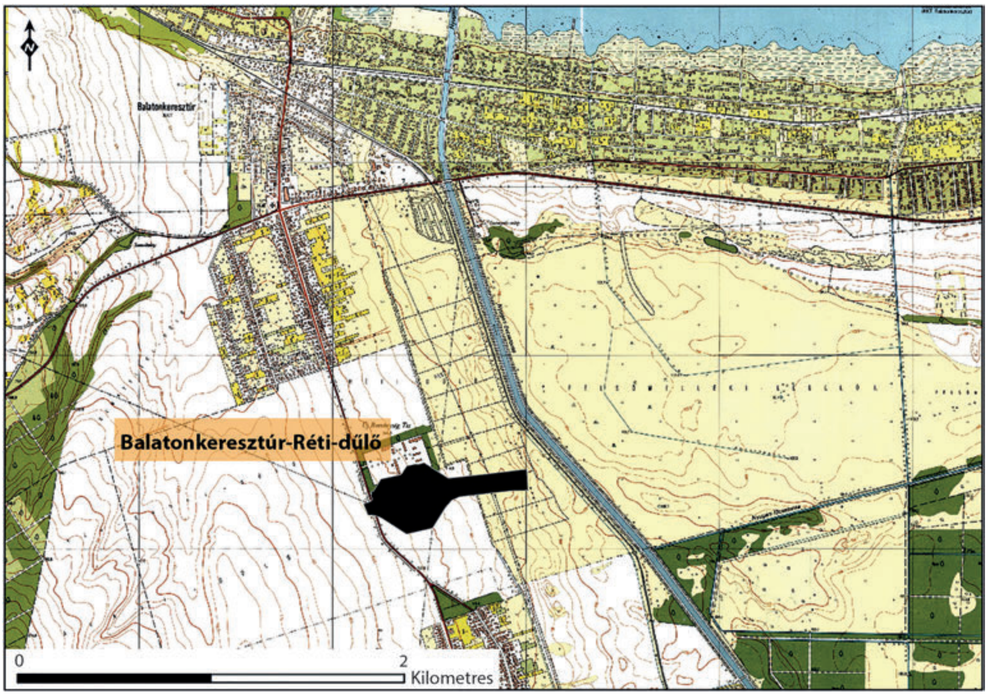

Fig. 5. Balatonkeresztúr-Réti-dűlő. Location of the excavated area on the southern bank of Lake Balaton.

The planned motorway track runs parallel to the shoreline of Lake Balaton on the eastern slopes of the Marcali Ridge, and runs across the archaeological site with a width of 100 m and a length of 900 m. The only exception is the territory of the complex service area, where it broadens to 350 m. Except for a few shorter periods in history, the excavated hillside was occupied from the onset of the Middle Copper Age until the Middle Ages (Fábián 2004a; 2004b; 2005; 2007; Fábián et al. 2007; Fábián / Serlegi 2007; 2009). The western part of the excavated area was utilised as arable land, while its eastern part, which is connected to the marshland of the Nagyberek with a steep slope, was used as a grazing land before the excavation. Between 2003 and 2005, over 3000 archaeological features were excavated in an approximately 60 000 m^2 large area *(Fig. 6)*. The remains and heritage of several communities from at least seven archaeological periods were brought to light.

Archaeological periods

The population of the Middle Copper Age Balaton-Lasinja culture was the first to occupy the area. Their settlement, characterised by densely spaced pits, pit complexes, and a house with a foundation trench, was located in the western part of the investigated area, although a few sporadic features were also found on the steeper slope section (Fábián 2004a, 10; 2007, 28; Fábián et al. 2007, 42–44).

The population of the Late Copper Age Baden culture complex settled east of the Middle Copper Age settlement zone. During this period, the settlement features of both the Boleráz group and of the classical and late Baden phases lay closer to the edge of the Nagyberek. The centre of the Baden settlement was located in a level plateau-like area, while the remains of the Boleráz settlement were also found on the slope running east, towards the margin of the Nagyberek. Archaeological features on the plateau were made up of extensive pit complexes, middens and storage pits, hearths, and an oven with a foundation of pottery sherds of the Baden culture. In addition to these settlement features, several "sacrificial" pits containing entire animal skeletons and a few Baden graves were also excavated. A few graves with crouched burials located in close proximity to the marshy Nagyberek were associated with the Late Copper Age based on their grave goods (Fábián 2004a, 10; 2007, 27–28, Pl. VIII.1; Fábián / Serlegi 2007, 273–275; 2009, 203–205).

The settlement remains and graves of the Somogyvár-Vinkovci and Kisapostag cultures were concentrated in the western part of the excavated area. Features of these two cultures appeared but sporadically in the eastern part of the site. It seems likely that the eleven graves in which the dead were deposited in a slightly crouched position on their side with their hands drawn up in front of their faces uncovered in the central part of the site can be assigned to the second half of the Early Bronze Age. A few bronze jewellery items were recovered from

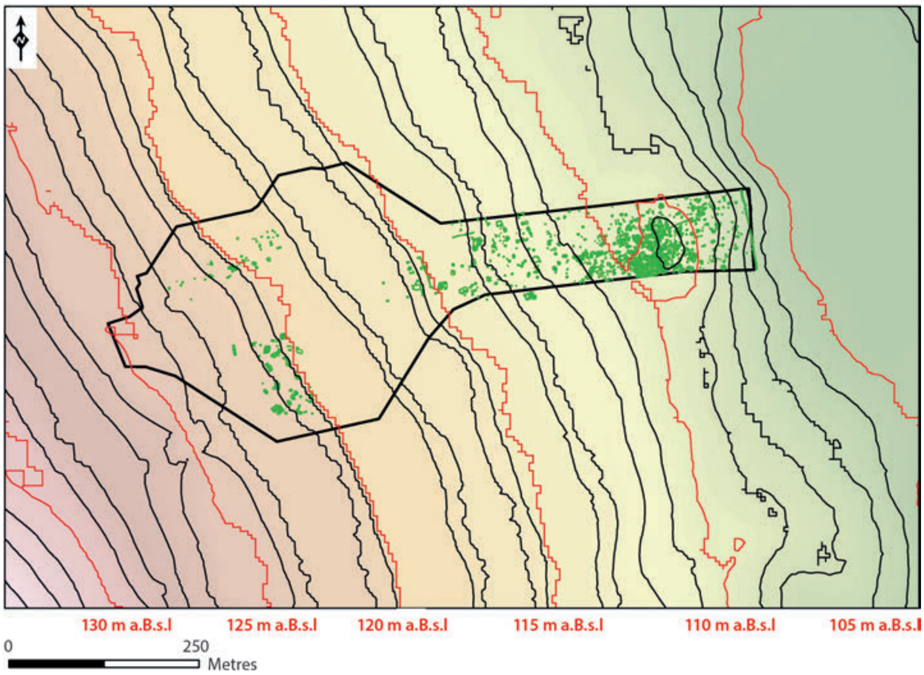

Fig. 6. Balatonkeresztúr-Réti-dűlő. Location of archaeological features within the excavated area.

these graves. The sporadic settlement traces that can most probably be associated with the Encrusted Pottery culture were also observed in this area (Fábián 2004a, 13 f.).

The Celtic population of the Late Iron Age occupied the eastern loess slope of the Marcali Ridge. Traces of intense occupation could be noted across most of the excavated area, extending to the edge of the Nagyberek. The heritage of this archaeological period on the lower part of the sloping area included eleven sunken-floored buildings, five ovens, numerous pits, and post-holes (Fábián 2004a, 13; 2007, 28).

The remains of three slightly sunken-floored buildings with a characteristic structure of six posts were excavated very close to each other within a small area, also in the eastern part of the site, close to the marshland. Based on these typical traits and on a few pits and storage facilities in their surroundings, as well as on a well lined with Roman *tegulae*, it seems likely that it was a Langobard settlement of the 6th century AD (Skriba 2006, 55–93; von Freeden / Vida 2007, 378–383). Vessel fragments with typical stamped ornamentation, iron tools, and *tegulae* were brought to light from the floor of the houses, from the post-holes, and from the fill of a few pits (Fábián 2007, 29).

Although traces of the Árpádian Age occupation could be noted across the entire archaeological site, these appeared to be quite sporadic. Most of the settlement features, among them a sunken-floored building, pits, and the remains of three ovens, were concentrated in the plateau area of the site. A little farther to the west from the house, five graves with extended burials were discovered. The skeletal remains of two adults and three children were recovered from these 10th to 11th century graves. An unusual grave, which contained an extended burial lying on its side, lacking any grave goods, can also be associated with the medieval occupation at this site. This grave was excavated on the northern periphery of the site (Fábián 2004a, 14; 2007, 29).

A more significant concentration of features from the later periods of the Middle Ages was uncovered on the east to west running loess plateau and on the upper section of the hillside, while no traces of occupation were detected on the lower section of the slope bordering the Nagyberek area. This 13th to 15th century settlement can perhaps be identified with the medieval village of *Cholta* located south-west of present-day Balatonkeresztúr (Kiss 2006, 7–11). On the western side of the horizontal plateau, very intensive settlement features lying directly underneath the modern surface were documented. The foundations of a multi-roomed dwelling house were preserved in a good state, enabling the reconstruction of the details of its structure. An oven with a foundation of pottery sherds that was repeatedly renewed was uncovered inside the house, alongside significant amounts of archaeological finds. In addition to this house, numerous post-framed, sunken-floored workshops, pits, hearths, a few wood-lined wells, and an east-west oriented narrow ditch section reflects the site's late medieval occupation (Fábián 2004a, 14–15; 2007, 29).

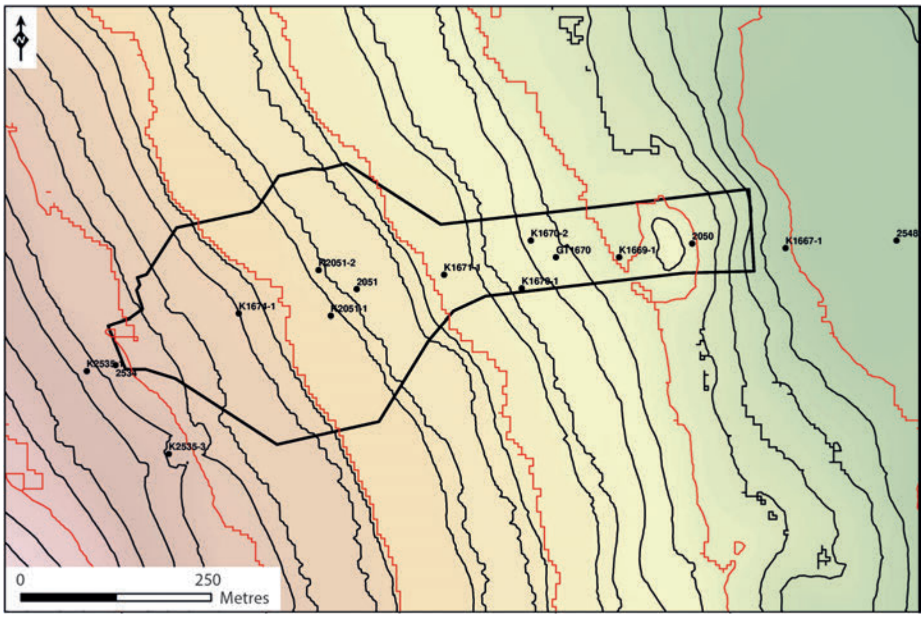

Fig. 7. Balatonkeresztúr-Réti-dűlő. Coring points within the excavated site and in its vicinity.

Due to the extensive excavated areas, the impact of the geomorphologic conditions on human occupation could be clearly observed. The plateau in the lower third of the loess ridge was a popular location for settlement in all archaeological periods. This is underlined by the densely intersecting features. The density of the archaeological features decreases both east and west of this area and a clear change in the utilisation of the various parts can be seen during the different periods (Fábián / Serlegi 2007, 275 f.).

The static groundwater model

The stratigraphy of the archaeological site

The intensity and the tendencies observed in the utilisation of the occupation areas during successive archaeological periods at the Balatonkeresztúr site provided an excellent opportunity for examining the earlier outlined theory of the optimal hydrological zone. This called for the reconstruction of the site's geological stratigraphy and groundwater conditions. Since a targeted geological survey with this particular purpose had not been conducted at the site, the only information available on the area's geology was the documentation of the soil mechanics survey carried out prior to the construction of the motorway[4].

The stratigraphy and groundwater level conditions of the archaeological site were compiled based on the description and evaluation sheets of the corings. The original purpose of the corings was to provide soil mechanics data for the construction of the motorway, and thus the available data did not contain an exact stratigraphic description of the cores. For this reason, it was not possible to evaluate the geological evolution of the site in detail, or to determine the geological age of the identified layers. Besides the depth data of the different layers described on the basis of the soil mechanics survey, the gravel, sand, silt, and clay fraction of the layers, as well as their density and compaction ratios were recorded. In addition, the groundwater level was also documented. Due to the depth data of the layer boundaries and that of the groundwater levels, the documentation was suitable for the reconstruction of the site's subterranean geomorphologic conditions, as well as for the compilation of the groundwater levels of two different time periods.

A total of 17 cores were extracted in the territory and in the close vicinity of the so-called complex service area *(Fig. 7)*. Ten coring profiles could be used for compiling a shallow geological cross-section along an approximately north-east to south-west axis across the site *(Fig. 8)*. Eight of the ten corings used for this purpose were extracted on the eastern slope of the Marcali Ridge (K2532-1, 2534, K1674-1, 2051, K1671-1, GT1670, K1669-1, 2050), whilst two from the Nagyberek area (K1667-1, 2548). The depth of the corings varied, the deepest reached 18 m of relative depth (K2535-1), whilst the shallowest ones were 5 m in depth (2050, 2051).

4 The survey was carried out by the Soil Mechanics Bureau of the Fővárosi Mérnöki Tervező P.L.C. (FŐMTERV), commissioned by the former Nemzeti Autópálya (National Highway) P.L.C. The data used in this paper was provided by FŐMTERV with the permission of the Nemzeti Autópálya (National Highway) P.L.C. for scientific purposes.

Most of the corings were performed in February 1992 (4 pieces) and during the summer of 2003 (5 pieces), and an additional one in November 2001.

If we compare the water level values of the lake with the relation between the extent and level of the surface waters and the hydrological conditions of the groundwater, we can determine whether the groundwater levels recorded during the soil mechanics coring represent low, moderate, or high groundwater level tendencies.

Based on the data of the Central Hydrological Inventory of the VITUKI[5], the water level of Lake Balaton in February 1992, at the end of winter, can be considered as average. The water level was measured to be 1.02 m higher (104.43 m a.B.s.l.[6]) than the zero point (103.41 m a.B.s.l.) of the Siófok water depth gauge. This value is still within the current regulatory maximum.

During the driest summer of the past two decades, in August 2003, the water level stood 0.35 m above the zero point of the Siófok water depth gauge. This value was 103.67 m a.B.s.l., which is 0.35 m below the current regulatory minimum[7]. It indicates an extremely low water level under natural conditions as well. Based on these data, we may conclude that the 1992 winter groundwater level can be identified as a moderate one, whilst the 2003 summer level as an extremely low one.

Methodology of the construction of the static groundwater model

When constructing the geological stratigraphy of the area, the starting points were the description and evaluation sheets of the soil mechanics corings. Since the corings of 2003 were carried out after the beginning of the excavation, the drilling began on a lower surface because the uppermost humus layer of the soil had already been removed by that time. In these areas, no humus layer thickness values were available, but according to other coring data, an average of 0.6 m can be used for the calculations. The deeper layers of the core profiles were distinguished based upon their particle size distribution, such as sandy, silty, or clayey. The same layers could be matched between the different core profiles. By knowing the coordinates of the boreholes and the altitude values of their bases, the relative height of the layers, described on the evaluation sheets, could easily be converted to an absolute altitude value. Based on this information, the three-dimensional spatial position of the layer boundaries could be generated. Subsequently, the raster files of the layer boundaries could be produced with interpolation, on which the continuous boundaries of the related layers between the neighbouring cores could be drafted. As a result of this method, only the theoretical boundary of the layers could be defined by the interpolation between the ten core profiles. These cover an almost 1 km long cross-section. A similar interpolation method was used for constructing the area's groundwater table.

Results of the static groundwater model

Based on the compiled cross-section, it can be observed that the stratigraphy of the deeper parts of the hillside is similar to the modern surface *(Fig. 8)*. Underlying the 0.6 m thick humus layer is a sandy-silty sediment of varying thickness, reaching as much as 10 m at some points. This layer is followed in depth by a shallower clayey sediment reaching a thickness of 3 to 6 m. The next layer is another, but thinner sandy-silty layer, which is again followed by a clayey one. No information is available on the thickness of the lowermost clayey layer and even the deepest cores did not fully penetrate this sediment unit.

We may in general assert that the layers of the subterranean geomorphology are similar to the current surface conditions, the only exception being the boundary zone between the Marcali Ridge and the Nagyberek, where clayey layers and the deeper-lying sandy-silty sediments have a steeper inclination before reaching a flat section. At this point, the gap between the relief of the modern surface's humus horizon and of the geological older surface is filled by the thickening of the uppermost sandy-silty sediment material. The two cores of the Nagyberek area (K1667-1, 2548) indicate that silty and clayey, grey-coloured lacustrine sediments were deposited during the Holocene over the deep-lying sandy and clayey layers. The appearance of these lacustrine layers on the geomorphologic boundary between the hillside and the marshy area conforms to the geological evolution of Lake Balaton described in the above.

Based on the groundwater level data recorded on the description and evaluation sheets of the shallow geological cores, the groundwater table of two, climatically different periods could be modelled. By considering the relation between the dynamics of the surface water system and the groundwater movements of the area, as well as the measured values of the groundwater depth, a moderate and an extremely low groundwater level could be reconstructed *(Fig. 8)*.

In both hydrological cases, the depth of the groundwater level is the deepest on those surfaces of the studied hillside, which lie between 126 and 127 m a.B.s.l. Based on the coring data, the depth of the groundwater level

5 Research Institute of Environmental Protection and Hydrology Non-Profit Ltd.

6 Http://www.hydroinfo.hu/vituki/archivum/ba.htm.

7 Http://www.kvvm.hu/balaton/lang_hu/vizszintb.htm.

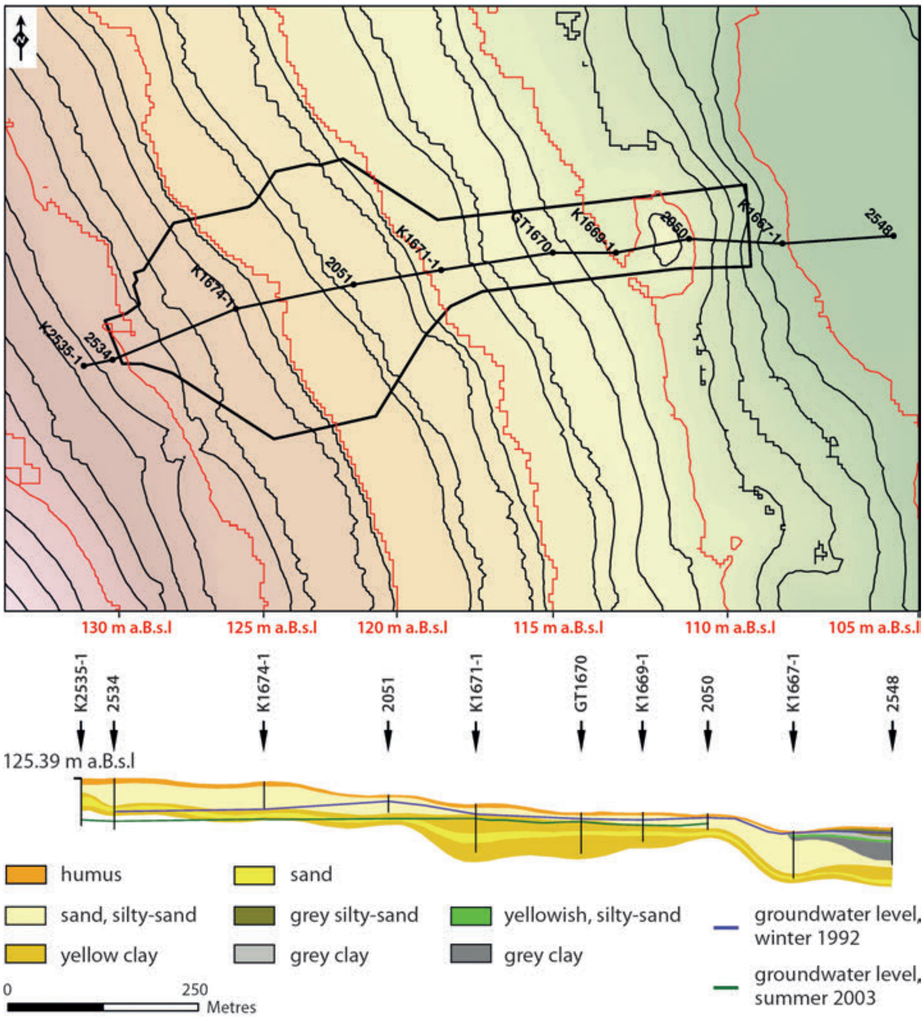

Fig. 8. Balatonkeresztúr-Réti-dűlő. Coring points used for modeling and compiled soil mechanics cross-section of the investigated area.

may even be set at 8 to 10 m in relative depth, and the groundwater level difference between the two hydrological situations can add up to almost 1.5 m (8.5 m at moderate water level and 9.8 m at extremely low water level). Based on the outcome of the model, both groundwater tables have a parallel position along the entire length of the slope under any of the reconstructed hydrological conditions. The only exception can be seen in the middle section of the slope, around 116 to 117 m a.B.s.l., where the groundwater level is relatively close, not even within a 2 m relative depth of the surface when the lake's water level is high. At low water level, the groundwater table is located much deeper. It must be added, though, that in 2003, the groundwater table was not reached within a 6 m relative depth at coring point K1674-1. This would suggest a deep-lying groundwater table; however, only the interpolated data are available on the depth of the groundwater in 2003 on the long cross-section part between cores K2535-1 and K1671-1. The results of the interpolation are supported by the groundwater data of two other cores (K2051-1, K2051-2). These cores were also extracted in summer 2003, presumably for control purposes. Although they do not fall in the line of the analysed cross-section, they are positioned perpendicular to core 2051 from 1992 (cf. *Fig. 7*). The groundwater level in core 2051 was measured to be at 116.3 m a.B.s.l. in winter 1992. Both in core K2051-1 and core K2051-2, the groundwater level was found to be 3.5 m deeper at 112.9 m a.B.s.l. than in core 2051. This observation underlines the accuracy of the interpolated data.

Starting from the middle section of the slope, until the plateau-like horizontal area, which lies at 110 to 111 m a.B.s.l., the two groundwater tables run approximately parallel to each other at a relatively low depth below the surface. At the horizontal part of the plateau, the groundwater table lies at a moderate depth. At 110 m a.B.s.l. on the steeper slope section running to the edge of the Nagyberek, the groundwater table is approximately parallel with the inclination of the surface and lies at a moderate depth. In this steeper part, the difference between the depth of the groundwater level between the two previously described hydrological conditions is greater than on the plateau. At the boundary between the Marcali Ridge and the Nagyberek area, the groundwater was located relatively close to the surface (it was observed at 1.1 m relative depth in core K1667-1 in summer 2003). Moreover, the interpolation results of the 1992 data also give a fairly high groundwater level for this area.

In sum, it can be said that the deep-lying older geological layers of the eastern slope of the Marcali Ridge are composed of a variety of clayey and sandy-silty sediments. The subterranean geomorphology and inclination conditions of these layers are more-or-less similar to that of the surface conditions. The older geological layers can also be found under the area of the Nagyberek. At the lowest end of the slope, within the area of the marshland, lacustrine sediments were deposited on the older geological sediments. Based on the description of the geological evolution of Lake Balaton, these clayey and silty sediments could have already been deposited in the Holocene when periodical flooding affected the embayments of the lakeshore. The modelled depth of the groundwater was based on the data gained from the soil mechanics survey. The groundwater level in the upper sections of the hillside is located deep, irrespective of the lake's water regime, but by moving in an eastern direction on the slope, it rises closer and closer to the surface.

On the horizontal plateau, no significant differences can be reconstructed at around 110 to 111 m a.B.s.l. for the groundwater levels of the two different water regime options. In the steeper section running towards the Nagyberek area, the two reconstructed groundwater table positions show a more significant depth difference. However, at the boundary between the Nagyberek marshland and the foot of the hillside (Marcali Ridge), both are situated low. In order to correctly interpret the outputs of the model, it must be added that the groundwater data is divided between the 10 coring points, which were used for constructing the approximately 1 km long cross-section. As a result of this, the length of the interpolated sections between the two points increases. It can be said that the two modelled groundwater tables run parallel, which enhances the usefulness of the model, but it must be emphasised that the model is not suitable for determining the absolute altitude values of the groundwater level between the two known points (cores). Obviously, this is also valid for the absolute altitude values of the stratigraphic boundaries of the geological layers. In this latter case, the resolution of the model is somewhat higher, due to the higher number of available data points.

The characteristics of the groundwater table, which was reconstructed based on the data of the corings, show the best correlation with the characteristics of the hypothesised optimal hydrological zone of the horizontal plateau at 110 to 111 m a.B.s.l. Namely, it is not situated too deep and shows great stability. This area is only 100 m away from the edge of the Nagyberek, which was part of the lake's basin and of the surface water system in the lake's natural condition. Consequently, we can conclude that the hypothesised optimal hydrological zone in this area was located on the horizontal plateau.

Occupation zones of the archaeological periods within the site

It was necessary to test and verify the functionality of the static groundwater model, which was based on the recent groundwater data of the Balatonkeresztúr site. In addition, it was also important to verify the correctness of the conclusions regarding the optimal hydrological zone theory. One obvious question is to what extent these observations and assertions can be used for the examination of archaeological periods. It was therefore necessary to compare the conclusions drawn from the recent data with the data gained through the excavation of human settlements. For this reason, the extent and position of the occupation zones, the centre of the settlements of the various archaeological periods were compared to the outcome of the model. The aim was to see whether or not the archaeological data support the model-based localisation of the optimal hydrological zone.

Middle Copper Age: Balaton-Lasinja culture (4300–4000 BC)

The occupation zone of the Middle Copper Age is located on the higher altitude surfaces, approximately at 120 m a.B.s.l., on the eastern slope of the Marcali Ridge *(Fig. 9)*. In both hydrological cases, i.e. at low and high water level conditions, the groundwater in this section of the examined area is located at a great depth, regardless of the lake's water level. Given the determinative role of the groundwater conditions mentioned above, extremely high groundwater levels could be reconstructed for this period on the slope. Beyond the central part of the Middle Copper Age occupation zone at 120 m a.B.s.l., features with typical finds of this period were found sporadically across the excavation area. Among others, a well-like feature was also uncovered[8]. The well was located approximately 10 m lower than the settlement centre, roughly on the lower boundary of the modelled optimal hydrological zone at 109.5 m a.B.s.l.

8 Szilvia Fábián's kind pers. comm.

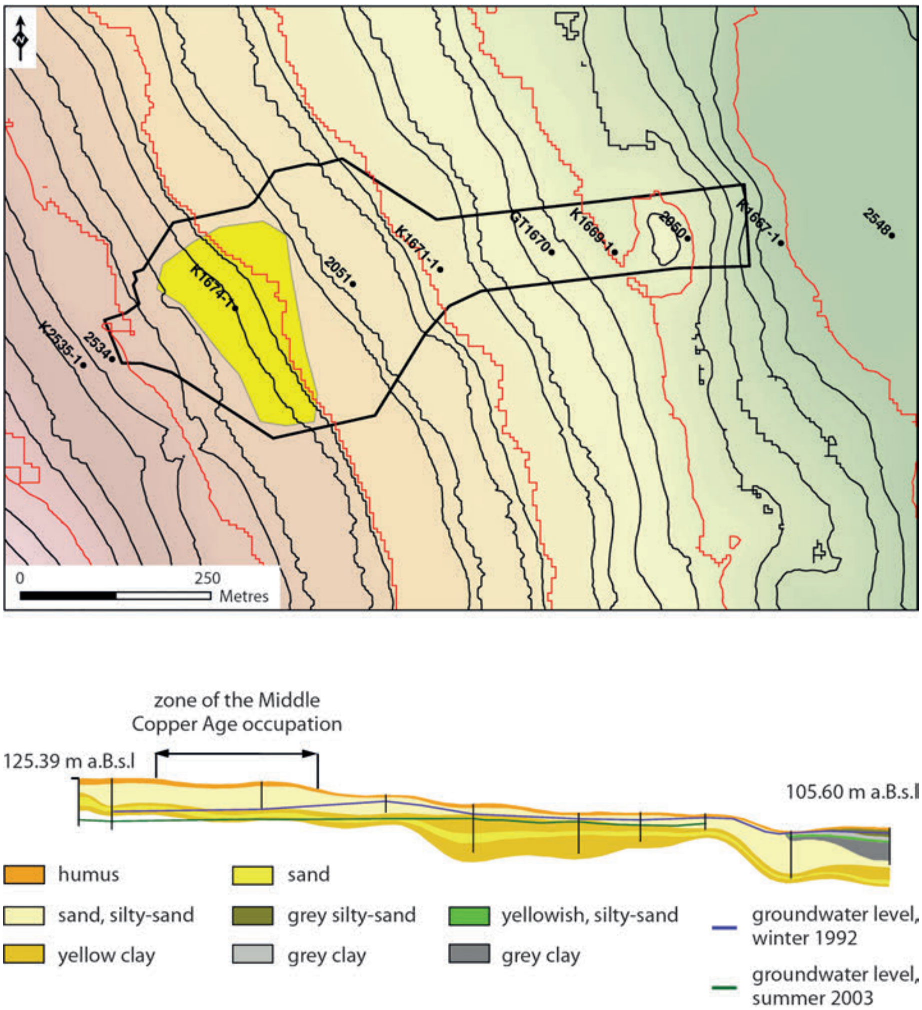

Fig. 9. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Middle Copper Age.

Based on the spatial distribution of the Middle Copper Age features, the other determining factors of the human occupation strategy must also be mentioned. It can be noted that the settlement's centre is located farther and above the altitude of the optimal hydrological zone. The water supply features, however, are positioned farther from the settlement features, directly in the zone that meets the criteria of the optimal hydrological zone, and therefore have the ideal groundwater level characteristics. It can be assumed that in certain periods, the settlement centres were located farther, but still on the economically feasible boundary of the optimal zone. However, no far-reaching conclusion can be drawn regarding the impact of environmental and cultural factors based on the data gained from the analysis of one single archaeological site. This requires a regional study of the settlements and a complex analysis of the period's settlement strategy.

Late Copper Age: Boleráz-Baden culture (3600–2900 BC)

The occupation zone of the Late Copper Age is concentrated on the horizontal plateau located at the lower section of the slope at 110 to 111 m a.B.s.l. There are no features of this period below 107 m a.B.s.l. *(Fig. 10)*. Among the finds of the different archaeological periods, the Late Copper Age material has been most fully analysed. Through the typological assessment of the ceramic finds, Szilvia Fábián was able to distinguish three different phases within the Late Copper Age occupation of the site, during which there were also structural changes in the settlement. These three, archaeologically distinct phases were later confirmed by the radiocarbon dates (Fábián / Serlegi 2009, 206–215; Serlegi et al. 2012, 140–142).

The earliest Boleráz occupation is characterised by a relatively dispersed settlement structure within the Late Copper Age occupation zone. The settlement features of

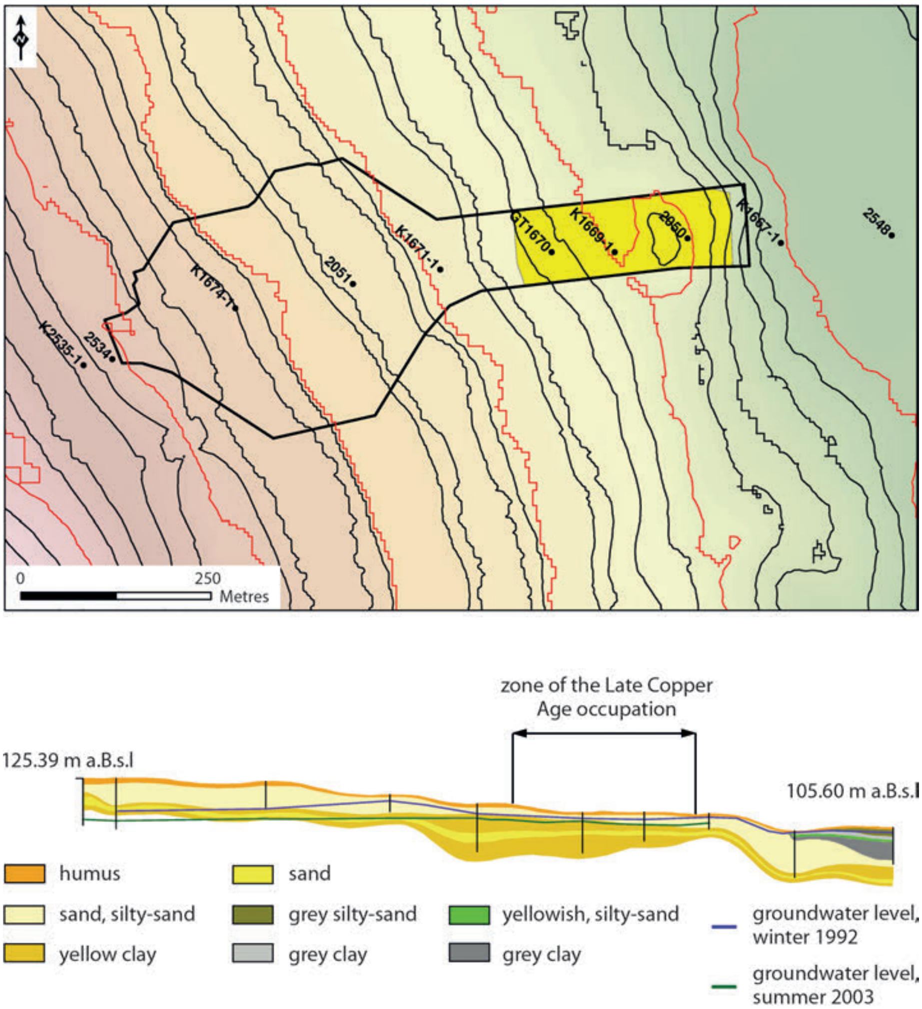

Fig. 10. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Late Copper Age.

the earliest phase can be found on lower altitude surfaces during the Late Copper Age. In the ensuing early classical Baden period, a settlement concentration can be noted across the excavated area, reflected by the greater density of settlement features on the horizontal plateau. During the late classical Baden period, this concentration process continued: the extent of the settlement became smaller and was restricted to the plateau *(Fig. 11)*.

Based on the observations regarding the settlement structure, a continuously rising groundwater level can be reconstructed, resulting in the horizontal diminution of the area suitable for occupation as well as of the centres of the subsequent settlements.

In order to examine the possible climatic changes regulating the rising groundwater level and to determine the climatic characteristics of this period, Painter's mussel shells *(Unio pictorum)* from significant features of the three occupation phases were submitted to stable isotope ($\delta^{18}O$) analysis (Barna 2009, 59–63; Demény et al. 2010, 87 f.; Schöll-Barna et al. 2012, 87–100; Serlegi et al. 2012, 144–146).

Relatively stable climatic conditions can be reconstructed for the Boleráz period. Based on the stable isotope analysis, the climate became more humid, wet, and extremely volatile during the transition between the Boleráz and the early classical Baden period, when the previously dispersed settlement structure starts to become more concentrated. The analysis of the mollusc shells also revealed that the humid climate of the early Baden period became similar to that of the Boleráz period by the end of the late classical period.

It can be assumed that during the Late Copper Age, the concentration of features within the assumed optimal hydrological zone was due to the effect of the changing surface water system and the increase of the groundwater level in its wake. These later alternated as a result of the climatic changes, which turned the area more humid and wetter. However, it is clearly observable that the settlement's occupants did not wholly abandon

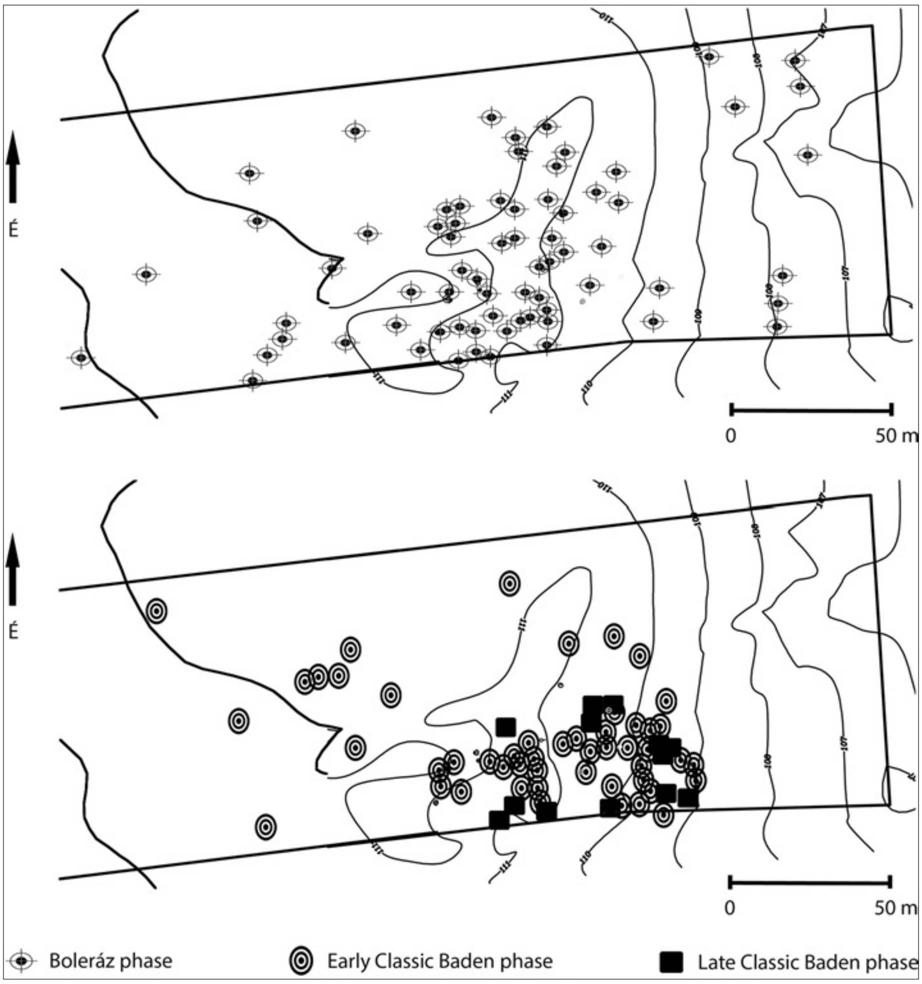

Fig. 11. Balatonkeresztúr-Réti-dűlő. Archaeological features in the occupation zone of the Late Copper Age belonging to the three different phases.

the area even under more extreme climatic conditions, indicating that even under significantly robust climatic changes, as shown by the stable isotope results for this period, the groundwater conditions in the area remain stable enough in the optimal hydrological zone.

Early and Middle Bronze Age: Somogyvár-Vinkovci, Kisapostag, and Encrusted Pottery cultures (2500/2400–1600/1500 BC)

The occupation zone of the Early and Middle Bronze Age cultures is located in the middle section of the hillside *(Fig. 12)*. Except for the Middle Copper Age, this is the period when no traces of occupation can be observed on the slope extending east of the horizontal plateau. Unfortunately, due to the current state of the archaeological assessment of the finds and the low number of excavated features, a detailed analysis of the features of this period was not possible. However, it must be noted that during the construction work after the completion of the preventive archaeological excavations, two additional Early Bronze Age pits were found in the central area of the Middle Copper Age occupation zone (Honti et al. 2007, 42–44). In addition, finds of the Early Bronze Age Somogyvár-Vinkovci and Kisapostag cultures were recovered from the fill of a few features of the Balatonkeresztúr–Kiserdei-dűlő archaeological site during a preventive excavation (site M7/S36), located at 130 m a.B.s.l. at a distance of several hundred metres west of the line of the motorway (Honti et al. 2004, 9 f.). It is impossible to determine on the basis of the currently available data whether or not the excavated features belong to the same settlement. However, it is an indication that the Early Bronze Age population established its settlement on the higher altitude surfaces where the groundwater level is at least 9 to 10 m below the surface. It cannot be assumed that any shift in the groundwater level at such a depth would have influenced the settlement features and the selection of the occupation area. Wells dating from this period are not known from the site. It is very likely that during the Early and

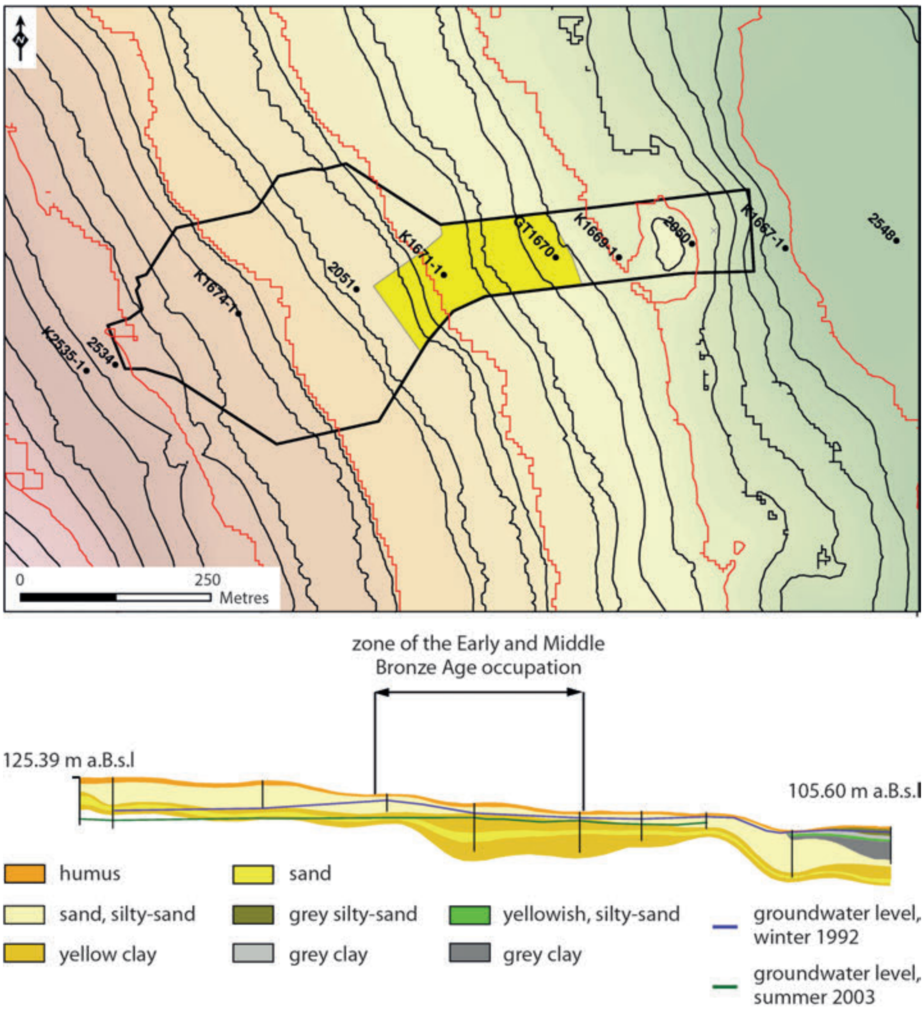

Fig. 12. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Early and Middle Bronze Age.

Middle Bronze Age, the settlement's water supply features were located near the boundary of the optimal hydrological zone, but the excavated area did not include this part of the settlement. Similar to the Middle Copper Age, the reasons for locating the centre of the Early and Middle Bronze Age occupation at such a high altitude could only be determined after a regional study, which would reveal the possible cultural reasons behind the occupation strategy of the period's communities.

Late Iron Age: La Tène C–D culture (4th century BC to 1st century AD)

The Late Iron Age occupation zone was observed in the entire lower section of the hillside within the site *(Fig. 13)*. This is the first period in which settlement features could be found across the entire section of the slope, reaching the boundary of the Nagyberek area. In this area, the model assumes the near surface location of the groundwater, which is underlined by the observations made during the excavation. Currently, no detailed assessment of the finds of this period is available. However, considering the Late Iron Age settlement structure of Balatonkeresztúr–Réti-dűlő, as well as the generally established climatic conclusions based on the dendrochronological analysis of this particular period, the following tentative conclusions can be drawn. Based on the features observed relatively low, below the lower boundary of the optimal hydrological zone at 105 m a.B.s.l., it can be assumed that the groundwater was permanently located at a low level on the hillside. This might indicate a prolonged drier and warmer climatic period. This climatic trend is underlined by the dendrochronological analyses of the Iron Age of the Carpathian Basin too. The so-called Pannonian oak chronology covers the period from 170 BC to AD 90, and the growth indices of the trees reflect an extremely dry and warm period (Grynaeus 2004, 93 f.). In the light of these data, a low groundwater level and reserved surface water regime can be reconstructed for this period, which could have led to a temporary expansion of the boundary of the optimal hydrological zone.

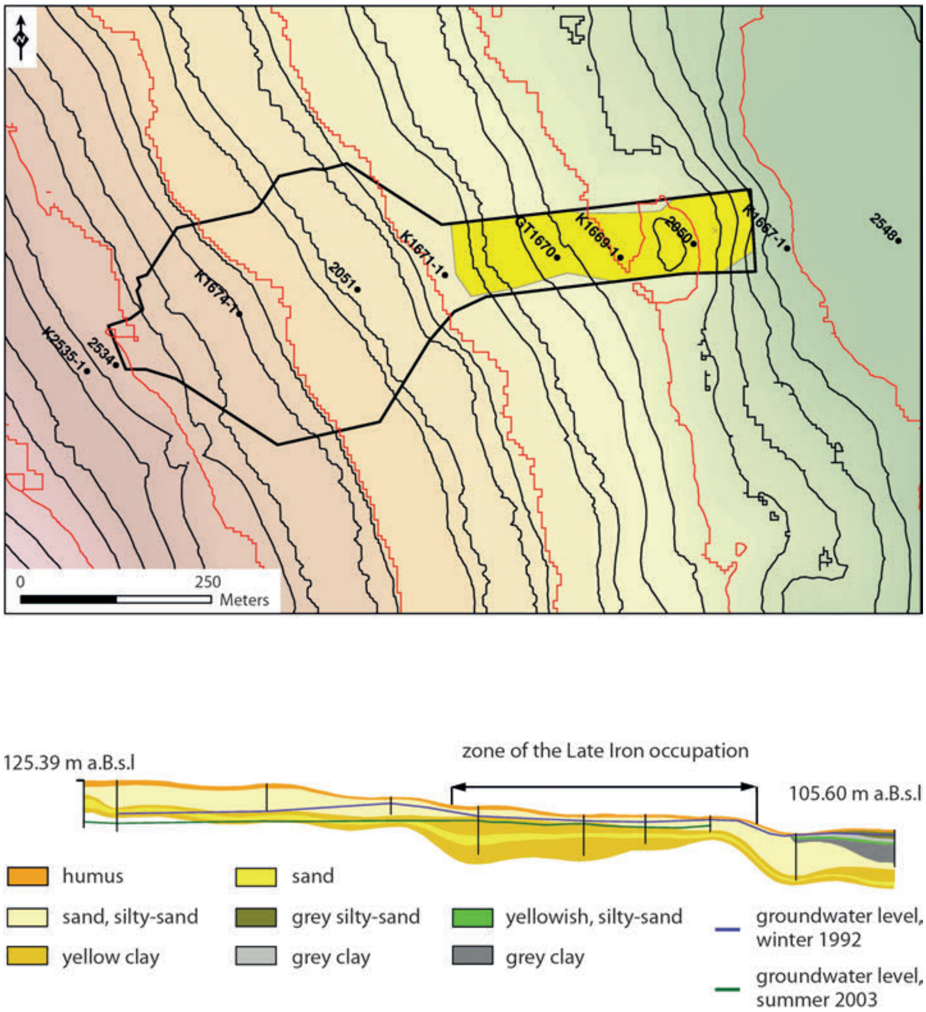

Fig. 13. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Late Iron Age.

Migration period (Langobard occupation, 6th century AD)

The occupation zone of the Migration period within the site was observed in the lowest section of the hillside, on the boundary with the Nagyberek area *(Fig. 14)*. Similarly to the Late Iron Age, low ground water data can be expected. During this period, settlement traces were excavated below the hypothesised boundary of the optimal hydrological zone in the lowest part of the slope. Essentially, the period's settlement features do not reach the optimal hydrological zone, which is approximately the horizontal plateau of the site.

Árpádian Age (10th to 11th centuries AD)

The occupation zone of the settlement that can be dated to the Árpádian Age is located on the horizontal plateau in the middle section of the hillside. Its boundary reaches the edge of the plateau to the east; its features do not occur under 110 m a.B.s.l. *(Fig. 15)*. The greater part of the settlement's centre is well-detectably located within the hypothesised optimal hydrological zone.

Medieval period (13th to 15th centuries AD)

The occupation zone of the Medieval village of *Cholta* overlaps with the territory of the Árpádian Age settlement. In the later period, the area is characterised by a significantly denser settlement structure and a higher concentration of features *(Fig. 16)*. The period's settlement features do occur under 110 m a.B.s.l., suggesting groundwater conditions similar to those of the Árpádian Age. There is no direct data on the destruction of the settlement; however, analogies to the phenomena observed at Balatonkeresztúr would suggest that the abandonment of the settlement can be associated with the impact of the Little Ice Age (LIA). Environmental changes during the

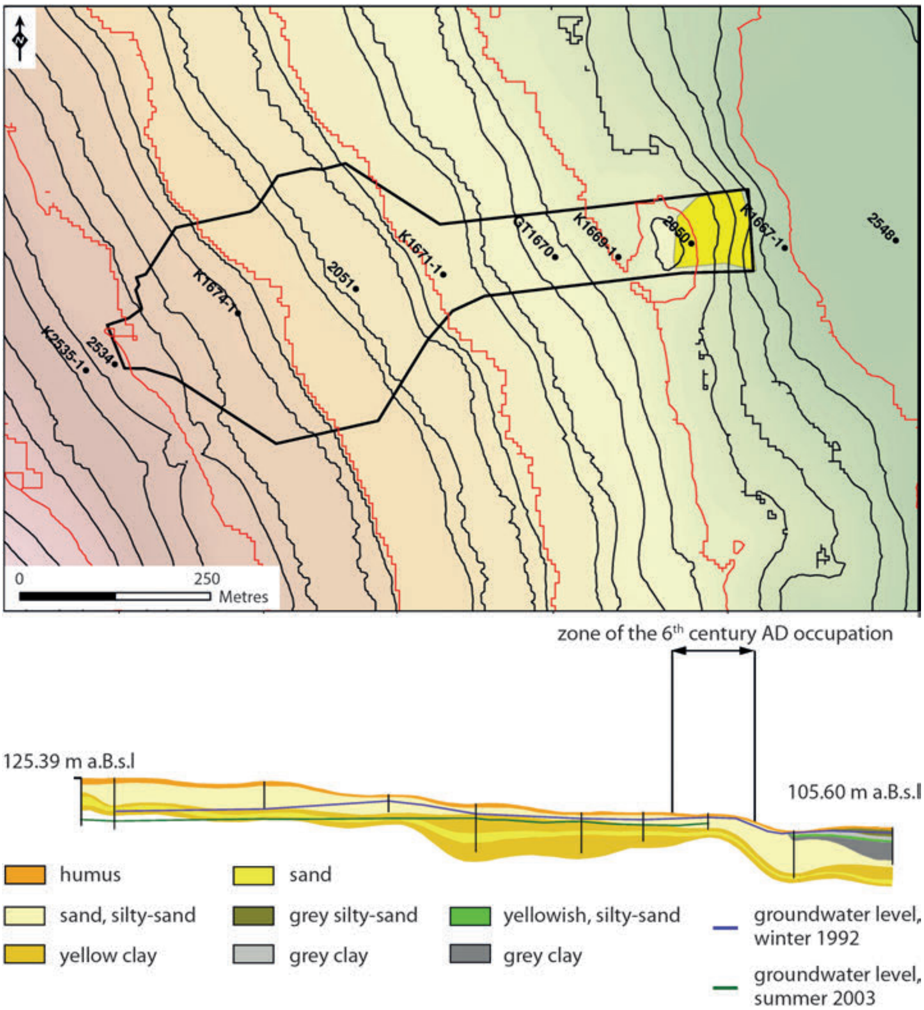

Fig. 14. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Migration Period (6th century AD).

LIA in the Lake Balaton area affected the groundwater levels, which most likely influenced the site's occupation strategies (Mészáros / Serlegi 2011, 215).

The relation between the static groundwater model and the location of the occupation zones during the examined archaeological periods

The results of the stratigraphic and static groundwater model constructed from the soil mechanics coring data and the location of the occupation zones of the different archaeological periods of the site show a good correlation. The results confirm the relation between the criteria of the optimal hydrological zone theory and one of the hydrology-related aspects of human occupation strategy. We may assert that the groundwater table, which was interpolated based on the record of the modern groundwater level data from the soil mechanics corings, does not show significant alternations at the horizontal plateau located at 110 to 111 m a.B.s.l., although more significant groundwater fluctuations can be noted in some sections of the hillside. The groundwater level remains at an ideal moderate depth on the plateau satisfying the criteria set against it.

The centre of six settlements (Late Copper Age, Early and Middle Bronze Age, Late Iron Age, Migration period, Árpádian Age, and the Medieval period) of the seven archaeological periods recorded at Balatonkeresztúr was mainly located in the optimal hydrological zone predicted by the model *(Fig. 17)*. However, some spatial variations can be identified between the settlement centres in the territory of the zone.

The settlements of the Middle Bronze Age are located on the highest altitude relief, on the upper boundary of the zone. The settlement traces of the Late Copper Age, the Árpádian Age, and the Medieval period can be found at roughly similar altitudes and extend across the entire territory of the zone. Archaeological features

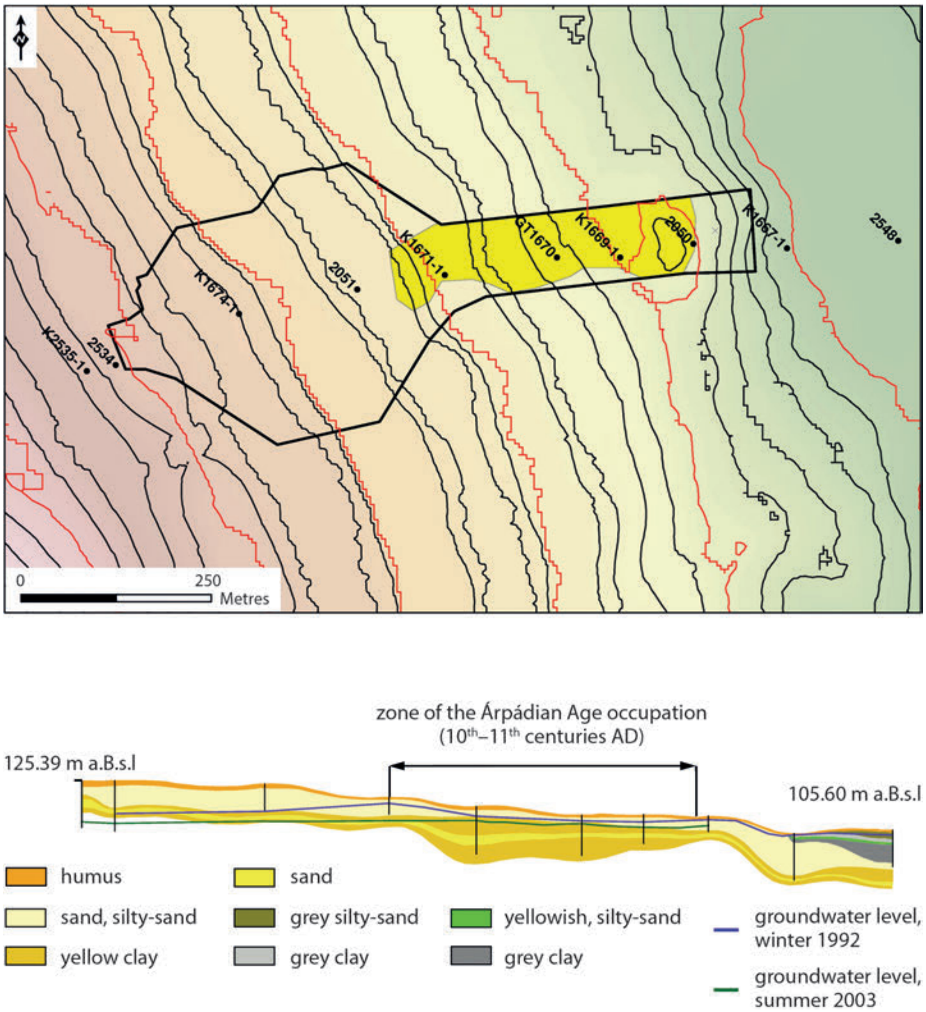

Fig. 15. Balatonkeresztúr-Réti-dűlő. The occupation zone zone of the Árpádian period (10th to 11th century AD).

associated with certain periods of the Late Copper Age could be observed at 108 m a.B.s.l on the hillside, which is below the lower boundary of the hypothesised zone. According to the period's internal chronology, these features represent the earliest, Boleráz period. In the second half of the Late Copper Age, as well as during the Árpádian Age and the Medieval period, the concentration of the settlements can be identified on the horizontal plateau at 110 to 111 m a.B.s.l.; in other words, these settlements were established in the area of the optimal hydrological zone. The features of the Árpádian Age and the Medieval period do not exceed the 110 m a.B.s.l. limit, which is the lower boundary of the zone. Yet, their features located west of the site are in line with the Bronze Age settlement features on the highest altitude surfaces. In this section, no traces of a Late Copper Age occupation were detected. The settlement features of the Late Iron Age and the 6th century AD can be found even on the steeper slope section of the hillside below the horizontal plateau. This is well below the lower boundary of the hypothesised optimal hydrological zone, already located near the Nagyberek area.

The single archaeological period with an occupation centre well beyond the boundary of the optimal hydrological zone, located on the highest altitude surfaces of the hillside, is the Middle Copper Age. The features of this period are located on a relief where the depth of the groundwater unequivocally reflects its impact on the features, under any environmental conditions. The location of the period's water supply features near the boundary of the optimal hydrological zone highlights the fact that the central part of the Balaton-Lasinja occupation was independent of the territory of the optimal hydrological zone. Based on the observations made at the Balatonkeresztúr–Kiserdei-dűlő site, this possibility also arises in the case of the Early Bronze Age.

Our observations indicate that with the exception of the Middle Copper Age, the central area of the settlements was always located in the area of the hillside,

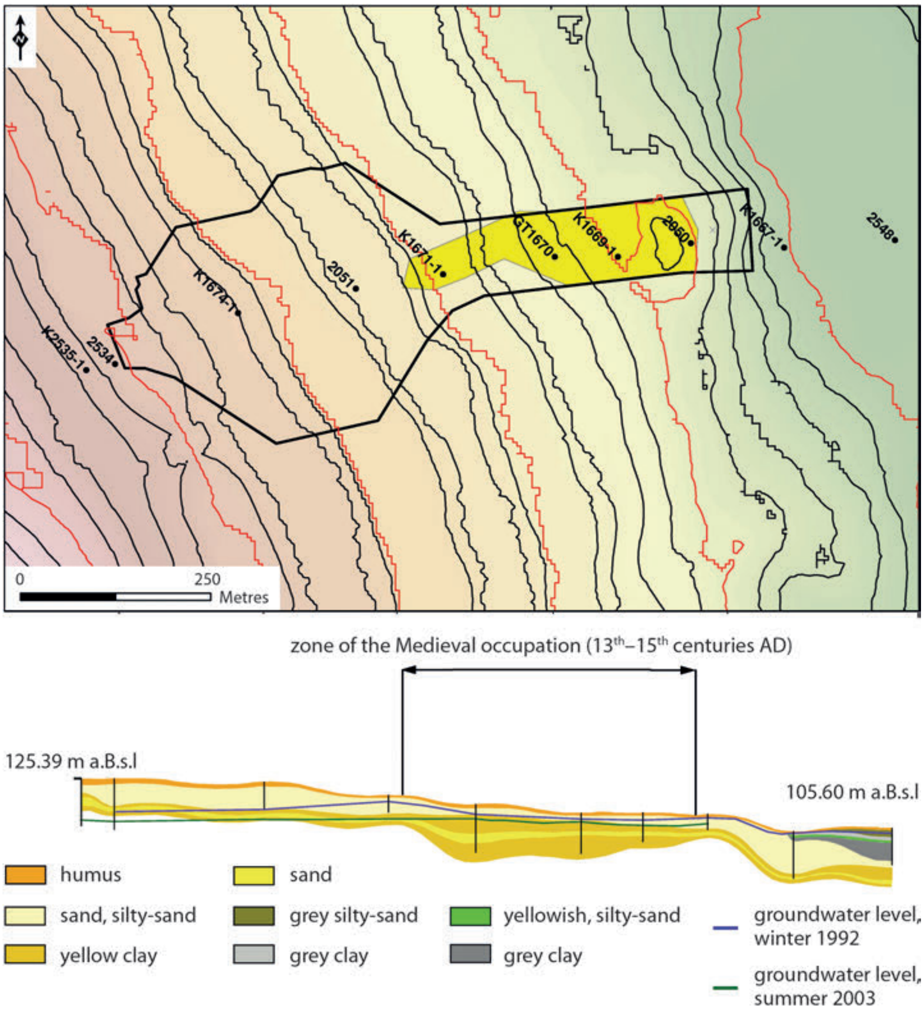

Fig. 16. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Medieval period (13th to 15th century AD).

which is hypothesised by the model as the optimal hydrological zone.

The comparison of the conclusions drawn from the static groundwater model constructed from the data of the soil mechanics corings with the archaeological data undoubtedly support the decisive role of the optimal hydrological zone in the shaping of human occupation strategies. However, based on the model, only the criteria of the groundwater table characteristics of the optimal hydrological zone can be justified. The available data are unsuited to reconstructing the parameters of the optimal distance of the settlements from the water surface, which would undoubtedly provide further details on the hydrological aspects of human occupation strategies.

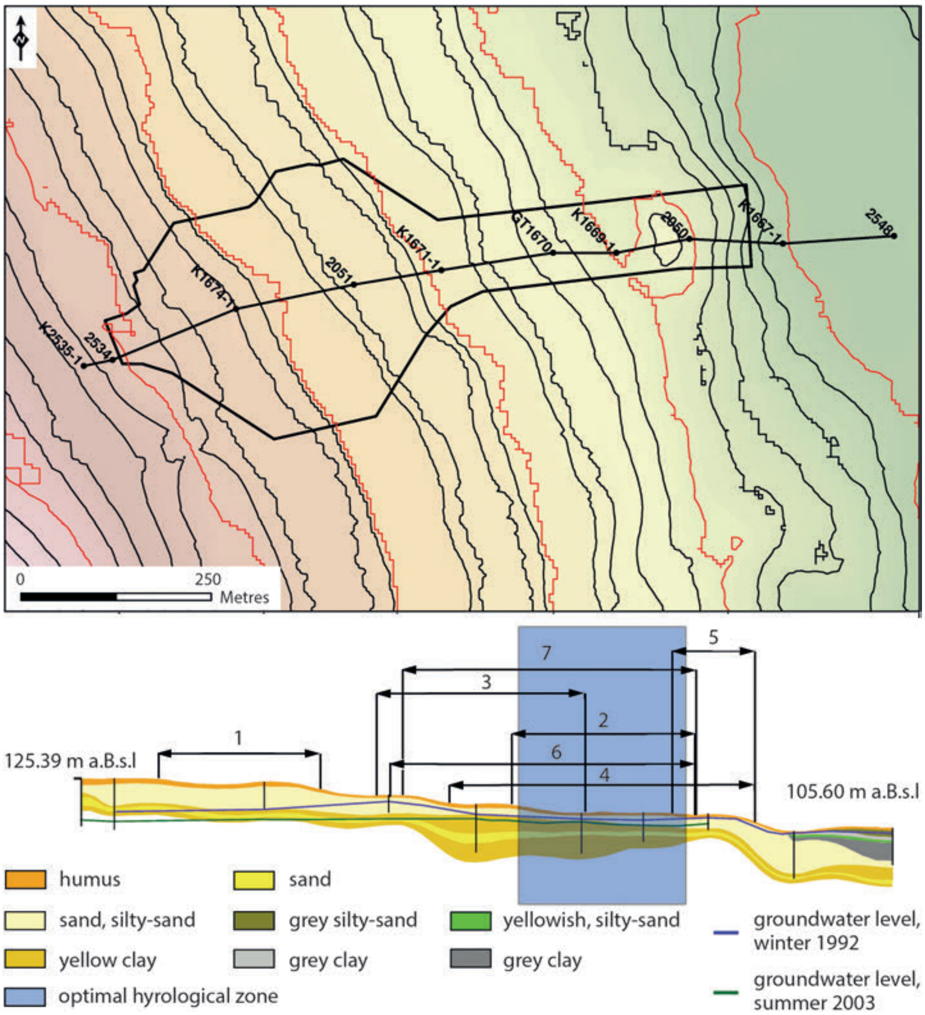

Fig. 17. Balatonkeresztúr-Réti-dűlő. The occupation zone of the different archaeological periods and the area of the optimal hydrological zone (blue).1 Middle Copper Age; 2 Late Copper Age; 3 Early and Middle Bronze Age; 4 Late Iron Age; 5 Migration period (6th century AD); 6 Árpádian period (10th to 11th century AD); 7 Medieval period (13th to 15th century AD).

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Abstract: Groundwater under scrutiny: A hydrological aspect of human settlement strategy in the vicinity of the southern shoreline of Lake Balaton

Hydrological conditions in the Carpathian Basin underwent a significant change in the wake of anthropogenic activities impacting the environment. The regulation and management of surface waters led to changes in the subsurface natural water systems. The depth and stability of the groundwater table are at least as important as the presence of surface water bodies among the parameters determining the locations suitable for human settlement. Discussed here are the effects of the relative groundwater table depth and its movement on human settlement, based on the insights provided by the comparative analysis of the data gained from the investigation of the multi-period archaeological site at Balatonkeresztúr-Réti-dűlő (site M7 / S35) and the static groundwater model constructed from the data provided by mechanical drillings and surveys ahead of the construction of the M7 motorway.

Zusammenfassung: Grundwasser auf dem Prüfstand: Ein hydrologischer Aspekt menschlicher Siedlungsstrategie im Nahbereich der südlichen Uferlinie des Balaton

Die hydrologischen Gegebenheiten im Karpatenbecken durchliefen erhebliche Veränderungen in Folge anthropogener Aktivitäten und ihres Einflusses auf die Umwelt. Die Regulierung und Steuerung von Oberflächengewässern führte zu Änderungen in den natürlichen unterirdischen Wassersystemen. Bei den Parametern, die entscheidend dafür sind, welche Plätze für die menschliche Besiedlung nutzbar sind, sind Tiefe und Stabilität des Grundwasserspiegels mindestens ebenso wichtig wie die Verfügbarkeit von Oberflächenwasser. In diesem Beitrag werden die Auswirkungen diskutiert, die die relative Tiefe des Grundwasserspiegels und ihre Veränderungen auf die menschliche Besiedlung hatten, auf der Grundlage der Erkenntnisse aus der vergleichenden Untersuchung der Daten, die aus der Erforschung des mehrperiodigen archäologischen Fundplatzes Balatonkeresztúr-Réti-dűló (Fundplatz M7 / S35) vorliegen, sowie auf Grundlage des statischen Grundwassermodells, das anhand von Daten aus Bohrungen und Surveys im Vorfeld des Baus der Autobahn M7 gewonnen wurde.

Absztrakt: A talajvíz tényező: az emberi megtelepedési stratégia hidrológiai szempontjai a Balaton déli partvonala mentén

Az elmúlt két évszázad antropogén eredetű természetátalakító folyamatai nagyban megváltoztatták a Kárpát-medence vízrajzi képét. A felszíni vizek rendezése magával vonta a felszín alatti természetes vízrendszerek megváltozását is. A felszíni vízfolyások mellett, a talajvíztükör mélysége és stabilitása legalább ugyan olyan fontos az emberi megtelepedés lehetséges helyét meghatározó paraméterek között. Jelen kutatás vizsgálati fókuszpontjában a talajvíztükör relatív mélységének és mozgáskarakterisztikájának emberi megtelepedésre gyakorolt hatása áll. A vizsgálatok alapja az M7 autópálya építését megelőző, Balatonkeresztúr-Réti dűlő (M7 / S35) több korszakú lelőhely településrégészeti adatainak és a kivitelezést megelőző talajmechanikai vizsgálatok eredményei alapján készült statikus talajvízmodell következtetéseinek összehasonlító elemzése.

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References of figures:
Fig. 1, 4–18: author. – *Fig. 2:* Gábor Timár. – *Fig. 3:* after data from the former Hungarian Ministry of Environmental Protection and Hydrology, graphics G. Serlegi and O. Wagner (RGK).