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Genesis of Iron Pans in Bronze Age Mounds in Denmark

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INTRODUCTION

The history of research in the Early Bronze Age in Denmark has to a considerable degree been connected with the burial mounds; one of the reasons being that a number of these mounds have offered unique conditions of preservation. The descriptions of well-preserved oaken log coffins by Boye (1896), Thomsen (1929) and Broholm & Hald (1939) reveal a common feature by these finds; the grave bed is situated in a mound core of very wet or waterlogged soil. The core is often separated from the mantel of more dry material by an iron pan, which is also found below the mound, and in this way the iron pan effectively seals the wet core. It has often been suggested that it is the wet anaerobic conditions of the core which has hindered the decay of the oaken log coffins and bodies, but even though the connection between the iron pan and the remarkable conditions of preservation has been known for long, only few investigations of the genesis of the iron pan have been carried out.

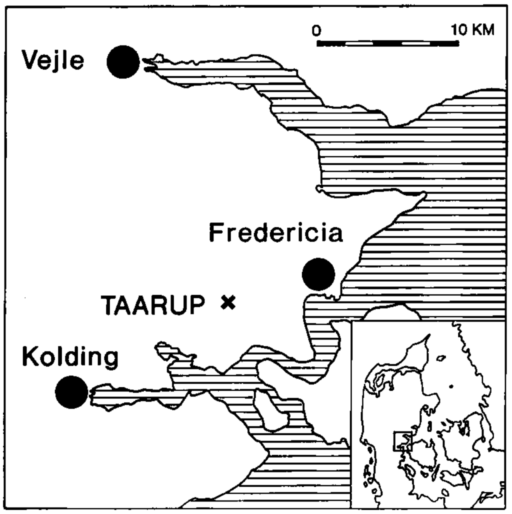
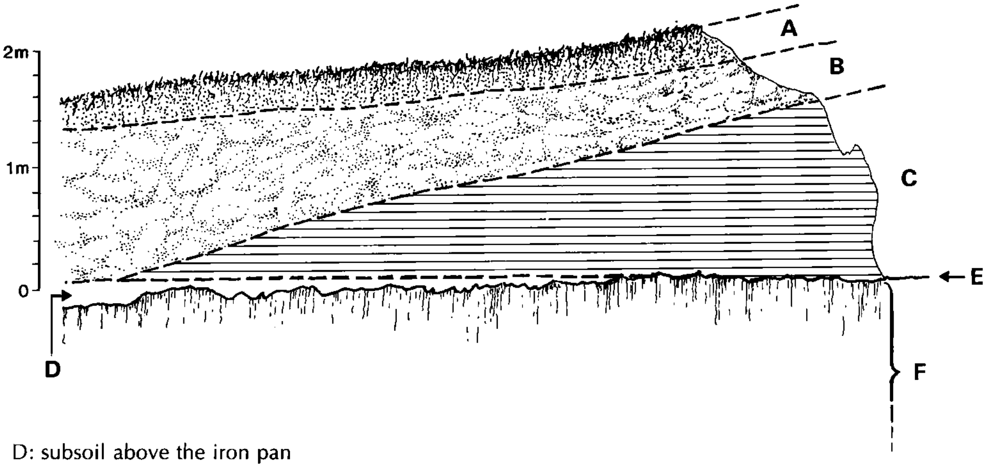


Fig. 1. The location of the Bronze Age mound at Tårup in East Jutland.

In 1992 one of the largest Bronze Age burial mounds in Denmark was partly destroyed during a highway construction at Tårup between Kolding and Fredericia in eastern Jutland (Fig. 1). The mound was nearly circular with a diameter of approximately 60 metres and an estimated height of at least 4 metres. The central part of the mound was totally destroyed, and only the marginal parts were intact when the archaeological investigations were carried out. These were conducted by Vejle Museum.

The investigations revealed that the mound had been erected in several stages, of which the last one could be dated to the Early Bronze Age – probably period II. The oldest part was a dolmen from the Early Middle Neolithic, which in period I or II of the Early Bronze Age had been covered by a turf mound having a diameter of 15 metres. The construction of the large mound began with the erection of a circular mound with an estimated diameter of 20 metres in close proximity to the older mound covering the dolmen. This new mound also consisted of turfs, the outlines of which, however, were difficult to recognize during excavation. In section the mound appeared dark blueish grey with many rusty mottles, mainly surrounding the coarse pore system. Superimposing this, a mantel of more brownish soil was found with much more distinct turf structures. These belonged to the final stages of the monument, in which the blueish mound and the mound covering the dolmen were built together and greatly extended. Finally the large mound was surrounded by a 1.5 metre deep ditch. Except for the unique size, the construction of the Tårup monument is rather typical for the Bronze Age with several building phases and the turfs placed upside down. The small dark coloured Bronze Age mound only seems to have been freestanding for a short period of time, and in the following description this phase will be referred to as the mound core, whereas the later stages of extension are called the mantel.



A: ploughlayer
B: mantel
C: core

D: subsoil above the iron pan
E: iron pan
F: subsoil below the iron pan

Fig. 2. A schematic drawing of the investigated profile wall.

Fig. 2 shows a schematic drawing of the section used for detailed examination of the genesis of the iron pan. A greyish brown plough layer of sandy loam is superimposing the mantel of similar texture class. It is yellowish brown with part of more greyish brown colours. Distinct turf structures are present consisting of greyish brown topsoil and more yellowish brown subsoil. Few rusty mottles are present in the right part of the mantel; in the left part rusty mottles are more common. Below the mantel the central core is found. It is a dark blueish grey sandy loam with many rusty mottles. In the left side of the profile wall the core is missing and the mantel is resting directly on the sub-soil.

The substratum, on which the mound was build, is a yellowish brown loam. In shallow depth meltwater deposits of medium sand are found securing a good drainage of the superimposing more clayey deposits. Thus, no mottlings were observed in the substratum. On the border between the central core and the original subsoil a continuous thin reddish brown cemented iron pan was observed. It was approximately 1 cm thick and so strongly cemented that hammering was necessary for crushing the sample. To the right on the section it was located exactly on the border between the two layers, while in the remaining part it was situated up to five centimetres down into the original subsoil, but no more. The continuous iron pan was only found below the core. In the part where the mantel is resting directly on the substratum the iron pan is weak and discontinuous if present.

Mounds with iron pans have been registered mainly in Jutland, on both clayey and sandy soils, and in the majority of these finds the situation is identical to the situation in Tårup, with only a well-developed iron pan on the bottom of the mound between the subsoil and the turfs. The burial mounds in which there has also been developed an upper layer sealing the core make out a minority (Aner & Kersten 1973ff).

Already Boye (1896) offered the iron pans some attention, but did neither discuss its genesis nor its influence on preservation. Already in 1898, however, Sarauw argued on the basis of a theory developed by Emeis in 1875 that the iron pans beneath burial mounds as well as those in the top of the mounds were a result of podzolization (in Danish: *al-dannelse*). Therefore he saw the phenomenon as an indication of heath vegetation at the time of construction of the burial mound.

In 1921 the discussion of the iron pans was renewed with the excavation of the famous Egtved log coffin. Here the wet core of the mound was completely surrounded by a thin, strongly cemented iron pan, which had been penetrated by later digging into the inironed central core. Afterwards the hole was refilled, and a new iron pan around the intrusion was formed showing the process of creating iron pans was still potentially active many years after the funeral. Based on results from soil samples from the mound, the geologist A. Jessen concluded: The mound core consisted of soil material from a wetland while the mantel was constructed of dry farmland soil. The iron pans were still considered to be formed by podzolization, but now the genesis was seen as a result of the use of wet soils in the mound core

(Thomsen 1929).

This theory was questioned somewhat when a new well-preserved log coffin was discovered at Jels in 1935 (Broholm 1938) and another one later in the same year at Skrydstrup (Broholm & Hald 1939). Even though the iron pans, which also here surrounded the core, were interpreted as a podzolization product, the geologist W. Christensen returned to the view that the lower pan predated the mound (Broholm & Hald 1939), and in Jels, J. Iversen concluded that even though the core of the mound appeared very different from the mantel, they actually consisted of the same soil material (Broholm 1938).

During the excavation of another Bronze Age burial mound near Skrydstrup, Becker (1946) also found that the soil material of the core and mantel had originally been identical. Furthermore, Becker explained the genesis of thin iron pans according to the theory of K. Gripp (Gripp 1942). According to this theory podzolization played an important role. The upper iron pan was unstable, and through a continuous process of precipitation by influence of oxygen and disintegration, the pan will slowly move downwards and in the end reach the lower iron pan with fatal consequences for the conditions of preservation in the mound. This explanation was generally accepted, and today the iron pans are described in Danish archaeological literature as "al-kapper" (e.g. Jensen 1988) which in soil science means a horizon enriched by iron, aluminium and organic matter due to podzolization.

GENESIS OF THIN IRON PANS

The development of thin iron pans follows one of the two main processes in the soil: podzolization or reduction/oxidation (gley formation).

The podzolization process, which leads to the formation of a spodic horizon (in Danish "al"), is typical for well-drained sandy soils in Denmark under coniferous or heather vegetation (Petersen 1976). Although the podzolization process is not fully understood in detail, the process is in broad terms as follows: The soil is leached due to excess of rain and pH drops to about 4. Worms and other soil mixing animals disappear and a mor layer of more or less decomposed litter, branches etc. is developed upon the mineral soil. Organic acids from the mor layer make complexes with the immobile iron- and aluminium (hydr)oxides in the top soil. These complexes are mobile and they will be translocated by the infiltration water to a certain depth where the iron- and aluminium (hydr)oxides will be precipitated together with organic matter. This might be due to increasing pH, changes in biology or due to an oversaturation of the iron-aluminium-humus-complexes. Normally the precipitation of iron and aluminium will not take place in a narrow part of the soil but cover a depth of half a metre or more. The organic matter content is mainly precipitated in the uppermost part of the spodic horizon making it black, while the maximum value of iron and aluminium (hydr)oxides is found somewhat further down in the spodic horizon, where reddish brown colours dominate due to the ferri iron. Only in well-sorted sand deposits such as dune sands and fluvial sands, some part of spodic horizon might be deposited as narrow bands between the different sand beds. In the eluvial topsoil, where the leaching of iron and aluminium has taken place, the soil particles lose their brownish colours and turn into greyish or white colours.

Thus, the typical podzol will have the following horizon sequence: The uppermost part of the mineral soil is the greyish eluvial horizon due to a lack of brownish iron(hydr)oxides. Below the eluvial horizon, which normally has a thickness of about 30 cm, the black humus-spodic horizon occurs superimposing the reddish-brown iron-spodic horizon. Below the spodic horizons, the yellowish brown parent material is found.

In wet soils reduction/oxidations processes dominate. Due to the high water content in these soils, the diffusion of oxygene and carbondioxides is restricted and the biological activity (metabolism) gives rise to oxygene depletion in the root zone. Under such conditions several elements in the soil are reduced, e.g. sulphates to sulphides, nitrate to nitrogen (gas) and ferri iron (Fe^{3+}) to ferro iron (Fe^{2+}). While ferri iron is almost immobile in the soil, ferro iron is mobile and it will follow the water movements, or by diffusion move towards a more oxidized part of the soil and there precipitates as ferri iron. Hereby the more reduced parts of the soil will be blueish or greyish (ferro iron or a complete lack of iron), while the more oxidized part will be rusty or reddish brown (ferri iron). In some cases the ferro iron will be oxidized and precipitated as ferri iron in thin pans if a sudden change in redox conditions occurs over some lateral distance. Such strongly cemented iron pans are called placic horizons. Contrary to e.g. iron and manganese, aluminium does not change valence due to oxidation/reduction conditions and it will remain in an immobile form. Therefore, the gley processes will not lead to a rearrangement of the aluminium content in the soil, which happens by the podzolation process.

It is possible analytically to separate the two processes and show which of these have been the dominating soil forming process. If podzolization has taken place, the precipitation of organic matter, iron oxides and aluminium oxides in a thin spodic horizon gives rise to at least a local maximum of all three elements in these horizons. Furthermore, most of the iron and aluminium are precipitated linked to organic matter so the major part of the non-silicate iron and aluminium must be in organic form. Contrary, the gley process only involve iron and this on an inorganic form. This leads to a movement and precipitation of iron exclusively and there is no distinct maximum of organic matter and aluminium connected to the iron pan.

SOIL SAMPLING AND ANALYSIS

Soil samples have been taken at different depths from two sites on the exposed section, Fig. 2. One sample was collected from the ploughlayer, 3 samples have been taken from the mantel: one from the upper part, one from the vegetation layer of one of the turfs in the lower mantel and one from the subsoil of the turf also in the lower mantel. Two samples have been taken from the core and three samples have been taken below the core in the subsoil, one above the iron pan, one of the iron pan and one immediately below.

In the soil laboratory texture analyses were carried out using sieving for determining the sand fractions and the Andreasen-pipette method for determining the silt and clay fraction. The content of organic matter was determined by using an IR-Leco apparatus where the carbon content of the soil is determined based on the amount of carbondioxide ignite from the sample after heating to 1600°C. The organic matter content is then calculated based on the assumption that 58% of the organic matter is carbon. On samples suspended in water and 0.01 M calcium cloride, pH was measured potentiometrically. For both liquids a soil-liquid ratio of 1:2.5 was used. Dithionite-citrate and pyrophosphate soluble iron and aluminium were determined as described in Soil Conservation Service (1972). It is a general assumption that the extraction of iron and aluminium with dithionite-citrate (Fe_d and Al_d) gives the total amount of non-silicate iron and aluminium in the soil, while the extraction with pyrophosphate (Fe_p and Al_p) only gives the organic-bound iron and aluminium. This is surely true for iron where dithionite reduces the iron, and citrate makes complexes with the ferro iron. This makes a very effective extraction of the non-silicate-bound iron. This is not the case for aluminium, however, which is not reduced by dithionite. Therefore in some cases the pyrophosphate-soluble aluminium might be higher than the dithionite-soluble.

RESULTS AND DISCUSSION

Table 1 shows the soil texture and organic matter content in different layers. The mound is made of a poorly sorted sediment with a clay content between 10-15%. Geologically it is a sandy loamy till. The undisturbed subsoil below the mound has about 20% of clay – the low clay content and high content of gravel and coarse sand in the iron pan are due to a strong cementation of clay-particles so it was impossible to disperse them totally. The subsoil is poorly sorted too and it is geologically a loamy till. The texture analyses show that the mound is made of nearly the same material as the subsoil, which means that the constructors have used the soil just

	>2000	500-2000	200-500	125-200	63-125	20-63	2-20	<2	OM
ploughlayer	1	5	10	15	14	16	20	19	2.1
upper mantel	1	5	9	15	16	26	18	11	1.1
lower mantel	1	6	11	15	15	25	16	10	1.0
lower mantel	1	5	11	16	16	22	17	13	1.1
upper core	1	5	10	26	16	19	14	11	1.1
lower core	1	5	9	15	17	21	19	15	1.3
subsoil:									
above iron pan	2	9	15	17	13	5	13	26	0.3
ironpan	30	16	9	11	8	5	9	12	0.9
below iron pan	2	8	13	17	13	6	14	26	0.3

Table 1. Texture and organic matter content. Grain sizes in µm, figures in percentage. OM means organic matter content.

	non-silicate		organic		
	Fe%	Al%	Fe%	Al%	OM%
ploughlayer	0.6	0.1	0.2	0.3	2.1
upper mantel	0.3	0.1	0.2	0.3	1.1
lower mantel (plowlayer)	0.3	0.1	0.2	0.4	1.1
lower mantel (subsoil)	0.4	0.1	0.2	0.2	0.9
upper core	0.3	0.1	0.2	0.3	1.1
lower core	0.5	0.1	0.2	0.3	1.3
subsoil above iron pan	0.4	0.1	0.3	0.5	0.3
ironpan	14.5	0.3	0.4	0.2	0.9
subsoil below iron pan	0.8	0.1	0.2	0.3	0.3

Table 2. Non-silicate and organic bound iron, aluminium and organic matter content (OM) in the different soil layers.

around the mound for building the grave. The minor difference in clay-content between the mound and its substratum may be due to the fact that most of the Danish tills show clay illuviation. By that process clay minerals are translocated from the topsoil (e.g. 0-40 cm) to the soil layer immidiately below (e.g. 40-130 cm), where they are deposited as clay cutans on the soil peds. The mound is then built up by clay eluviated topsoil placed on a clay illuviated subsoil. Furthermore, many turfs in the mound show two layers, a dark topsoil with a little more organic matter content than a brighter sub-soil, which also indicates that the mound is built up by near-by topsoil. The central core is made of the same material as the rest of the mound, and there is no evidence that it should have been taken from a nearby wetland. This is in accordance with results from a number of Bronze Age burial mounds, e.g. from Arnum, Jels, Skrydstrup and Egtved where analysis of the core shows pollen from heather vegetation or from dry farmland (Thomsen 1929; Broholm & Hald 1939).

Table 2 shows the organic matter content, and the dithionite-citrate soluble and pyrophosphate soluble iron and aluminium in the different horizons. The organic matter content is highest in the plough layer exceeding 2%. In the mantel the vegetation layer of the turf shows a slightly higher organic matter content than the bottom. The core has between 1 and 1.5% of organic matter indicating that it is not wetland deposits. Below the core in the subsoil, the organic matter drops, but shows a minor local maximum in the iron pan.

The content of pyrophosphate soluble aluminium (Al_p) is significantly higher than the dithionite-citrate soluble aluminium (Al_d). The iron pan has not a local maximum for Al_p but a minor one for Al_d. The dithionite soluble iron (Fe_d) content is significantly higher than the pyrophosphate soluble. The iron pan shows a significant maximum for Fe_d (10-20%) but not for Fe_p. If we use the general assumption that the extraction of iron and aluminium with dithionite-citrate (Fe_d and Al_d) gives the total amount of non-silicate iron and aluminium in the soil, while the extraction with pyrophosphate (Fe_p and Al_p) only gives the organic-bound iron and aluminium, it is possible to determine whether the soil forming process has been a podzolization or a gleying.

If podzolization has occured, there should at least be a local maximum of iron, aluminium and organic matter content in the iron pan, and according to Soil Survey Staff (1975) and FAO (1990) the iron pan must fulfil the following equation:

$$\mathrm{Fe}_d + \mathrm{Al}_d < 2 \star (\mathrm{Al}_p + \mathrm{Fe}_p)$$

This means that the organic bound Fe + Al is to account for more than half of the total amount of non-silicate iron and aluminium. Furthermore, above the iron pan an eluvial horizon should be found containing bleached sand grains, because the iron coatings have been removed by the podzolation process.

If gleying is the main process, the inorganic iron content must show a distinct maximum in the iron pan and it must exceed the amount of organic bound iron several times $\mathrm{Fe}_d>>>\mathrm{Fe}_p$. Furthermore, there should not be a distinct local maximum for organic bound aluminium and iron and organic matter content in the iron pan. The presence of gley features like mottlings in the neighbouring soil layers will strongly support the theory of reduction/oxidation as the driving process in the iron pan formation.

Table 2 shows that the chemical data do not support the podzolization process; the amount of organic iron and aluminium is too small compared to the inorganic amount, there is no local maximum for organic bound iron and aluminium in the iron pan and bleached mineral particles were not observed above the iron pan. Contrary, the analytical data clearly support the gleying process, especially the extreme high content of inorganic iron (Fe_d). A mineralogical investigation of the iron pan by X-ray revealed that the iron was mainly goethite but also a trace of lepidocrosite formed under wet condition was detected. The gley process is also sup-

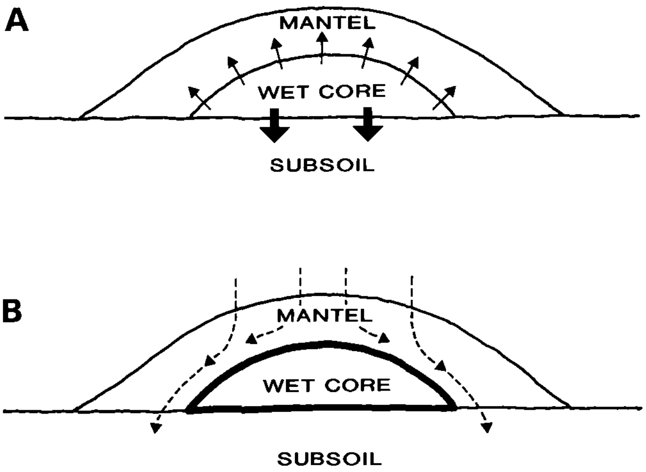


Fig. 3. A schematic drawing showing the water movement in a Bronze age mound.

A: just after the construction of the mound
B: some years later when an iron pan was developed.

Full arrows: water movement from the core out into the mantel
Dotted arrows: percolation water in periods with excess of precipitation.

ported by the field observations of mottlings in the core, the blueish colour which is typical for wet anaerobic soil material, and the reports of free water in the log coffins from the excavation of some mounds. Furthermore, a gley process might happen very fast, within months, while the podzolation process, developing a hard pan, will take at least decades. The corpse will never survive the time it will take to form the iron pan by podzolization. It must therefore be concluded that the process forming the iron pan is gleying and not podzolization. The traditional Danish word "alkappe" for this type of iron pan is therefore misleading, because "al" is more or less equivalent to the spodic horizon indicating the podzolization process.

One question then arises; how does the wet and anaerobic condition turn up in the core surrounded by a well-drained mantel or substratum. It has been shown through many pollen analyses that the core of the Bronze Age mounds is made of nearby soil material from dry farmland. This is also the case for the Tårup mound according to texture analyses showing the glacial till origin of the material. It is not possible, based on the present investigation, to give a final explanation but a hypothesis could be as follow: the mound is normally placed on the top of a minor hill, so it must be assumed that the subsoil is well-drained, no groundwater is present near the surface. The corpse stored in the oaken log coffin is placed in the centre of the mound surrounded by stones. Then the central core of the mound is constructed using wet farmland soil to ensure that the soil could be packed tightly around the body. If the soil material is dry, which it will be in summertime, it has to be rewetted to ensure compaction. The core is made very compact compared to the mantel, which are made of the same material as the core but has been placed more loosely and may be in a more dry form. The construction of the two visually distinct stages of the mound can only have been separated by a short time span, and in this way both core and mantel belong to the same continuous building sequence. The beginning decay of the body and the turfs will create anaerobic conditions in the core, and the ferri iron (oxidized form) will be reduced to ferro iron (reduced form). Ferro iron is mobil contrary to ferri iron and will by the water be transported to the subsoil or up in the drier mantel, where the soil water suction is lower, Fig. 3. Here aerobic conditions dominate and the ferro iron will precipitate as ferri(hydr)oxides forming the iron pan. This might be so strongly developed that it impede water movement. First the bottom iron pan will be developed to the stage of non-permeable for water because of the gravity (more water goes downwards than upwards). In the period where the lower iron pan is impermeable for water contrary to the upper pan the excess of precipitation will fill up the central core with water. When the upper iron pan becomes impermeable too, we have a completely cealed corpse stored in anaerobic water containing some organic acids from the initial decay, which at this stage has completely stopped.

The analytical data strongly support the above-mentioned theory but final proves need hydrological investigations and further soil physical and chemical investigations in other excavations, especially some with well developed iron pans completely surrounding the core. Furthermore, simulation experiments developing iron pans in imitations of Bronze Age mounds could also clarify the genesis of the iron pan and the methodology used for building up mounds.

CONCLUSIONS

The following conclusions can be made:

- The mound of Tårup is made of loamy till taken from nearby dry farmland. The material is clay-eluviated topsoil, and the material building up the brownish mantel and the blueish core are identical.

- The genesis of the iron pan below the core is oxidation/reduction processes (gleying).

- The Danish word "alkappe" for the iron pan is misleading, because no podzolization has taken place.

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REFERENCES

ANER, E. & K. KERSTEN 1973 ff: *Die Funde der älteren Bronzezeit des Nordischen Kreises in Dänemark, Schleswig-Holstein und Niedersachsen,* Bd I ff, København-Neumünster.

BECKER, C.J. 1946: Bronzealderhøje ved Skrydstrup. *Fra Nationalmuseets Arbejdsmark* 1946, pp.30-38.

BOYE, W. 1896: *Fund af Egekister fra Bronzealderen i Danmark.* Kjøbenhavn (reprinted edition, Wormianum, Århus, 1986).

BROHOLM, H.C. 1938: Jelsfundet. En sønderjydsk Mandsgrav fra den ældre Bronzealder. *Aarbøger for nordisk Oldkyndighed og Historie* 1938, pp.1-20.

BROHOLM, H.C. & M. HALD 1939: *Skrydstrupfundet. En sønderjysk Kvindegrav fra den ældre Bronzealder.* Nordiske Fortidsminder, Det Kgl. Nordiske Oldskriftselskab, København.

FAO-Unesco 1990: Soil map of the world, Revised legend. FAO Rome.

GRIPP, K. 1942: Der Aufbau des Bronzezeitlichen Grabhügels von Harrislee. *Nachrichtenblatt für Deutsche Vorzeit* 1942, pp.90-95.

JENSEN, J. 1988: *I begyndelsen.* Gyldendals og Politikens Danmarkshistorie, bd 1. København.

MADSEN, H.B., A.H. NØRR & K. AA. HOLST 1992: *The Danish Soil Classification.* Atlas of Denmark 1,3.

PETERSEN, L. 1976: *Podzol and podzolization,* Thesis. DSR Royal Vet.- and Agricultural University, Copenhagen.

SARAUW, G.L.F. 1898: Lyngheden i Oldtiden. Iagttagelser fra Gravhøje. *Aarbøger for nordisk Oldkyndighed og Historie* 1898, pp.69-124.

Soil Conservation Service 1972: *Soil survey laboratory methods and procedure for collecting soil samples.* U.S. Dep. Agric. SSIR 1. U.S. Govt. Print. Office, Washington, D.C.

THOMSEN, Th. 1929: *Egekistefundet fra Egtved, fra den ældre Bronzealder.* Nordiske Fortidsminder II,4. Det Kgl. Nordiske Oldskriftsselskab. København.

Soil Survey Staff 1975: *Soil Taxonomy.* U.S. Dep. Agric., U.S. Govt. Print. Office, Washington, D.C.