Environmental changes in Sauðlauksdalur, N-W Iceland: evidence from sedimentary- and historical data

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Jarðvísindadeild
Háskóli Íslands
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10 eininga ritgerð sem er hluti af
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Leiðbeinandi
Jón Eiríksson

Jarðvísindadeild
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Útdráttur

Sauðlauksdalur er dalur staðsettur í Patreksfirði á Vestfjörðum. Þar hefur átt sér stað stórfellt sandfok inn í dalinn síðustu aldir, sandfok sem hefur myndað stórt sandflæmi í dalnum og sandodda meðfram ströndinni. Þetta sandfok hefur ógnað þar búsetuskilyrðum, og er baráttan við sandinn vel skráð niður í frásögnum margra manna, meðal annars Björn Halldórssonar sem var prestur þar á 18. öld. Sandfokið í dalnum hefur minnkað verulega eftir 1920, og má rekja það bæði til enda Litlu Ísaldarinnar og uppgræðslu sandanna af hálfu Landgræðslu ríkisins. Átta snið voru tekin, og innihéldu tvö þeirra bæði sandlög og jarðlög. Snið 48 var valið til að rannsaka vegna staðsetningu þess í dalnum og fjölda jarðvegslaga. Alls voru þar fimmtán mismunandi jarðvegsslög, 4 moldarlög, 8 sandlög, 2 moldar og sand lög og 1 leir og malar lag. Fjögur jarðlög voru valin til aldursgreiningar með ^{14}C greiningu og öll sandlögin voru sigtuð, ásamt tveimur sandlögum úr sniði 52. Sandurinn reyndist vera miðlungs stór sandur og uppruninn frá sandöldum við ströndina og lengra inn í landi. Sandurinn er gulur að lit, samansettur af bæði brotnum skeljum sjávardýra og basalt brotum. Sandlögin eru lagskipt fremst í dalnum, en engin lagskiptin var sjáanleg í sandlögunum í sniði 48. Aldursgreiningin á jarðlögunum mistókst, en líklegt er að eitt lagið sé frá hlýskeiði miðalda, og að sandfokið hafi þá byrjað fyrr en Litla Ísöldin hófst, en hinsvegar náð hámarki á því tímabili. Líklegt er að veðurfarsbreytingar sem urðu á tíma Litlu Ísaldarinnar hafi valdið umhverfisáhrifum sem juku á sandfokið inn í dalinn.

Abstract

Sauðlauksdalur is a valley located in Vestfirðir in N-W of Iceland. There has been an on going aeolian transport of sand into the valley for the last centuries, and it has formed a large sand field in the middle of the valley and a sandspit at the beachfront. The farmland in the valley has been badly damaged by this sand and the battle against it has been well documented throughout the centuries. The transport of sand into the valley has decreased since AD 1920, a decreased that can be traced to both climate changes after the end of the Little Ice Age and efforts by Soil Conservation Service of Iceland to increase vegitation on the sand field and the beach. Eight sections were dug, and two of them contained both soil and sand layers. Section 48 was chosen for study due to its location in the valley and multiple soil layers. In all there were fifteen different layers in the section, 4 soil layers, 8 sand layers, 2 soil and sand layers and one clay and gravel layer. Four layers were chosen for radiocarbon dating and all the sand layers, including two from section 52, were sieved. All the sand samples were medium grained sand and originated from dunes at the beach and inland. The sand is yellow in colour and consist of both seashell- and basalt rock fragments. The sand deposits are layered at the front of the valley, but no layering was visual in the sand layers of section 48. The radiocarbon dating of the soil layers failed, but it is likely that one of the soil layers was formed during the Medieval Warm Period. The aeolian transport of sand therefore began before the onset of the Little Ice Age, but reached its maximum during that period. It is likely that climate change during the Little Ice Age had an effect that increased the amount of aeolian transport of sand into the valley.

Hér með lýsi ég því yfir að ritgerð þessi er samin af mér og að hún hefur hvorki að hluta né í heild verið lögð fram áður til hærri prófgráðu.

Jóhannes Marteinn Jóhannesson

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1 Introduction

Sauðlauksdalur is located in Patreksfjörður, NW-Iceland (i.i Vestfirðir). It is a U-shaped valley formed by glaciers during repeated glaciations of Iceland. The valley itself is oriented south-west to north-east and is about 6 km long. The valley probably derives its modern day name from the plant *Triglochin palustre L.* (i.i Mýrarsauðlaukur, i.e. Marsh Arrowgrass)(Björn Halldórsson, 1983), but there is also a possibility that the name comes from the plant *Salix herbacea L* (i.i Grasvíðir, smjörlauf or sauðlaukur), i.e. dwarf willow)(Ingólfur Davíðsson, 1956). The earliest spelling of the name of the valley was Dalur (Íslenskt fornbréfasafn, 1923-1932) and Sauðlausdalur (Byskupasögur, 1953) but the name changed gradually over time to Sauðlauksdalur (Hannes Þorsteinsson, 1923). The valley is typical for that region, in that it has a sandy beach consisting of marine material, rather than the common basaltic sand typical for beaches in other regions of Iceland. A sandy spit, protruding from the otherwise gravelly and rocky coastline has formed at the mouth of the valley. Sandstorms originating from the spit have plagued the farmland of Sauðlauksdalur for at least the last three centuries and over time an extensive sand field has formed on the valley floor. Currently, this sand field reaches about 1.7 km from the shoreline into the valley and extends upwards to the mountain sides on each side of the valley. Through this sand field runs a river, called Dalsvaðall. The river flows across the sand field, forming an outlet river from the lake in the valley. The lake is called Sauðlauksdalsvatn and is located almost in the middle of the valley. There are many other small brooks in the valley. The biggest one is Sauðlauksdalsá which runs into the lake. Most of the other small streams also run into the lake, but a number of the brooks disappear into the sand on the valley floor. There has been a farm in Sauðlauksdalur for centuries (Íslenskt fornbréfasafn V, 1902) and a church has been there since the early 16th Century (Íslenskt fornbréfasafn V., 1902). The current farm lies just west of the lake basin and can be seen on fig.1.1, as a white dot in a middle of a dark area, which are the fields around the farm. A road across the sand field was constructed in 1953 along with the bridge that goes over the river Sauðlauksdalsá (Þ.J., 1953). An airport is located on the sandspit, just north

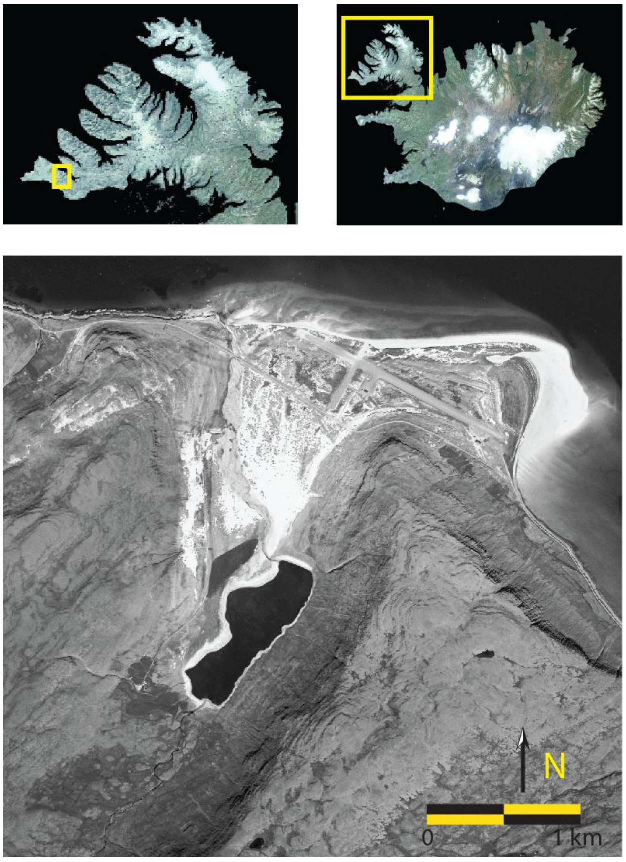


Figure 1-1. The location of Sauðlauksdalur in Iceland.

of the road. It was constructed in 1965 (Egill Ólafsson, 1985). The valley has been a home to well known persons in Icelandic history, the most famous among them is probably pastor Björn Halldórsson. Björn Halldórsson was a minister there from 1753 to 1778 and is well known in Iceland for his numerous writings and agricultural experiments (Björn Halldórsson, 1983). In 1929 it became one of the first areas in Iceland to have measures taken against the land degrigation caused by the sand, when the then newly formed Soil Conservation Service of Iceland started its attempts to halt the eolian transport into the valley (Arnór Sigurjónsson, 1958).

The extensive quantity and the make up of sand found in Sauðlauksdalur, and in many places along the coastline in that area, are quite unique for Iceland. Almost all sand in Iceland is of volcanic origin (O. Arnalds, F. O. Gisladottir and H. Sigurjonsson, 2001) but in Sauðlauksdalur and along the coastline in that area, the sand is predominantly made up from material of marine calcareous origin. This type of sand and the land degrading that it has caused in that part of the country have not been extensively studied in Iceland. This study is the first combined geological and historical study of Sauðlauksdalur and the sand spit. The main objectives of the present study are:

1. To determine at what time the buildup of the sand field in the valley began.
2. To find out if there is a link between environmental changes in Sauðlauksdalur and climate change during the Little Ice Age in Iceland.
3. To try to ascertain the reasons for changes in amount of wind born material being carried into the valley.
4. To find out if the sand buildup ceased at some periods in time and if any soil formation was possible in those periods.
5. To find out if any change occurred over time in the sand itself, that is, particle size and the composition of the sand.

In order to find answers to these research questions, a number of sections were studied in and around the current sand field in Sauðlauksdalur, in an effort to both reach to a layer under the sand and to take samples from each overlying layer if there were any. To support the findings from the geological aspect of this project, the historical data about the valley were examined, farmers from the adjacent valley were interviewed about the recent situation in Sauðlauksdalur and information about Sauðlauksdalur that the Soil Conservation Service of Iceland has gathered over the years was examined.

1.1 Historical accounts of environmental changes in Sauðlauksdalur

Sauðlauksdalur was a part of the area that a man named Þórólfr spörr settled during the Icelandic settlement in the 9th and 10th centuries. Þórólfr settled most of the south and west parts of Patreksfjörður (Íslendingasögur, 1946). Sauðlauksdalur is not mentioned as having been settled then, but it is considered likely that the valley was settled not long after the first settlement in the fjord, either by relatives of Þórólfr spörr or workers from his camp (Grímur Grímsson, 1972 and Ólafur Þ. Kristjánsson, 1964). The first mentioning of Sauðlauksdalur itself in texts, and evidence that it has been settled, comes from Bishop Páll Jónsson’s Kirknatal (Íslenskt fornbréfasafn (1923-1932), Guðmundar saga Arasonar (Byskupasögur, 1953) and Prestssaga Guðmundar Arasonar (Sturlungasaga, 1953). The first document is anacount of churches in Iceland made around 1200. In it Sauðlauksdalur is called Dalur (i.e.

Valley) and that there is a church there (Íslenskt fornbréfasafn, 1923-1932). The second and third texts come from two books about the life of the Catholic priest Guðmundur Arason. The priest lived from 1203-1237 (Byskupasögur, 1953), so presumably the settlement must have taken place at that time at the latest. The first confirmation of a settlement comes in the year 1458 from a letter of land properties owned by Kristín Björnsdóttir. There is no description of the farmland or the valley itself in the letter, but in it Sauðlauksdalur is valued at 36 hundred (Íslenskt fornbréfasafn V. 1902). This valuation would have put Sauðlauksdalur well above the average farmlands in the country, since the best farms were valued at 60 hundred and good average farms were valued at 24 or 20 hundred. The original valuation of most of the farms in Iceland is believed to have been made around 1100 AD, but it is not mentioned weather the value of Sauðlauksdalur is from that time or later (Arnór Sigurjónsson, 1973)

There are two theories what the meaning of the name of Sauðlauksdalur. As mentioned earlier, its original name was Sauðlausdalur (Íslenskt fornbréfasafn V., 1902 and Byskupasögur, 1953), but gradually changed over to Sauðlauksdalur and by the 18th century the farm and the valley are only known by that name (Hannes Þorsteinsson, 1923). The former theory is that the name Sauðlausdalur, as it appears, seems to indicate that it was a sheepless valley (Finnur Jónsson. 1924), that is sauð (i.e. sheep), laus (i.e. less, without) and dalur (i.e. valley). The latter theory however argues that Sauðlausdalur is another form of the name Sauðleysudalur, that is sauð (i.e. sheep), leysu (i.i. engi, hagi, i.e. a field, pastor) and dalur (i.e. valley). Sauðleysudalur would then be another form of the name Sauðhagadalur and would indicate that the valley had good grazing lands for sheep (Hannes Þorsteinsson, 1923 and Finnur Jónsson, 1924). That theory has been supported by the fact that in Sauðlauksdalur there are good grazing lands (Finnur Jónsson, 1924) and the valley contains more grazing land than most places in that area.

The first documentary indication of sand in Sauðlauksdalur comes from the early 18th century, when Árni Magnsússon and Páll Vídalín travelled around Iceland to document the state of farms and their farmlands, as well as to make a head count of all Icelanders. This documentation was done in the year 1703 for Sauðlauksdalur. In it they describe the farmland as being heavily spoiled by sand being blown on to the fields. The grazing land is wide and has a good vegetation cover, although winters are more harsh there than normal. Two outlying farms were also part of the farm, one lying above the farm (Efri Dalshús) and one below it (Neðri Dalshús), both though located within the fields surrounding the main farm. The farmlands of the outlying farms were also being spoiled by sand. Two other farmlands that lie east and west of Sauðlauksdalur were described as well. In Kvígindisdalur, which is the farm west of Sauðlauksdalur, grazing land was being spoiled by sand being blown onto the fields as well, possible even more so than in Sauðlauksdalur. The farm east of Sauðlauksdalur, Hvalsker, was however not being spoiled by sand blowing onto the farmlands (Árni Magnússong and Páll Vídalín, 1938).

In 1744-1749, a land description was compiled (Sýslulýsingar: 1744-1749, 1957). for the Vestfirðir region. In it Sauðlauksdalur is not described in much detail, but it is said that the river that flows from the lake to the sea, goes through sand. That would mean that the sand field in the valley has formed by then. The extent of the sand field and the size of the river at that time, can be seen by that there are only two places where people can go cross the river without sinking in the sand. Those two places were right by the outlet from the lake and where the river flows into the ocean (Sýslulýsingar: 1744-1749, 1957).

In 1753, when Björn Halldórsson became the priest in Sauðlauksdalur, it was believed that the farm would have to be deserted due to the amount of land degradation that had occurred in the valley due to sand being blown over the fields (Þorsteinn Þorsteinsson, 1983) Björn describes the land at his farm as being dry and sandy, and in some places the sand has destroyed the vegetation cover. The sand was not the only problem, since most if not all the walls around the fields had been destroyed allowing cows and sheep to roam free on the fields, eating and trampling down the grass. At that time Sauðlauksdalur could only support 6 – 8 cows on winter fodder, but was able to support twenty cows in earlier times. In an effort to battle the sand transport, Björn built a wall in order to prevent more sand reaching onto the fields around his farm. This wall was made from soil and stones, about 130 cm wide and 160 cm high. The wall was in three parts, the first part that was made was supposed to shield the north-eastern part of the fields. The other two parts extended out to the east from the first one and where located north of the farm (Björn Halldórsson, 1983). Other efforts to halt the sand were also made, such as changing the path of some of the small streams around the farmhouses, both to provide water to the farm and in effort to try to wash the sand away from the fields. Sand was also shoveled off the fields to prevent it from suffocating the vegetation and soil was spread over the more sandy areas (Hannes Þorsteinsson, 1924). Björn made attempts to cultivate the sandy areas in his lands as well. He collected seeds from *Leymus arenarius* (i.i Melgresi, i.e. Lyme grass) and sowed it in sandy land. The next year after he had sowed it, the Lyme grass had already started to grow well and to bind the sand, as well as providing fodder for his cattle. Björn mentions two other species that were useful in the battle against the sand. These species were *Carex Arenaria* (i.i Sandstör and/or Sandi, i.e. sand sedge) and S*alix lanata* (i.i. Sandvíðir and/or loðvíðir, i.e. woolly willow). Both species seem to have established themselves in the area naturally (Björn Halldórsson, 1983).

Eggert Ólafsson and Bjarni Pálsson (1974) travelled through the area in 1752-1757, while working on their travel book. They did not add much information about the area at that time, but confirm that Lyme grass grows in the valley and that it is used to vegetate the sand field. Sauðlauksdalur had no forest at that time, but Eggert and Bjarni mention that a few years earlier there was a search for peat in the valley and in several places both peat as well as some big, rotten, logs of birch were found (Eggert Ólafsson and Bjarni Pálsson, 1974). There are other sources that mention an old forest being in Sauðlauksdalur, and that it was used to make charcoal (Búi Þorvaldsson, ca. 1970) This forest had been completely used up by 1854, (Ólafur Pálsson, 1861) and it is probable that it had already been used up by the end of the 15th century when Sauðlauksdalur is given the logging rights in Trostanfjord (Íslenskt fornbréfasafn, 1903-1907). That logging right was however seldom or never used due to the distance between the two places (Ólafur Pálsson, 1861).

Eggert and Bjarni also mention that both the river and the lake in the valley were getting smaller. They say that 60 years before (around 1700), people could row their small boats up the river and into the lake, but around 1760 the lake was a quarter of a mile from the shoreline and the river just about a foot deep (Eggert Ólafsson and Bjarni Pálsson, 1974). The situation at the farm was not made better when in 1777 a plague of grass worms spread through the land and spoiled grass and other vegetation in Sauðlauksdalur (Björn Halldórsson, 1983).

Despite the effort of Björn to try and stop the sand from spreading in the valley, it continued after he left Sauðlauksdalur. During the winter of 1789, seven years after Björn left, the farmland in Sauðlauksdalur was so badly damaged by sand and gravel that it was considered beyond repair (Hannes Þorsteinsson, 1924), and in 1805 Sauðlauksdalur was on the verge of becoming desolated (J. Johnsen, 1847) but the farm continued to be in settlement.

Sand was not the only thing that spoiled vegetation and fields in Sauðlauksdalur. In the 19th century, at least three landslides occurred. The first one happened in the early part of the century, in which the upper fields around the outlying farm, Efri Dalshús, were destroyed. The second landslide happened probably between 1820 and 1830 and the last one happened 1858. These landslides damaged land with good vegetation on it, but no fields were destroyed (Búi Þorvaldsson, ca. 1970)

In 1847, the priest in Sauðlauksdalur considers the farm desolated due to the sand, but believes that with some expenses the farm can be saved. (J. Johnsen, 1847). By 1854 Sauðlauksdalur has had 2/3 of its fields destroyed by sand, and it is said that the amount of sand being blown in on to the farmlands is increasing from year to year and the lake continues to get shallower The farm is judged to be able to support 3 cows, 40 sheep, 15 lambs and 2 horses. The outlying farm Neðri Dalshús does not exist there anymore (Ólafur Pálsson, 1861) and its land has been taken over by the main farm due to its own field being badly damaged (Búi Þorvaldsson, ca. 1970). In 1877 or 1878 Sauðlauksdalur was awarded extra money from the church in order to shovel sand, presumably off the fields around the farm (Álitsskjal brauða- og kirknamála-nefndarinnar, 1878).

In the summer of 1886 Þorvaldur Thoroddsen went to Sauðlauksdalur. He said that it should soon be deserted, due to sand blown in on to the farmland. Most of the fields around the farm were then gone but the wall that Björn Halldórsson built could still be seen, although it was almost completely covered by sand. At the mouth of the valley there was a large sandtip, made of only seashell sand. The sand is blown into the mountain side as well as into the valley and the lake continues to decreas in size and depth (Þorvaldur Thoroddsen, 1959).

In 1888 Sauðlauksdalur is described as being in a poor state. One-third to half of the farmland has been destroyed due to the sand. The rest of it is badly spoiled. In that year and a few years before, possibly since 1878 or before, the amount of sand blown on the fields was still so high that in order to get any real amount of hay from the fields, the sand had to be shoveled off the fields (Hermann Jónasson, 1888).

In 1898 the wall built by Björn Halldórsson is almost covered by the sand on both sides, and can hardly be seen. 3/5 of the farmland is beneath sand and the rest is badly damaged due to the sand. The main reasons why there is still 2/5 of the farmland left are the small streams that run around and through the farmland. The farmland has been extended and sand has been shoveled of the fields, so much that it has taken many days to do so. Between 1894 and 1898 the sand blowing in Sauðlauksdalur did almost stop and the field was not damaged further during that time. The reason given for the decrease in sand blowing in on to the farmland, was that groundwater was tying up the sand on a small patch of land. This patch was flat and was created naturally just north-west of the lake. On the northern part of the fields around the farm was a small sand field, estimated to be the size of a 20 days worth of harvesting time. Seeds from Lyme grass were planted around the farm in the summer of 1898, however in the fall the sand had been blown away from the roots, where the grass had no shelter from the wind, and much of the Lyme grass perished due to that. *Hippophae rhamnoides* (i.e; common sea-buckthorn i.i; Sandbúi) was also planted in the spring of 1897 but the seeds did not take and it failed (Einar Helgason, 1902).

In 1899 thirty days worth of harvesting, of the total fifty from the farmland, had been lost under the sand and the other 20 days worth where sparsely covered by the sand. That same year the priest there also harvested Lyme grass (Stefán Guðmundsson, 1899).

In 1902 the vegetation at the mouth of the valley was mostly gone due to the sand. The sand covers were at its biggest near the sea and in the western part of the valley, especially on the mountain side. There was much less sand in the eastern part. On the west side of the lake there was a small field forming, and produces then about 30-40 horses of hay per summer.

The farmhouse is about 1400 fathoms from the sea at that time, and the sand extends to the farmhouses. The fields inside the old walls around the farm were mostly gone, being covered by thick layer of sand, in some places reaching 83 cm in thickness. This layer was entirely made up of sand, but with large amount of roots within it, and it lay on top of a soil-layer that used to be a field at some point, but had turned into peat (Einar Helgason, 1902).

Quite a few ideas had risen by the turn of the century on how to try to stop and reverse the sand spread. One approach was to try to change the courses of a few of the small streams that ran around the farm, so that it would flow over the fields and take the sand with them, but that idea was rejected. Another idea was to try to block the outlet of the lake so it would rise and cover greater area of the sand field, but that was also rejected. The only solution that was thought to be viable at the time was to try to plant seeds in the sand and try to make it fertile (Einar Helgason, 1902).

In 1902 the vegetation has started to spread, probably mostly due to the groundwater starting to bind the sand at the valley floor. The fields had also been cut differently during the last few years, that is, the stems were left larger than usual in the field and were therefore better able to bind the sand in the field. At the coast there was some wild Lyme grass growing and slowly spreading. The priest and the farmer in Sauðlauksdalur, Þorvaldur Jakobsson was given a grant in order to try to put seed of Lyme grass in larger area of the sand and that effort was scheduled to start in 1903 (Einar Helgason, 1902).

In 1907 the river changed its course through the sand field. It had run through the west side of the sand field but the channel was shifted over to the east side. When that happened the river started to fill up a lagoon (Búi Þorvaldsson, ca. 1970) which was located in the middle of the sand spit and can been seen as a darker spot of sand in fig. 1.4.
In 1912 the farmland was getting better as can been seen by that, that in 1897 the amount of hay from the field was 145 horses but in 1912 it was 230 horses (Guðmundur Hjaltason, 1913).

In 1915 and 1916 the farmland had started being destroyed again by the sand, but it is said that the condition of the farm has mostly stayed the same since the time of Björn Halldórsson. Sand has reached high on to both of the mountain sides and the area between the lake and the beach is completely covered by sand. The lake is at that time about 1,5 km long, but it is stated that it most certainly was longer and that maybe it was once a sea-cove. Sand is both being blown into the lake and carried by the rivers that run into the lake. At that time it was four meters deep at the deepest point (Bjarni Sæmundsson, 1917)

In 1915 there was a map made of Sauðlauksdalur, that was a part of the mapping project of Iceland done by the the Danish General staff.

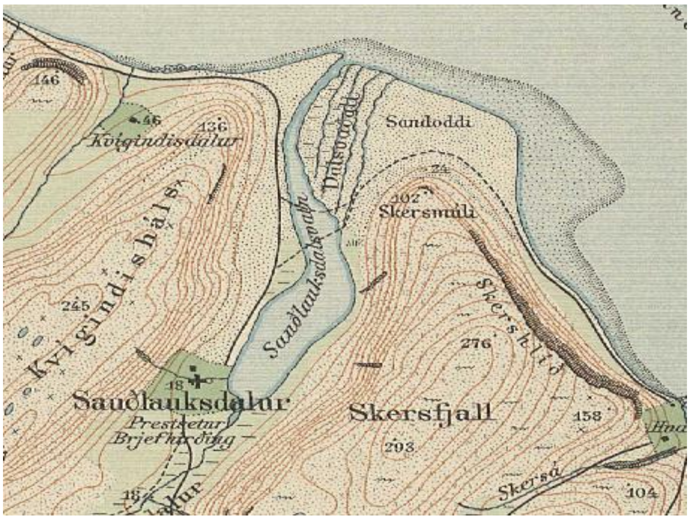


Figure 1-2. Map of Sauðlauksdalur from 1915.

On this map it can be seen that both the lake and river are considerable larger than they are today (fig. 1.7). The river has reverted to its former course on the west side of the sand field, and flows from the lake in one major outlet and a few smaller ones. The sand reaches to the fields around the farmhouse, but not beyond it. Also, the small field on the north-western part of the lake can been seen, a field that probably started to form at the end of the 19th century. The small patch of wild Lyme grass that is supposed to have been growing along the coast cannot be seen on the map. The lagoon is missing as well, possibly due to it having been filled up in the preceding years. The sand spit has formed by then and seems to be much more extensive during low tide. The wild growing Lyme grass at the coast was almost completely wiped out during the winters of 1917-1918 and 1920-21, when the vegetation was covered with sand during freezing conditions (Búi Þorvaldsson, ca. 1970).

In fig. 1.3 from between 1919-1925, it can clearly be seen that the western and southern part of the fields around the farmhouses are in good shape. The fields are covered with grass and no sand is visible on them. Some sand appears to be around the church, but it is hard to tell if it is sand or something else. The situation in the valley can not be seen clearly, but the lake appears to be rather large, perhaps larger than it is today.

In the spring of 1929 the first fence was set up in Sauðlauksdalur by the Soil Conservation Service of Iceland. Its main goal was to prevent sheep and other grazing animals from getting to the fragile growth. The fence was about 2 km long and about 55 hectares in size. The fence was located right next to the farmland and extended outwards from it. This fence had some effect, but was too small to have a significant impact (Gunnlaugur Kristmundsson, 1958). In 1942 another fence was set up and was about 14 km long and covered about 1800 hectares. After the second fence was set up, sand did not reach the fields around the farm as easily (Sandgræðslan 50 ára, 1958).

Figure 1-3. Picture of the farm and church in Sauðlauksdalur, taken during the summer between 1919-1925

Figure 1-4. Areal photo of Sauðlauksdalur from 1945

By 1945 there had been some major changes in the valley, as can be seen on fig. 1.4. The lake has become much smaller and the river as well. The outlet from the lake is no longer at the northern tip of it but at the middle of it in the western part. The small field on the north-western part of the lake is still there and a new patch of land has formed east of it, probably due to the lowering of the water level in the lake. The sand reaches to the fields of the farm, especially on the eastern and northern side of it.

In 1946 the third fence was set up, this time at the mouth of the valley. That fence was about 7,5 km long and enclosed about 400 hectares of land (Gunnlaugur Kristmundsson, 1958). The land inside the new fence came from three different farms, Sauðlauksdalur, Kvígindisdalur to the west and Hvalsker to the east. In 1948 grass seeds were for the first time spread over the area (Um sandgræðslu og heftingu sandfoks, 1957) and in 1952-1953 Lyme grass and other plant species were sown in the sand at the sand tip (Friðgeir G. Olgeirsson, 2009) as well. In order to strengthen the growth of these plants, fertilizer was spread almost yearly over the area. From 1954 to 1975 there was about five tons of fertilizer spread yearly over the protected area (Sveinn Runólfsson, 2012) and in 1975 and 1976 seeds where spread there again along with more fertilizer. Spreading of fertilizer continued, with some pauses, until 1991 (Sveinn Runólfsson, 2012)

In 1970 and 1972-3 a new grass field was made, about 7,75 hectares in Sauðlauksdalur (Hannes Björnsson, 1995). That field is probably mostly made from the field that had started to form on its own on the north-western bank of Sauðlauksdalsvatn, and can been seen well on fig. 1.6 as a dark spot near the lake.

By 1967 the sand blowing in the valley had almost stopped (Páll Sveinsson, 1972), although it occasionally blew sand over the farm itself (Grímur Grímsson, 1972). But by 1972, the sand had started being blown into the valley again and further measures had to be taken to stop it. The likely reasons for the sand starting to cause problems again were that sand blowing from the beach had increased in the previous 3-5 years due to prevailing wind from the east and increase in loose sand due to the building of the airport and the activity around it (Páll Sveinsson, 1972)

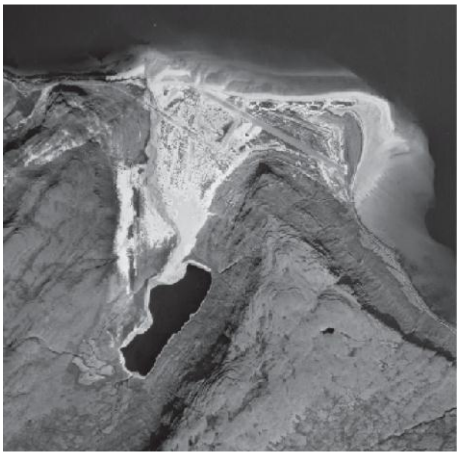
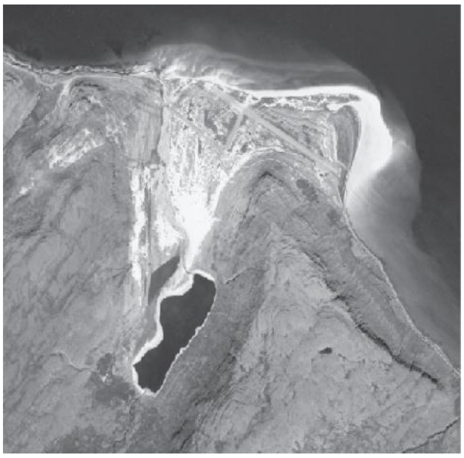



Figure 1-5 and Figure 1-6. Aerial photos of Sauðlauksdalur. The one on the left is from 1983 and the one on the right is from 1991

It can be seen on fig. 1.5 that by 1983 the vegetation cover in Sauðlauksdalur has increased. The sand tip, apart from the sand spit, is mostly covered by vegetation, just the easternmost tip of it along the coast is without some. The only area without vegetation is the sand field in the middle of the valley. The sand on the western and eastern hills in the valley has been almost completely covered with vegetation as well. The sand vegetation cover near the farm itself has also increased and the lake has remained about the same size. In fig. 1.6 it can be seen that no great changes have occurred between 1983 and 1991. The vegetation has continued to spread somewhat and the outlet from the lake is now on its northern tip.

In 1993 the Agricultural research institute did a small report for Sauðlauksdalur, with focus on the land inside the protected area on the sand tip (Þorsteinn Tómasson, 1994). The reason for the making of this report was a dispute that had risen, about the use of the land inside the protected area, between The Soil Conservation Service of Iceland and Þórir Stefánsson, the farmer on Hvalsker (Þorsteinn Tómasson, 1994).

The study was done in the fall of that year and the findings were that the area was still very fragile and could not withstand increase in grazing or other changes in the use of the land. The effect of increase grazing or use would lead to further land degradation and the amount of windblown sand going into the valley would increase. There was, however, a lot of sand being tied up by Lyme grass. The whole area was given the land degradation scale from 4 – 5 (extensive and very extensive degradation). The sea was breaking up the shoreline on the west side of the sand tip, and that caused increase in material being shifted to the east side of the sand spit (Þorsteinn Tómasson, 1994), causing more material to become available to be shifted by the wind. The protection of the area has been beneficial, the Lyme grass has spread around the area and the amount of windblown sand has diminished. Even though that the Lyme grass has spread, the thickness of it is not good enough to entirely prevent sand storms, especially during the winter and during storms (Þorsteinn Tómasson, 1994).

In 1995 a second study was made by the Agricultural Research Institute on behalf of Sveinn Runólfsson, the director of The Soil Conservation Service of Iceland. The aim of the study was to estimate the state of vegetation in a 4 hectares field on the sand spit. Seventeen different species of plants were discovered to be in the field. Soil samples were also taken from the top five cm. (Guðni Þorvaldsson, 1995)

During the time that The Soil Conservation Service of Iceland had been trying to cultivate the sands of Sauðlauksdalur there had always been problem with grazing animals getting into the fenced area and causing damage to the vegetation. Soon after the fence was put up in 1946, a small field made of Lyme grass formed on the sand tip. This field was cut for its seeds, both by The Soil Conservation Service of Iceland and the farmers of Hvalsker. In 1990 a dispute rose between The Soil Conservation Service of Iceland and the farmer of Hvalsker over the right to those seeds, how much of the field should be cut, and lack of efforts in preventing grazing animals to get within the fence. This dispute caused the end of the activities of The Soil Conservation Service of Iceland there, since it became clear that the efforts to protect the area effectively would never succeed under those circumstances. Since then there have been no further attempts been made to protect the area from further land degradation. (Sveinn Runólfsson, [w.y]).

1.2 Current environmental state of Sauðlauksdalur

Figure 1-7. Aerial photo of Sauðlauksdalur taken in 2008.

The current situation in Sauðlauksdalur can be described as being fairly stable. The vegetation cover that was set in place by The Soil Conservation Service of Iceland in the last century is holding ground in most places, the size of the sand field seems to be stable as well. There are, however, still active aeolian processes in the valley, bringing sand into the valley, but it seems that sand does not reach as far into the valley as before and not in sufficient quantity in order to spoil vegetation or spread the sand field further. The sand spit remains the most vegetated part of the sand field and the cover extends to the road that lies right through the valley mouth. High sand dunes have formed in some places along the coastline due to the vegetation binding down the sand that comes up on the coast. The western side of the sand spit is relatively flat, besides the numerous dunes that lie along the coastline. The dunes are mostly covered in Lyme grass. The east side of the sandspit and the area around the airport are more uneven and with high number of sand dunes. These sand dunes are not as high as the one along the cost and tend to have only Lyme grass on their highest point while the lower part of the dune and the are between dunes is without vegetation. The airport has been without vegetation. The airport has been closed for commercial use for some time now and has little effect on the current situation in the valley. The landscape south of the road is quite different from the one north of it. To the south, the vegetation cover is much less continuous and the number of sand dunes is much higher. Most of the vegetation is limited to the top of the sand dunes. The sand dunes themselves vary in size, both in height, length and width, but almost all of them have erosive escarpments on them, facing north-east. In between the sand dunes there is little or no vegetation to be found. Surface ripples are common in the sand field as well. They are mostly abundant on the flatter parts of the sand field, especially on the west side of the valley, but they can also be found between the bigger dunes and on top of those who don’t have vegetation cover. The groundwater level in the sand field is almost at the surface of the lowest parts of the sand. The areas closest to the lake are the lowest parts of the sand field and the groundwater level seems to break the surface of much of that area. At low points, well inside the sand field, there are some “wet” spots where groundwater is able to reach the surface. There are also a number of small streams running down the slopes on both sides of the valley. Most of them

Figure 1-8. Sand dunes along the coast, covered with Lyme grass

Figure 1-9. Sand dunes with escarpments

Figure 1-10. Small sand ripples in between dunes

Figure 1-11. “Wet spot” in between dunes that lie just south of the road, on the eastern side of the valley.

Figure 1-12. Groundwater at the surface, just north of the lake.end up in the lake but some run straight into the sand and disappear into it shortly after.

Basaltic rock fragments in different sizes can be found in between the dunes and on the more flat parts of the sand field at the western side of the valley. The source materials of these fragments seem to be the mountainsides on the side of the valley, rather than underlying layers of gravel and bedrock

Figure 1-13. Rock fragments, a deflation lag, at the surface of the sand.

Figure 1-14. Rounded stones in a former river course running through the sand fiel

The river channel seems to have been stable for the last decades although the outlet from the lake itself has changed. The river is rather small, shallow and slow flowing. In the sand field, heaps of rounded stones can be found lying in a line from south to north. The stones are visible on the surface on the western side of the sand field just east of the current river channel and there are at least three lines of stones to be found there. These lines of stones are evidence of older channels running through the sand but they lie about one metre higher than the current channel. Those channels were probably formed during the time when the river seems to have been bigger and cut across the sand field in numerous channels, as can been seen on fig. 1.2 in the last chapter. The extent of the sand field can be seen well on the mountainsides on the west side of the valley. There, the sand has reached high on to the mountainside and formed a large and elongated sand dune. This sand dune stretches from the mouth of the valley to just south above the farmland.. This long sand dune, or patch of sand, is now mostly covered by vegetation apart from a long and narrow patch on the west side as can been seen well on fig. 1.15. The situation on the east side of the valley is quite different from the west side. The east side is almost completely covered by vegetation but there are quite many open soil escarpments there, especially in the area that is closest to the valley mouth. The amount of sand reaching the east side seems to have been much smaller than that of the west side. The landscape around the lake differs from other parts of the valley. On both the north-east- and west-side of the lake there are large, flat areas that are now covered by vegetation. The flat area, or field, on the west side lies probably a little bit lower (0,5-1 m) than the area on the north-east side. The field on the west side probably used to be under water when the water level was higher in the lake, but was then formed when the water level in the lake got lower in early to mid 20th century. This can be seen by comparing figs. 1.2 and 1.4. The field on the north-east side is both similar to the west one in size and how flat it is. It seems, however, to be drier, probably because the water level has some effect on the westernmost one, and there is more Lyme grass there. There are no documented sources about that area

Figure 1-15. Sand along the west side of the valley.

ever being under water, but it is possible that it once was and was therefore formed in similar way as the western one.

Figure 1-16. A field on the east side of the valley floor, north of the lake.

Figure 1-17. A field on the western side of the valley floor, north-west of the lake

The lake still has the same size as in 1945, but the outlet of the lake is now situated at the western edge of the lake. The lake seems to still be getting shallower and an attempt was made to barge or dam the outlet from the lake in an attempt to make the water level rise. In order to do that, a load of stones was placed where the outlet from the lake is, but it did not hold for long and had seemingly no affect on the lake itself.

The situation around the farm itself and further in the valley appears to be stable. The farmland does not have any sand on it anymore and the fields are clear. There is, however, sand to be found along the river streams that run through the fields there, and in some ditches that are there as well. Around the farm there are a number of examples of broken soil in escarpments, but these are probably not caused by wind erosion but rather from sheep grazing in the area.

Figure 1-18. The abandoned farm and the church in Sauðlauksdalur.

2 The Little Ice Age in Iceland

The little Ice age (LIA) refers to the period between AD 1250 and 1900. (Ogilvie, and Jónsson, 2001). Dramatic climatic changes occurred during that time period in many places, including Iceland. From AD 0 to 1200, the climate in Iceland seems to have been rather stable (Geirsdóttir, Miller, Axford and Ólafsdóttir, 2009b). with a mild period between AD 900 and 1200 (Geirsdóttir, Miller, Thordarson and Ólafsdóttir, 2009a, and Ran, Jiang, Knudsen and Eiríksson, 2011). This mild period is the so called Medieval warm period (MWP), a period when a period of warmer and milder climate, usually extending from the 9th century to the 14th century, prevailed. (Hughes and Diaz, 1994, Bianchi and McCave, 1999, and Cronin, Dwyer, Kamiya, Scwede and Willard, 2003). During the MWP in Iceland sedimentation rates in lakes decreased (Larsen, Miller, Geirsdóttir and Thordarson, 2011).

2.1 Climatic changes during the little ice age

Evidence from numerous studies show that the average temperature decreased around 1250, signaling the onset of LIA (Eiríksson, Knudsen, Haflidason and Heinemeier, 2000 and Geirsdóttir et al., 2009a). In some periods during the LIA the temperature was about 1-2°C lower than the AD 1961 to 1990 temperature average (Smith, Andrews, Castañeda, Kristjánsdóttir, Jennings and Sveinbjörnsdóttir, 2005 and Geirsdóttir et al., 2009b). Studies show furthermore that within the LIA period, there are multiple short periods in which particularly cold climate prevailed. From studying diatom-based reconstruction of palaeoceanographic changes, four of these short periods have been discovered. Those periods were from AD 1325-1375, 1460-1500, 1610-1670 and 1810-1910. Those cold periods indicates variations in the hydro-dynamic conditions on the North Icelandic shelf (Ran et al., 2011). Evidence from ice rafting material and faunal composition suggest that cooling during the LIA reached its peaks around AD 1600 and again in AD 1850. (Eiríksson et al., 2000), while evidence from chironomids and other lake sediment proxies show the coldest period of LIA being during the 18th and 19th centuries (Axford, Geirsdóttir, Miller and Langdon, 2009). Measurements of biogenic silica have the lowest values during the periods AD 1450-1600, 1780 and 1900 (Geirsdóttir et al., 2009b).

Glacial advance and retreat during the LIA in Iceland has been studied extensively. Most glaciers in Iceland reached its Holocene maximum during the LIA. Lambatungnajökull advanced during the 17th century and probably continued advancing through the 18th, reaching its most advanced stance in the late 18th century, most likely between AD 1780 and 1795. After that time, the glacier started to retreat, but had multiple advances in the 19th century and the early parts of the 20th. The regional glacier maximum seems to have been in the middle to late 18th century (Braswell, Dugmore and Sugden, 2006). Langjökull reached its maximum advance either between 1700 and 1850 (Geirsdóttir oet al. 2009b) or during the 19th century (Larsen, Miller, Geirsdóttir and Ólafsdóttir, 2012). Mountain ice caps glaciers in central Iceland advanced between AD 1690-1740 and the late 19th/early 20th century, with the maximum most likely before 1721. (Kirkbride and Dugmore, 2006). Moraines from Drangajökull, located in Vestfirðir, can be found in adjacent valleys from the glacier. Between AD 1700 and1756, the glacier advanced. From AD 1756 to 1840 there is no data on the conditions of the glacier but it is presumed that a considerable recession occurred during the latter half of that period. Around 1840 there seems to have been a sudden and extensive advance of the glacier, reaching the size and extent of the glacier in 1756, and perhaps further. After this advance the glacier started to retreat again (Eythorsson, 1935).

The LIA was however not a continuous cold period, but contained milder periods from time to time. Between AD 1400 and 1460 and again during the 16th century, mild climate prevailed (Massé, Rowland, Sicre, Jacob, Jansen and Belt, 2008) and a period with warm summer existed in the late 17th and early 18th century. In the middle of the 19th century the cooling of the LIA started to recede (Geirsdóttir et al., 2009a) and sea surface temperature rose at around AD 1910, about ten years earlier than air temperature (Knudsen, Eiríksson, Jiang and Jónsdóttir, 2009).

2.2 Soil erosion during the little ice age

Once the LIA started, sedimentation rates increased at Hvítárvatn between AD 1400 and 1600 with a peak at ca AD 1500. For the next two centuries sedimentation decreased again, but after ca 1700 they increased again with peaks around 1845 and 1900. (Larsen et al. 2011). At Haukadalsvatn, in west Iceland, severe soil erosion happened between AD 1450 and 1500 (Geirsdóttir et al., 2009a), and at Stóra Viðarvatn intensified soil erosion happened during the cold periods of LIA (Axford et al., 2009). Increased soil erosion happened as well in some parts of Iceland during the severe sea-ice interval during ca. AD 1780 to 1920 (Jennings, Hagen, Harðardóttir, Stein, Ogilvie and Jónsdóttir, 2001).

3 Materials and methods

The Sand and soil samples investigated in this study where obtained in 2011, during a field trip to Sauðlauksdalur (65° 32,20'N 023° 59,960W). In all, eight sections were dug. Section 1, near the river, was dug first. Section 43 and 50 were then taken, located close to the valley's mouth. Since they failed to produce soil layers, sections 45, 46, and 47 were taken further south in the valley. They did however not produce sand layers. Section 48 was then taken, close to the farm, and produced multiple soil and sand layers. Finally section 52 was dug on the other side of the valley, but that produced only sand layers as well. From section 48 soil and sand examples where taken from each individual layer, eight sand layers, six soil layers and one clay and gravel layer. Sand samples were taken from section 1 and 53 as well. The sections were dug by using a JCB 8018 super excavator, able to dig about 2 meters down and hired from a local contractor, and shovels.

3.1 Sand samples

The sand samples were taken from the layers by using a trowel to carve out a segment from the layer, and were then placed in a marked individual sample-bag. The samples were then dried at room temperature at the Institute of Earth Sciences, Askja after the field trip was over. Most of the sand samples, except samples from section 50, contained high amount of organic material. For it to be possible to sieve the sand samples, the organic material had to be removed. Carver's (1971) guideline for removing organic material from sand samples was used. Each sand sample was put into a 400 ml Erlenmeyer bottle and water was added to saturate the sand. Then 10 ml of 35% Hydrogen Peroxide (H_2O_2) was poured into the solution and the sample was then heated up to 40°C and kept at that heat until frothing had stopped. This was repeated until all organic material had been removed from the sample. After the organic material had been removed, the sample was boiled to remove any excess H_2O_2 and then dried again at a room temperature. This was repeated with all the samples with organic material in it. The sand samples were then sieved. Before sieving, each sample was weighed to 0,001 gr. and then poured into a sieve stack, with the larges sieve being 1 mm and the smallest 0,063 mm. The sieve stack was then shaken for about 10 minutes. The sand from each sieve was then poured on to paper and then into pre-weighed aluminum trays. Then each aluminum tray was weighed and the weight of each sand sample calculated by subtracting the weight of the aluminum tray from the total weight of each sample in order to get the real weight of the sand. The weight of the sand from each sieve was then put in a table using Microsoft Excel. Then the retained weight, weight in % and cumulative weight in % was calculated.

Two methods were used to obtain the sample statistics, graphic values and Gradistat. Gradistat (Blott, S.J. and Pye, K., 2001) for Excel was used to calculate mean, sorting, skewness and kurtosis. In order to obtain the graphic values for each sand sample, the layout from Friedman and Sanders (1978) was used. Cumulative frequency curves, or ogive, (see index #) were made by plotting on a graph the cumulative weight in % on the ordinate and the grain size in phi units on the abscissa. This was done for each layer from section 38 and 52 and values for $\phi5$, $\phi16$, $\phi25$, $\phi50$, $\phi75$, $\phi84$ and $\phi95$ from each layer were determined from the graph. The following equations (Folk & Ward, 1957) were then used to determine the graphic values and in which catagory (Folk, 1974) each sample lied.

Graphic mean: $M_Z = \frac{\phi 16 + \phi 50 + \phi 84)}{3}$

Inclusive graphic standart deviation (sorting): $\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6,6}$

The results from the equation determine how well the sediments are sorted by using the categories below:

< ø 0.35	Very well sorted
ɸ 0.35 to ɸ 0.5	Well sorted
ɸ 0.50 to ɸ 0.71	Moderately well sorted
ɸ 0.71 to ɸ 1.0	Moderately sorted
ɸ 1.0 to ɸ 2.0	Poorly sorted
ɸ 2.0 to ɸ 4.0	Very poorly sorted
> ɸ 4.0	Extremely poorly sorted

Inclusive graphic skewness: $S_K = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$

The results from the equation determine how greatly the cumulative curve of the sediments are skewed by using the categories below:

ɸ 1.0 to ɸ 0.3	Very fine skewed
ɸ 0.3 to ɸ 0.1	Fine skewed
ɸ 0.1 to ɸ -0.1	Near symmetrical
ɸ -0.1 to ɸ -0.3	Coarse-skewed
ɸ -0.3 to ɸ -1.0	Very coarse skewed

Graphic kurtosis: $K_G = \frac{\phi 95 - \phi 5}{2,44(\phi 75 - \phi 25)}$

The results from the equation determine in which way the cumulative curves of the sediments are curved by using the categories below

< ø 0.67	Very Platykurtic
ø 0.67 to ø 0.90	Platykurtic
ø 0.90 to ø 1.11	Mesokurtic
ø 1.11 to ø 1.50	Leptokurtic
ø 1.50 to ø 3.00	Very leptokurtic
> ø 3.00	Extremely leptokurtic.

The probability plots were made by using Granplots spreadsheet application for sieved data (Balsillie, J. H, Donoghue, J. F., Butler, K.M., and Koch, J.L., 2002).

3.2 Soil samples

The soil samples were taken from the layers by using a trowel to carve out a segment from the layer. The soil material was placed in cool storage after the field trip, and was kept there until work began on them. Four soil layers where chosen for carbon dating due to their location within section 48. Those layers from section 48 were number II (at 80,5 cm depth), IV (at 67,5 cm depth), VI (at 60 cm depth) and X (at 15 cm depth). The lowest part of each of the samples were cut off and with the use of a Olympus Szx10 microscope, biological matter was picked out from them and put into small glass vials. The samples where then sent to the AMS ^{14}C dating Laboratory at Aarhus University for radiocarbon dating.

3.3 Pictures and Illustrations

All pictures from Sauðlauksdalur were taken with Canon 300d and all Illustrations were made using Adobe Illustrator CS5. The graph of the vertical section of section 48 was made using PILA 2010 and the panorama picture of Sauðlauksdalur was made using Microsoft ICE.

4 Results

4.1 The lithological record

Eight sections were dug during the field work in Sauðlauksdalur. Of these eight sections, three (section nr. 43, 50 and 53) contained only sand layers, two (section nr. 1 and 48) contained both sand and soil layers, 2 (section nr. 46 and 47) contained only soil and one section (nr. 45) contained soil layers with sporadic sand granules. Sand samples were taken from sections 1, 46, 48 and 52, and soil samples from section 48.

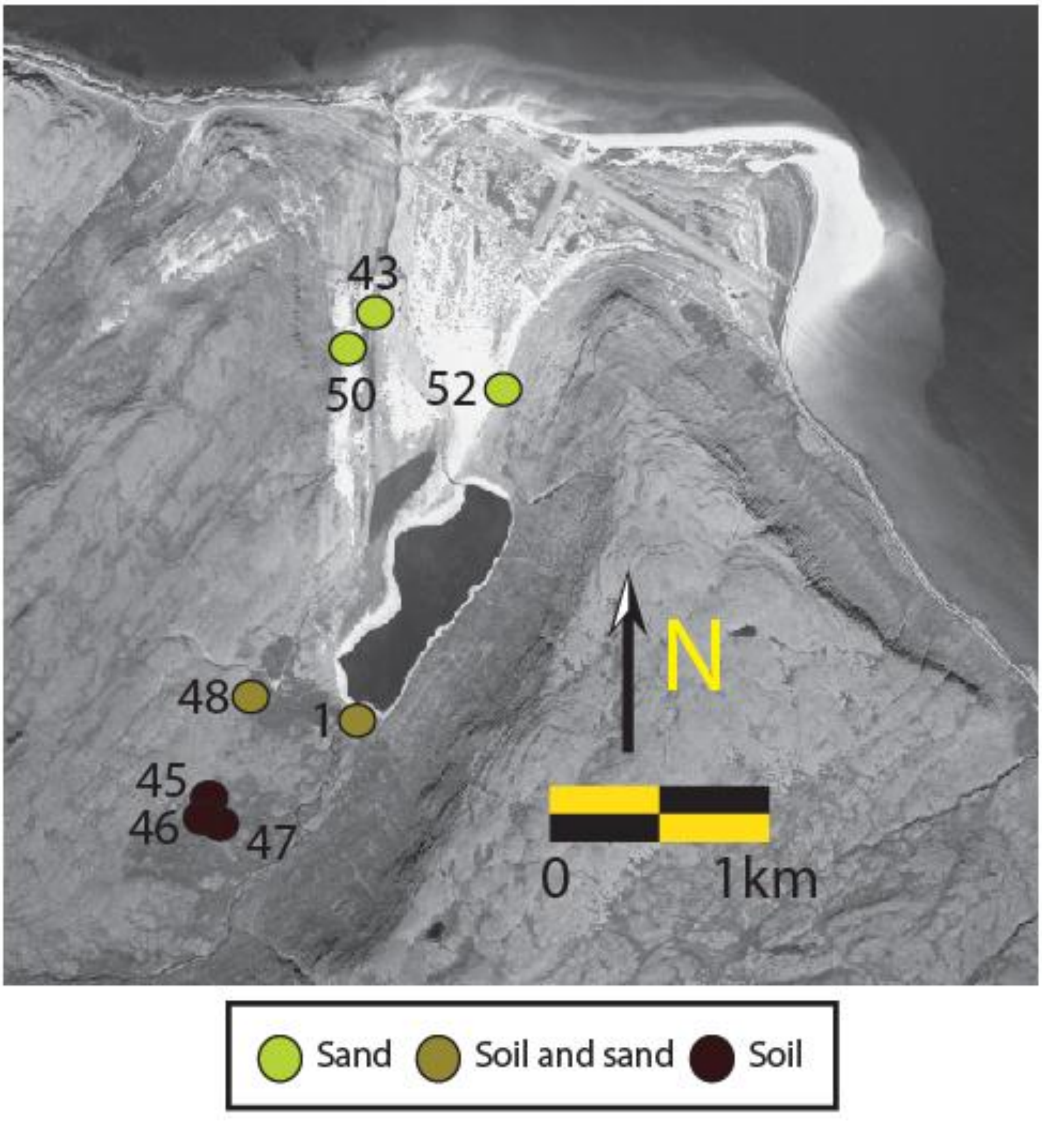


Figure 4-1. Shows the location of the sections that were dug in Sauðlauksdalur.

The sand that is found in Sauðlauksdalur is light in color, made from marine calcareous material and probably heavier than the tephra rich sand of Iceland's highland zones. (Þorsteinn Tómasson, 1994). In 1995 there were taken samples at the sand-spit from the top five cm of the soil. The bulk density of the soil was 1.3 and was mostly made of sand and the pH value was rather high or 7.6, probably due to the soil being made mostly from sand of marine origin (Guðni Þorvaldsson, 1995). The content of the sand samples taken in Sauðlauksdalur were analyzed by Dr. Leifur Símonarson. The sand was mostly made out of broken *Cirripedia* (i.i. Hrúðurkarlar, i.e. Barnacles) and *Chlamys islandica* (i.i. Hörpudiskur, i.e. Iceland scallop), but it contained some pieces of *Mytilus edulis* (i.i. Kræklingur, i.e. Blue mussel) and *Echinoidea* (i.i. Ígulker, i.e. Sea urchin) as well. In two of the sections, section 1 and 48, the sand became more gray or blue in color with depth. Dr. Leifur Símonarson believes that that is due to the aging process of the marine material found in the sand, but does not indicate change in the marine fauna that made up the sand material.

4.2 Description of the Sections

4.2.1 Section 1

The pit section was located along the riverbank of the river that flows into Saudlauksdals lake (N65° 32.087 - W023° 59.549). Three soil layers and seven sand layers were noted within the section. As can be seen on fig. 4.2, the soil layers have suffered extensive disturbance, probably due to effect from the river or the lake. The sand in the section is white and yellow in color, but the yellow color fades with depth and the lowest layer is more blue or gray in color.

Figure 4-2. Alternating sand and soil layers from section *1*.

4.2.2 Section 43

This section was located on the western side of the river (N65° 33.123 – W023° 59.445), close to the valley mouth. The section was dug using the excavator and the sand found there was yellow, with white and black fragments, and it had larger rock fragments on its surface. The groundwater level was reached about a half a metre down through the sand and therefore it was impossible to dig further down. The section only produced sand-layers which had no distinguishable layering.

Figure 4-3. Section 43 with no layering in the sand.Section 45

The section was located in a man made ditch south of the farm (N65° 31.942 – W024° 00.292). One side of the ditch was excavated with a spade and revealing dark brown soil. There were a few yellow sand granules in the top 8 cm, but they were sporadic and did not form a discrete layer.

4.2.3 Section 46

The section was located in a man made ditch south of the farm (N65° 31.859 – W024° 00.371). One side of the ditch was excavated with a spade and it revealed dark brown soil and a small thin layer made from sandy and gray material.

4.2.4 Section 47

The section was located in a man made ditch south of the farm (N65° 31.911 – W024° 00.418). One side of the ditch was exposed with a shovel and it revealed dark brown soil with no sand.

Figure 4-6. Section 45

Figure 4-4. Section 46

Figure 4-5. Section 47

4.3 Section 48

This section was located in the field (N65°32.146 - W024°00.060) just south-west of the farm in Saudlauksdalur. A pit about 105 cm metres deep was dug. A detailed description of section 48 can be found in table 1 and fig. 4.7 and 4.8. The sand in section 48 is yellow, white and black in color. The yellow and white particles are from marine origin while the black particles are most likely rock fragments from the rock layers that make up the largest portion of the bedrock in the region. Based on lithological and sedimentological records four sedimentation facies/environments were found in section 48,(1) Soil, (2) Soil and sand, (3) gravel and clay, and (4) sand. No direct indications were found of disturbance caused by human activity in the section but bio-turbation was heavy within the sand-layers, specially the top three layers. Like in section 1, the color of the sand fades with increased depth. It fades from being yellow in the top layers to being more yellow-gray in the lower layers.

Table 1. Description of the layers within section 48

Layer	Thickness (cm)	Layer description	Type of layer
X	15	Soil with yellow and white sand. The sand makes up almost 50% of the layer, specially in the lowest 5 cm. The turf itself is about 5 cm in thickness.	Soil and sand
Ixc	5	Yellow and white sand, with minor amount of soil.	Sand
Ixb	10	Yellow and white sand, with minor amount of soil. The yellow color has started to fade.	Sand
Ixa	10	Yellow and white sand, with minor amount of soil.	Sand
VIIIb	5	Yellow and white sand, with soil.	Sand
VIIIa	4	Soil with high content of sand. The sand makes up almost 50% of the layer	Soil and sand
VII	6	Yellow, gray and white sand, with minor amount of soil. The yellow color has almost disappeared, been replaced by gray.	Sand
VI	5	Soil.	Soil
Vb	1,5	Yellow, gray and white sand, with minor amount of soil.	Sand
Va	3,5	Yellow, gray and white sand. Has very clear lower boundary, but the top boundary fades into sand and soil layer.	Sand
IV	2,5	Soil. The layer is not continuous, it has a couple of small lenses (>2mm in thickness) of sand within the soil layer.	Soil
III	5	Yellow, gray and white sand. Has very clear lower boundary.	Sand
II	8	Soil.	Soil
Ib	23	Soil and some blue clay. The blue clay is in small patches throughout the layer.	Soil
Ia	2	Some gravel and blue clay. There were some red stones at the bottom of the layer. The blue clay is in small patches throughout the layer.	Gravel and clay

As can be seen in table 1, soil layers make up 38,5 cm of the section, soil and sand layers make up 19 cm, the gravel and clay layer make up 2 cm, and sand layers make up 46 cm. There was some soil formation, or at least remnants of vegetation, within each of the sand-layers. The lower sand-layers, layers III, Va, Vb and VII, contained less soil and remnants of vegetation than the top four sand layers, VIIIb, Ixa, Ixb, and Ixc. Layers VIIIa and X are almost equally divided between sand and soil within each layer. VIIIa and X contain a little more than 50% soil, with the rest made up of sand. For further description of the soil layers see chapter 4.4.

There are four episodes where sand-layers were formed. The first episode consists of layer III, the second episode consists of layers Va and Vb, the third episode is layer VII, and the fourth consists of layers VIIIb, Ixa, Ixb and Ixc. Episode three and four might be the same episode, with a small time period where eolian transport diminished slightly to allow some soil to form in layer VIIIa. There are three episodes where soil layers were formed. The first episode consist of layers Ia, Ib and II. The second episode is layer IV and the third is layer VI. There are two episodes where sand and soil layers were formed together. The first episode is layer VIIIa and the second episode is layer X.

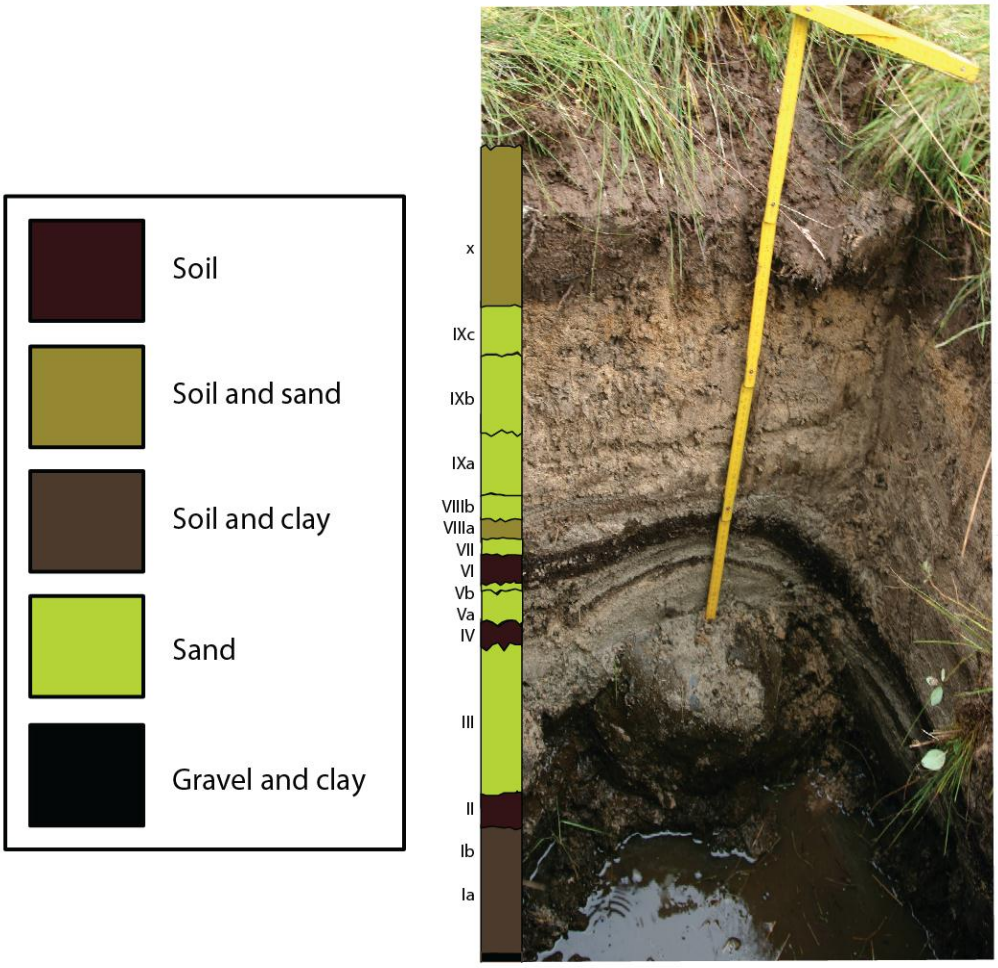


Figure 4-7. Section 48, showing both the column and vertical section.

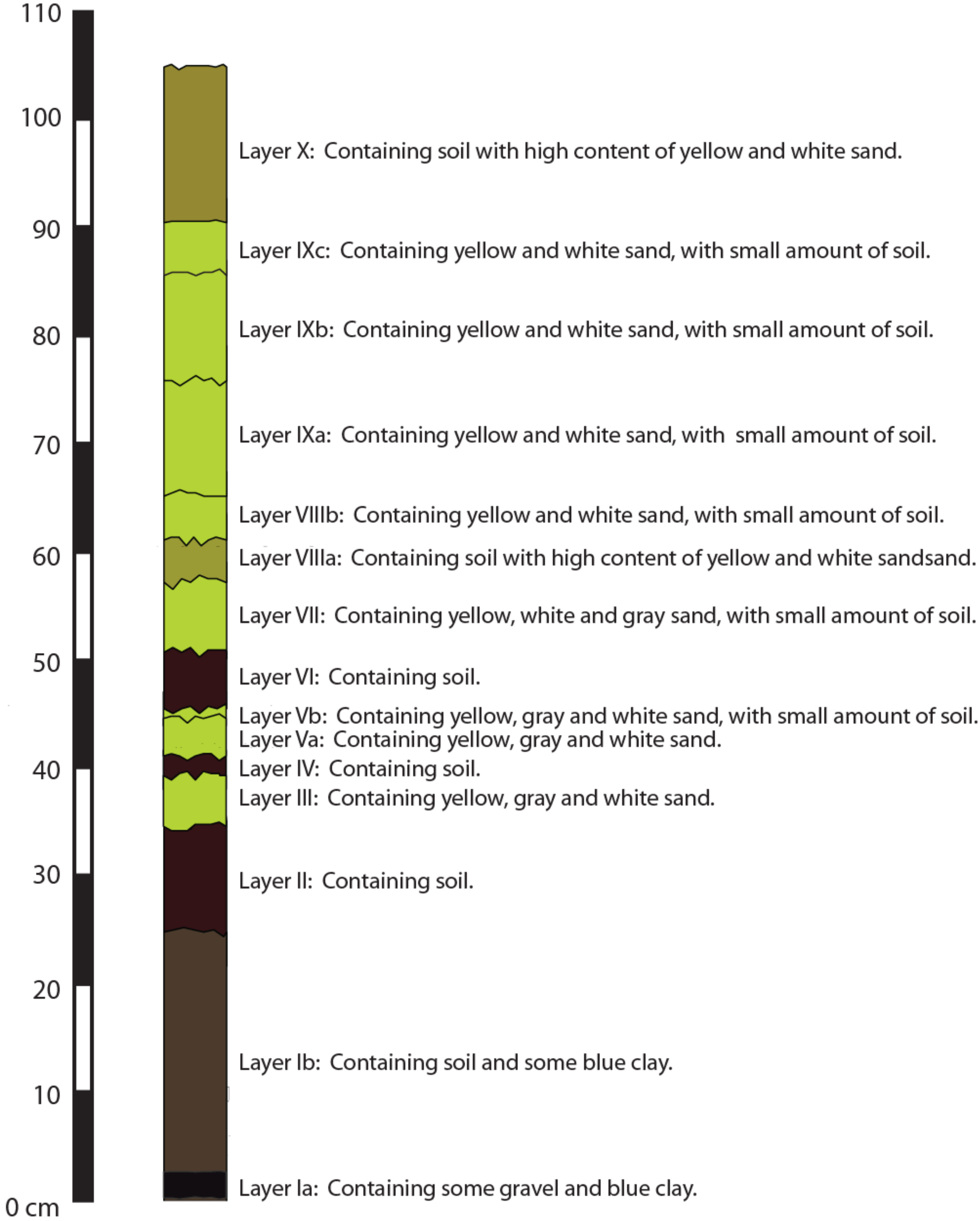


Figure 4-8. Column for section 48.

4.2.5 Section 50

The section was located on top of the northern part of the large sand dune (N65° 33.031 – W023° 59.616) that runs along the western margin of Sauðlauksdalur. There were multiple sand layers within the section, but no soil. The limit of the excavator was reached, about two metres in depth, without penetrating the dune. The sand there was divided into two kinds of layers, black and gray layers and yellow and white layers, which form layering within the dune. The yellow and white layers are more numerous with a number of them between each dark layer.

4.2.6 Section 52

The section was located on the eastern side of the sand-field in the valley, on a sand bank located next to a dried up river outlet (N65° 32,899 – W023° 58,669). There were multiple sand layers within the section, but no soil. The ground water level was reached and therefore it was impossible to dig further down. The sand there was divided into two kinds of layers, black and gray layers and yellow and white layers, which form layering within the dune. The yellow and white layers are more numerous with a number of them between each dark layer.

Figure 4-9. *Section 53.*

Figure 4-10. *Section 50.*

4.3 Grain size analysis from sections 48 and 52

Eight sand layers from section 48 were sieved as well as two layers from section 53. On figs. 4.11 – 4.18 the weight% and the cumulative % of the grain size for each layer in section 48 can be seen. On figs 4.19 and 4.20, the weight% and the cumulative % of the grain size distribution for two of the layers in section 52 can be seen.

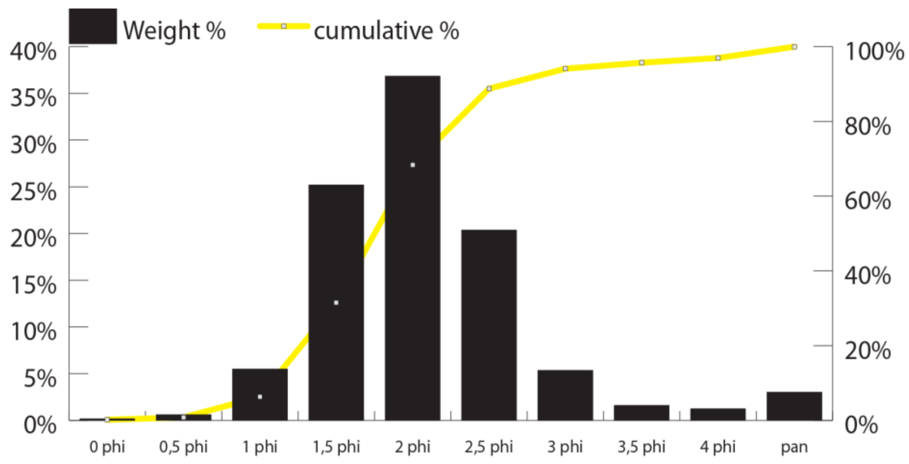


Figure 4-11. Section 48, layer III.

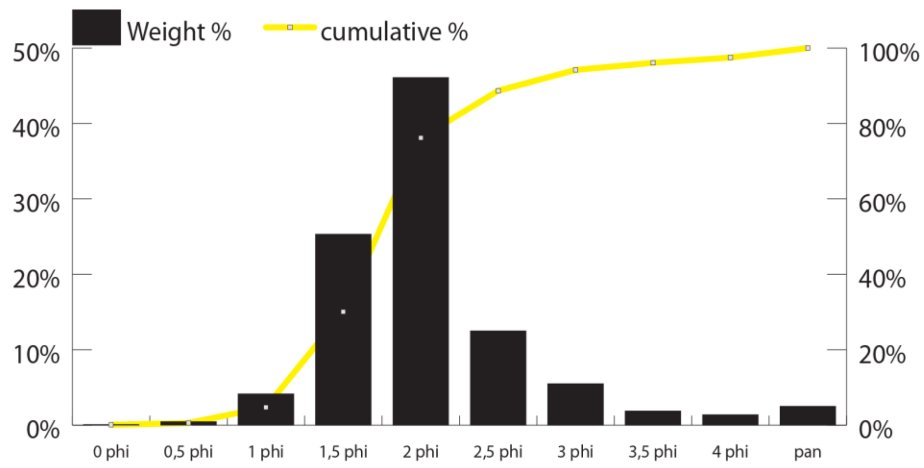


Figure 4-12. Section 48, layer Va.

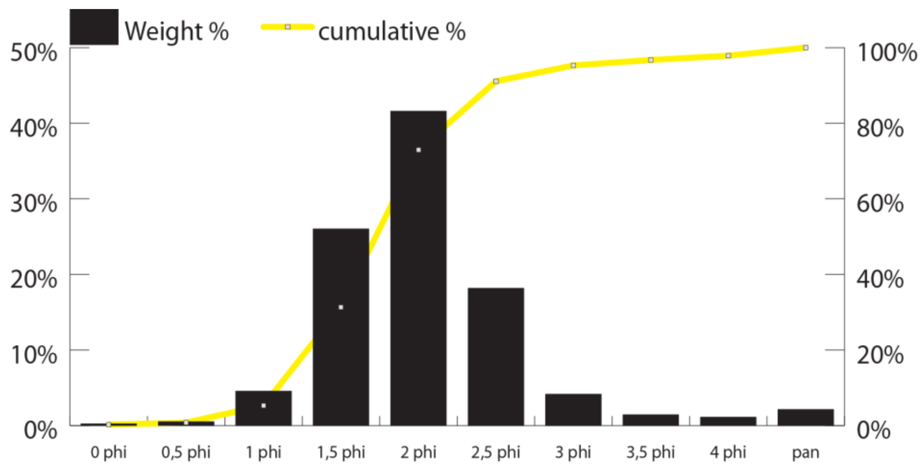


Figure 4-13. Section 48, layer Vb

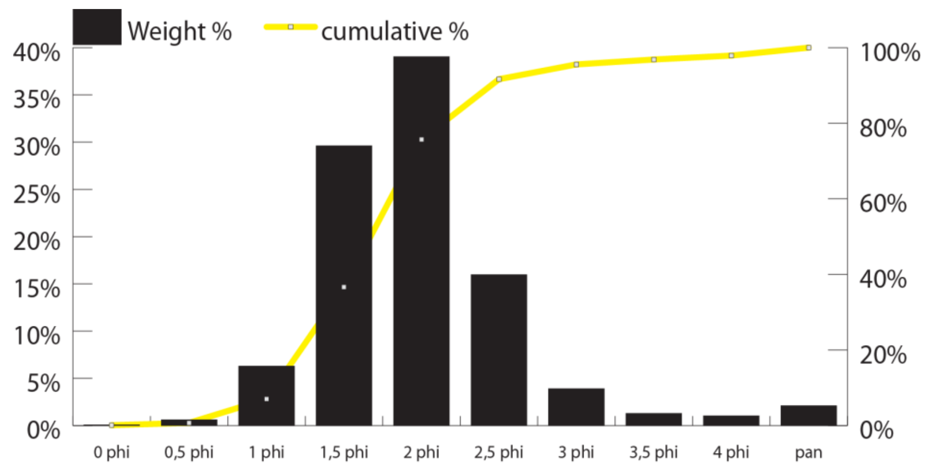


Figure 4-14. Section 48, layer VII.

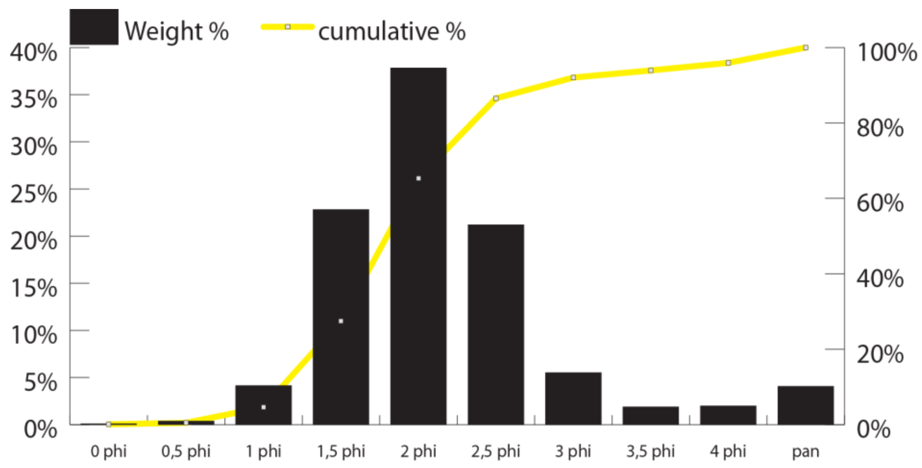


Figure 4-15. Section 48, layer VIIIb.

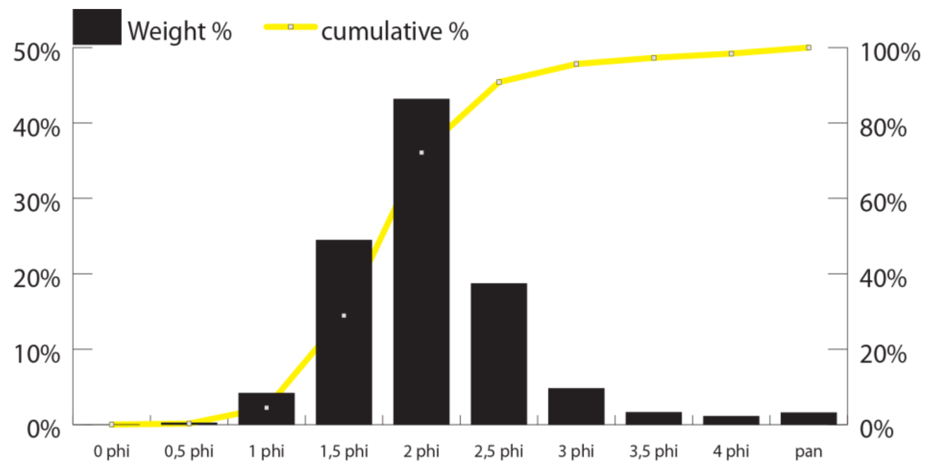


Figure 4-16. Section 48, layer Ixa.

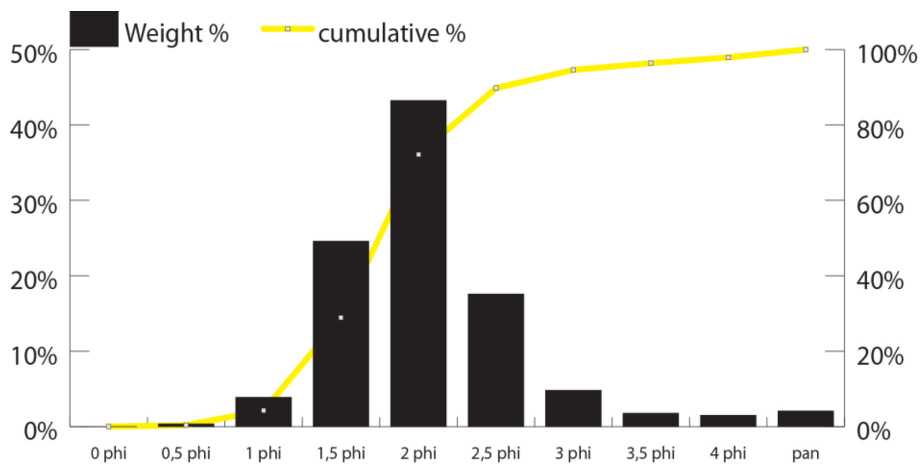


Figure 4-17. Section 48, layer Ixb.

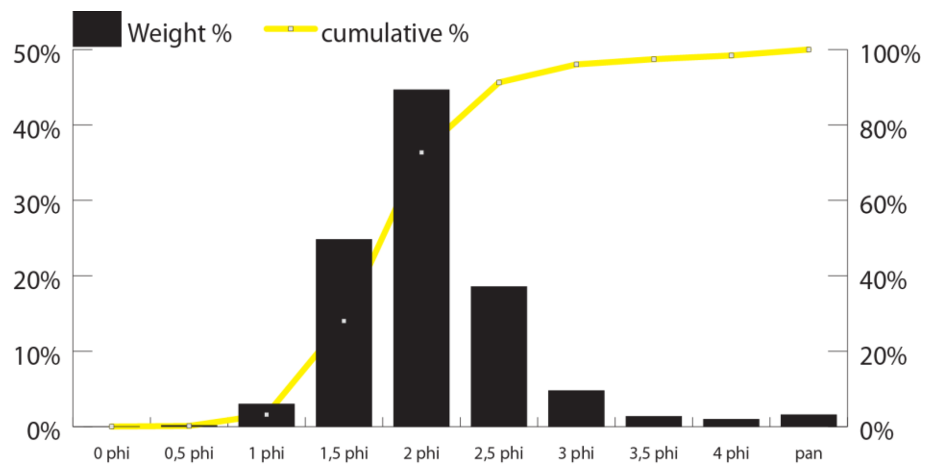


Figure 4-18. Section 48, layer Ixc.

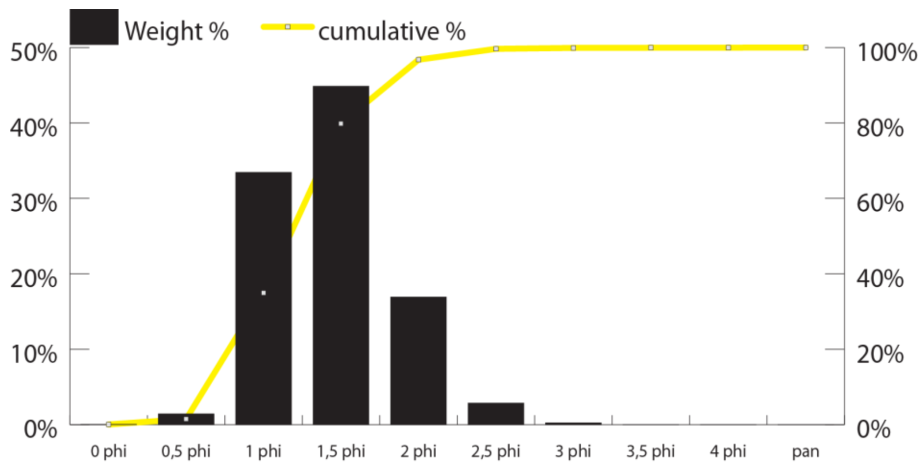


Figure 4-20. Section 52, layer I.

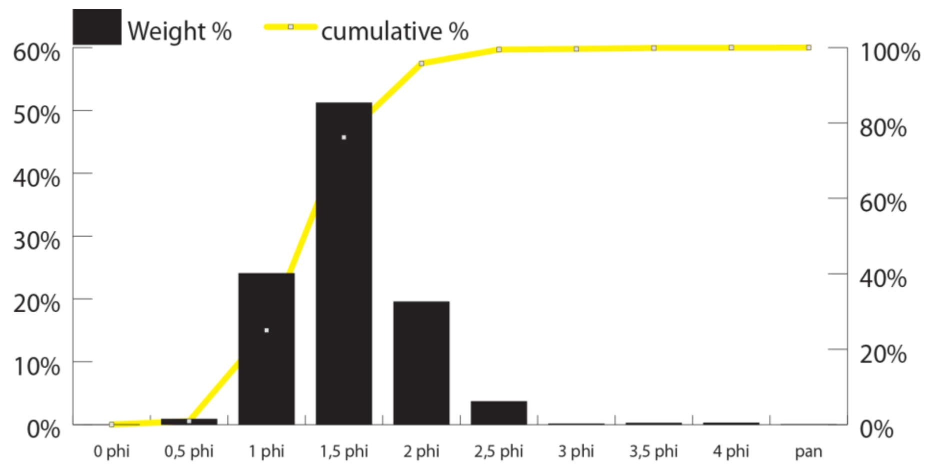


Figure 4-19. Section 52, layer III.

Table 2 and 3. The values of sand grain size distribution from sections 48 and 52. Table 2 is derived from graphic values, Table 3 is derived using gradistat.

Table 2										
Section/Layer:	**48/III**	**48/Va**	**48/Vb**	**48/VII**	**48/VIIIb**	**48/Ixa**	**48/Ixb**	**48/Ixc**	**52/I**	**52/III**
Graphic mean (M_Z)	1,78	1,76	1,74	1,71	1,84	1,76	1,78	1,78	1,17	1,26
Inclusive graphic standart deviation (σ)	0,67	0,62	0,58	0,59	0,70	0,56	0,59	0,54	0,44	0,43
Inclusive graphic skewness (S_K)	0,15	0,25	0,13	0,14	0,26	0,13	0,18	0,16	0,05	0,03
Graphic kurtois (K_G)	1,32	1,59	1,22	1,25	1,43	1,17	1,30	1,22	0,93	1,17

Table 3										
Section/Layer:	**48/III**	**48/Va**	**48/Vb**	**48/VII**	**48/VIIIb**	**48/Ixa**	**48/Ixb**	**48/Ixc**	**52/I**	**52/III**
Mean (M_Z)	1,77	1,74	1,74	1,69	1,82	1,76	1,76	1,76	1,17	1,25
Sorting (σ)	0,65	0,60	0,57	0,59	0,71	0,56	0,59	0,54	0,44	0,43
Skewness (S_K)	0,16	0,22	0,14	0,13	0,24	0,14	0,19	0,15	0,06	0,04
Kurtois (K_G)	1,24	1,52	1,20	1,24	1,45	1,19	1,30	1,21	0,97	1,19

The results from the graphic values and the gradistat were almost identical and did not vary in the outcome of in which catagory each sample should be in. In all layers from section 48 the most common grain size is 0.25 mm, followed by 0.355 mm and then 0.25 mm. The samples are therefore medium grained sand and moderately well sorted, typical for inland dunes. All the grain size graphs from section 48 are fine skewed and leptokurtic, except layer VII that is fine skewed and very leptokurtic. The positive values for skewnes in the samples from section 48 indicate that there is an excess of fine particles in the samples. The reason for a second peak, in the pan, on the graphs from section 48, is probably due to the leftovers of H_2O_2 in the sand after the removal of biological matter. As can be seen on the graphs from section 52, there are no such secondary peaks, and the sand samples from that section were not treated with H_2O_2. In both the layers from section 52 the most common grain size is 0.355 mm, followed by 0.5 mm and then 0.25 mm. The samples are therefore medium grained sand and well sorted, typical for inland dunes. Both the grain size graphs from section 52 are near symmetrical, indicating an almost normal distribution in the grain size from these two layers. Layer I is mesokurtic while layer III is lepotkurtic.

The sample statistics, see table 2 and 3, from both the sections indicate that the parent material is beach sand that has been washed ashore, and then fine material, silt and clay, has been separated and washed back into the sea by wave action (Friedman, G. M. And Sanders, J. E., 1978). This would explain the lack of silt and clay in the samples, as well as the low values in sorting and skewness. The sand left on the beach after the wave action, has then been transported into the valley by eolian transport.

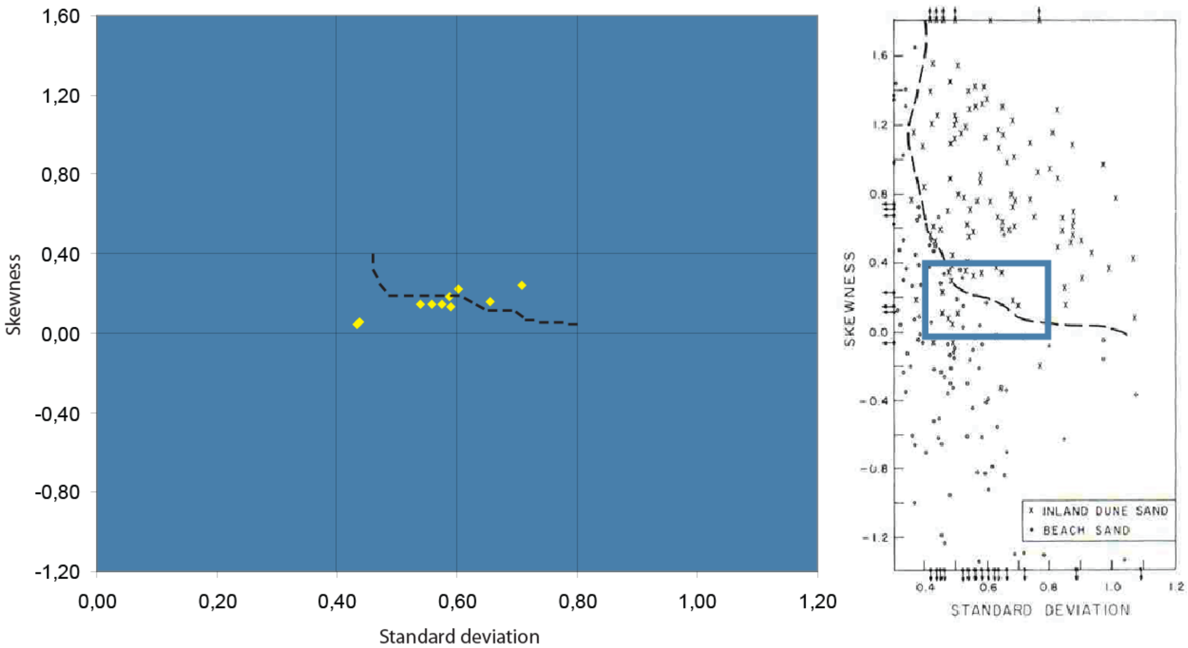


Figure 4-21. The graph on the left shows the skewness plotted against the standart deviation from section 48 and 52. The black line is from Friedman (1979), cf. Figure 10. The graph on the right is a plot of skewness and standard deviation for beach and inland dune sands from Friedman (1979). The blue square shows where the black line is from.

In Fig. 4.21 the skewness of the samples from sections 48 and 52 are plotted agains the standard deviation. The standard deviation values range from 0.43-0.71 while the skewness values range from 0.04-0.24. These figures indicate that the grain size distribution of sand samples is mainly consistent with inland dune sand deposits (Friedman, Gerald M., 1979).

On fig. 4.22 the mean was plotted against the standart deviation in order to distinguished between inland dune sand and river sand. As can be seen when comparing the two graphs from fig. 4.22, the samples from section 48 are all inland dune sand while the samples from section 52 fall slightly under the line, but are however most likely inland dune sand as well.

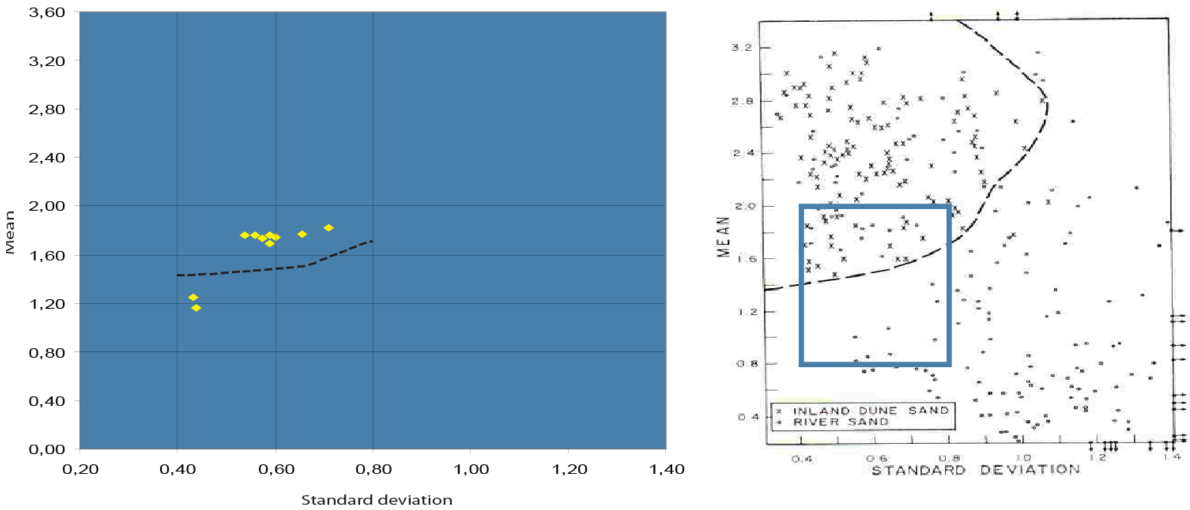


Figure 4-22. The graph on the left shows the mean plotted against the standart deviation from section 48 and 52. The black line is from Friedman (1979), cf. Figure 17. The graph on the right is a plot of mean and standard deviation, for inland dune and river sands from friedman (1979).The blue square shows where the black line is from.

In Fig. 4.24 the samples from section 48 and 52 are plotted on a probability scale. The weight from the pan was excluded, as material smaller than 4 phi was not analyzed. The reason for that is that in the sand samples from section 48 most of the material that was smaller than 4 phi was H_2O_2, and that is most likely the reason for the difference in the plots between section 48 and 52, as the two layers in section 52 have much smaller suspension population. The results from the pan were excluded from section 52 as well, to maintain coherent results.

On figs. 4.24-4.27 the probaility plot from Sauðlauksdalur is compared with examples from beach dune ridges from fig. 8 from Visher (1969). The plots are similar in most aspects but the plot from Sauðlauksdalur seems to missing most of its traction population and the suspension population from samples from section 48. The lack of traction population stems most likely from the distance between the beach and the sections locations, as bigger granuals would not have been transported such a distance from its source material. The lack of suspension population is probably due to the finer material than 4 phi not being suspended onto the beach, but rather washed back into the ocean by wave action. Material smaller than 4 phi is therefore not readily available to be transported into the valley and suspended there. Another factor is the difference in material. The material that makes up the sand in Sauðlauksdalur is both of marine origin and basalt fragments from bedrock made from basalt. The fragments from marine origin have less density and weight than the basalt fragments and could therefore skew the grain size, as bigger grains from marine origin weigh the same as smaller fragments of basalt.

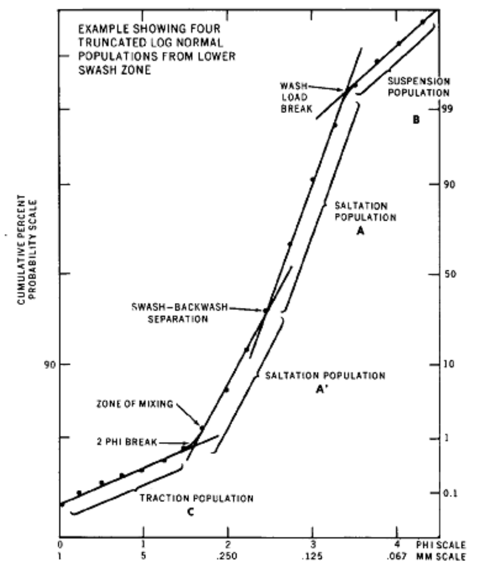


FIG. 4.—Relation of sediment transport dynamics to populations and truncation points in a grain size distribution.

Figure 4-23. Relation of sediment transport dynamics to populations and truncation points in a grain size distribution from Visher (1969).

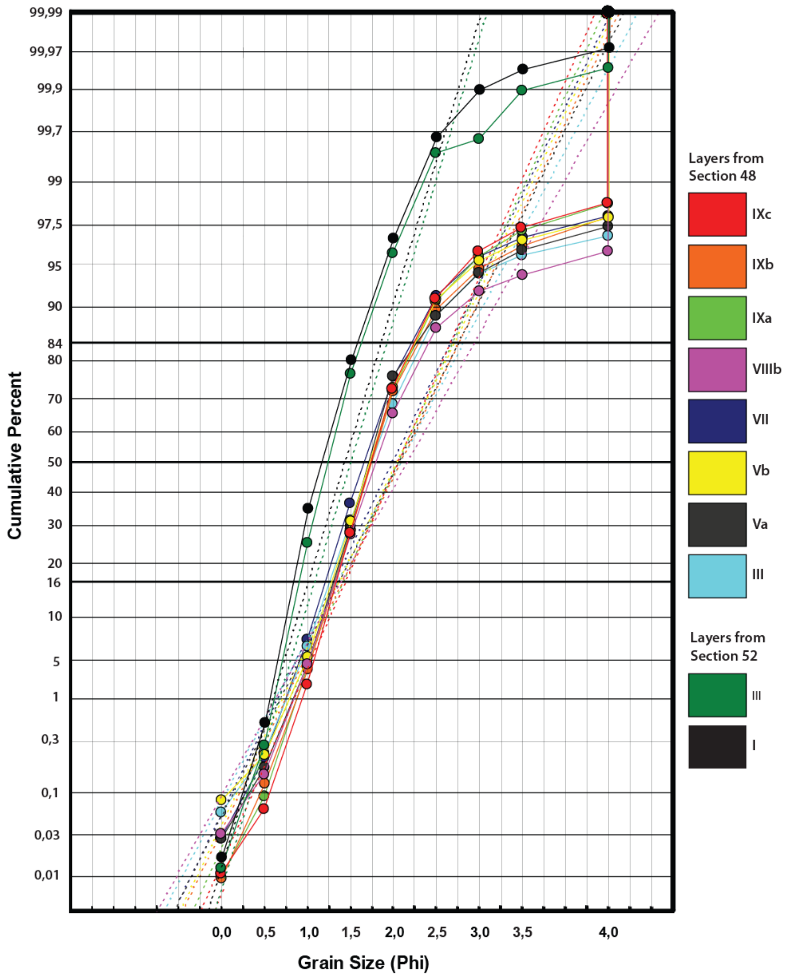
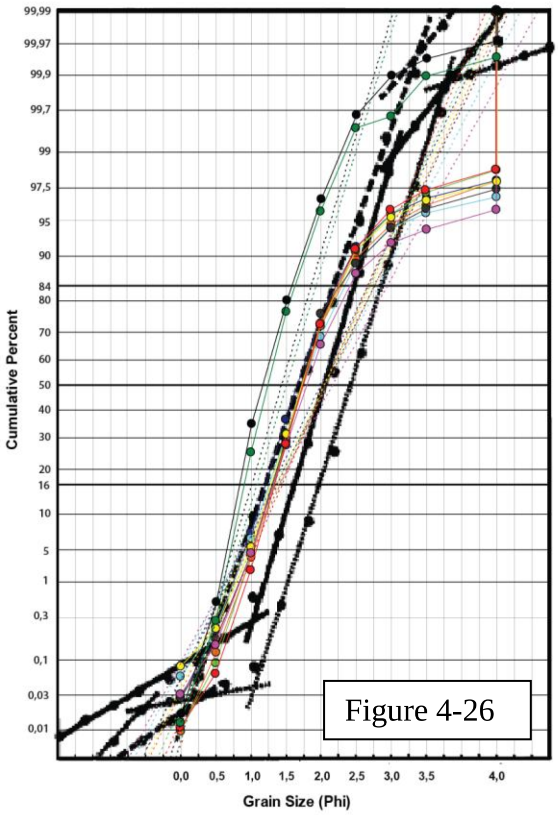
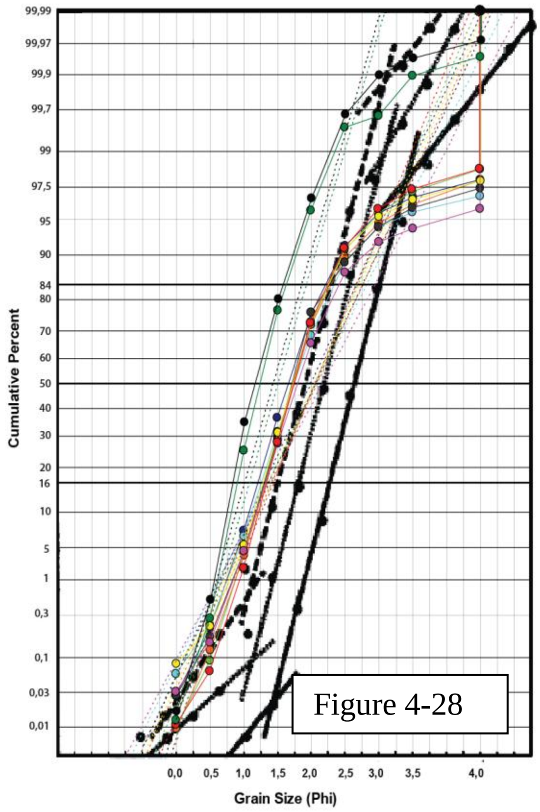
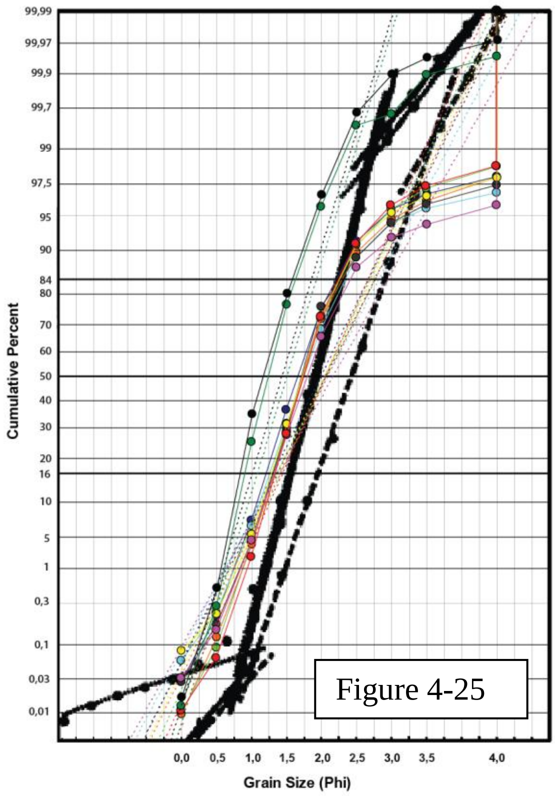


Figure 4-24. Propability plot from section 48 and 52 from Sauðlauksdalur. Each different color represents different layer from each section.







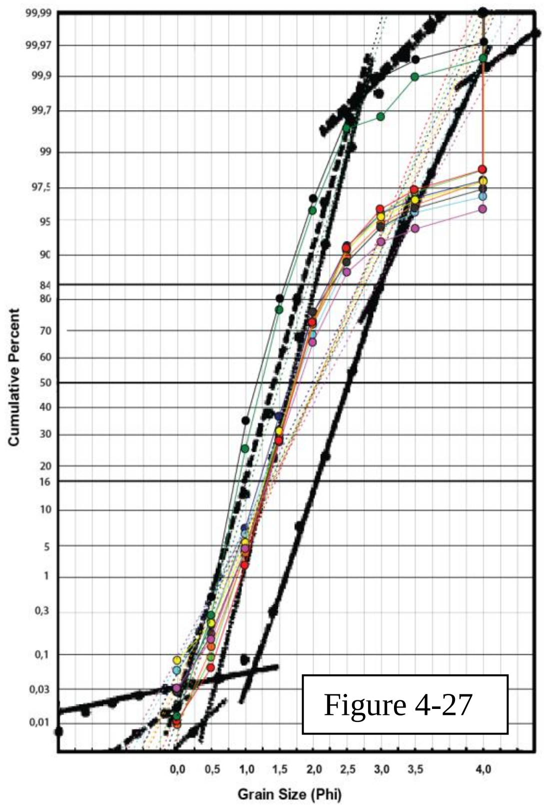


Fig 4-25 to 4-28. Shows the probability plot from sections 48 and 52 compared with probability plot of beach dune ridges from Visher (1969). cf. Figure 8.

4.4 Analysis of soil samples from section 48

The materials that made up the soil samples were mostly pollen, grass, small fragments of some sort of wood and other plant material. Four soil layers where chosen to be radiocarbon dated, due to the location of them within the section. These soil layers where layer II, IV, VI and X (although categorized as soil and sand layer). The sample from layers II, IV and VI were taken from the top part of the layers and from the bottom part of layer X. Layers II, IV and VI where almost identical in substance, containing the forementioned samples of plant material. There was no sand within layer II, layer IV was so thin it was difficult to determine weather or not the sand granules were from the soil layer itself or the sand layers above and below it, but must likely contained some sporadic traces of sand. Layer VI had no sand within itself, except on the boundaries with layer III and VII. Layer X was different in substance than the others, being a soil and sand layer. The plant matter that was found there was mostly small fragments of black vegetation, most likely some kind of wood, which was present in the other three samples as well, but in much less quantity. Layer X contained very high concentration of sand, roughly 50%. The four soil samples were sent to the Institut for Fysik og Astronomi at Aarhus University. The results from the carbon dating can be seen in table 4 and fig. 4.28.

Table 4. The radiocarbon dating results for layers II, IV, VI and X

layer #	material (species)	pMC	C14 age	d13C	calibration and correction	Calibrated age
II	Plant	101,49 ± 0,27	-119 ± 30	-27,68 ± 0,05	Kueppers04	1955.64AD (95.4%) 1956.26AD
IV	plant		145 ± 30	-28,49 ± 0,05	IntCal09	1717AD (29.1%) 1782AD
VI	Plant		400 ± 30	-26,68 ± 0,11	IntCal09	1436AD (76.5%) 1523AD
X	Plant	109,7 ± 0,32	-744 ± 30	-29,28 ± 0,05	Kueppers04	1997.1AD (89.1%) 2000.1AD

As can be seen in table 4 and fig. 28 the radiocarbon dating did not produce a coherent results. Two samples, from layer II and X, were bombed and the samples from layer IV and VI give a contradicting results. The reason for the failure of dating of layer II and X is unknown. The samples material from layer II are in almost all aspect identical to that of layers IV and VI, and would not have been expected to be bombed. Layer X had very different sample material and, being very close to the surface, that could have affected the outcome. Layer X is most likely a very young layer, probably started to form late in the 19th or early in the 20th century. The reason for the contradiction results from layer IV and VI can not be explained. It is a possibility that the samples got mixed somewhere during the labeling of the samples, or during the extraction of plant material from the samples or when the plant material was being prepeared to be shipped to the Aarhus University.

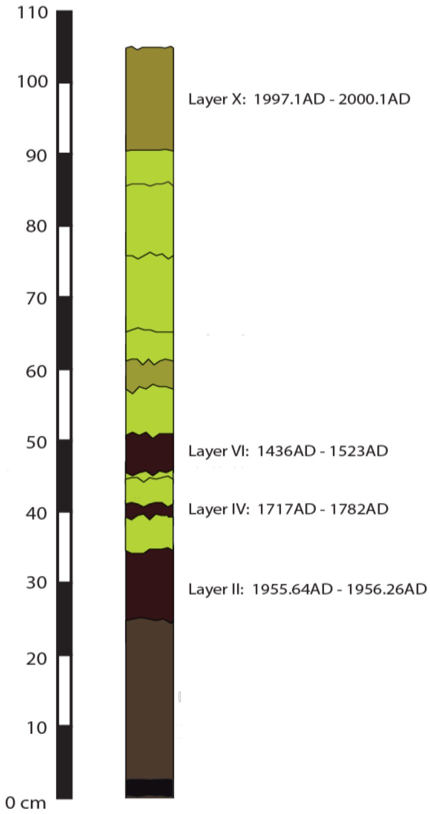


Figure 4-29. Column for section 48 showing the radiocarbon dates for layers II, IV, VI and X.

4.5 Chronology and historical accounts

From historical text we learn that eolian transport of sand into the valley had at least begun in the early 18th century. Other than that there is only the location of the farm itself, the valuation of the farm and the name that can give clues as to when the eolian transport of sand into the valley began.

It is unlikely that the farm had been placed there, when it was founded, if sand would have reached it and spoiled the farmlands around it. The valley is quite flat and has good vegetation extending further into it and settling the farm further in the valley would not have been a problem due to that. There are other factors that come into play though, as the valley experiences heavy snowfall during the winter time and having the farm further in the valley would probably cause extensive problems due to heavy snow. Another is that the location of the farm is in an area where streams are abundant and it is close to the lake. That could have been a factor in when the farm had been established. The ability to row a boat from the lake and into the fjord, as was possible in the late 17th/early 18th century (Eggert Ólafsson and Bjarni Pálsson, 1974), might have played a part for the location as well. This is specially true if at that time the sand-field was as hard to traverse as in the middle of the 18th century (Sýslulýsingar: 1744-1749, 1957).

The oldest valuation of the farm places it well above average for farms in Iceland. It is therefore likely that at the time of the valuation, the fields of Sauðlauksdalur were clear of sand, and perhaps there was a pause in the eolian transport at the time of the valuation. The valuation of the farm took place most likely in the 12th century (Arnór Sigurjónsson (1973). during the time of the Medieval warm period. If the eolian transport of sand is climate related, then there could have been a pause during the more favorable climate of the Medieval warm period. That would explain both the location of were the farm was placed and the valuation being so high at that time.

The name of the valley itself supports that there was a pause in the eolian transport of sand into the vally during, and two to three centuries after, settlement in the 9th century AD. One would imagine that the valley would have been called Sanddalur (i.e. Sand-valley) rather than Sauðlausdalur, if there had been a large sand-field in the middle of it. The name Sauðlausdalur, meaning a sheepless valley, is rather unlikely to give some indication of the environment at that time. It is very unlikely that there were no sheep in the valley during grazing periods, since there is abundance in vegetation and water there, and as can be seen from sections 45-47 the sand did not extend all the way into the valley. Sheep would have had an easy access to the valley as well, since the mountains surrounding it are not high nor steep. The only area where sheep could have had problem crossing is at the mouth of the valley, where the combination of water and sand can make it difficult to cross. Whether that was enough for the valley being called sheep less valley is doubtful. But Sauðlauksdalur, meaning good grazing lands, is quite accurate, since there are extensive fields there that have formed naturally and are deep enough in the valley so that they were not spoiled by the eolian transport of sand into the vally. The valley is also located in an area in the Vestfirðir where good grazing lands are not in abundance. It is then probable that the good grazing lands did outweigh the sand in importance when the valley got its name, specially if the sand field was smaller than it is today or there was a pause in the eolian transport.

The extent of the land degradation of Sauðlauksdalur can be seen well by how many cows it is able to support on winter fodder. The earliest estimate, probably made soon after settlement, has Sauðlauksdalur supporting 20 cows (Björn Halldórsson, 1983). In 1686 it is able to support six cows and in 1695 it is up to twelve cows (Björn Lárusson, 1967). Something must have happened in the valley during those nine years. The explanations for this increase are not given in the documents, but there are at least three plausible ones. The first explanation is that there was heavy eolian sand transport spoiling the fields around Sauðlauksdalur in 1686 but stopped soon after, so when the estimate was taken again in 1695, the fields were clear from sand and hay from those fields was in more abundance than before. It is therefore plausible that one of the soil layers formed during this time, perhaps layer nr. VIIIa or less likely layer VI. The second explanation is that Sauðlauksdalur could have had one or more outlying farms in 1686, but had been reintegrated into the main farm in 1695 and the third explanation is that some improvements were made in or around the farm itself that had the effect of increasing the volume of winter fodder available for the farm. In the middle of the 18th century the number of cows the farm is able to support is again down to six to eight (Björn Halldórsson, 1983). In 1847 the number is down to four (J. Johnsen, 1847) and in 1854 the number is down to three (Ólafur Pálsson, 1861). The land degradation is therefore severe, and almost all of the fields in 1854 must have been destroyed or being covered repeatedly by sand.

The first clear indication of eolian sand transport into Sauðlauksdalur from historical documents comes from Jarðabók Árna Magnússonar og Páls Vídalíns (1938) from the early 18th century. The extent of sand being brought onto the fields of the farm is hard to estimate, since “being heavily spoiled” is an estimate made at that time but no further description follows. It is also quite interesting that the farm Kvígindisdalur in the next valley was, apparently, suffering more from sand erosion and fields being spoiled by sand (Árni Magnússong and Páll Vídalín, 1938). That sand much have come from Sauðlauksdalur, since there is no beach in front of that valley, just a rock cliff. It is therefore likely that some sort of sandspit had formed at the mouth of Sauðlauksdalur, and most likely the sand-field in the valley as well. It can be seen from the current situation, that despite the valley being highly vegetated in many areas, sand can still reach the farmland around the farm. It would however not be described today as being heavily spoiled by sand, since the sand has little affect on the fields, so the eolian transport of sand in the early 18th century was likely much greater then than in modern days.

By the middle of the 18th century the sand transport had gotten worse (Þorsteinn Þorsteinsson, 1983) and probably reached its peak, a peak that lasted until the latter parts of the 19th century. During that time, the sand started (or continued) to actively destroy the farmland in the valley, either by suffocating the underlying growth or by causing land erotion. The efforts of Björn Halldórsson to stop the sand from destroying the farm seem to have been in vain, since the farmland there was badly damaged when he had arrived and his wall and other efforts seem to have had little affect, at least in the long run (Hannes Þorsteinsson, 1924). He did, however, manage to grow many different species at his farm, including having a field for his vegetables made not far from the farm. It is therefore plausible that a soil layer could have formed during Björns time there, most likely layer VIIIa. After his days in the valley, the farm continues to degrade, or at least does not improve, and no further attempts seem to have been made to battle the sand until the late 19th century.

During the first half of the19th century the farm is in bad shape. The encroaching sand continues to destroy fields around the farm and the farm itself is in jepardy of becoming abandoned (J. Johnsen, 1847). It is not until the end of the 19th century, when Þorvaldur Jakobsson became a priest in Sauðlauksdalur, that a renewed effort (Einar Helgason, 1902) started halting the aeolian sand transport from reaching the farmland. Most of the same procedures were made, as Björn had made a century earlier, but then the amount of eolian transportation into the valley seems to have diminished (Einar Helgason, 1902). It is therefore reasonable to believe that other causes for less eolian activity came into play. These causes could be many, as large environmental changes were both happening in Iceland and the valley itself at that time. In the valley, the lake had gotten smaller, reaching it current size somewhere in between 1915 and 1945. When the lake got smaller, small patches of land got exposed in front of the lake, where the groundwater level is almost at the surface or even at the surface (Einar Helgason, 1902). This patch could have hindered the sand from getting further into the valley as well. The river seems to have contained more water earlier than it has in modern days, and therefore had higher flow power. Old river beds, found in the sand-field, have quite large, rounded stones in the bottom,(see fig. 1.14) while current river bed is covered with dirt at the bottom and has no large stones in it at the surface. The transport of material must therefore have been higher at the first part of the 19th century and earlier to have been able to transport these stones, possibly during floods caused by snow-melt events while the snow cover was very extensive, e.g. during the LIA.

There is another factor that might have affected the eolian transport rate as well. Lyme grass was planted at the sandspit at the end of the 19th century (Einar Helgason, 1902), and it could have stabilized the sand somewhat, perhaps enough to diminished the amount of sand reaching from the sandspit onto the sand-field, which would in itself cause less loose sand being available in the sand-field to be transported further in the valley and onto the farmland.

There is at least a pause in eolian sand transport between 1894-1898 (Einar Helgason, 1902). and again from the beginning of the 20th (Einar Helgason, 1902) century to 1915/16 (Bjarni Sæmundsson, 1917). It is likely that during those two intervals layer X started to form. Layer X has started forming at the latest in 1919-1925 since, as can be seen on fig. 1.3, the fields around the farm are clear of sand and that the location of section 48 has vegetation cover at that time, and probably has had it since. Eolian sand transport continues to decrease as the 20th century passes, coincided with increase vegetation in the valley and efforts to protect the fragile environment in Sauðlauksdalur.

4.5.1 Plausible chronology derived from historical evidence and radiocarbon dating of the layers in section 48

By comparing the historical evidence to the ^{14}C results, a better picture can be formed. Due to the C14 dating failure of layers II and X, and the contradicting results from layers IV and VI, there are four plausible scenarios that the historical evidence can support, or at least do not contradict those results. The four plausible scenarios are; 1. That soil layer IV was correctly dated; 2. That soil layer VI was correctly dated; 3. That the results or the samples for layers IV and VI got turned around at some point. 4. That all the ^{14}C results are wrong.

1. If soil layer IV is correctly dated, then a soil layer 2,5 cm in thickness formed during the 18th century, and then two soil layers, layers VI and VIIIa formed after that time. That scenario is unlikely but soil could very well have formed in Sauðlauksdalur during the late 17th/early 18th century. Historical documents suggest that some eolian transport was taking place at the beginning of the 18th century in Sauðlauksdalur, but the amount of sand reaching the farm is unknown but most likely less than in the late 18th and 19th century. Both sedimentation rates and climate were favorable in Iceland during the late 17th/early 18th century as well (Larsen et al. 2011 and Geirsdóttir et al., 2009a). There are a number of things arguing against this scenario though. First, there is no sand within layer VI, so the eolian transport must have stopped completely or at least did not reach the farm during the formation of said soil layer. It is however fairly certain sand reached the farm repeatedly and seemingly on a regular basis after the middle of the 18th century and layer VI should therefore, if formed after the start of the 18th century, have sand within it. Second is that between the end of the formation of layer IV and today, three layers with soil have formed, layer VI, VIIIa and X. That does not allow a great time for each layer to have been formed.

2. If layer VI is correctly dated, then no distinct soil layers were formed in the sampling area between 15th/16th and late19th early 20th century. There is no contradicting evidence for that from historical documents, since the first available description of the farmland was made at the start of the 18th century. The only argument against this scenario, is that the farm seems to have been in settlement through out this period and that the farm changed owner multiple times during that time (Íslenskt fornbréfasafn, 1900-1904). The amount of sand being accumulated at section 48 location is considerable, with only one sand layer that has a high quantity of soil. It is therefore hard to imagine that during those five centuries, the field where section 48 is located could have been used for extensive harvesting or grazing, at least not without shoveling sand off from it. The heavy sand formation were section 48 is located does not prove that the farm should have been abandoned. The sand could have had a harder time reaching the eastern and southeastern parts of the fields than it did with the north and the west parts, and therefore enough of clear fields for hey harvest were in place, or at least to keep the farm from being abandoned. There is nothing from historical texts that can disproove this or confirm it. It is likely that some sort of a soil layer formed in those five centuries, most likely at the end of the 17th century and into the middle of the 18th. Layer VIIIa could have been

formed during either of those periods and that would fit in with both the geological- and historical data.

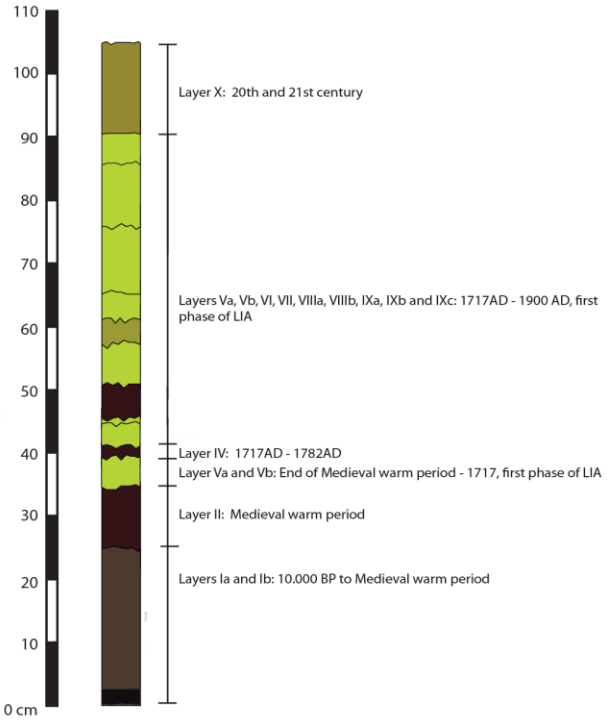


Figure 4-30. The column for section 48 if layer IV is correctly dated.

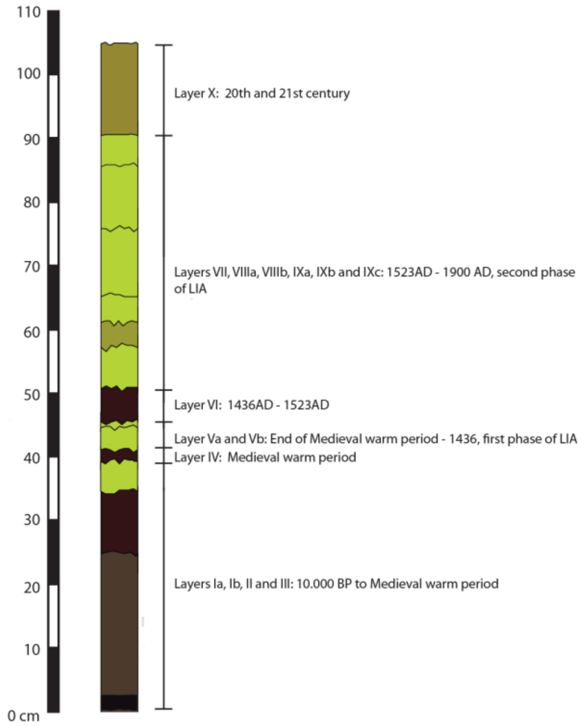


Figure 4-31. The column for section 48 if layer VI is correctly dated

3. If samples from layer IV and VI got turned around. This would seem to fit rather well with the historical data. Layer IV would then have been formed during the 15th/16th century, layer VI at the end of the 17th and the beginning of the 18th and layer VIIIa is then probably formed during the latter parts of the 18th century. This scenario would also suggest that the eolian transport of sand is strongly related to the LIA, as sand had not been transported so deep into the valley before the start of LIA and ceased being transported so deep at the end of LIA as well. Furthermore, both during the 15th/16th century and again at the end of the 17th and early 18th century there were periods with mild climate in Iceland (Massé, Rowland et al,, 2008 and Geirsdóttir et al., 2009a). The problem with this scenario is layer VI. If it was in fact formed during the 18th century, it should contain at least some sand, since eolian transport was problematic from the start of the 18th century and had become problematic in the middle of it. But the soil layer has no sand, except on its borders, which would suggest that it was formed during another time period. Another factor is that, there is no conclusive evidence wich would suggest that the soil samples, that got sent to Aarhus University for radiocarbon dating, ever got turned around.

4. If all the ^{14}C dates are wrong. The historical data has large holes in it, specially before the start of the 18th century. The data suggest that during the Medieval warm period, favorable conditions in Sauðlauksdalur prevailed. It is therefore highly likely that a soil layer was then formed, likely without any sand in it. The layer formed during the Medieval warm period would then most likely be either the top part of layer II or layer VI. Layer X started to form in the latter parts of the 19th century or the beginning of the 20th one. Layers Ixa – Ixc were likely formed during the latter part of the LIA, in the 17th, 18th and 19th centuries. Layer VIIIa and VIIIb could then have been formed during a more favorable time during the LIA,

perhaps at the start of the 16th century. Layer VI would than have been formed during the MWP and layer V and down, before that time.

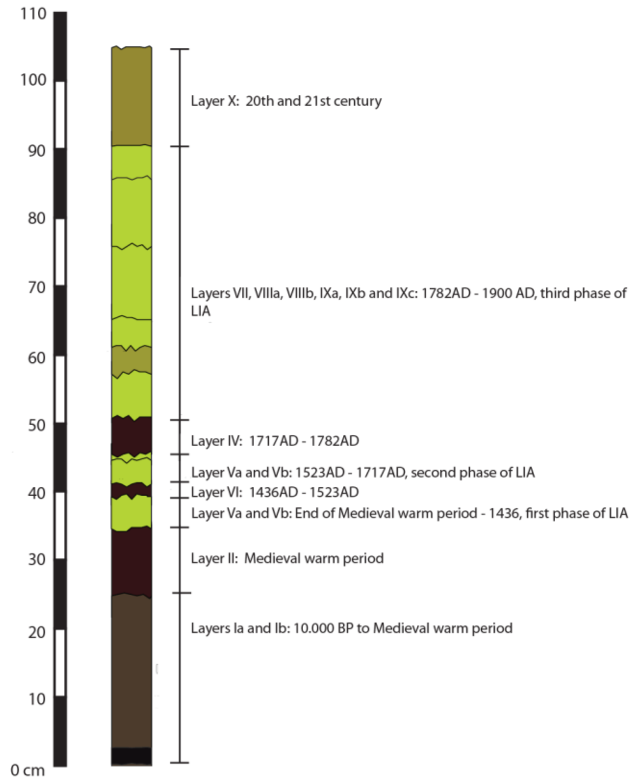


Figure 4-32. The column for section 48 if the dating of layers IV and VI got turned around.

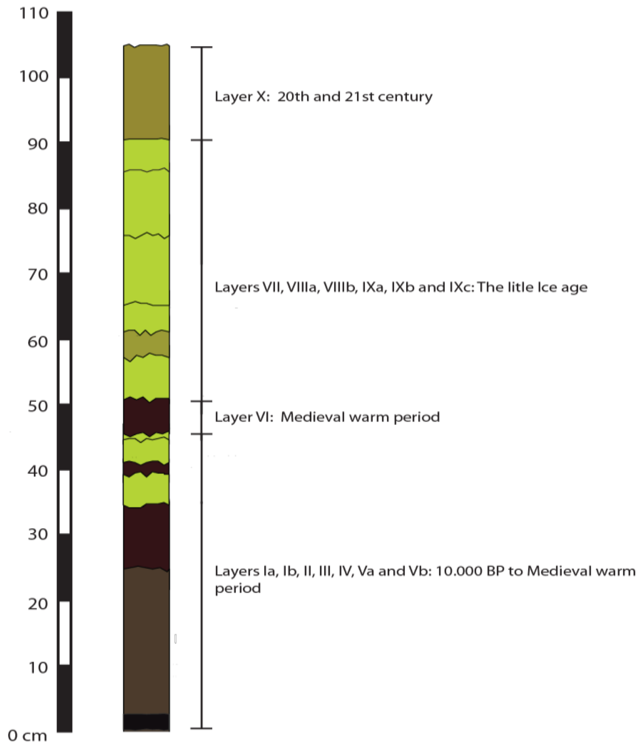


Figure 4-33. The likely dating of column for section 48 if all the radiocarbon dating failed

4.6 Chronology and sedimentation rates for section 48.

Due to the contradicting radiocarbon dating of section 48, the sedimentation rates for the area can not be calculated.

The are two dating columns that are more likely to give an accurate picture of the sedimentation build up in Sauðlauksdalur. These two columns can be seen on fig. 4.31 and 4.32 and the latter is the most likely one to give an accurate picture of the timing of each layer.

If the column, that asumes that the dating of layers IV and VI got turned around, the sedimentation rate between these two dated layers can be calculated. The sedimentation rate for that time period was 0,258 mm per year, or 5 cm in ca. 194 years. If the sedimentation rate was stable during the formation of the sand layers, then it would have taken the 46 cm thickness of all the sand layers 1785 years to form.

If the column, that asumes that the dating of layers II, IV, VI and X were all wrong (see fig. 4.32), then section can be devided between plausible periods when the layers were formed and the sedimentation rates calculated for each period. The first period, from 10.000 BP untill the start of the Medieval Warm Period, would then have formed 45,5 cm of layers in ca. 8950 years. That would mean that the sedimentation rate was 0,051 mm per year. The second period, the Medieval Warm Period, would then have formed 5 cm thick layer in ca. 350 years, or 0,143 mm per year. The third period, the Little Ice Age, would then have formed 40 cm of layers in ca. 650 years, or 0,615 mm per year. The fourth and final period, 20th and 21 century, would then have formed 15 cm thick layer in ca. 111 years, or 1,351 mm per year.

5 Discussions

5.1 Connections between increase in aeolian sand born material and climate change during the Little Ice Age

There are multiple scenarios in which the climate changes during the period of the LIA had an affect on the rate of eolian transport of sand into Sauðlauksdalur.

1. Increase in marine productivity due to change in ocean currents? The introduction of colder or warmer seas could have had a positive affect on marine productivity, specially the seashell forming species. This positive affect could be in the form of either increase production among one or more species, or that the range of fauna increased locally. With the increase in seashell production, more of seashells were washed up on the shore of Sauðlauksdalur, and caused increase in material that was available to be transported by wind into the valley.
2. Change in ocean currents? A change in currents around the Vestfjörð area, that could have affected the current system in Patreksfjörður and either increased or decreased the amount of sediment load it brought with it to be deposited in front of Sauðlauksdalur. The changes in the sediment being brought in by the currents could then have diminished or increased the amount of sediments available for eolian transportation into Sauðlauksdalur.
3. Climate change that caused changes in wind and weather patterns. If an increase in northern winds happened during the LIA, that could have caused more sediments being brought into the valley by eolian transport and for more extensive periods. The increase in northern wind would as well have cause a relative decrease in the affect of southern winds to bring sediments back out from the valley with eolian transport. This would have allowed more sand to reach far into the valley and to stay there accumulating into sand layers over time.
4. As colder climate prevailed during the LIA, vegetation got more fragile and decrease in productivity. The sand being transported into the valley would therefore have more affect on the vegetation, as it would take less of sand to suffocate the underlying vegetation, and vegetation would have a harder time growing through the sand which had settled on top of it. Less vegetation on the valley floor would also have allowed the sand to be transported more easily and further into the valley, as the vegetation ability to tie the sand down would have diminished. The affect of grazing animals on the vegetation could also have been a factor. Increase in grazing animals, or a decrease in vegetation growth would have had a negative affect on the overall vegetation cover and would have made erosion by wind more effective, causing more sand and soil to be eroded and carried into the valley.

6 Conclusion

The sand from the sections in Sauðlauksdalur originates from a marine source, consisting of shell fragments from a number of different species, with small basaltic rock fragments as well. The sand is washed onshore at the sandspit in front of Sauðlauksdalur. The grain size of the sand decreases with the distance from the sandspit and the grain size and the sorting of the sand has remained the same in Sauðlauksdalur during the history of eolian sand transport into the valley. The sand from section 48 was moderately well sorted and medium grained. The sand from section 52 was well sorted and medium grained. The samples that were taken from these two sections are typical for beach and inland sand dunes.

There have been at least four episodes where sand has been carried both in so much quantity and so far into the valley that the sand has formed its own sand layer around the farm Sauðlauksdalur. During these four episodes it seems that little vegetation has thrived to produce soil around the farm. The last episode is by far the largest episode, being 30 cm in thickness while the other three episodes led to an aggregate thickness of 16 cm.

There have been three episodes were soil layers have formed in section 48. Therefore the sand transport into the valley has ceased at least three times, allowing stable vegetation and soil formation. The largest episode of soil forming, when layer Ib and II were formed, most likely started to accumulate soon after the last glaciation of Iceland ended, and apparently takes place before any eolian sand transport into the valley begins. This first episode is 31 cm in thickness, while the other two episodes are 7,5 cm thick combined.

There have been two episodes where sand and soil layers were formed. This seems to indicate that at some point the sand transport into the valley was not so extensive that vegetation could not produce soil there, but enough to prevent soil layers to form without heavy concentration of sand mixed within it.

Due to the failure of the ^{14}C dating of the four soil samples, the age of the sand field and the timing of each period of increased eolian transport are unknown. Dating of layer IV is 1717-1782 AD and layer VI 1436 – 1523 AD, and therefore contradict each other and are both most likely wrong. The only possibility is that the dating samples got turned around at some point but there is nothing to indicate that that happened. The most likely scenario is that no distinct soil layers were formed during the LIA, layer VIIIa being the closest thing to a soil layer forming during that time. Layer VI was most likely formed during the MWP. The eolian sand tranport had therefore begun before the MWP, but in much less quantity than later during the LIA. During the LIA the sedimentation rates probably reached its peak between the middle of the 18th and the late 19th century.

From the sections taken, the current size of the sand-field, and topographical features, the spread of the sand in the valley can be estimated. The sand-field used to be much larger than it is today, and the sand reached far south into the valley. On fig. 6.1, the yellow area shows the likely area where sand was transported to.

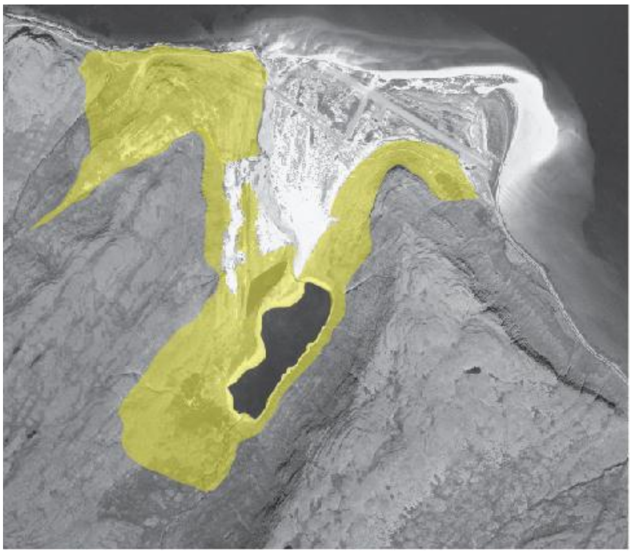


Figure 6-1. The yellow area shows the likely maximum extent of the eolian transport of sand in Sauðlauksdalur.

There are probably three main reasons why the sand did not reach further into the. The first reason is that the surface wind probably slows down when it reaches further into the valley, due to the vegetation, and then sediment that is being carried by the wind is deposited. The second reason is that rolling and sliding particles, and probably in some extent particles being carried by saltation and in suspension, are hindered from further travel by the vegetation deeper in the valley. The vegetaion deeper in the valley has probably been probably thicker, due to not being a harvested field but a prairie. A third reason is that there is an elevation increase not far south off the farm. This elevation increase could have easily made it impossible for larger particles to be carried further upslope into the valley.

It is interesting, as can be seen on fig. 4.1 that the three sections at the mouth of the valley only contain sand layers, both the sections in the middle of the valley contain both soil and sand layers, while the three sections taken further into the valley contain only soil. It is therefore likely that sand did not reach further into the valley than where section 45,46 and 47 are. In the middle of the valley there seem to have been periods where sand did not reach so far into the valley and soil was able to form, only to be covered by sand in later period. At the mouth of the valley, soil layers seem to have been unable to form, or if they formed at all were either buried deep beneath the sand or were eroded away when the eolian transport of sand increased again.

The sand-field and the sandspit are still mostly uncovered with vegetation, but the vegetation that is already there seems to be keeping the sand-field from growing larger, and was in fact spreading over the unvegetated parts of Sauðlauksdalur. Due to the efforts of The Soil Conservation Service of Iceland in Sauðlauksdalur being cancelled, the future of the vegetation cover in Sauðlauksdalur is unclear but the cover seems to be holding at present. Despite the progress in increasing the vegetation cover in Sauðlauksdalur, it most likely would not take a major climatic change to destroy most of the current vegetation that is covering the sand, and submerge Sauðlauksdalur once again beneath a sand carpet.

The problems encountered in the absolute dating of soil samples remain unexplained. Conceivably, the section site may have been subject to reclamation efforts involving digging and spreading of older soil over younger deposits, and as mentioned above, mistakes in labeling or sample preparation cannot be excluded with absolute certainty. A series of pits up-valley, away from the cultivated areas around the farm, and additional radiocarbon dates might eliminate these uncertainties.

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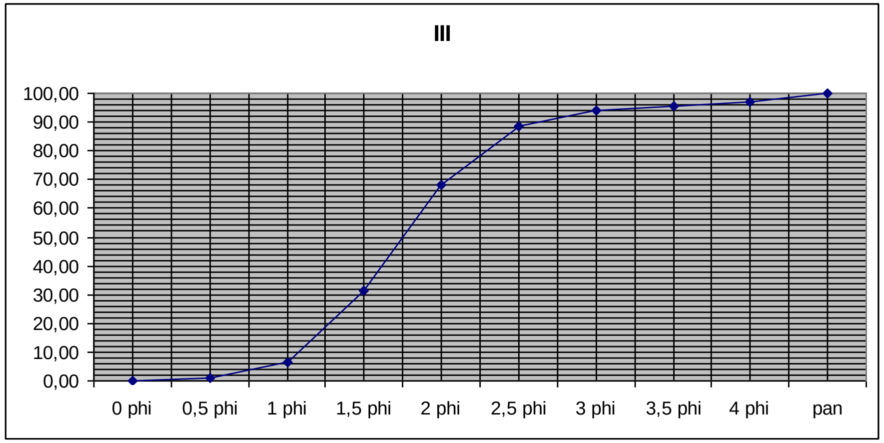
Appendix A – Tables and cumulative graphs for the sand layers from section 48 and 52

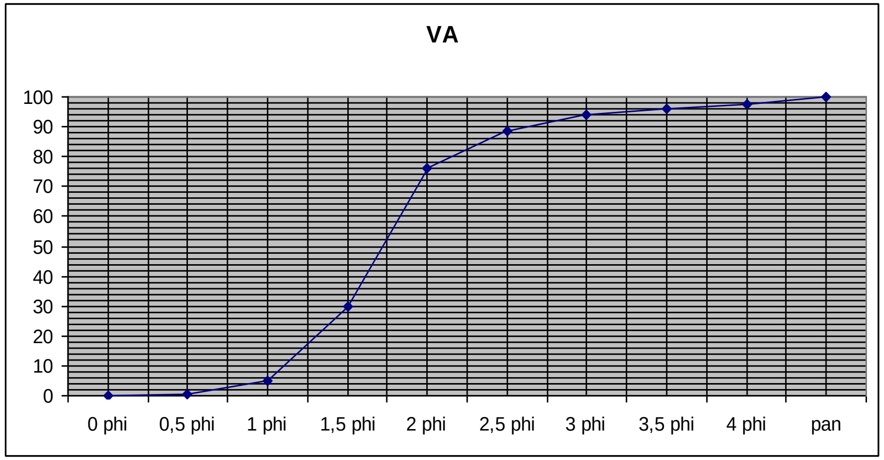
Section 48, layer III

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,13	0,18%	0,18%
0,71	0,45	0,62%	0,80%
0,5	3,97	5,50%	6,30%
0,355	18,21	25,22%	31,52%
0,25	26,61	36,85%	68,37%
0,18	14,72	20,38%	88,76%
0,125	3,87	5,36%	94,11%
0,09	1,16	1,61%	95,72%
0,063	0,9	1,25%	96,97%
pan	2,19	3,03%	100,00%
Total	72,21		



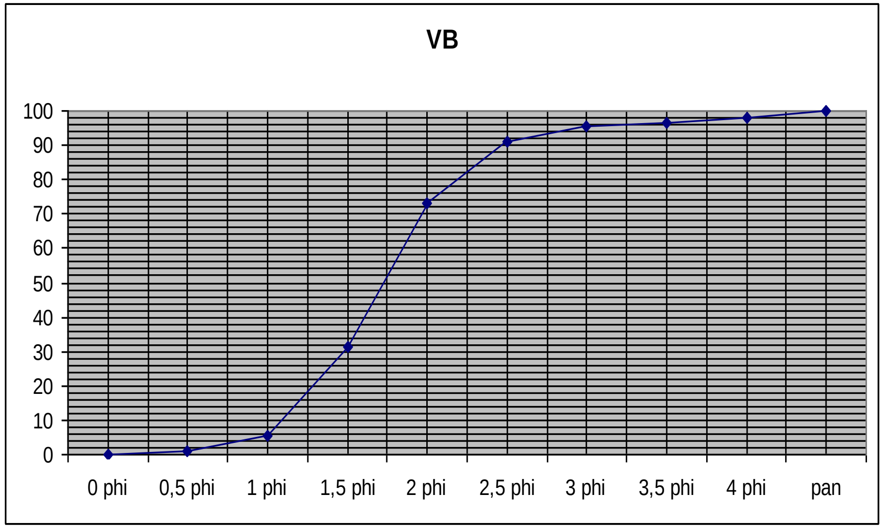
Section 48, layer VA

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,1	0,09%	0,09%
0,71	0,53	0,48%	0,57%
0,5	4,58	4,17%	4,74%
0,355	27,82	25,33%	30,07%
0,25	50,65	46,11%	76,18%
0,18	13,73	12,50%	88,68%
0,125	6,05	5,51%	94,19%
0,09	2,07	1,88%	96,08%
0,063	1,54	1,40%	97,48%
pan	2,77	2,52%	100,00%
Total	109,84		



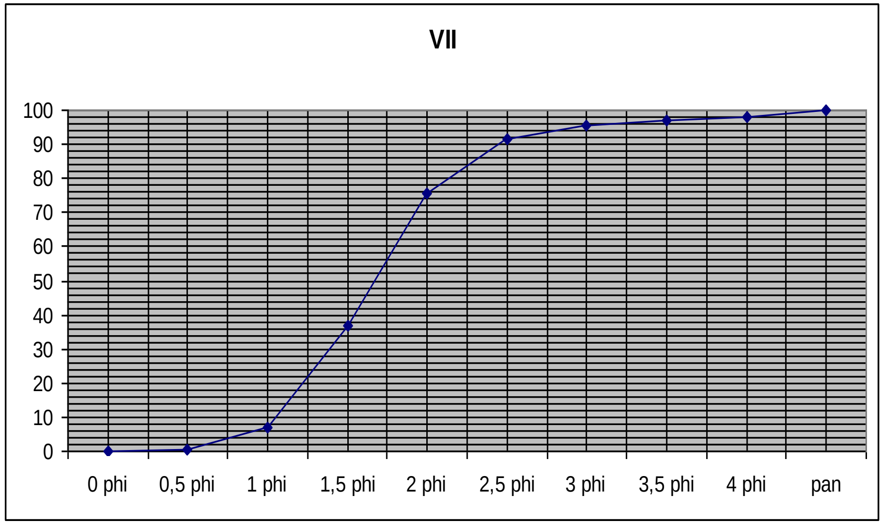
Section 48, layer VB

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,38	0,24%	0,24%
0,71	0,81	0,52%	0,76%
0,5	7,1	4,55%	5,31%
0,355	40,6	26,03%	31,34%
0,25	64,89	41,60%	72,94%
0,18	28,35	18,17%	91,11%
0,125	6,51	4,17%	95,29%
0,09	2,27	1,46%	96,74%
0,063	1,74	1,12%	97,86%
pan	3,34	2,14%	100,00%
Total	155,99		



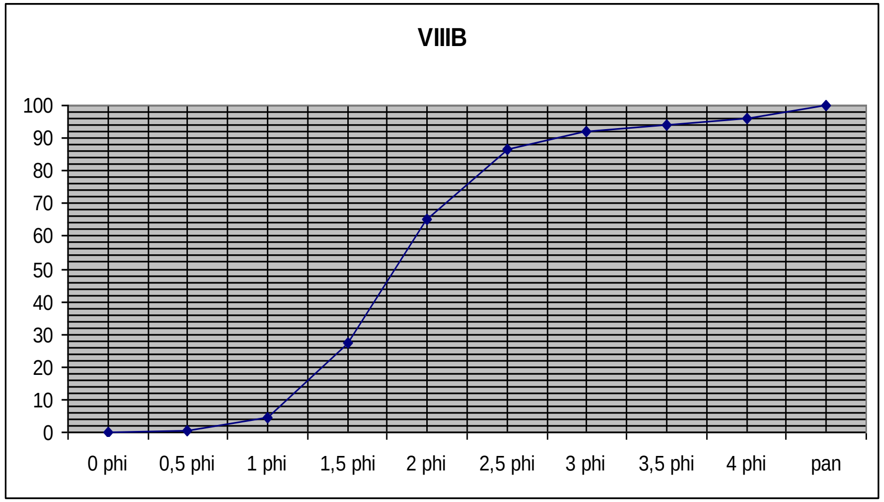
Section 48, layer VII

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,2	0,09%	0,09%
0,71	1,42	0,63%	0,71%
0,5	14,3	6,30%	7,02%
0,355	67,19	29,62%	36,63%
0,25	88,59	39,05%	75,68%
0,18	36,23	15,97%	91,65%
0,125	8,87	3,91%	95,56%
0,09	2,94	1,30%	96,86%
0,063	2,37	1,04%	97,90%
pan	4,76	2,10%	100,00%
Total	226,87		



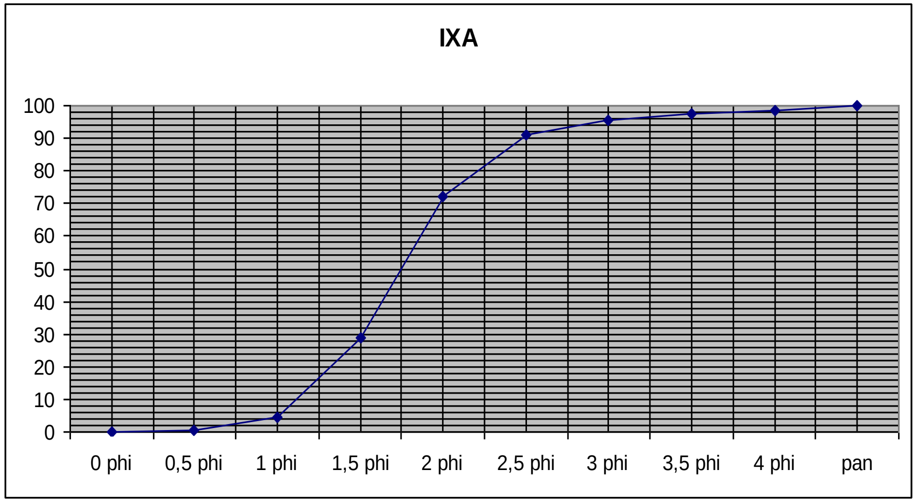
Section 48, layer VIIIB

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,16	0,10%	0,10%
0,71	0,59	0,38%	0,48%
0,5	6,5	4,16%	4,64%
0,355	35,67	22,83%	27,47%
0,25	59,13	37,85%	65,32%
0,18	33,13	21,21%	86,53%
0,125	8,6	5,51%	92,04%
0,09	2,96	1,89%	93,93%
0,063	3,13	2,00%	95,94%
pan	6,35	4,06%	100,00%
Total	156,22		



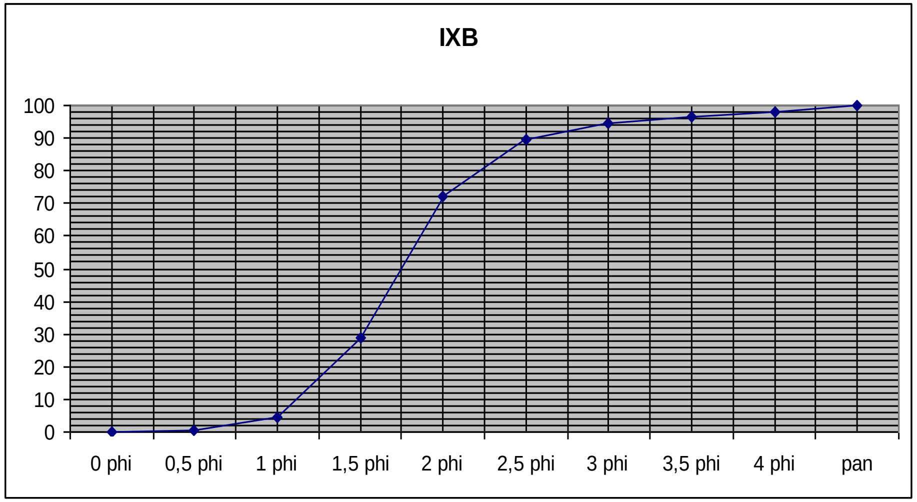
Section 48, layer IXA

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,11	0,03%	0,03%
0,71	0,92	0,25%	0,28%
0,5	15,5	4,19%	4,47%
0,355	90,43	24,47%	28,94%
0,25	159,56	43,18%	72,12%
0,18	69,16	18,71%	90,83%
0,125	17,78	4,81%	95,64%
0,09	6,05	1,64%	97,28%
0,063	4,14	1,12%	98,40%
pan	5,91	1,60%	100,00%
Total	369,56		



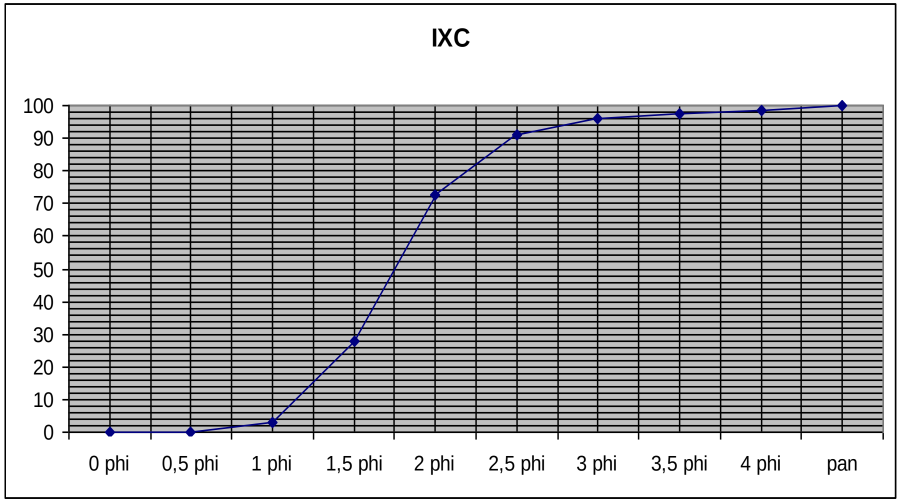
Section 48, layer IXB

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,17	0,03%	0,03%
0,71	2,05	0,36%	0,39%
0,5	22,38	3,91%	4,30%
0,355	140,92	24,61%	28,90%
0,25	247,75	43,26%	72,16%
0,18	100,86	17,61%	89,77%
0,125	27,64	4,83%	94,60%
0,09	10,27	1,79%	96,39%
0,063	8,69	1,52%	97,91%
pan	11,97	2,09%	100,00%
Total	572,7		



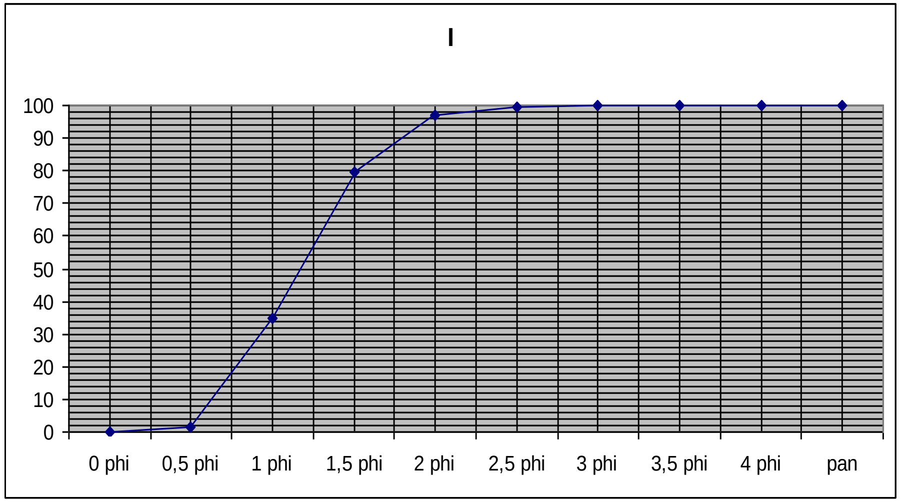
Section 48, layer IXC

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,14	0,03%	0,03%
0,71	0,68	0,16%	0,19%
0,5	13,07	3,00%	3,19%
0,355	108,12	24,83%	28,02%
0,25	194,51	44,66%	72,68%
0,18	80,92	18,58%	91,26%
0,125	20,87	4,79%	96,05%
0,09	6,02	1,38%	97,44%
0,063	4,28	0,98%	98,42%
pan	6,89	1,58%	100,00%
Total	435,5		



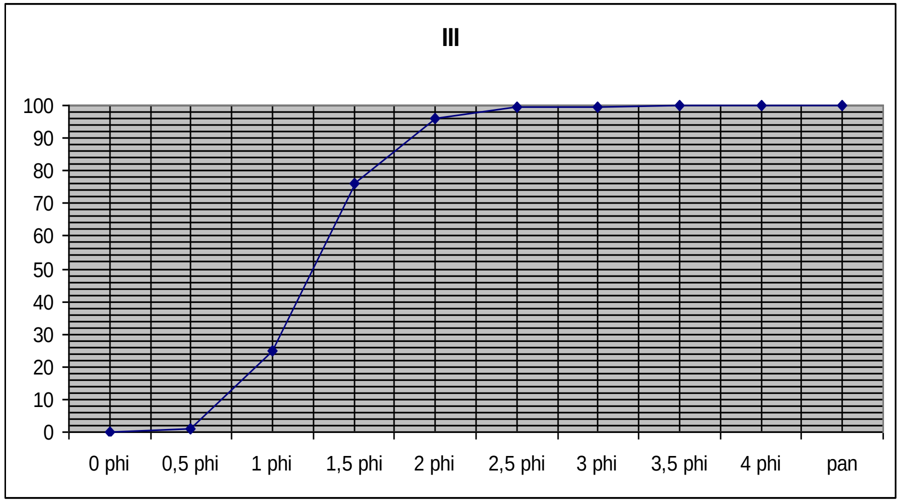
Section 52, layer I

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,15	0,05%	0,05%
0,71	4,14	1,44%	1,49%
0,5	96,52	33,47%	34,96%
0,355	129,4	44,88%	79,84%
0,25	48,83	16,93%	96,77%
0,18	8,3	2,88%	99,65%
0,125	0,72	0,25%	99,90%
0,09	0,12	0,04%	99,94%
0,063	0,08	0,03%	99,97%
pan	0,09	0,03%	100,00%
Total	288,35		



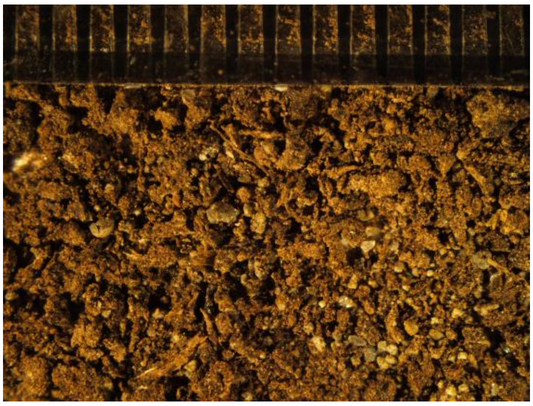
Section 52, layer III

Sieve size	Wt. Retained	Weight	Cumulative
(mm)	(gr)	(%)	(%)
1	0,25	0,04%	0,04%
0,71	5,75	0,89%	0,93%
0,5	156,01	24,07%	25,00%
0,355	331,9	51,22%	76,22%
0,25	126,74	19,56%	95,78%
0,18	23,94	3,69%	99,47%
0,125	1,04	0,16%	99,63%
0,09	1,71	0,26%	99,90%
0,063	0,31	0,05%	99,94%
pan	0,37	0,06%	100,00%
Total	648,02		

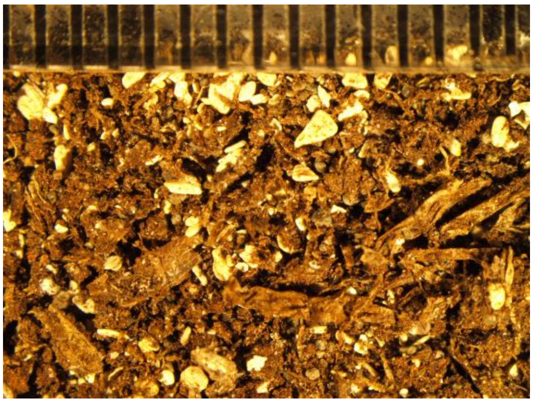


Appendix B –Pictures of the soil layers from section 48

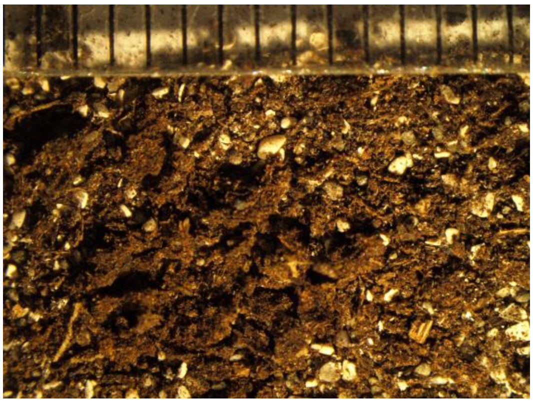
Layer II



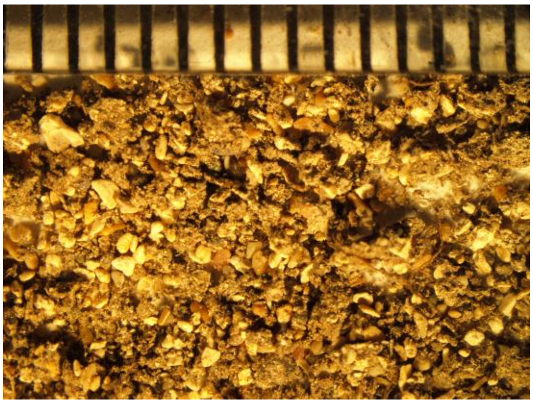
Layer IV

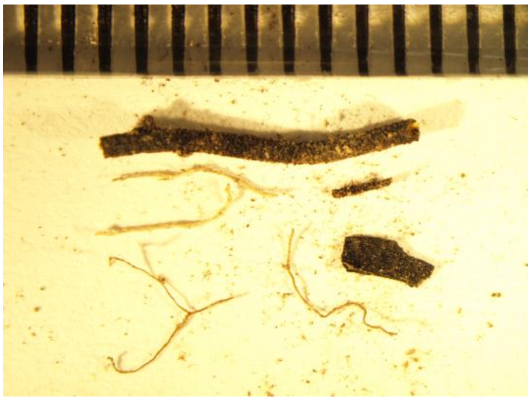


Layer VI



Layer X





Sample II

Sample IV

Sample VI

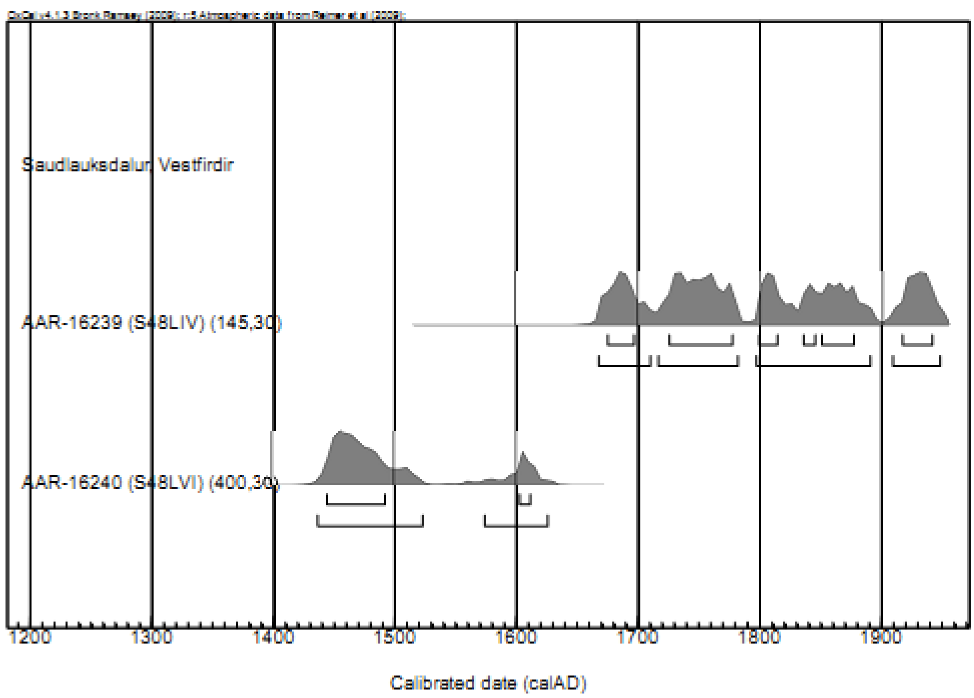
Sample X

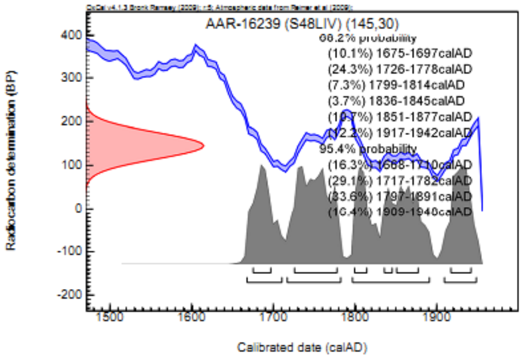
Appendix C – The complete result from the radiocarbon dating

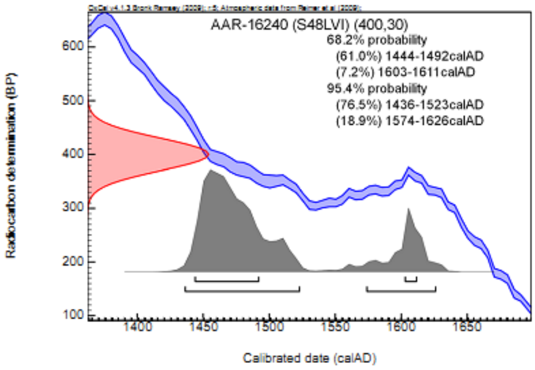
“14C ages are reported in conventional radiocarbon years BP (before present = 1950) in accordance with international convention (M. Stuiver & H.A. Polach: Discussion of reporting 14C data. Radiocarbon 19(3) (1977) p. 355).”

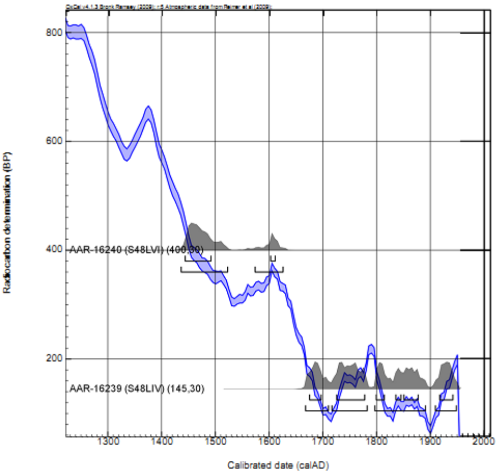
“Thus, all calculated 14C ages have been corrected for fractionation so as to refer the result to be equivalent with the standard δ13C value of -25‰ (wood). Reported δ13C and δ15N values have been measured by high-precision stable-isotope mass spectrometry. The values represent the isotopic composition of the original sample and is therefore useful for interpretation regarding association with the terrestrial/marine/freshwater food chains as well as trophic levels.”

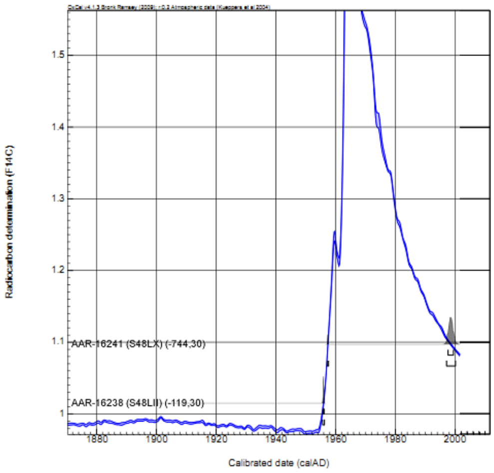
“Calibrated ages in calendar years have been obtained from the calibration curves in Reimer et al. 2009 Radiocarbon vol. 51(4) pp 1111-1150 by means of the Oxcal v4.1 calibration programme (Bronk Ramsey., 2009, Radiocarbon, 51(1) 337-360) using the terrestrial calibration curve, IntCal09 (for marine samples, see below). The probability method has been used to calculate the calibrated age ranges corresponding to 68.2% probability (1 sigma) and 95.4% probability (2 sigma) with the probability of each range given in brackets (indicating the probability that the true date belongs to the interval in question).”

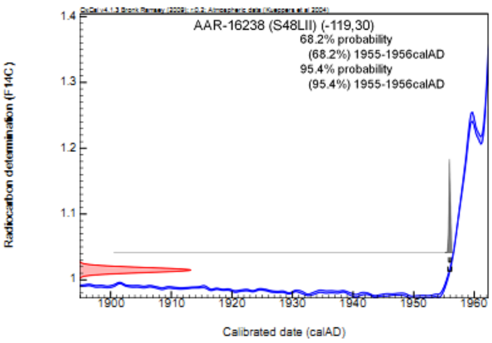


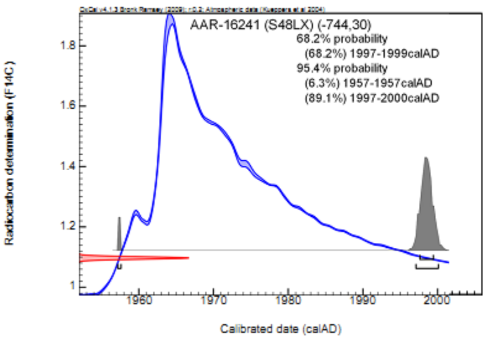

AAR-16239 (S48LIV) (145,30)
68.2% probability
(10.1%) 1675-1697calAD
(24.3%) 1726-1778calAD
(7.3%) 1799-1814calAD
(3.7%) 1836-1845calAD
1851-1877calAD
1917-1942calAD
95.4% probability
(16.3%)
(29.1%) 1717-1782calAD
(10.4%) 1909-1940calAD
Radiocarbon determination (BP)
Calibrated date (calAD)


AAR-16240 (S48LVI) (400,30)
68.2% probability
(61.0%) 1444-1492calAD
(7.2%) 1603-1611calAD
95.4% probability
(76.5%) 1436-1523calAD
(18.9%) 1574-1626calAD
Radiocarbon determination (BP)
Calibrated date (calAD)


AAR-16239 (S48LIV) (145,30)
Radiocarbon determination (BP)
Calibrated date (calAD)


AAR-16241 (S48LX) (-744,30)
AAR-16238 (S48LII) (-119,30)
Radiocarbon determination (F14C)
Calibrated date (calAD)


AAR-16238 (S48LII) (-119,30)
68.2% probability
(68.2%) 1955-1956calAD
95.4% probability
(95.4%) 1955-1956calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)


AAR-16241 (S48LX) (-744,30)
68.2% probability
(68.2%) 1997-1999calAD
95.4% probability
(6.3%) 1957-1957calAD
(89.1%) 1997-2000calAD
Radiocarbon determination (F14C)
Calibrated date (calAD)