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RESEARCH ARTICLE

The hydrology and preservation condition in the flat-topped burial mound – Klangshøj at Vennebjerg in Vendsyssel

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ABSTRACT
Klangshøj is a flat-topped burial mound similar to the Royal Jelling mounds, although smaller. The myths tell that a well has existed on top of the mound as at Jelling and a spring had flown at the base of the mound. In order to verify the myths and a similar hydrology in Klangshøj as found in Jelling, several borings have been carried out in a north-south line across the mound.

The investigation showed that Klangshøj is built of sods mainly harvested from heathland. The sods are of different grain sizes from fine sand to clay. The preservation conditions were excellent in three of the six borings, where undecomposed plant remnants, occasionally greenish, were observed. A ^{14}C-dating showed that the mound was built in the Viking Age. The hydrology in Klangshøj is the same as in the Jelling mounds, with a permeable bioturbation zone covering almost impermeable, distinct sod layers. This form a perched groundwater table in the transition zone, which keeps the distinct sod layer below anaerobic, i.e. the preservation conditions extremely favourable. The perched water table drains internally as in the Jelling mounds, and there are no current nor fossil evidence to suggest a spring was ever present at the foot slope, as the local legend suggests. Moreover, it seems unlikely that a well, similar to the one on the Jelling mound, has existed on the top of the north-facing slope, as the amount of water the well would have been able to collect is little.

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1. Introduction

More than 80,000 burial mounds have been constructed in Denmark in the period 1500 BC to AD 1000. Most of the burial mounds are located in the higher part of the landscapes and are relatively well drained, but in some cases, a perched water table has developed in the mounds. The documented mounds with perched water table are mainly built in the Early Bronze Age about the 13th century BC (Randsborg 1996, Holst *et al.* 1998, Breuning-Madsen *et al.* 2001) but examples from the Viking Age about the 10th century AD also exist (Breuning-Madsen *et al.* 2012). They were in average about 15 m in diameter and 3–4 m in height, though some were much larger with diameters up to 70 and 9-m high.

The development of perched water tables in burial mound seems to follow two different routes:

i: The burial mounds from the Bronze Age were built of sandy or loamy sods over oak log coffins containing deceased persons. In some cases, iron pans due to redox processes have developed in the central part of the mound close to the base and formed a perched water table sustained by precipitation surplus (Breuning-Madsen and Holst 1998, 2003, Holst *et al.* 1998, Breuning-Madsen *et al.* 2000, 2001). This water table has formed an anaerobic core sometimes totally encapsulated by iron pans. Upon excavation, the core appears bluish or black, anaerobic, and contains substantial amounts of water, while the surrounding mantle is normally brown or yellowish brown and aerobic. In the mantle, the plant material on the sods is decomposed whereas the core contains large quantities of undecomposed organic matter including well preserved plant remains (e.g. Henriksen 2005). The primary burials are normally found within the core, and when excavated more than 3000 years after interment, well-preserved oak log coffins have been uncovered. In that way, some of the most

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remarkable discoveries from prehistoric Denmark have been made inside such burial mounds, as corpses, costumes, food, weapons and other implements are extremely well preserved.

ii: In the Viking Age, during the second half of the 10th century, perched water tables were formed in the two huge mounds constructed as a part of the Royal monuments in Jelling, East Jutland, Denmark (Breuning-Madsen *et al.* 2012). The North Mound is approximately 60 m in diameter and 7.5 m tall and built of more than 2,000,000 mainly sandy loamy sods. It contained a large wooden chamber about 7-m long, 3-m wide and about 1.5-m high. The South Mound is 65–75 m in diameter and 9.5 m tall and built of more than 2,500,000 loamy or sandy loamy sods. There were no burials in that mound. Information on the burial mounds can be traced from an engraving made by H. Rantzau at the end of the 16th century showing that at the top of the North Mound, a pond is depicted (Lindeberg 1591). In the explanatory text, Rantzau states that there was a stone-built well at the bottom of the pond. Later reports describe the form of the well as a funnel where the well is the tap. The top of the funnel had a circumference of about 30 m or a diameter of 9–10 m (Krogh 1993). The well was used to supply the inhabitants of Jelling with good drinking water. This shows that a perched water table that could feed the well with water must have been developed in the North Mound. In 1820, the well was filled up with soil material after an excavation into the centre of the mound.

In 2009, borings were made in the two mounds (Breuning-Madsen *et al.* 2012) in order to explain the development of the perched water tables. This study found that the genesis of the perched water table was very different than the perched water tables formed in the Bronze Age burial mounds, although the basic mound construction is rather similar. All mounds are built by grass or heathers sods placed with the vegetation surface downwards. First of all, it is not iron pans that generate the perched water tables in the huge burial mounds but changes in the hydraulic conditions between the bioturbation zone and the sods below. These changes cannot be ascribed to abrupt changes in the texture, as the two burial mounds are very uniform in that respect. It can be explained by biological activities in the soil layers above the muddy layer forming vertical cracks due to annual drying/rewetting processes and root burrows, while the muddy layer below has impeded the biological activity in the lower soil layers. The conditions that might have a huge impact on the formation of the perched water table due to abrupt changes in the hydraulic condition are: (i) precipitation surplus, (ii) the texture of the building material, (iii) the shape and size of the mound, and (iv) the root depth of the vegetation on the mound. (i) is important as a precipitation surplus will give time for the water to penetrate into the subsoil with low hydraulic conductivity. The texture (ii) is important, as a huge burial mound built of sand will not generate perched water tables due to the high hydraulic conductivity of pure sand. The size and shape (iii) seem to play an important role. The large dimensions, 8 to 10-m high and 60–70 m in diameter, in combination with the loamy texture may compact the two to three million sods leaving little space for the water to penetrate. The bioturbation loosens the upper 2 m and hereby develops the big differences in hydraulic conductivity between the bioturbation zone and the sods below. The shape of the mounds with a huge flat top and steep slopes may keep the water surplus in the mound for a longer period as it has to flow a long distance at a low gradient from the centre of the mound to the steep slopes. This might explain why the hydrological conditions in the Jelling mounds have not been described in other mounds in Denmark or other places in Northern Europe.

The description of the special hydrological condition developed in the Jelling raise the question: is it possible to find similar mounds in Denmark? An extensive literature survey showed that at Vennebjerg in Northern Jutland, a burial mound Klangshøj might have similar hydrological conditions as the Jelling mounds. In the *Museal berejsning,* in 1924, Klangshøj is described as 6-m high with a diameter of 45 m (http://www.kulturarv.dk/fundogfortidsminder/Lokalitet/15294/, [accessed 18 March 2016]). It is located on a ridge, it is partly demolished and the myth tells that there should have been a well in a small depression close to the top of the mound, and a spring called 'crutch-Karen's spring' (Danish: Krykke-Karens kilde) flowed in ancient times from the base of the mound towards the north. In 2001, the National Museum describes the mound as an prehistoric burial mount that might not be 6-m high as stipulated at the former inspections in 1949, 1938 and 1992 because the mound is built on a natural summit in the landscape (Breuning-Madsen *et al.* 2012).

If the myths are correct, the well and the spring from the base indicate that the hydrological conditions in Klangshøj are rather similar to the conditions in the two Jelling Mounds. Thus, the purpose of the study is clarifying the following questions:

i: Is the preservation condition of the organic matter in Klangshøj as optimal as in the Jelling mounds?
ii: Is Klangshøj a burial mound from the Bronze Age, Iron Age or Viking Age?
iii: Is the hydrological flow pattern in Klangshøj identical to the two Jelling mounds?
iv: Has the mound fed a spring running out of the mound at the base towards the north?
v: Has there been a well close to the top of the mound?

1.1. Location

Klangshøj is located at Vennebjerg, a small village in Vendsyssel, Northern Jutland about 6 km west of the town Hjørring, Figure 1. Vennebjerg is situated on a small hill formed for about 20,000 years ago during the late Weichselian Ice Age. Geologically it consists of a mixture of loamy till and sandy melt water deposits. About 15,000 years ago, the Yoldia Sea transgraded the lower part of Vendsyssel and the small hill was left as an island in the Yoldia Sea. Due to an uplift of the landscape which exceeded the raise of the sea level, there was a regression of the Sea, and Vennebjerg is today surrounded by the former sea bottom, the Yoldia sand and to a lesser degree Yoldia clay.

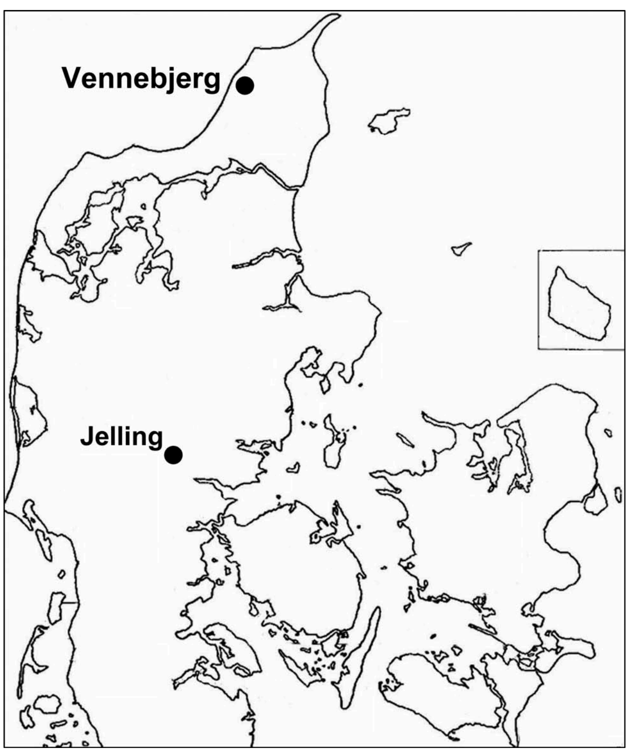

Figure 1. The location of Klangshøj at Vennebjerg and Jelling in Jutland.

The Klangshøj mound is located immediately west of Vennebjerg Church and it is reshaped several times due to human activity. The east side, facing the cemetery has been disturbed when building the church dike. The south side is relatively unaffected, although the long-time plowing at the base of the mound has steepened the south-facing slope. Excavation for the road may also have contributed to this. The west side is the most affected, as it was excavated about year 1900 to make a ground for common activities for the local community and different types of sport. The north side is the least affected, although a monument to a local teacher has been erected and a path to the top of the mound was made. Moreover, the majority of the mound was overgrown with trees and shrubs when investigated, which complicates the superficial analysis of the mound and potentially impair the preservation conditions in the mound due to deep root development.

2. Method

2.1. Field work

Field work was carried out in August and November 2013 in order to describe and map soil horizon sequences in the mound and for evaluation of the drainage conditions and preservation condition for plant remnants. In total, six deep borings were carried for detailed examination and several test borings were carried out for localisation of a former well and spring if they have existed. A seventh borehole (G) turned out to be outside the mound and is not further discussed. The six borings were placed in a north-south transect over the mound at a place with minimum human disturbance due to excavations of the mound towards west and south and the disturbance of the eastern part of the mound due to building of a stone wall fencing the church yard. Only the north-facing slope was not strongly modified by human activity. The test borings were carried out slatternly distributed at the top part of the north-facing slope in order to trace the well and at the foot slope in order to find the outlet of the former spring. All horizontal positions were measured with a Trimble R8 RTK dGPS (accuracy: horizontal = 8 mm, Trimble Navigation Ltd., Sunnyvale, CA, U.S.A.). Samples for soil physical and chemical analyses was collected from the six borings, and in order to trace the origin of the sods building up the mound, samples from the surrounding fields were collected. Furthermore, water was collected from the boreholes C and D in November in order to determine the chemistry of the soil water perched in the mound.

The borings were carried out using a hand-driven chamber auger for stony soils (Eijkelkamp, Giesbeek, NL). The auger consists of a hollow auger head (ø = 7 cm), an attachable handle and multiple 1-m extension rods. At each down-lead and uptake, a 10 to 15-cm long soil cylinder is extracted. All borings reached the yellowish brown subsoil below the mounds. The deepest boring of 3.5 m corresponded to about 25 down-leads and uptakes. The soil cylinders in the chamber were described according to a soil profile description system developed for Danish burial mounds (Breuning-Madsen and Holst 2003). Soil samples for chemical, physical and archaeobotanical analyses were collected from the six borings. A secondary boring to the surface of the low-conductivity layer was left open to determine the influx of water over a 3-day period. It was made close to boring C (Figure 3), which has the most well-preserved vegetation surfaces, and therefore supposedly the lowest vertical hydraulic conductivity. At the same location, a borehole was drilled in November 2013 and the water table was measured the next day.

2.2. Analyses

In the laboratory, the samples were air dried and sieved through a 2-mm mesh, and the soil chemical and physical analyses were carried out on the soil material finer than 2 mm. The following analyses were carried out on selected samples (double determination). The texture was determined by use of hydrometer method for silt and clay fraction and sieving of the sand fraction (Day 1965). Total carbon content was determined by dry combustion at 1250°C under oxygen addition (ELTRA 1995). Soil pH was determined potentiometrically in a suspension of soil and 0.01 M $CaCl_2$ at a soil–liquid ratio of 1:2.5.

About 100 cm^3 soil from the turf vegetation samples were used for the archaeobotanical analyses. The samples were wet sieved through a mesh size of maximum 0.3 mm to remove any fine sand and clay. The plant remains were then extracted from other materials and identified using a stereo microscope at 8x–100x magnification.

3. Results and discussion

3.1. Estimation of mound volumes

Figure 2(a) shows a digital elevation model of the current mound and the surroundings and Figure 2 (b) shows elevation profiles of an intact (NW) and an excavated part of the mound (SW). Table 1 show the average slopes of the mound sides, calculated as the elevation difference between the mound shoulder and the bottom of the respective side (N, E, S, W) divided by the horizontal distance between the shoulder and the foot slope.

Figure 3 show a transect through the mound with the location of the boreholes. It shows that the burial mound is built on top of a natural hill, which makes the mound look much bigger than it is. The natural hill raises about 4 m above the surrounding landscape; it is rather flat topped but slightly undulating. On top of it, a 3-m high mound was constructed. The mound has been reshaped several times by human activities. Excavations and/or plowing close to the hill foot has removed considerable parts of the south and west-facing sides, which results in steep slopes of 44% to the south and 56% to the west (see the difference between the NW and SW profiles in Figure 2(b)). The sides towards the north and the east have both an average slope of 34%. They appear less disturbed than the south and west slope, except for the construction of the church stone wall on the east side. Thus, the north-west side of the mound is the only side with a shape deemed comparable with the original mound. To calculate the volume of the current mound, a surface volume calculation was

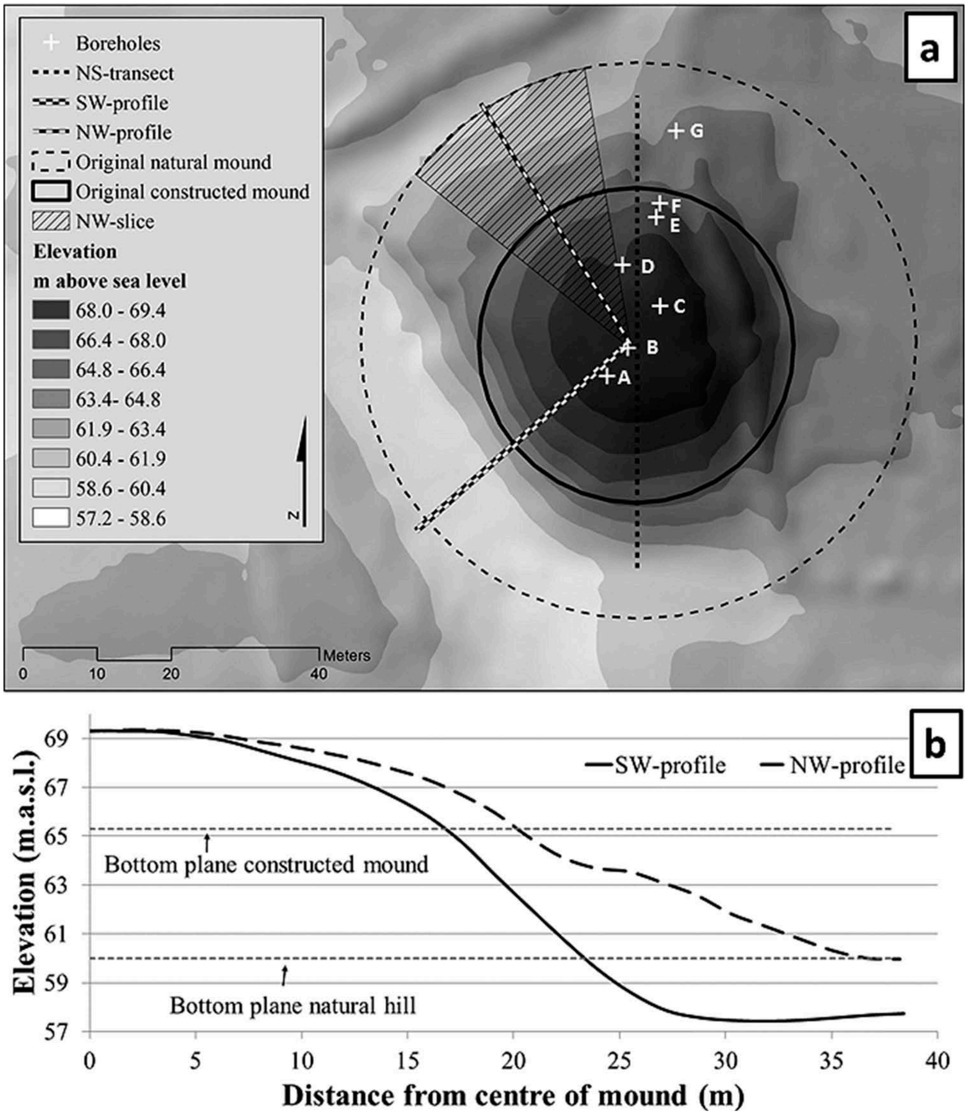

Figure 2. (a) DEM showing the Klangshøj mound and the locations of the borings, transects and profiles; (b) the north-west (intact) and south-west (excavated) profiles with the bottom planes of the natural hill and the constructed mound indicated as short dashed lines.

made in ArcGIS 10.2.2 (ESRI, Redlands, CA, U.S.A.) based on a high resolution LiDAR DEM (160x160-cm raster data, Danmarks Højdemodel, DHM-2007, Styrelsen for Dataforsyning og Effektivisering). To calculate the volume, it is necessary to define a bottom plane, although the mound construction site was not a plane plateau (see old surface in Figure 3). Based on the average (arithmetic) elevation of the old A-horizon below the mound known from the borings, the bottomplane for the constructed mound was set to 65.3 m.a.s.l. This yields an approximate current volume of the constructed mound of 2470 m^3 (Table 1). Assuming that all sides of the original mound had a similar shape as the north-west-facing side (Figure 2(b)), which appears to be the least disturbed part of the mound, a total volume of the original constructed mound would have been 2635 m^3 (Table 1). This suggests that ~165 m^3 (6%) of the original constructed mound was excavated, primarily on the south-west side (see profile in Figure 2(b)). If the same calculation is made for the natural hill underneath the constructed part, assuming this was also shaped like an imperfect truncated cone, the original hill volume is estimated to 14,260 m^3. As the shape of the natural hill underneath the constructed mound was not circular nor particularly flat topped, this is a rather rough estimate. It can be considered a conservative

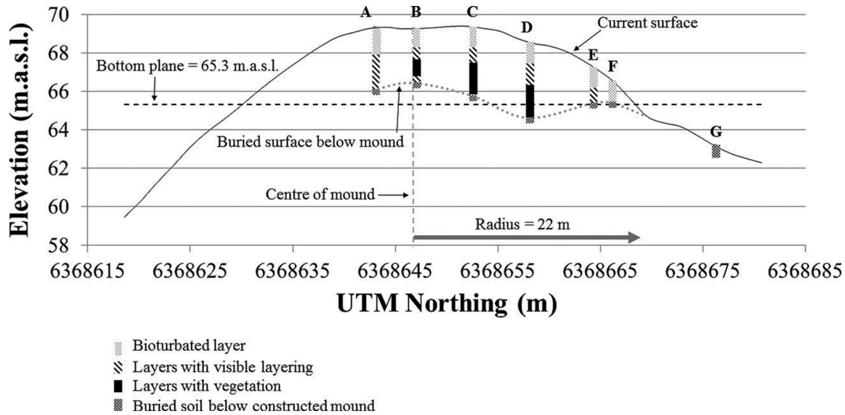

Figure 3. NS-transect with the location of the borings. Note the uneven, buried surface below the mound. The colours of the borings represent the approximate layering as described in the text.

Table 1. Data about the constructed mound and the natural hill underneath. Data about the natural mound are calculated as the difference between the entire mound and constructed mound. The excavated volumes are the difference between the estimated original volumes and the current volumes. Thus, natural erosion/deposition processes are considered negligible.

Side		Average slope[a]
North		34%
East		34%
South		44%
West		56%
Area ratio calculation	**Bottom plane elevation, m.a.s.l.**	**Area, m2 (2D)**
North-west (intact) 'slice' of mound[b]	60.0[c]	439
Entire mound[d]	60.0[c]	4536
Entire mound area:NW-slice area		*10.3*
Current mound volumes	**Bottom plane elevation, m.a.s.l.**	**Volume, m3**
Constructed mound	65.3[e]	2470
Natural hill[f]		11629
Entire hill	60.0	14099
Estimated original mound volumes	**Bottom plane elevation, m.a.s.l.**	**Volume, m3**
Constructed mound[g]	65.3	2635
Natural hill[f]		14260
Entire hill[g]	60.0	16895
Excavated volumes	**Volume, m^3**	**% of original**
Constructed mound	165	6
Natural hill	2631	18

a: (elevation of mound shoulder – elevation of footslope) /horizontal distance from shoulder to footslope
b: calculated with surface volume function in ArcGIS
c: average elevation of the surrounding landscape
d: area = $\pi \times r^2$, r = 38 m (measured in GIS towards NW)
e: position of bottom plane is the average elevation of the buried A-horizon underneath the constructed mound (difference between the borehole surface elevation and surface elevation of buried A-horizon in the boreholes)
f: difference between entire hill and constructed mound
g: [volume of NW-slice] × [Entire mound area:NW-slice area]

volume estimate, as the landscape to the east is higher than 60 m.a.s.l. (see Figure 2(a)), i.e. the original volume was likely bigger than what our truncated cone estimate suggests. Nonetheless, the landscape immediately west of the excavation has an elevation of about 58–60 m, which corresponds relatively well to what was used in the calculation. Therefore, the excavated volume is likely a reasonable estimate, although the volume fraction of the total is less reliable. The calculation suggests that the excavation removed about 2600 m^3 of the natural hill. This likely altered the preservation conditions in the mount as the distance from the surface to the sods with plant remnants became smaller. This caused a degradation of the vegetation remnants and lowered the organic C-contents, as oxygen entered the reduced layers close to the south-west shoulder.

3.2. Interpretation of the bore logs

Table 2 shows the bore logs from the six borings along a south-north tracee crossing the burial mound, Figure 3. All data is assessed in the field based on simple field tests and expert knowledge. A few descriptions have later been modified based on analytical data from the lab. Table 3 shows the pH and the carbon content in the sediments. The soil physical and chemical conditions change along the south-north tracee and hereby the preservation conditions in the mound. In the following, the preservation conditions in the mound are presented and discussed based on the six borings.

Boring A is located towards the south shoulder, i.e. close to the edge of the top plateau towards the south slope that has been steepened by ploughing at the base. The uppermost 130 cm consist of clayey sand with acid pH and 3.5% organic matter. The top 77 cm is classified as the bioturbation zone without sod structure. It is homogeneous and well-drained topsoil material that was moist and greyish brown at the sampling time. In the lower part, faint sod structures were noted and the layer can be considered as a transition horizon towards the more wet layers below, although the layer today must be considered well drained as mottles were not encountered. At

Table 2. Borelogs from the six borings in a south-north transect crossing Klangshøj, Vennebjerg. G is omitted, as it was outside the constructed mound. Texture) The texture is according to the Danish Soil classification system (Breuning-Madsen *et al*. 1992). Moisture) very wet = water logged; wet = wetter than field capacity; moist = field capacity until close to wilting point; dry = water content close to wilting point.

	Depthcm	Texture[a]	Horizon[b]	Layer[c]	Vegetation	Gley	Interpretation[d]	Colour	Moisture
A	0–77	cS	A	HO	0	0	BI	Greyish brown	Moist
	77–130	cS	A	SL	0	0	Sod	Dark greyish brown	Moist to very moist
	130–210	S,cS,C	A	SL/KL	Veg. layer (remnants)	(Gley)	Sod	Dark greyish brown	Very wet to wet
	210–325	S (C)	A/AC	KL/HE	0	0	Sod	Greyish brown	Moist to very moist
	325–357	S	C	HO	0	0	C	Yellowish brown	Moist
B	0–90	cS	A	HO	0	0	BI	Greyish brown	Dry
	90–150	S+cS	A/AC	SL	0	0/Gley	Sod	Greyish brown	Moist with depth very wet
	150–166	cS over C*	A	KL	0	Gley	Sod	Dark grey	Very wet
	166–195	sC+(S)	A	KL	Veg. layer	Anarobe	sod	Dark grey	Wet
	195–219	cS	A	KL	Veg. layer	Anarobe	Sod	Dark grey	Wet
	219–230	S	AC	KL	0	Anarobe	Sod	Dark grey	Very moist
	230–282	cS,sC,C	A	KL	0	Anarobe	Sod	Dark grey	Very moist with depth moist
	282–296	cS	A3C1	HE	0	Gley	A/C	Reddish brown	Moist
	296–305	S	C	HO	0	0	C	Light greyish brown	Moist
C	0–87	S	A	HO	0	0	BI	Greyish brown	Dry
	87–129	S	A	SL	0	0	BI	Greyish brown	Moist
	129–188	cS	A	KL	0	Gley	Sod	Dark grey	Very wet
	188–250	cS+C	A	KL	Veg. layer	Anaerobe	Sod	Dark grey	Very wet
	250–310	S+sC	A	KL	Veg. layer	Anaerobe	Sod	Dark grey	Wet
	310–349	S+cS	A	KL	Veg. layer	Anaerobe	Sod	Dark grey	Moist
	349–366	S	AE	HO	0	0	A	Dark grey	Moist
	366–378	S	E	HO	0	0	C	*Grey*	Moist
D	0–85	S+cS	A	HO	0	0	BI	Greyish brown	Dry
	85–100	S	A/C	HE	0	0	Disturbed sods?	Dark grey	Very moist
	100–134	S+sC	C	KL+SL	0	Anaerobe	Disturbed sods?	Dark grey	Very wet
	134–312	cS+sC+S	A	KL	Veg. layer	Anaerobe	Sod	Dark brownish grey	Very wet with depth wet
	312–381	cS+S	AC	KL	Veg. layer	Anaerobe	Sod	Dark grey	Wet
	381–388	cS	A	KL	0	0	A	Dark grey	Moist
	388–403	S	C	HO	0	0	C	Yellowish brown	Moist
E	0–88	S	A	HO	0	0	BI	Brownish grey	Dry
	88–138	S	A	SL	0	0	BI/Sod?	Greyish brown	Dry
	142–158	S	A	HO	0	Gley	BI/Sod?	Greyish brown	Moist
	171–178	S	C	HO	0	Gley	BI/Sod?	Yellowish brown	Moist
	178–184	S	A1C3	KL	0	Gley	A/C	Yellowish brown	Moist
	184–207	S	C	HO	0	Gley	C	Yellowish brown	Moist
F	0–89	S	A	HO	0	0	BI	Brownish grey	Dry
	89–106	S	AC	SL	0	0	A/C	Brownish grey	Dry
	106–121	S	C	HO	0	0	C	Greyish brown	Dry

a: S = fine sand; cS = clayey fine sand; sC = sandy clay; C = clay
b: A = topsoil material; C = subsoil material
c: HO = homogenic; HE = heterogenic; SL = faint layered; KL = distinct layered
d: BI = bioturbation layer; mound sod; A = (buried) topsoil; C = subsoil

Table 3. Texture (FK), carbon content (%w) and pH ($CaCl_2$) in the bioturbation zone, turfs and the soil below the mound, respectively.

Site	Layer	Depthcm	Carbon %	pH[a] ($CaCl_2$)
A	Bioturbation	20–95	2.0	4.1
A	Sods with vegetation (remnants)	130–210	1.3	4.7
A	C horizon below mound	347–357	0.6	4.1
B	Bioturbation	30–107	1.6	4.1
B	Sods with vegetation	166–219	3.1	4.9
B	Ap/C below mound	282–296	0.8	4.8
C	Bioturbation	18–117	1.5	4.2
C	Sods without vegetation	154–169	0.9	4.6
C	Sods with vegetation	271–310	3.6	4.7
C	A-horizon below mound	349–362	2.7	5.6
C	C-horizon below mound	368–378	0.3	5.5
D	Bioturbation	20–115	1.8	4.1
D	Sods with vegetation	144–262	3.0	4.5
D	Sods with vegetation	262–350	2.6	5.0
D	C-horizon below mound	395–403	0.5	5.9
E	A-horizon	16–142	1.3	4.2
E	C-horizon	171–207	0.5	4.3
F	A-horizon	53–70	1.0	4.5
F	C-horizon	110–121	0.3	4.4

a: Very acid <4.0; acid 4.0–4.9; slightly acid 5.0–5.9; neutral 6.0–7.9

130 to 210-cm depth, a wet to very wet dark greyish brown soil layer with only few mottles had developed. It consists of a mix of faint and distinct sods, of which some had a vegetation layer at various degrees of decomposition. The sod are made op of topsoil material and the texture varies from sand to clay. It is acid and has about 2.2% organic matter, which is low compared with similar layers in the other borings (Table 2). Below the wet soil layer from 210–325 cm the soil material was moist, the vegetation layer on top of the sods were decomposed, part of the soil material did not have sod structure but were heterogenic. Most of the soil material was topsoil (A-material), but a minor part was yellowish subsoil (C-material). The texture varied from sand to clay, it was acid and lower in organic matter than the layer above. Below 325 cm, it was exclusively yellowish brown subsoil showing the thickness of the mound material was 325 cm at this site. The buried C-horizon was acid with about 1% organic matter.

Boring B is located close to the middle of the small plateau on top of the mound. In order to avoid the disturbed soil around the flagpole in the mound centre, the boring was made ~1.5 m away from it. The top 90 cm is classified as the bioturbation zone without any sod structures. It consists of homogeneous greyish brown, well-drained clayey sandy soil material (A) that was dry at the sampling time. It was acid and contained about 2.8% organic matter. From 90–150 cm, faint sod structures are dominating, the top part is well-drained fine sand or clayey sand, but with depth, the abundance of redoximorphic mottles increased, which indicate periodical waterlogging of the sediments. This is also evident from in the moisture content increasing from moist to very wet with depth. Underneath, a thin 16-cm transitions zone is found between the relatively well-drained top part and a very wet layer below. It consists of clayey sand over clay. It has pronounced gley features and distinct sod structures, but no plant remnants are observed on the sod surfaces. From 166 cm and half a metre below, undecomposed plant remnants are observed on the sod surfaces. The layer is dark grey without mottles (anaerobic) and built of topsoil material. The sediments had a texture of mainly sandy clay or clayey sand, acid pH and contained about 5.3% organic matter. A sandy sod layer made of topsoil and subsoil material was observed underneath (219–230 cm). This layer is dark grey and anaerobic but without vegetation layers, indicating periodically aerobic conditions, and it is also relatively dry compared to the layers above and below. From 230 cm depth to the base of the mound at 282 cm, the mound material consists of anaerobic distinct sods made up of dark grey sandy to clayey topsoil material. There were no remnants of the original vegetation on the sod surfaces and it became drier with depth (from very moist to moist). The soil below the mound is a heterogenic mix of topsoil and subsoil with gley features. It consists of reddish brown clayey sand, is acid and contains about 1.4% organic matter. The gley can be seen as the transition from the anaerobic mound material to the well-drained subsoil below that consists of homogeneous light greyish brown sand.

Boring C is located at the top plateau on the north shoulder. The top 87 cm is bioturbated without sod structures. It is homogeneous sandy topsoil material, greyish brown when dry; it is acid and contains about 2.6% organic matter. Below this layer, a transition zone towards the distinct sod-layer is found (87–129 cm). It consists of moist, homogeneous, greyish brown sand that showed increasing tendency to faint sod structures with depth. The uppermost layer with distinct sods consists of gleyey (mottles), clayey sand without

Figure 4. Picture of greenish plant remnants on top of a sod used for building the mound.

vegetation layers on top of the sods, indicating periods with aerobic conditions where decay of the plant remnants has taken place. This is also reflected in the low organic matter content of 1.5%. The layers from 188 cm to the bottom of the burial mound (349 cm below the surface) showed distinct sods with vegetation layers, some of which were greenish in colour (Figure 4). They are all dark grey topsoil material with persistent anaerobic conditions in the top of the layer. The layer becomes dryer with depth, with moisture conditions changing from very wet in the top part to moist at the bottom of the constructed mound. This coincides with changes in texture from clay at the top to sand at the bottom. The layer is acid with 6% organic matter, which is the highest content found in the mound. The soil below the mound comprises a dark grey A-horizon above a grey subsoil. They are only slightly acid with an organic matter content of 4.6% in the A-horizon and 0.5% in the subsoil below (C-horizon).

Boring D is located at the top part of the north slope with a gradient of approximately 10°. This location is where a former well should have existed, according to the local community custom. The bioturbation zone is 85-cm thick greyish brown topsoil, the pH is acid and the organic matter content is about 3.1%. The texture is homogeneous sand or clayey sand. Below, a 15-cm thick heterogeneous, dark grey layer is found, which is a mix of A and C material. The sand in this layer is very moist and might be disturbed sods from a previous excavation, which is also thought to be the case for the layer below. This layer consists of very wet, anaerobic C-material that is a mixture of sand and clay and faint and distinct sods without vegetation layers. From 143 cm to the bottom of the mound at the depth of 381 cm, the mound consists of distinct sods with well-preserved vegetation layers, clearly indicating anaerobic conditions. It comprises a mixture of textures from sandy clay to pure sand; it is mainly topsoil material mixed with some subsoil material in the lower part of the mound that is less wet compared to the top part. The colour is primarily dark grey, although the upper part in some places is brownish grey. The top layer is acid with 5.2% organic matter but with depth it turns into being slightly acid and show a decrease in organic matter content to about 4.5%. Below the mound, a 7-cm thick clayey sandy A-horizon is overlying yellowish brown, sandy subsoil. They are slightly acid, and the subsoil contains 0.9% organic matter.

Boring E is located on the middle part of the north-facing slope with a gradient of approximately 15°. The uppermost 138 cm is brownish grey to greyish brown well-drained sand, with acid pH and 2.2% organic matter. It consists of a homogeneous bioturbation zone upon a similar horizon with faint layering. These may be sod remnants indicating that the layer might be a part of the mound. From 142 cm to the depth of the boring (207 cm below the surface) the soil layers are gleyey, indicating increased wetness and reducing conditions in parts of the year, probably during winter when the precipitation surplus is largest. The layering shifts between greyish brown A and yellowish brown C material, which might represent slope processes where precipitations surplus has washed down upslope soil material, before the mound was constructed. The layers are acid with an organic matter content of 0.9%.

Boring F is located close to the base of the mound and has sandy texture. It has a 100-cm thick brownish grey A-horizon above a greyish brown subsoil. The A horizon consists of mull and there are no signs of sods. Nonetheless, it might be a part of the constructed mound where the sods have been bioturbated. The soil is well drained as there are no gley features, which is typical for a soil with this texture. The layers are acid and the A-horizon contains

Table 4. The results from the archaeobotanical analyses of samples from Klangshøj. The figures are number of observations. Bold numbers marked with an asterisk represents the number of charred plant remains. 100 cm^3 soil samples were analysed.

Species	Popular name (fossil type)	Boring D Depth (cm)370–381	Boring D Depth (cm)180–190	Boring B Depth (cm)170–181
Calluna vulgaris	Heather (twig-fragments)	≈600	≈800, **10***	≈500, **5***
Calluna vulgaris	Heather (flowers)	≈200	≈100, **10***	12, **6***
Calluna vulgaris	Heather (seeds)	≈100	≈200, **5***	9
Dianthus deltoides	Maiden pink (seeds)	1		
Carex pilulifera	Pill sedge (seeds)		2	3
Carex sp.	Sedges (seeds)	6	2	
Cerastium fontanum	Common mouse-ear (seeds)	3		
Epilobium sp.	Willowherb (seeds)		**1***	
Plantago lanceolata	Ribwort Plantain (seeds)			**1***
Poaceae	Grass family (seeds)			1
Potentilla erecta	Tormentil (seeds)	1	7	26
Viola canina	Heath Dog-violet (seeds)		1	8
Viola canina	Heath Dog-violet (capsules)			2
Bryophyta	Mosses (stems and leaves)	≈1000	≈1000	4

about 1.7% organic matter while the subsoil contains about 0.5%.

3.3. Preservation conditions in the mound

Comparing the preservation conditions in the six borings it can be concluded that very good conservation conditions have persisted in the deeper part of the mound on the northern shoulder. Generally, a bioturbation layer slightly less than 1-m deep is underlain by a transition zone towards wet layers with continuously anaerobic conditions. In this transition zone gley (mottles) is abundant, indicating seasonal wetting/drying cycles leading to alternating anaerobic and aerobic conditions. During winter time with precipitation surplus, a perched groundwater table in these layers must be expected, while they will be dry or moist during summer time. Underneath, layers saturated by water throughout most of the year are found. These are greyish or blueish in colour without reddish brown iron-oxide nodules and mottles. The moisture level gradually decreases from *very wet* at the top to *wet* at the bottom. The same pattern was observed in the Jelling mounds (Breuning-Madsen *et al.* 2013), and it can be explained by relatively rapid drainage through the bioturbation layer, and to some degree through the transition layer below. Roots, worms and soil structuring forms vertical macropore systems bypassing the normal percolation through the soil matrix. In the anaerobic layer below, such pores have not developed, i.e. the permeability is low enough to periodically sustain a perched water table. This creates anoxic conditions, allowing the sods to be preserved with undecomposed vegetation layers on some of the surfaces. Hence, brownish and occasionally greenish remnants of mainly heather and mosses are found in these layers (Table 4).

Human activities have altered the preservation conditions in Klangshøj, which is reflected in the very thin anaerobic layers of boring A and B (80 cm and 53 cm, respectively). In boring A, this is primarily due to the steepening of the south slope due to plowing, which leads to a lower permanent groundwater table in the southern part of the mound. The result is that the vegetation on the sod is oxidized and decomposed. The excavation along the west side of the mound might have lead to oxygen penetration even into the central part of the mound. This is the likely explanation why boring B only contained about half a metre of sods with vegetation remnants, although it is close to the centre of the mound. Boring C is the less disturbed boring. Here, we find about 1.6 m of anaerobic sods with well-preserved and occasionally greenish vegetation covers. Even during the sampling in August (absolute minimum groundwater level) the soil was very wet, although no perched groundwater was detected after 3 days. Within 24 h in November, however, enough water had gathered in the borehole to form a perched groundwater. The thickest anaerobic soil layer with plant remnants was found in boring D on the top part of the north slope (~2.5 m). The profile appears disturbed, probably by human activity. For example, below the bioturbation layer a heterogeneous mixture of top and subsoil materials are found. The preservation conditions in boring E and F are poor, as they are mainly aerobic, although gley is common in the deeper layers of boring E (see further discussion about hydrology in section 3.5).

3.4. Archaeobotanical analyses

Due to the very good preservation conditions in parts of the mound, it is possible to determine the flora in the vicinity of the mound at the time of construction. Two archaeobotanical analyses were made on well-preserved samples from boring D and one on a sample from boring B. The results from the analyses are seen in Table 4. The macrofossil analysis shows that the sods were cut in areas where the vegetation was dominated by heather and mosses and other plants typically growing in heathlands. As the sampling was done with an auger with a diameter of 7 cm, each sample only represented a turf surface of *c.* 38 cm^2. An individual sample can therefore be dominated by a single plant which by chance happened to be in this particular surface area. Therefore, the large variation between the samples is expected. The results of the macrofossil analyses is very similar to the results from the analyses of samples from the Jelling mounds (Henriksen *et al.* in press), except the lower number of represented plant species. This is probably due to the drier, sandy soils at Vennebjerg. Also similar to the findings from Jelling, there were charred plant remains in the samples from Klangshøj, shoving that the heathland had been managed by occasional burning of the heather.

The extraordinary preservation conditions in the borings on the top plateau made it possible to collect a vegetation sample for ^{14}C age determination. A heather twig collected from boring C (370–381 cm) was dated to 1060 ± 30 BP (uncal) (Cal CE 897–925 and 943–1024). The calibrated dating is also shown in Figure 5. Thus, Klangshøj at Vennebjerg was constructed in the Viking Age, most probable slightly later than the two Royal Viking mounds at Jelling, although there is a little probability that it is temporary with these.

Although Klangshøj is much smaller (less than half the height and diameter) and is sandier than the Jelling mounds, there are similarities between the two monuments. The mounds have the same shape with a plateau at the top decreasing the possibility for rapid run-off, and they are built using sods probably collected from agricultural set-aside covered by heather vegetation. Furthermore, it seems like Klangshøj is constructed so the clayey sods act like impermeable layers forming the wet layer below the bioturbation zone, as was also the case in the Jelling mounds. The anaerobic conditions in the mound make it possible to estimate the carbon content in the Viking Age soils around Klangshøj and to compare it to similar studies in Denmark (Breuning-Madsen *et al.* 2013). Table 5 shows that the carbon concentration is highest in the well-preserved sods from the Jelling mounds built of loamy material, while the sandy mounds from the Bronze Age showed the lowest carbon concentration. Klangshøj has an intermediate value, which corresponds to the varying textures of the sods ranging from sand to clay. Breuning-Madsen *et al.* (2013) explained the difference in carbon concentration between the Jelling Mounds and the sandy Bronze Age mound to the difference in drainage conditions of the parent material. The loamy soils at Jelling led to imperfect drainage of the soils in the vicinity of the

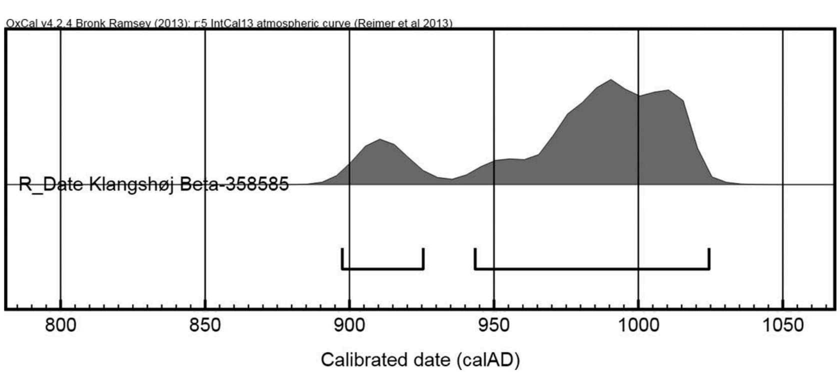

Figure 5. AMS radiocarbon date of plant remnants from Klangshøj calibrated with OxCal v4.2.3 (Bronk Ramsey 2013) and IntCal13 (Reimer *et al.* 2013).

Table 5. The carbon concentration in sandy and loamy burial mounds with anaerobic cores.

Type of mound	Texture[a]	Time	Carbon %
Skelhøj, Lejrskov, Hüsby	S	Bronze Age	1.57 (3)
Klangshøj	S,cS,sC,C	Viking Age	3.05 (8)
Jelling	C	Viking Age	3.74 (29)

a: see Table 2 for abbrivations.

construction site, which inhibit the decomposition of the organic matter, at least during parts of the year. On the contrary, the soils at the Bronze Age construction sites were excessively drained due to the coarse parent material. Following this logic, the intermediate texture of the soils at Vennebjerg would lead to intermediate drainage conditions, which should be reflected in an organic matter content of the sods in Klangshøj in between the sods from the loamy and the sandy mounds. As shown in Table 5, this is the case, i.e. the present study leans support to the hypothesis that the organic matter content of prehistoric soils was primarily determined by the texture of the parent material.

3.5. The hydrology in Klangshøj

The investigation of the presence of a standing groundwater at location C showed that a shallow groundwater was formed after 3 days in August and after 1 day in November. The presence of a perched water table is also demonstrated in Table 2 where some of the soil layers were very wet in August. Thus, it is clearly demonstrated that a perched groundwater has developed below the plateau on the top of Klangshøj. It has no direct connection to the topographic groundwater, which is located several metres below the mound. Although the perched water table might not be permanent, the soils in parts of the mound will still be very wet and anaerobic, for the 1000-year old vegetation to remain greenish and undecomposed. Even a short aerobic period would have resulted in degradation of the chlorophyll in the heather leaves, which would have caused the plant remains turn brown. In periods with precipitation surplus, the water will feed the perched water table that will raise and create a run-off as shown in Figure 6. The vast majority of the runoff will be internal, which creates the gleyey soil layers just above the sod layers with undecomposed vegetation or in the top of the latter. Surface run-off will only happen on the slopes. The percolating water on the plateau will run in all direction following the contour of the layer with vegetation covered sods. When the sod layer disappears, as seen at the outskirts of the mound along the north slope (boring E), the water percolates vertically downwards due to gravity until it meets the primary groundwater. The extensive gley features in the subsoil of boring E is thought to be a consequence of substantial amounts of percolating water running off the edge of the well-preserved sod layer. That internal drainage dominates is further supported by boring F that is well drained without any gley features. Thus, according to the observations in the current study, it seems highly unlikely that water has ever been running out of the mound forming a spring, as the local legend suggests. Neither an inspection at the foot of the mound (boring G) showed signs of wetness or water running out of the mound. In that respect, the hydrology in Klangshøj is the same as found in

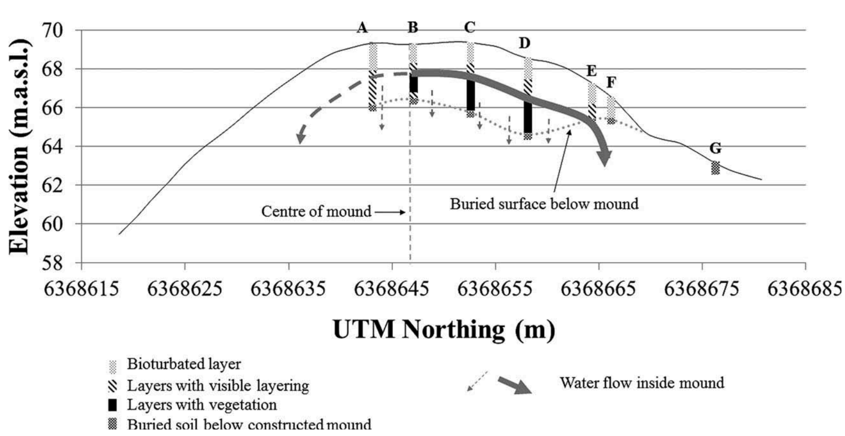

Figure 6. The perched groundwater flow in Klangshøj. The thickness and structure of the arrows indicate the relative magnitudes of the flow.

the two Jelling mounds where all the percolating water is drained internally. The cuts into the mound on the south and west slopes of Klangshøj have changed the hydrology around boring A and maybe also boring B, lowering the perched groundwater table. As mentioned previously, this is reflected in the partly decomposed or missing vegetation on sod surfaces, and the significantly lower carbon content compared to well-preserved sods in other borings (e.g. boring C and D).

The legend about the well that previously existed on Klangshøj is similar to the one on the North Mound in Jelling. The latter existed for centuries, and gave high-quality drinking water to the locals. Calculations have estimated that the well could provide about 50–100 m^3 water from the perched water table, which was only fed by precipitation. As the genesis of this well has been investigated thoroughly (Breuning-Madsen *et al.* 2012), it serves as a good basis for the assessment of whether Klangshøj was ever able to sustain a well. The well on the Jelling mound can be explained by a combination of an intrusion into the mound from the top and the existence of a waterlogged soil horizon at shallow depth. As indicated earlier, Klangshøj fulfils the latter preconditions, as the transition layer between the layers with well-preserved sods the layers above is very wet and semi-viscous (muddy). However, if a well was to be created, a deep intrusion into the centre top-plateau would have to be made to allow water and mud from the water-saturated layer to flow into the intrusion. The mud would settle at the bottom of the intrusion leaving a water phase at the top. The mud should be removed from time to time and a depression will develop around the intrusion as the result of cavitation due to the gradual outflow of material from the waterlogged muddy horizon into the intrusion. Considering the diameter of the plateau is about 12 m, the water inflow will come from the about the 3-m radius around the intrusion, the rest will drain internally towards to edges of the mound, as described above. The 3-m radius gives about 30 m^2 from where the precipitation surplus will run into the well. Anticipate a precipitation surplus of 400 mm per year which is representative for the study area today, the amount of water flowing into the well would be about 12 m^3, which is an amount of little practical significance. According to the legend, however, the well was not located in the middle of the top-plateau but on the north slope close to boring D. As the internal run-off of the precipitation surplus would be almost evenly distributed in all directions, only a very little amount of water will feed a well placed on the slope, i.e. far less than 12 m^3. Furthermore, considering the gradient at the suggested well site a substantial downslope outflow of water would be expected, making the extractable amount even smaller. Thus, the amount of water that could have been collected from the well at the site suggested by the legend would have been negligible and of no practical use. Despite the indication of an intrusion in boring D to a minimum depth of about 135 cm, there is no evidence to suggest the presence of a permanent well on Klangshøj.

4. Conclusion

Klangshøj on Vennebjerg is a flat-topped burial mound similar to the Royal Jelling mounds, although significantly smaller. It is built of sods mainly harvested from heathland, probably located in the vicinity of the mound. The sods are of different grain sizes, mainly fine sand or loamy sand but layers of sandy clay and clay were present in all borings at the top plateau. The preservation conditions were excellent in three of the six borings, and undecomposed plant remnants, occasionally greenish, were observed in three of the borings. A ^{14}C-dating showed that the mound was built in the Viking Age. The hydrology in Klangshøj is the same as in the Jelling mounds, with a permeable bioturbation zone covering almost impermeable, distinct sod layers. This form a perched groundwater table in the transition zone, which keeps the distinct sod layer below anaerobic, i.e. the preservation conditions extremely favourable. The perched water table drains internally as in the Jelling mounds, and there are no current nor fossil (e.g. gley) evidence to suggest a spring was ever present at the foot slope, as the local legend suggests. Moreover, it seems very unlikely that a well, similar to the one on the Jelling mound, has existed on the top of the north-facing slope, as another legend tells. The intrusion (boring D) is rather shallow only to a depth of about 135 cm and the amount of water the well would have been able to collect is negligible, even if it would have been created in the centre of the top-plateau.

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References

Breuning-Madsen, H. and Holst, M.K., 1998. Recent studies on the formation of iron pans around the Oaken log coffins of the bronze age burial mounds of Denmark. *Journal of Archaeological Science*, 25, 1103–1110. doi:10.1006/jasc.1998.0288

Breuning-Madsen, H. and Holst, M.K., 2003. A soil description system for burial mounds - development and application. *Danish Journal of Geography*, 103 (2), 35–45.

Breuning-Madsen, H., Holst, M.K., and Henriksen, P.S., 2012, The hydrology in huge burial mounds built of loamy tills - A case study on the genesis of perched water tables and a well in a Viking Age burial mound in Jelling, Denmark. *Danish Journal of Geography*, 112 (1), 40–51. doi:10.1080/00167223.2012.707797

Breuning-Madsen, H., Holst, M.K., and Rasmussen, M., 2001. The chemical environment in a burial mound shortly after construction - an archaeological experiment. *Journal of Archaeological Science*, 28, 691–697. doi:10.1006/jasc.1999.0570

Breuning-Madsen, H., Nørr, A.H., and Holst, K.A., 1992. *Atlas of Denmark*. Series I, Vol. 3. The Danish Soil Classification. Copenhagen: The Royal Danish Geografical Society, C.A. Reitzel.

Breuning-Madsen, H., Rønsbo, J., and Holst, M.K., 2000. Comparison of the composition of iron pans in Danish burial mounds with bog iron and spodic material. *Catena*, 39, 1–9. doi:10.1016/S0341-8162(99)00083-1

Breuning-Madsen, H., *et al.*, 2013. A comparison of soil organic carbon stocks in Viking Age and modern land use systems in Denmark. *Agriculture, Ecosystems & Environment*, 174, 49–56. doi:10.1016/j.agee.2013.05.004

Bronk Ramsey, C., 2013. OxCal 4.2. Available from: http://c14. arch.ox.ac.uk/oxcal [Accessed 18. March 2016].

Day, P.R., 1965. Particle fractionation and particle-size analysis. In: C.A. Black, *et al.*, eds. *Methods of Soil Analysis*. Agronomy No 9. Madison, Wisconsin: American Society of Agronomy, 545–567.

ELTRA, 1995. *CS500 simultaneous carbon/sulphur determinator*. Neuss, Germany: ELTRA GmbH.

Henriksen, P.S., 2005. *Makrofossilanalyser af bygningstørv fra Skelhøj, en bronzealderhøj ved Kongeåen*. København: Nationalmuseet, NNU Rapport nr. 20, 2005, 1–6.

Henriksen, P.S., Jessen, C., and Christensen, C., in press. Landscape and vegetation: pollen and macro fossil analysis of the vegetation in the North and South Mounds. *In*: A. Pedersen and M.K. Holst, eds. *The Jelling Monuments and their Local Setting. PNM*. Vol. 20. The National Museum of Denmark, Copenhagen.

Holst, M.K., Breuning-Madsen, H., and Olsson, M., 1998. Soil forming processes in and below a Bronze age burial mound at Lejrskov, Southern Jutland. *Danish Journal of Geography*, 98, 46–55. doi:10.1080/00167223.1998.10649410

Krogh, K.J., 1993. *Gåden om kong Gorms grav*. Herning: Poul Kristensens Forlag.

Lindeberg, P., 1591. *Hypotyposis arcium, palatiorum et monumentorum, ab Henr. Ranzovio, pro rege Holsato, conditorum*. Typis Jacobi Wolfij, Hamburg. http://www.europeana.eu/portal/record/03486/A16C0B1E85620B950BB95437A8849C3CFC02AF5C.html

Randsborg, K., 1996, The Nordic Bronze Age: chronological dimensions. *Acta Archaeologica*, 67, 61–72.

Reimer, P.J., *et al.*, 2013. IntCal13 and marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon*, 55, 1869–1887. doi:10.2458/azu_js_rc.55.16947