Master Thesis, Department of Geosciences

Tidal Flat Sedimentation in an Arctic Environment

– a Field Study from Braganzavågen, Spitsbergen

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Master Thesis in Geosciences

Discipline: Geology

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June 3rd, 2013

Title: Tidal Flat Sedimentation in an Arctic Environment
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Front page: Background view from the field area in Braganzavågen.

Abstract

This study is located in the innermost part of Van Mijenfjorden, in the bay of Braganzavågen; close to the mining town of Svea. Two seasons of field work have been conducted during summer 2011 and 2012. During this field work the tidal flat was studied in detail to get an understanding of how tidal flat sedimentation in arctic environments behaves.

Since there previously has not been done much work on tidal flats in arctic environment, studies from other latitudes are crucial in the overall understanding of the depositional environment in Braganzavågen. However, the main emphasis is based on observations and data collected in field.

From the profiles made during field work, logs have been constructed, which are the basis for this thesis. In addition observations of morphology and sampling have been done. From the samples that have been collected there have been done grain size analysis and further mean grain size, skewness and sorting have been calculated.

It is believed that parameters like mean grain size, skewness and sorting can give an indication about the depositional environment for the sediments that have been studied. For the discussion the focus is on the depositional processes in the studied area in Braganzavågen, and in what extent the tidal sedimentation is the main process. Additionally study how this area behaves; where landforms/sediments are dependent on nearby features like alluvial fan, fluvial systems, marsh areas and tidal systems.

Acknowledgements

First a great thank you to my secondary supervisor, prof. Henning Dypvik, with your open door policy, great discussions, understanding and for always being available on mail. Also for pushing me to work steadily the whole time, without you there would not have been much of a thesis.

I would also like to thank my two field assistants Daniel Kramer and Matt Strzelecki for great help and support during the time in the mud, and not at least for being great polar bear guards. Also great thanks to the staff in Svea for excellent food and for making the field work a little easier.

Not to forget my fellow students and good friends at ZEB for great lunch breaks, motivation and discussions. Also big thanks to Mofak Naoroz for teaching and helping me with the grain size coulter.

Also my supporting family and friends deserve a thank you for always have encouraged me through this process; especially my father, grandmother, cousin Katrine, Magnus and Guri; for helpful proofreading of my work.

My supervisor prof. Maria Jensen deserves a thank you for giving me this opportunity to write this thesis and the freedom and trust she has given me through this work.

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1. Introduction

1.1. Object of thesis

This study is about gaining an understanding on depositional environments in the arctic, based on a field study from Braganzavågen, Spitsbergen. Field work for this study was conducted on a tidal flat located in Svalbard (Figure 1), where visual observations in the field are the main emphasis for this thesis. The purpose of this study is based on profiles (logs), surface sediments and morphology from the tidal flat in Braganzavågen, Van Mijenfjorden, Svalbard. Very little work has been done on high-latitude tidal deposits, and there is a lack of knowledge regarding tidally influenced sedimentary systems in such environments. This thesis project will contribute to this gap of knowledge. The main goal is to make sedimentological descriptions and interpretations of tidally influenced deposits in Braganzavågen based on surface morphology, shallow sections, surface descriptions and sections from the supra tidal part of the system. The data that have been collected in field will be described and compared to other examples of tidal flats to discuss any similarities and differences between them.

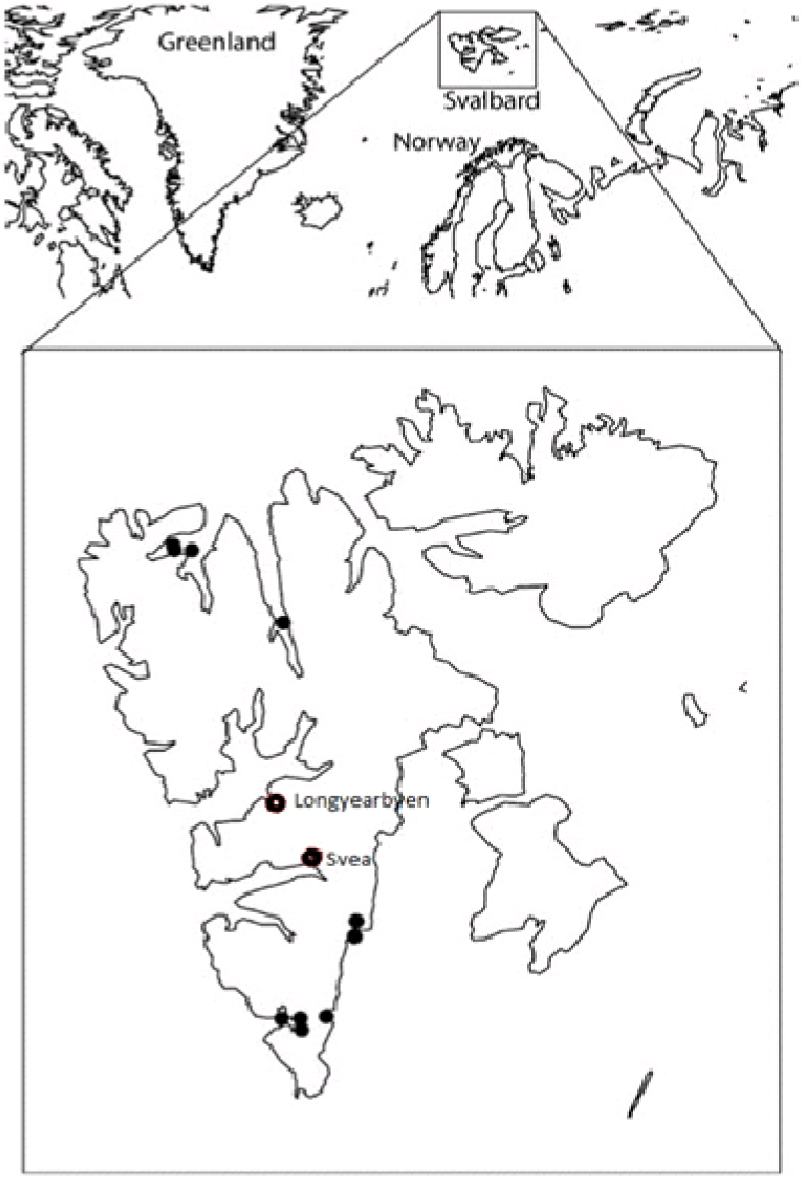

***Figure 1**: Regional location of Svalbard, and map over Svalbard with locations of Longyearbyen and Svea marked in red circles (modified from Glad et al. (2010)).*

The thesis will be based on data collected in field during summer season 2011 and 2012. The following samples have been collected; surface samples for grain size analysis and a general description of the surface morphology. Logs made in field is an important factor for the overall understanding of the depositional environment in Braganzavågen. Those data will be seen in combination with aerial photos images in order to gain knowledge on the entire sedimentary system. Aim of the field work is to describe the present surface morphology and shallow sections. This will results in a model of the sedimentation in the studied area.

All appendices referred to in the text are presented on the attached CD-ROM.

1.2. Geological setting

Braganzavågen is located on the border between the Central Tertiary Basin and Mesozoic cover rocks, as seen in Figure 3. The Mesozoic cover rocks in this case are related to the Adventdalen Group. When it comes to the Central Tertiary Basin it has gone through at least 2,5km of subsidence in the centre. It is believed that the Neogene story is not basinal because of later Cenozoic uplift and also because of erosion that exposed the strata with present summits as high as 1km above sea level. Sedimentary successions such as fluvial, deltaic and costal facies in terms of transgressive and regressive sequences are interpreted here (Harland et al., 1997). This location is a part of the Van Mijenfjorden Group which consists of several formations that reflects the alternating sandstone and shale dominance in the succession (Dallmann et al., 1999).

Van Mijenfjorden Group has been divided into formations from the Central Tertiary Basin, which each are marked in Figure 3. Svea and Braganzavågen are located in Carolinefjellet fm. (Figure 4) with Firkanten, Basilika, Grumant, Frysjaodden, Battfjellet and Aspelintoppen formations (Figure 3) laying positioned so that they contribute with sediments on to the tidal flat that are being studied in Braganzavågen.

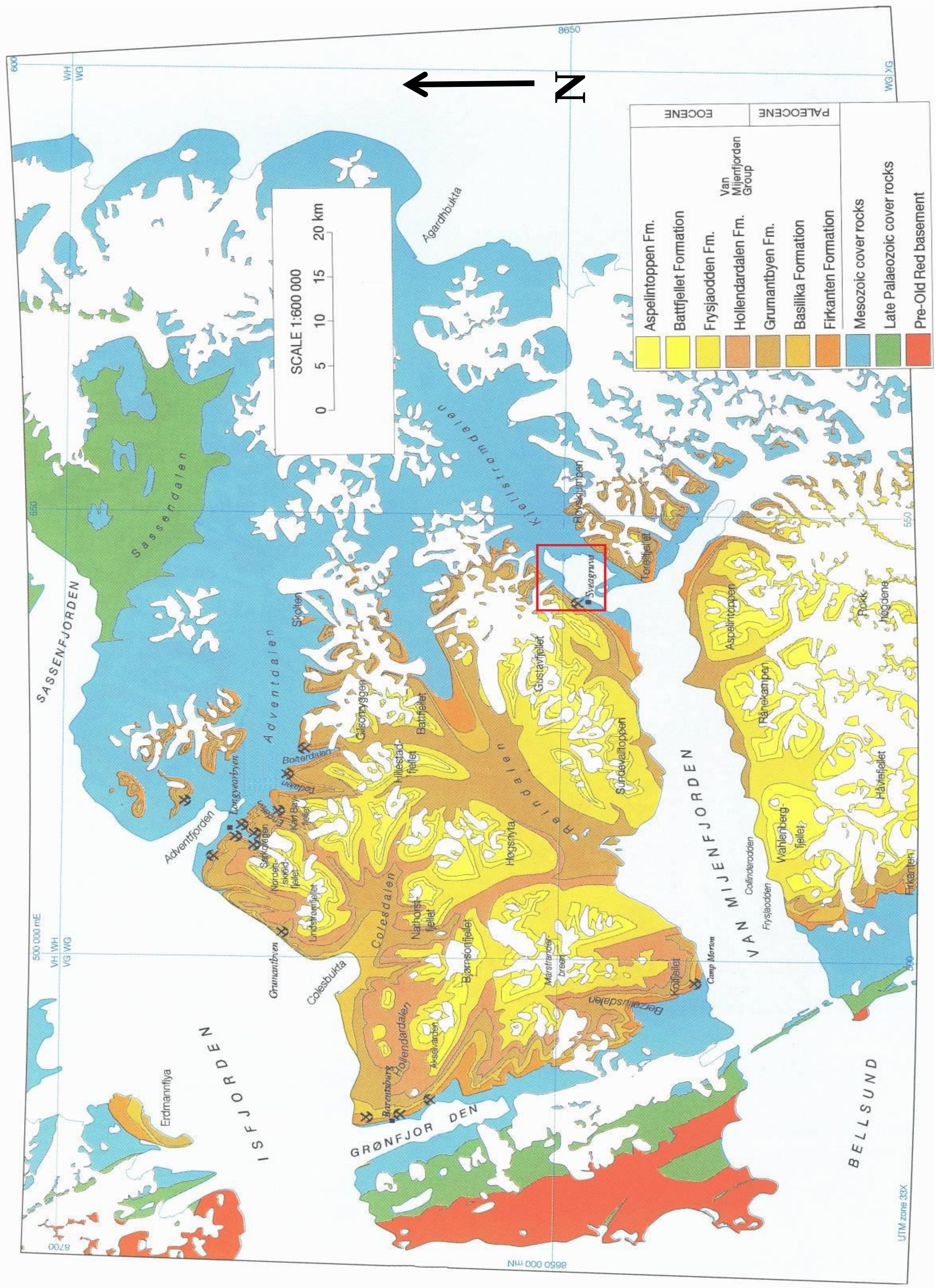

__Figure 2__: Geological map of the area around Svea and field area, which are marked in red. With all the formations that are found in the Central Tertiary Basin (modified from Dallmann et al. (1999)).

1.2.1. Firkanten Fm.

The formations seen in Figure 3 is further subdivided into members, first the Grønfjorden Mb. that is a thin basal conglomerate, then a shale-sandstone-coal sequence indicated to be a delta plain environment from the Todalen Mb. follows. From here Endalen Mb. continues with a delta-front sheet quartz-arenite sequence, and the final Kolthoffberget Mb. that is of fine sediments deposited as a delta front (Harland et al., 1997). This formation shows an overall transgressive trend from the delta front to prodelta/outer shelf facies (Müller & Spielhagen, 1990) with several smaller regressive cycles that are identified (Nagy, 2005).

1.2.2. Basilika Fm.

This formation is dominated by shale, indicating an overall deepening of the water level in the basin; this makes it the first transgressive phase in the Paleogene (Harland et al., 1997). The boundary to Firkanten Formation is marked locally by a sharp boundary between sandstone and shale (Nagy, 2005). This indicates a shift from regressive to transgressive trend. It contains rounded dropstones of metamorphic basement. Dolerite lithologies are common, same with bentonitic interbeds, and been interpreted as a muddy shelf conditions with repeatedly influx of silty sediments from east and northeast (Dallmann et al., 1999).

1.2.3. Grumantbyen Fm.

This formation is glauconitic, bioturbated and of massive character, and no evidence of any subaerial facies, this suggests that it is of entirely submarine, shelfal origin (Dallmann et al., 1999). Nonetheless the origin of this, however, has been problematic due to its massive character and high degree of bioturbation (Steel et al., 1981). Five major sandstone wedges or sheets have been recognized in this formation (Bruhn & Steel, 2003). It represents a regressive phase where conglomeratic sandstone is dominant at the top (Kellogg, 1975).

1.2.4. Frysjaodden Fm.

The transition between this formation and the underlying Grumantbyen Formations is a sharp boundary from sandstones/conglomerate into shale. Frysjaodden formation is divided into two members, Marstrandbreen Mb. and Gilsonryggen Mb., these are divided by the sand wedge of the Hollenderdalen Formation (Dallmann et al., 1999). The formation mainly comprises dark gray claystones and shales (Kellogg, 1975), however some turbidite deposits have been recognized (Steel et al., 1981). Dispersed bentonite layers are also present in the formation (Dallmann et al., 1999). This formation have been interpreted as a prodelta/shelf system deposit (Steel et al., 1985).

1.2.5. Battfjellet Fm.

This formation consists of well-laminated and cross-stratified, cliff-forming, sandstone that is interbedded with shales and siltstones (Dallmann et al., 1999), and forms a coarsening-upwards mega sequence together with Frysjaodden Fm. (Steel et al., 1981). It represents a late stage of coastal progradation and infill of the foreland basin, when the sediment input outpaced subsidence and the basin was filled to sea level (Dallmann et al., 1999). Steel et al. (1985) interpret the formation to be the product of a prograding deltaic and barrier coastline.

1.2.6. Aspelintoppen Fm.

This formations lower boundary is marked at the base of the first coals or thicker shaley intervals above the sandstone layers at the top of Battfjellet Fm. (Dallmann et al., 1999). The formation represents the youngest unit of the Tertiary succession in the Central Basin and represents the final basin fill. It consists mostly of alternations of sandstones with siltstones, mudstones and thin coals. It also has a distinct terrestrial influence, where sediment deposits such as distributary channels, crevasse splays and swamp are represented (Dallmann et al., 1999).

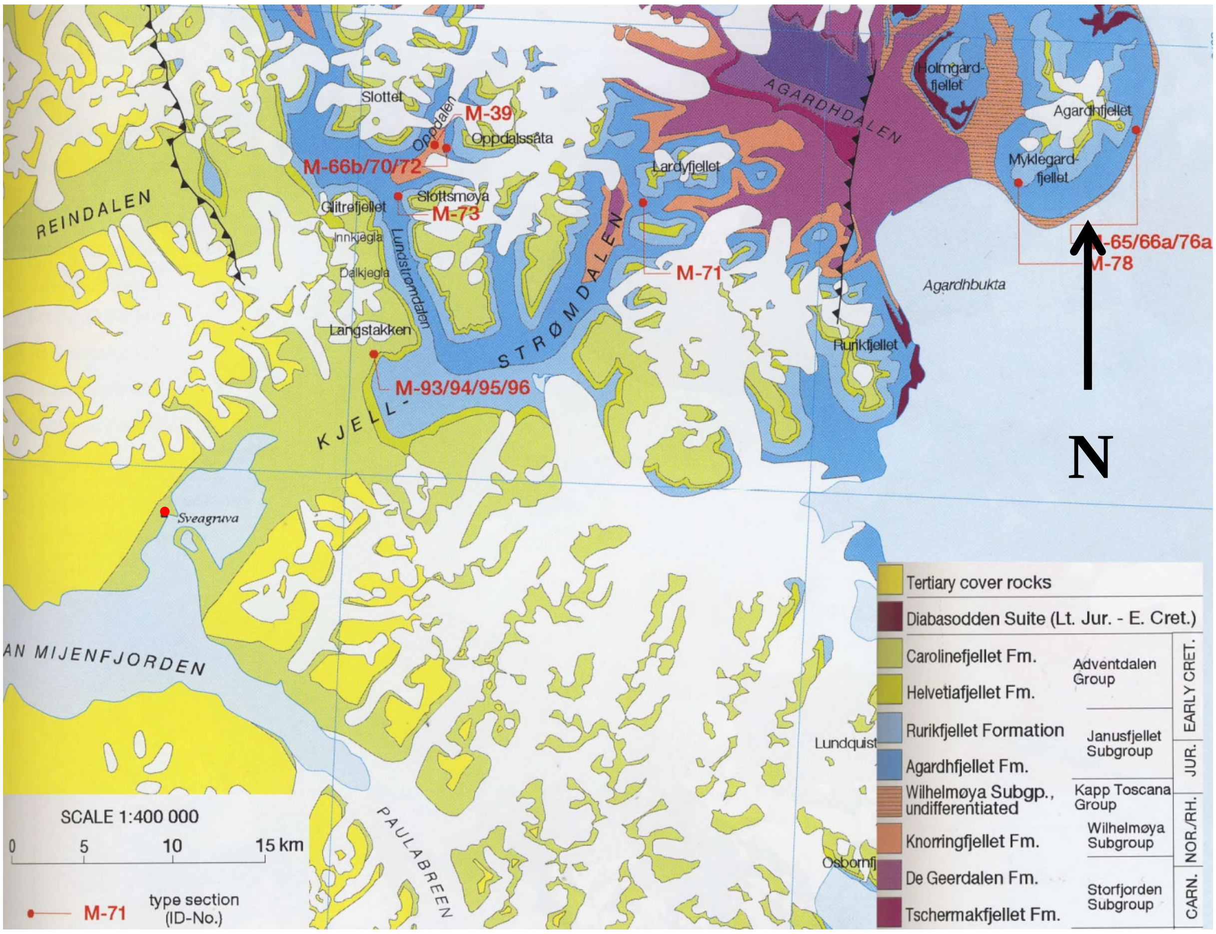

Figure 3*: Geological map over south eastern Spitsbergen, showing that Sveagruva is located in Carolinefjellet Fm. (modified from Dallmann et al. (1999)).*

1.2.7. Physical description over Braganzavågen

1.2.7.1. Physical description of geomorphology

The Kjellströmdalen valley ends at the bay of Braganzavågen and is about 4 km in width. Kjellströmelven is a braided river and is located Kjellströmdalen where it flows into the bay of Braganzavågen. Surrounding mountains are about 700-800 meters high, and with several glaciers in nearby areas. Another feature found in this valley is alluvial fans. One of these fans is in direct contact with the field area. This fan is dominated by alluvial processes which continue into the studied area. Fluvial processes contribute to bringing large amounts of sediments from more distal areas and depositing it in the bay. Channel erosion on the edge of the alluvial fan, in the studied area, also contributes with reworking of sediments.

In Braganzavågen a peninsula formed during the last surging of the Paula glacier. The surge is suggested to have happened between 600 and 250 years ago, and creates a dominant barrier (Rowan et al., 1982). This moraine shelters the Braganzavågen from the Van Mijenfjord, creating a large depositional bay; where sediments mainly from a nearby alluvial fan and a river from Kjellströmdalen are deposited in the bay of Braganzavågen.

1.2.7.2. Human influence

Human influence is easily seen in the field area. This is due to activity from the coal mine that is located in Svea. On the alluvial fan it was apparent that there has been human activity in form of digging and moving of large amounts of sediments. In what degree this human influence has an impact on the sedimentary environment that has been studied is uncertain. It is possible that the river does not flow naturally. However, it is unknown in what extent this human influence prevents the fluvial processes, on the distal parts of this alluvial fan.

Transportation of larger fragments of coal, that has been observed, most likely transported by wave activity from Kapp Amsterdam, where the harbour that the coal is transported out from Svea is located, shows that tidal currents are present.

1.2.7.3. Fluvial, tidal and other processes

These coal fragments that have been transported from Kapp Amsterdam show that tidal currents are present. In some areas the high tide are as high as 1,5 meters above mean sea level. This is based on data from Kartverket with a station on Ny-Ålesund and Kowalska and Sroka (2008) measured from Hyttevika Bay, west of Gullichsenfjellet, southwest in Wedel Jarlsberg Land. Then in what extent these currents are important for the sedimentary setting in the bay of Braganzavågen is uncertain. However the tidal currents in the strait are strong, and the tidal currents ensure that the freshwater and saltwater get mixed (Caline, 2010).

From approximately 2200 BC the sea level was roughly 5 – 10 m above today. This is due to isostatic depression from glaciers. Also a regional eustatic event that resulted in a sea level rise at that time (Hald et al., 2001). In this particular region this isostatic uplift is measured to 7,3 millimetres/year, based on measurements from Statens Kartverk (The Norwegian Mapping Authority). This indicates that this particular system is regressive.

Another important factor for Braganzavågen is the short arctic summer leaving the area frozen for substantial parts of the year. Where the inner part of the fjord freeze up as early as November/December and melting usually start in May/June (Høyland, 2009).

2. Background

The duration of ice and snow cover indicates that the tidal system is mainly fed by distal melt-water streams and gravitational processes on the adjoining slopes. This suggests that sedimentation is strongly variable by seasons. Because of ice cover and the requirements to observe an active system, the field season is limited to a short period of time during the year. Therefore two seasons have been scheduled in field for gathering of needed data in this project.

It is important to look into how tidal flat sedimentation works in general; there will be given an overview of the tidal processes. Classification of environments such as waves, tide and rivers and if these are related (Figure 5), are central in the understanding of the depositional environment in Braganzavågen. To form a tidal flat there has to be some tidal influence; how much is controlled by e.g. the difference between low and high tide; this vary greatly over the world with several meters in difference. Tide is a cyclic event occurring twice a day due to gravitational forces between the earth and the moon; that first was mentioned in 1687 by Newton as the 'equilibrium theory of tides (Figure 4)(Schwiderski, 1980).

Tides can be classified into three main classes; which are micro- meso- and macro tidal. These have a range of < 2 meters for micro; 2 – 4 meters for meso and > 4 meters for macro. More specific classifications with subdivision

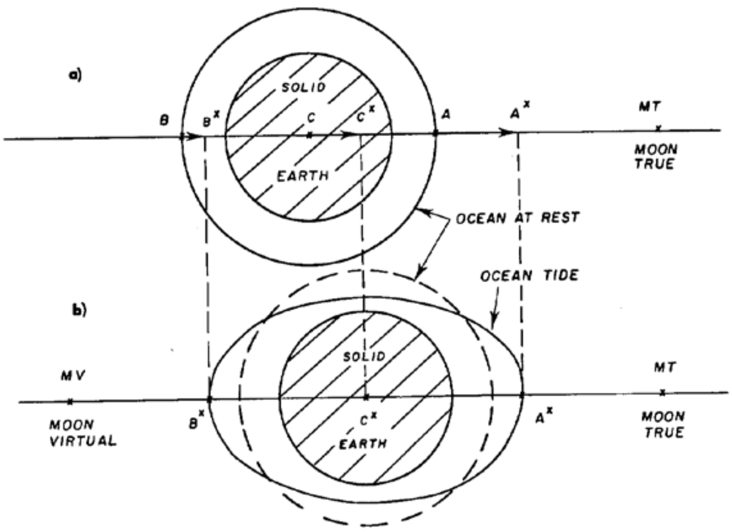

***Figure 4**: Newton's theory of equilibrium tide (Schwiderski, 1980). Shows how the lunar cycle influence the ocean tides.*

of these tide ranges are < 1 meter for micro tidal; 1 – 2 meters for low meso tidal; 2 – 3 meters for high meso tidal; and 3 – 5 meters for low macro tidal (Dieckmann et al., 1987).

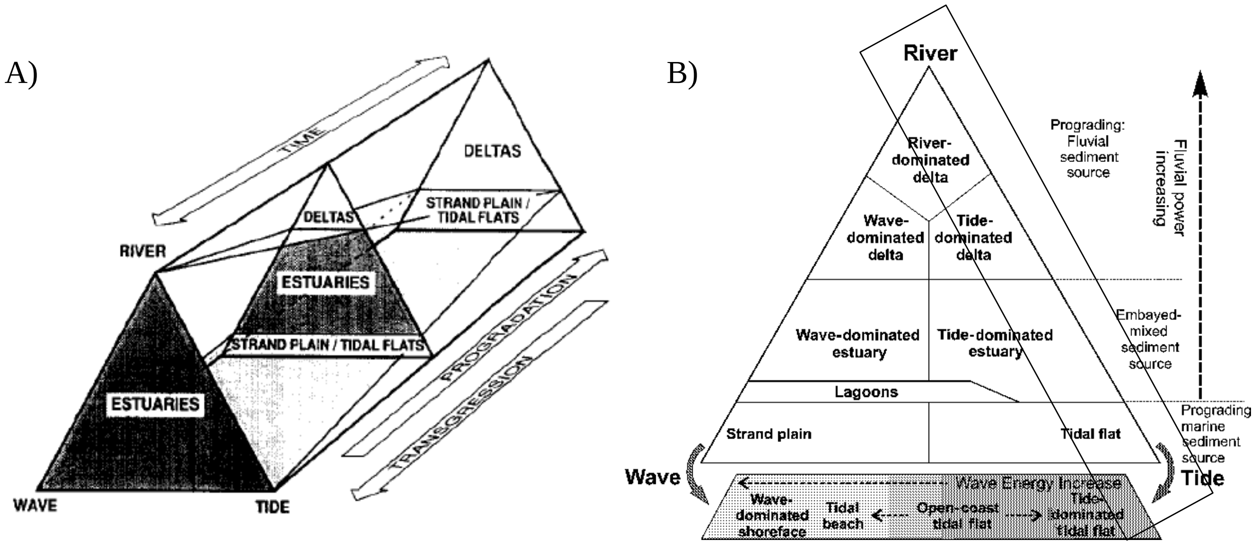

__Figure 5__: A) Displays the evolutionary classification of coastal environments relative to time and progradation/transgression. The dominating processes are river, wave and tide. In the uppermost area deltas are located; in the intermediate, wedge-shaped space, estuarie; and the bottom wedge represents non-deltaic, prograding coasts. During a sea level cycle, a coastal area will move forward and backward through the prism at a rate, and by an amount, determined by the rate of sea-level change, the sedimentation rate and basin size. (Dalrymple et al., 1992). B) Showing more detailed what the three coastal environments and how they influence each other, modified from (Yang et al., 2005).

2.1. General tidal flats

Tidal flats are covered by sediments that have been deposited by tidal currents. Resuspension by waves could also play an important role in how the sediments are deposited. This can cause periodic or cyclic transport of sediments in suspension over a tidal cycle; another factor is if the tidal flat is erosional or depositional (Anderson, 1973). Figure 6 shows a simplified division of a tidal flat according to sea level changes, and with a facies description showing the relationship between deposition and the environment.

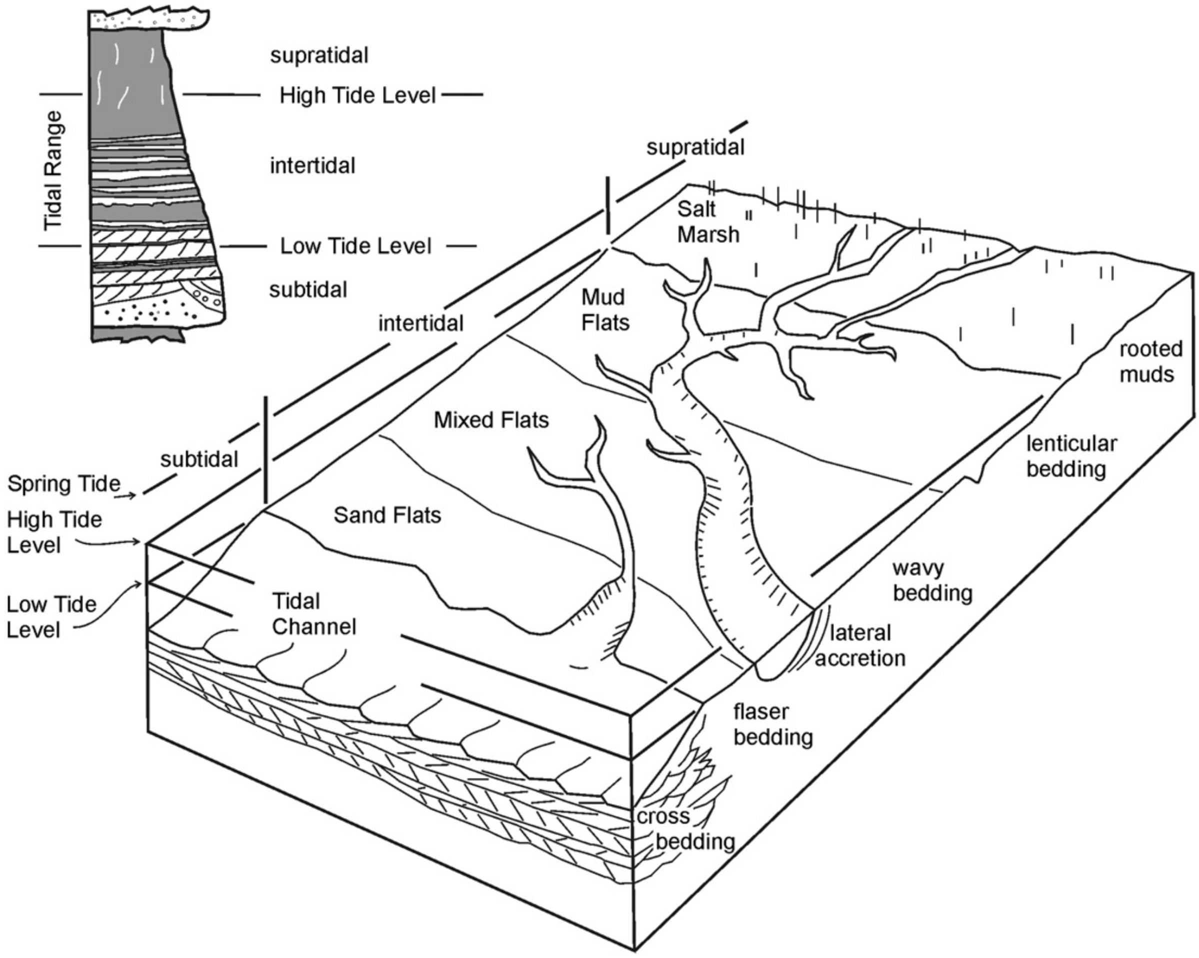

Figure 6*: Block diagram that shows typical facies and their relationship with the tidal flat (Bungenstock & Schäfer, 2009). Showing main structures found in the various parts of the tidal flat.*

The deposition is determined by the strength of the tidal current and interplay with the fluvial activity. The finest grained mud is deposited where the currents are weakest; which is mainly near the high tide level. The phrase “settling lag” from Pestrong (1972) mentions that particles from a weakening current are not deposited vertically below where they start settling down. They are however carried along the returning tide some distance before reaching the bottom. There is also a phenomena called “scour lag” (Pestrong, 1972). This means the difference between the maximum current velocities allowing deposition of suspended particles; and the minimum velocities required to erode the same material from the seabed. The occurrences of streaky, lenticular bedding or cross-bedding are indicators of rapidly changing currents and agitated waters (Tessier et al., 2009).

2.1.1. Morphology

On tidal flats a distinct and characteristic morphology can be developed. The sediments in the intertidal zone lies over a vertical distance of 1-4 meters, dependant on tidal range (Reineck, 1972). From the tides, currents are created and form gullies and channels; tide range controlling channels that will be cut. The tidal current will vary and may create small scale current ripples. Where gullies are formed, it is possible to form ripples and dunes (Ke et al., 1994; Reineck, 1972). Other structures of importance are bars, ridges and barrier islands. Often, a wedge-shaped body from the deposits that are elongated parallels to the shore line, is being formed. This body will often be intersected by channels and/or river estuaries. On the surface of tidal flats the most common features are current ripple marks; however also oscillation ripples can be present, both symmetrical and asymmetrical ripples. Sedimentary structures representing sub aerial exposure are present and important for the distinction of tidal flats, e.g. minor runnels and erosional depressions (Lanier et al., 1993). Here structures like flat depressions are made by oscillation ripples can be found, where surrounding areas is covered by algae mats (Reineck, 1972).

2.1.2. Distribution of material

The accumulated materials on tidal flats are usually mud dominated. If sand occurs it is mostly fine grained. Occurrence of gravel, clay pebbles and shells are seen along channel floors. The deposition of this material is often high in mud content near the high tide level; this is especially seen on wind- and wave- sheltered coast lines (Reineck, 1972). In mixed flat the mud content decreases and near the low tide level in sand flats there is a minor constituent. Towards the channels where mud content increases, and below the low tide level mud is especially abundant in the lateral deposits of big channels; except for channel floor sediments (Reineck, 1972).

2.1.3. Sedimentary structures

On tidal flats a great variety of structures are commonly observed. Structures like cross-bedding of dunes are common in the channels, then again rare in the intertidal zone (Yang et al., 2005). In mixed flats and lateral channel deposits structures like flaser bedding, wavy bedding, lenticular bedding, interbedding and interlamination of mud and sand or silt are common. The graded bedding lamination are sometimes graded upwards from coarse to fine, however, this can sometimes be reversed (Reineck, 1972). On sand flats structures like cross-bedding of small scale current ripples are common; which can sometimes show a herringbone cross-stratification structure (Yang et al., 2005). In the mud flats thick mud layers with thin stripes of sand are the most common feature. In arid climate, mud in the extreme high tide level becomes chaotic by excessive evaporation, and formations of mud cracks result in a generation of chaotic mud evaporate mixture (Thompson, 1968).

None of these structures, however, is restricted to tidal flat deposits. Then again the features observed occur frequently in tidal flats. They can also be observed in other fluvial settings such as channels or other environments where the flow strength fluctuates. The origin of these structures is often related to the alternating tidal currents. It is possible to recognize different bedding types in one vertical section, a result from changes in direction and force of wind and waves (Reineck & Wunderlich, 1968). Most of the layers found in tidal flats are deposited in shallow depressions are flat erosional patches, or shallow runnels, however, most of them are laterally deposited in point bars and other sheltered inclined places (Reineck, 1972). In horizontal areas, net accumulation is hardly seen, since erosion and sedimentation always are in progress (Reineck, 1972).

2.1.4. Sequences

Transgressive and regressive sequences at the shore line consist of separate elements (Dalrymple & Choi, 2007); as a start from bottom to top a transgressive sequence consists of sand flat deposits, mixed flat deposits, mudflat deposits, brackish and freshwater clay, peat with Sphagnum and older sediments. In tidal flats a rich supply of sediments is needed for deposition of tidal patterns e.g. mud drapes, consequently, meandering channels will rework the sediments and the distinct pattern will be eroded (Dalrymple & Choi, 2007), an example for a tidal sequence can be seen in Figure 7.

Following is the regressive sequence with sand, mixed sediments, mud and salt marsh deposits, that all are reworked or cut through by runnels and channels. As seen in fossil content and recent tidal flats, such sequence may not be fully developed.

Modern and ancient stratigraphic sequences have several indicators of tidal influence. Where the typical indicators are mostly dominated with cyclic deposition, these cycles can represent a short semi-diurnal tide or consist of cycles over multiple years. Most common is where those cycles typically are presented by alternation of sand and mud; heterolithic deposits, with ranges from a few millimetres to several decimetres (Davis, 2012). These typical tidal sequences include the intertidal and subtidal positions, with depths that can be up to hundreds of meters. Most common is the intertidal flat which contains channels in estuaries, deltas, coastal bays and open coasts. Preservation potential can wary greatly from very good to poor, depending on the environment; typically the tidal channels are among the best preserved while the upper intertidal zone usually is the most poorly preserved (Davis, 2012).

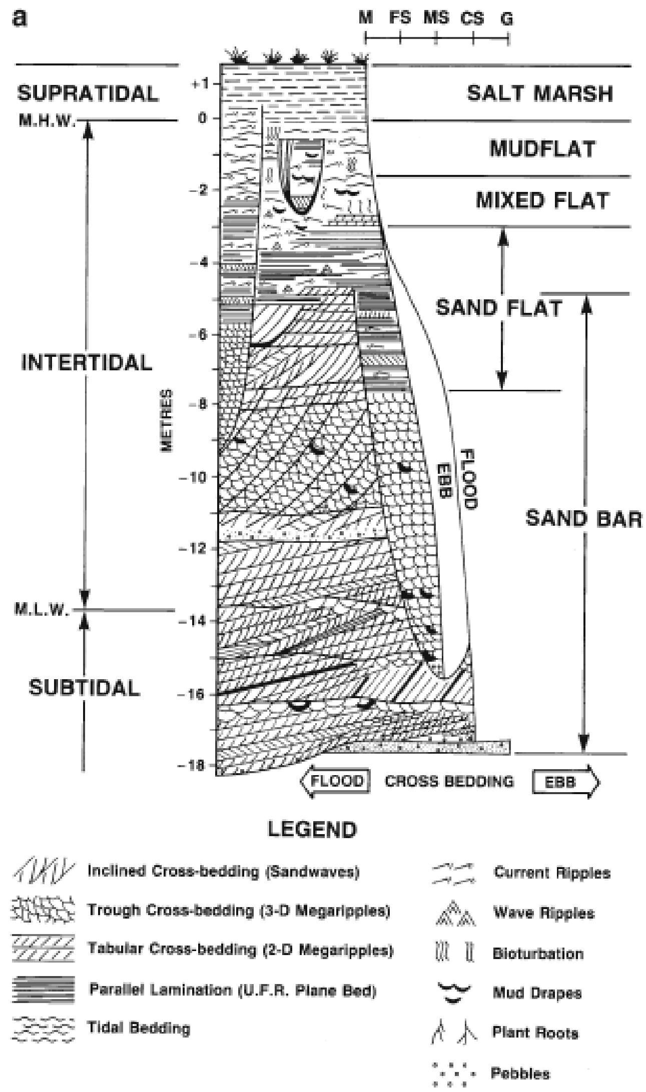

Figure 7*: Example for a schematic stratigraphic sections showing complete tidal sequences from the Bay of Fundy, Canada (Davis, 2012).*

2.1.5. Examples

Globally, tidal flats vary in size, tidal influence, morphology and active processes. In local regions these differences are also evident; e.g. tidal flats in the German Bay contain more mud compared to tidal flats located in the Netherlands, while tidal flats in Great Britain in general are mostly sandy. The origin of sediments could be of interest in studies of tidal flats; if they are from inland or transported over longer distance by offshore suspension. The tidal flat in San Francisco Bay gets its sediments from an inland drainage basins (Pestrong, 1972). Pestrong (1972) mentions large variations in sediment sizes occurring on the tidal flats of San

Francisco Bay. Depending on the nature of the sub environment within the embayment studied, these variations are also common in many tidal flats. In the sediments at San Francisco Bay tidelands Cooley Landing; a colour change in the sediments was observed. The topmost centimetres are of light greyish-brown colour. Just below this the colour changes to more deep blue-black. This change indicates a change from oxidizing conditions on the surface to a reducing environment at just a few centimetres depth (Pestrong, 1972).

Good examples of tidal flat sedimentation are found in The Wadden Sea (Figure 8). The Wadden Sea extends from Den Helder in the Netherlands to Blåvands Huk in Denmark. This is an area covering about 8000 km^2, of which 65 % is tidal flat (Pejrup, 1988). Large amounts of suspended sediments are transported across the studied area Pejrup (1988) estimated this to 60 -650 kg m^{-1} day^{-1}. These sediments come from the reworking of The North Sea seabed (Pejrup, 1988). On this tidal flat the lack of barrier island is typical in low macro tidal setting. Further on the meso tidal zone are bordered with barrier islands, where the trend is; the lower the tidal zones, the smaller the barrier islands. When it comes to the Wadden Sea case, low macro tidal barrier islands are no longer present (Dieckmann et al., 1987), this trend can be observed in Figure 8. On this tidal flat several important processes have been recognized: 1) delivering of sediments from seabed reworking in the North Sea, 2) tidal range of several meters, 3) a gradually subsiding sea bed, 4) a rise in relative sea level and islands that provide protection from wave erosion (Dieckmann et al., 1987).

Sedimentation rates vary greatly within tidal flats; as an example from Weser in Germany where the sedimentation rate vary from 0,3 and 1,6 meters annually (Witt et al., 2004). In Weser the dominant constituents are silt and clay, often stratified in fine lamina. This bedding is seldom parallel; mostly it is streaky and lenticular with non-uniform thickness of the layers (Augustinus et al., 2002).

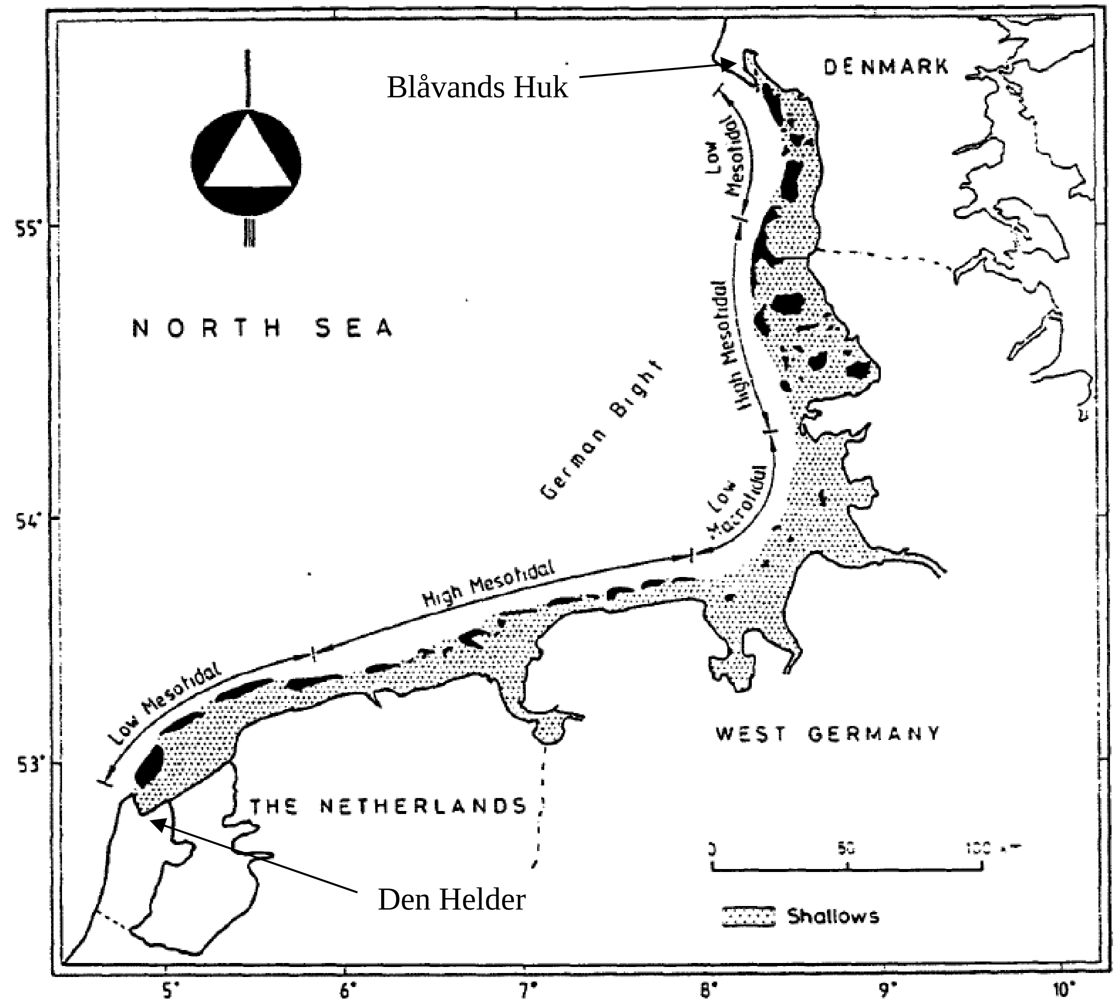

Figure 8*: Divided tides and barrier islands marked with black trough the large tidal flat in The Wadden Sea reaching from the coast of the Netherlands, Germany and Denmark, modified from Dieckmann et al. (1987).*

Many studies in the St. Lawrence Estuary has been done, which is located northeast of Quebec City, Canada (Dionne, 1969, 1970, 1973, 1993). In many ways these studies therefore may be of interest since there might be some similarities with this study. Both of the tidal flats are located quite far north and have long winters and short summers. The tidal flat in St. Lawrence is much larger than the one in Braganzavågen; however they both seem to have similarities.

2.2. Skewness, sorting and mean

These parameters are widely used in sedimentology in order to determine the sedimentary environment because they reflect processes. They are used to determine the dominant processes. It can be used as determination of the bimodality of grain size distribution, even if modes are not apparent (Folk & Ward, 1957). Martins (1965) found positive skewness in dune sands and river sands, nevertheless dune sands have a tendency of being better sorted than river sands. The reason for positive skewness was concluded to be that sediments transported by wind or river were generally transported unidirectional. A study done by Gao and Collins (1992) from Yangpu Harbour, southern China, has divided the material into three groups based on mean grain size; beach material with mean size of -1,5 ϕ to 3 ϕ. Intertidal flats had mean grain size of 5 ϕ to 7 ϕ. The sea-bed sediments in the area were generally coarser, better sorted and more negatively skewed (Gao & Collins, 1992). While another study also done by Gao and Collins (1994) in Christchurch Harbour, southern England, displayed that sediments from the tidal delta were the best sorted. Sediments within the Harbour were mostly positively skewed, and outside of the Harbour the negative skewness dominate.

Skewness explains how the grain size distribution approaches the normal Gaussian probability curve. Where there has been concluded that single source sediments e.g. aeolian sands, etc. have relatively normal curves, because sediments that have several sources e.g. beach sands with lagoonal clay, etc. have a tendency to show pronounced skewness (Folk, 1974). Studies from Friedman (1967) on differences between distribution of sand from beaches and rivers (Figure 9) based on skewness and standard deviation (sorting). From this there can be seen that there is a correlation between these parameters (skewness and sorting) and depositional environments.

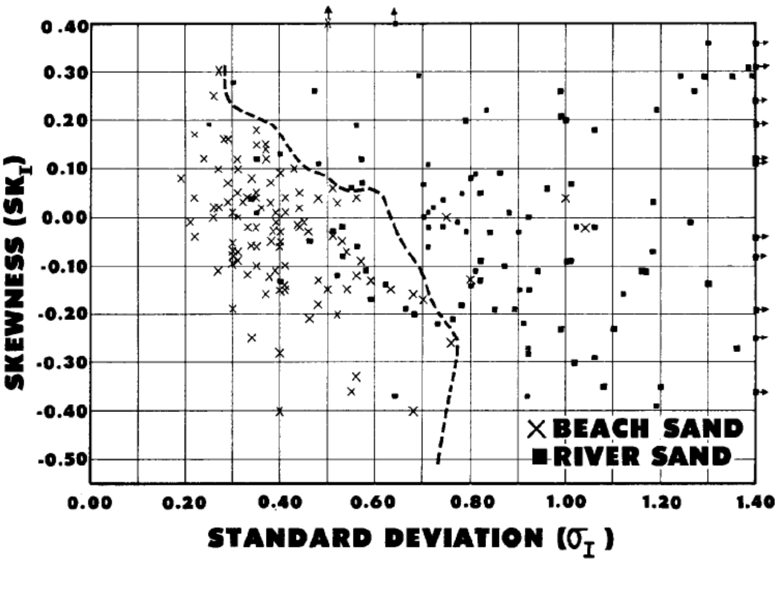

Figure 9: *Plot that shows the relationship between skewness and sorting. Based on two different environments; beach and river (Friedman, 1967). It can be observed a clear difference in these two environments based on skewness and sorting.*

2.3. Alluvial fan

An alluvial fan can be described as a deposit whose surface forms a segment of a cone that radiates downslope from the point where the stream leaves the source area (Bull, 1977). This has been observed in Braganzavågen, where the mentioned alluvial fan has its apex in close proximity to a river with its origin from glacial melt water. This fan is located in an environment with a side-valley formed by glacier activity, seen clearly from the mid-moraine that goes up the valley; this mid moraine is also used as a road to access one of the mine entrances. Alluvial fans are parts of erosional depositional systems, sediments being eroded from rock with mountainous source area; where it will be transported into a valley to be deposited, in this case Braganzavågen, as another increment on the cone-shaped body of deposits. Changes in the channels slope, depth and width are affecting the slope, and these changes can be due to changes in discharge of sediments and water (Bull, 1977). During winter there is no discharge in Braganzavågen due to ice and snow. However, during spring and summer melting of ice- and snow- cover and in some degree nearby glaciers, this makes erosion, in this case, a large contributor when it comes to changes in the discharge.

As a standard the common alluvial fan has a downstream decline in mean particle size and there are several reasons for this (Brewer & Lewin, 1993). The most obvious reason is a hydraulic sorting process, where larger clasts are not entrained, or do not travel as far as finer material. Physical reduction by severe abrasion during transport and lack of fine material due to sediment supply, is also a possibility. When it comes to skewness on the alluvial fan, it is highly skewed in the upstream part of the fan and has a tendency towards a more normal distribution in the lower sites of the fan. Grain sizes in alluvial fans diminish rapidly downwards on the fan, where all except the coarsest gravel are horizontally stratified (Blair, 1987)

From the steep gradients in surrounding areas it is likely that there have been developed alluvial fans in this area. From the terrain seen on Spitsbergen there are countless numbers of fans such as the one in Braganzavågen. Alluvial fans are often found in combination with tectonic settings (Gawthorpe & Colella, 1990). The reason for this is the making of new accommodation space for sediments that are being eroded from the mountain side, and the distinct fan formation are made during deposition in the area of accommodation space. The alluvial fan in Braganzavågen has an apparent trend of building outwards into the bay, and therefore classifies as a prograding alluvial fan that extends into the bay of Braganzavågen. It is only the lower part of the fan that has been studied, in association with the mapping of the tidal flat.

3. Methods

3.1. Field methods

The field area is situated outside the town of Svea which again is located in the innermost part of Van Miljenfjorden, about 45 km south of Longyearbyen (Figure 1). The field area is accessed by a 4 km drive with car from Svea and a 1 km long hike (Figure 11). In the field, surface samples, logs and description of the surface morphology were made. Mapping of the area was conducted during field season of 2011 and 2012.

For the actual mapping of the field area, *Brunton type 15 compass* was used to measure direction of surface structures, and a *Garmin GPSmap 62S* was used to pinpoint each locality with sufficient accuracy. For the logging equipment such as shovel, trowel, ruler and logging sheet, seen in Appendix A, were used to produce logs. Locations where the logs were made are chosen to achieve as good spreading as possible within the field area, so that the whole area is covered without any loss of crucial information. For the surface samples there were drawn several transects out from the alluvial fan to get the best spreading over the area. Those locations were also constrained by accessibility and fluvial processes. At each location the number of samples varies. This was depending on depth of log and how many each log contained, since there was taken one grain sample from each layer. Depth of logs depended on the morphology and location; about 100 samples were collected, at about 100 gram each, in small plastic bags. Layering in the profile was decided how many samples that were sampled at each locality. Logs were usually not longer than 10 to 15 centimetres, this due to water saturation in the sediments, which made the sediments collapse while digging down for a profile.

Figure 11*: Showing four different settings that the work area consisted of. A: Taken closest to the fjord, seen by the oversaturated material. B: Is taken further inland, observed that fluvial processes are more present. C: Is taken at the river mouth on the alluvial fan in the field area. D: Is taken furthest inland, here there was more marsh setting present.*

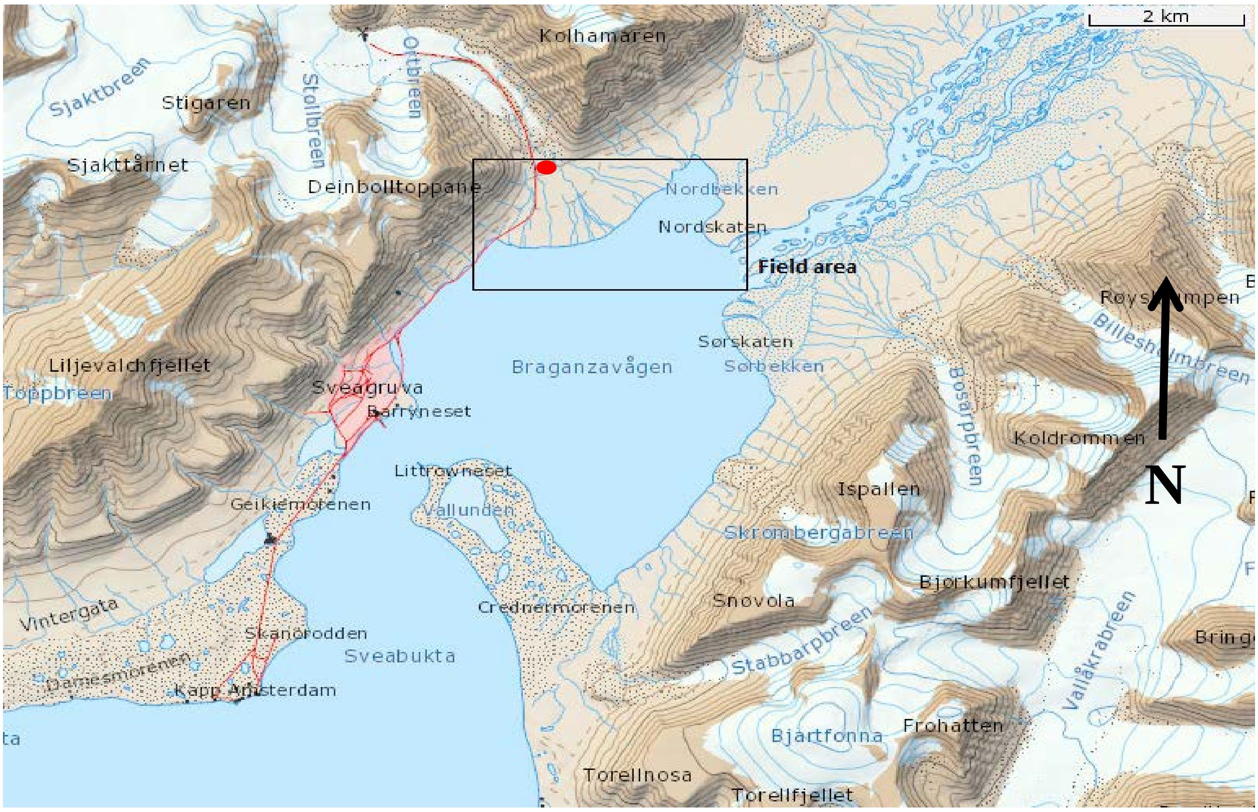

Figure 10*: Detailed map over the town of Svea and sounding areas such as Braganzavågen where the field area is marked in the black box, modified from (Topo Explorer Svalbard, 2009) , red mark indicates where Figure 12 was taken.*

3.2. Lab methods

From the field work several samples were collected which was intended for further grain size analysis. In total there have been analysed approximately 100 samples collected from the field work, each of these with a weight of 50 – 100 gram. From these samples a representative selection was chosen for further analysis. Each of these samples has gone through the same treatment in the lab at the University of Oslo.

Chosen samples were first put in a freezer for 24 hours, depending on sample size, and further were dried in a vacuum drier, it was sufficient to take 5-10 gram material for each sample. Each sample was then sieved at 1 mm, which was the largest the Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer could handle without being destroyed. All samples with particles larger than 1 mm had to be sieved manually. After manually sieving these results had to be included along with the results from the grain size coulter.

Weight of each sample that were analysed in the grain size machine varied with the grain size, usually between 0,2 and 0,4 grams was sufficient to get a representative measurement of the grain size for each sample. Each sample was analysed twice for control, and then an average of those two samples was made.

Based on the grain size analyses, following variables were calculated using an *Excel Worksheet*; skewness, mean grain size and sorting, were the formulas for those three groups are (Folk & Ward, 1957):

Formula 1*: Mean grain size.*

$$M_z = \frac{\varphi_{16} + \varphi_{50} + \varphi_{84}}{3}$$

Formula 2*: Sorting (standard deviation).*

$$\sigma_I = \frac{\varphi_{84} - \varphi_{16}}{4} + \frac{\varphi_{95} - \varphi_5}{6{,}6}$$

Formula 3*: Skewness.*

$$Sk_I = \frac{\varphi_{16} + \varphi_{84} - 2\varphi_{50}}{2(\varphi_{84} - \varphi_5)} + \frac{\varphi_5 + \varphi_{95} - 2\varphi_{50}}{2(\varphi_{95} - \varphi_5)}$$

These formulas are the logarithmic original graphical measures that give information about the grain size, except the mean formula which are the original from Folk and Ward (1957). These will be used to increase the understanding of the depositional environment in Braganzavågen. Cumulative plots have also been created to increase the understanding. In Table 1 values for sorting and skewness are listed; where a number indicates how much the sediment in the samples are sorted and skewed based on calculations from Folk and Ward (1957).

Table 1*: Gives information about sorting, skewness and kurtosis (Blott & Pye, 2001), where the number indicate in which degree the sample are sorted and skewed.*

Sorting (σ_1)		Skewness (Sk_1)	
Very well sorted	<0·35	Very fine skewed	$^+0·3$ to $^+1·0$
Well sorted	0·35–0·50	Fine skewed	$^+0·1$ to $^+0·3$
Moderately well sorted	0·50–0·70	Symmetrical	$^+0·1$ to $^-0·1$
Moderately sorted	0·70–1·00	Coarse skewed	$^-0·1$ to $^-0·3$
Poorly sorted	1·00–2·00	Very coarse skewed	$^-0·3$ to $^-1·0$
Very poorly sorted	2·00–4·00		
Extremely poorly sorted	>4·00		

Software used for making the model over the field area was *Garmin MapSource* for pin-pointing all of the localities. *Adobe Photoshop* and *Illustrator* were used to digitalize logs and cumulative plots.

3.3. Field observations

The field area (Figure 11) in Braganzavågen is a plain/tidal flat area that is influenced by an alluvial fan, the inclination has not been measured, nevertheless it is believed to be around 1-2° as seen in Figure 12. In this figure it is also possible to see the human impact on the fan. The field area holds some differences in enviromental settings as seen in Figure 10. Here it can be observed that the environment shifts from just mud and clay to more fluvial and marsh environment as getting closer to the inland from the fjord. Human activity have been moving large amounts of sediments around on the alluvial fan in relation to the on-going coal mining, where the main entrance to the mine is on the upper side of the apex.

Figure 12*: Overview of the field area, picture taken from the upper part of the alluvial fan, marked with a red point in Figure 11.*

Figure 13*: Photo from the more distal part of the alluvial fan transition to tidal flat, where elongated smaller islands can be observed. It can also be observed that the river is bending of to the right, where the bay is located.*

This change in surface morphology can be observed in Figure 10, where picture A is closest to the bay of Braganzavågen (Figure 11) and moving towards inland in picture D. Closest to the bay the environment was muddy without visible structures. When moving closer to inland the change is apparent, most evident is that the grain size is coarsening. Disperse smaller plants was observed, and further moving closer to land there are more vegetation, here the top layer mostly consists of organic matter. There is also a noticeable change from the fan area with large boulders of several centimetres in diameter out onto the flatter area where the grain size is decreasing significantly down to sand and silt. In the apex of the fan there is just one large river going out into the fan. When moving to the more distal parts of the alluvial fan it behaves more like a braided river system (Figure 17), and as expected the grain size decreased. In the mixing zone of the distal part of the fan and the tidal flat, the braided river system is migrating to several meandering rivers. They had a tendency to slowly bend towards the bay where they also were getting smaller most likely due to loss of energy, seen in Figure 13. That particular area consisted of some smaller islands that elongates outwardly from the alluvial fan as observed in Figure 13. It was also possible to see a transition from large boulders to much finer sediments.

The rivers originate from the alluvial fan were originally melted water from snow, ice and nearby glaciers, the observed depth was from a few centimeters to over one meter. This can also explain the sediment distribution observed in the area. Close to the distal areas of the fan and especially close to the river outlets where bedding in profiles mostly were observed, these are sites with the largest variations in grain sizes. Profiles made further on land on the marsh were similar to the more intertidal part where the grain size is silty and homogeneous; the only difference being the vegetation. Also on the marsh there were some meandering rivers, these were small and reminded more of a small stream. Due to the vegetation they seemed to act more like anastomosing systems. The sedimentation rate in this area appears to be lower than in the rest of the field area, where the sedimentation rate is higher in the subtidal zone than in the intertidal zone of the area (Stevens & Robertson, 2012).

In some localities surface ripples were observed and direction was measured. Different types of ripples were also observed, where there are some variations in the directions on currents. This indicates that there is more than one current direction. As seen in examples of asymmetrical ripples that have been observed, other forms of ripples were also found as seen in Figure 14. Further there has not been observed any bioturbation.

***Figure 14**: Different types of ripples that were observed in field.*

***Figure 15**: Small kettle holes on the tidal flat, centimetre scale lying next to them, photo taken in 2012.*

In the transition between the intertidal and supratidal zones, algal mats were also observed, and some cases of kettle holes in the mud, as seen in Figure 15, probably connected to freezing and thawing of winter ice.

When it comes to the morphology there has hardly been any observable change between the two field seasons. The largest difference is that the river system had changed a little, where the most apparent changes were from the outlet and from the meandering system; this would also be expected since this is a highly active system.

3.4. Log description

All of the logs can be found in Appendix B and Appendix C. Logs produced during season 2012 (Appendix B) are as seen from the appendices relatively similar in apperance, with only minor differences, as seen in Figure 16. The same trend is observed in logs made during the field season 2011 (Appendix C). Looking at data from 2012 grain size was quite stable throughout the whole area. The length of the log varies widely caused by local settings in water saturation in the sediments, where the variations range from 5 cm up to 40 cm. Common feature for most of the logs were that they consisted of few or none structures. Some of the logs contained bedding, with small variation in grain size. Some of them contained rootlets and smaller plants; these were usually located on the supratidal zone. The more homogenous silt logs were located closer to the subtidal zone, even though there are some homogenous silt profiles located furthest up on the supratidal zone; where in the intertidal zone there was some more mixed material with layering.

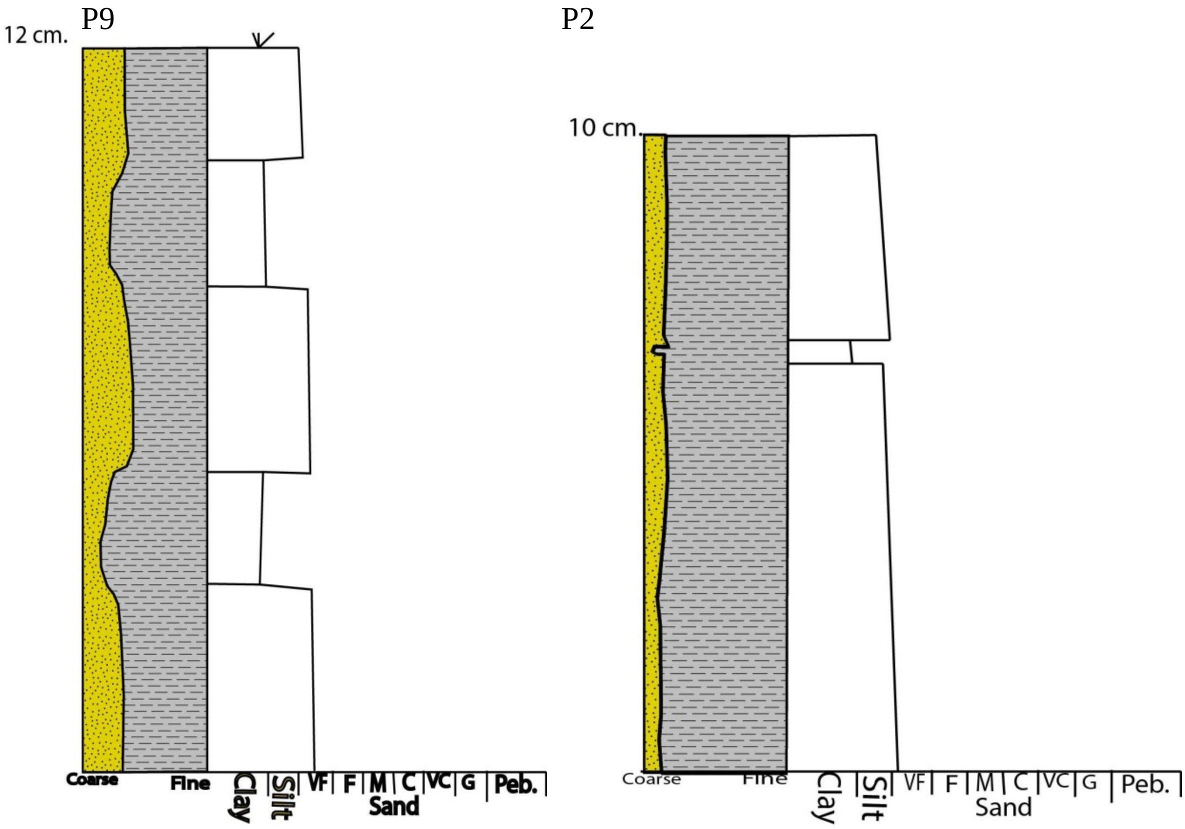

***Figure 16**: Example of two logs, P9 located on the intertidal part and P2 are from the distal part of the alluvial fan.*

An overall trend in the logs is that they were either homogenous or fining upwards, with a few exceptions they were coarsening upwards like P1 and P11 (Appendix B) and later in the result chapter. Observed in field they looked fining upwards, at least P11 (Appendix B). The reason for this mistake might have been caused by the small differences of grain size between the layers. Some of the profiles also contained seams of coal (P3, P4, P6, P7, P9, and P10 from Appendix B).

The profiles were made in different morphological settings throughout the field area, which will be more discussed later. The same is done with distribution of the different types of logs that have been observed.

When comparing the logs there were not many differences. However, the main difference was found closest to the rivers flowing out from the alluvial fan. Here deposition is more exposed for energy differences, and therefore had more bedding than surrounding areas.

3.5. Pitfalls

Grain size samples from field season 2011 were not used that much compared to field season 2012, due to lack of quality in the data. Other issues that may lead to misinterpretation of the data, was that not all structures were observed in field. Due to high saturation level digging profiles could sometimes be difficult, and some structures may be erased with this method. Due to the conditions in the field, it was difficult to determine the type of bedding which complicates the work for this thesis. Other important errors may also be made, such as mistakenly defined grain size trends or unfortunate method being used in the trend analysis.

Altitude has not been taken into consideration even though it can be a valuable parameter in the overall understanding on the area for explaining the dip in the studied area. A reason for not taking this into account, is that the right equipment was not available, and the GPS used does not give sufficient accuracy when it comes to altitude. The accuracy needs to be at centimetre scale when it comes to precision of measuring the dip in this area. Therefore it was chosen to disregard this parameter in the work done in Braganzavågen, and there were no possibility to obtain a better type like DGPS that are more accurate than a regular handheld GPS.

Also there is a possibility that X-ray images or other approaches could reveal structures that are not possible to observe with the naked eye alone, on the other hand this procedure was not intended to conduct at present time for this thesis.

4. Results

4.1. Introduction

Both seasons will be presented separately, due to unfortunate sampling during field season 2011, lab results from 2011 were therefore not considered to be at a sufficient level. They will, however, be presented in this chapter since they are a part of the overall results and are a fragment of the complete picture of the field area. All results are placed next to each other, to obtain an overview, based on geographical location, to gain an overall understanding of the apparent tidal flat. These are surface samples and logs from profiles made with accompanying samples. Also on some locations there has been observed ripples where the direction has been measured, to get an understanding of current directions that will be taken into the overall understanding of the study area. In several of the samples there have been performed grain size analyses, and calculations of mean grain size, skewness and sorting. To the grain size distribution three principal groups have been used after (Blott & Pye, 2001). Those are i) the average size, ii) spread of the sizes around the average (sorting), iii) the symmetry or preferential spread to one side of the average (skewness).

4.2. Field results

Profiles based on logs prepared during field work 2012 are highlighted in Figure 17. Marked in Figure 18 are the surface samples that were collected during field work in 2012. In Figure 19 locations from field season 2011 are marked. These are presented in chronological order in Appendix B. Logs are marked with a P (profile, Figure 17) and a locality number. Surface samples are marked with the letter T (transect, Figure 18) and an additional letter for which transect it belongs to and a locality number. Logs made in field are presented in appendix B, where the locality of each log is seen on the map in Figure 17 and the localities of each surface sample are shown in Figure 18.

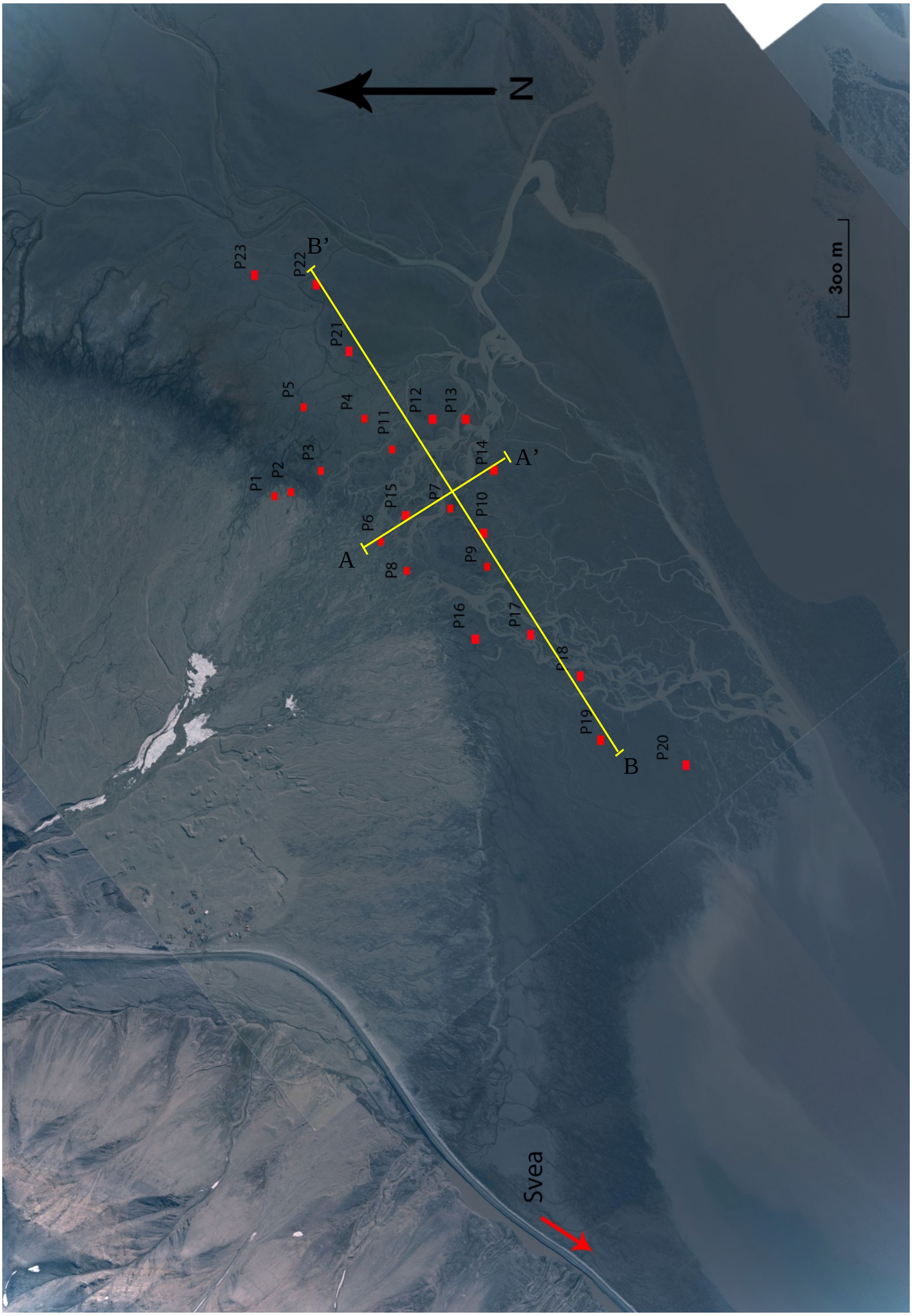

Figure 17*: Aerial photo showing where profile samples was taken and logs were created during field season 2012 (modified from "Norsk Polarinstitutt").*

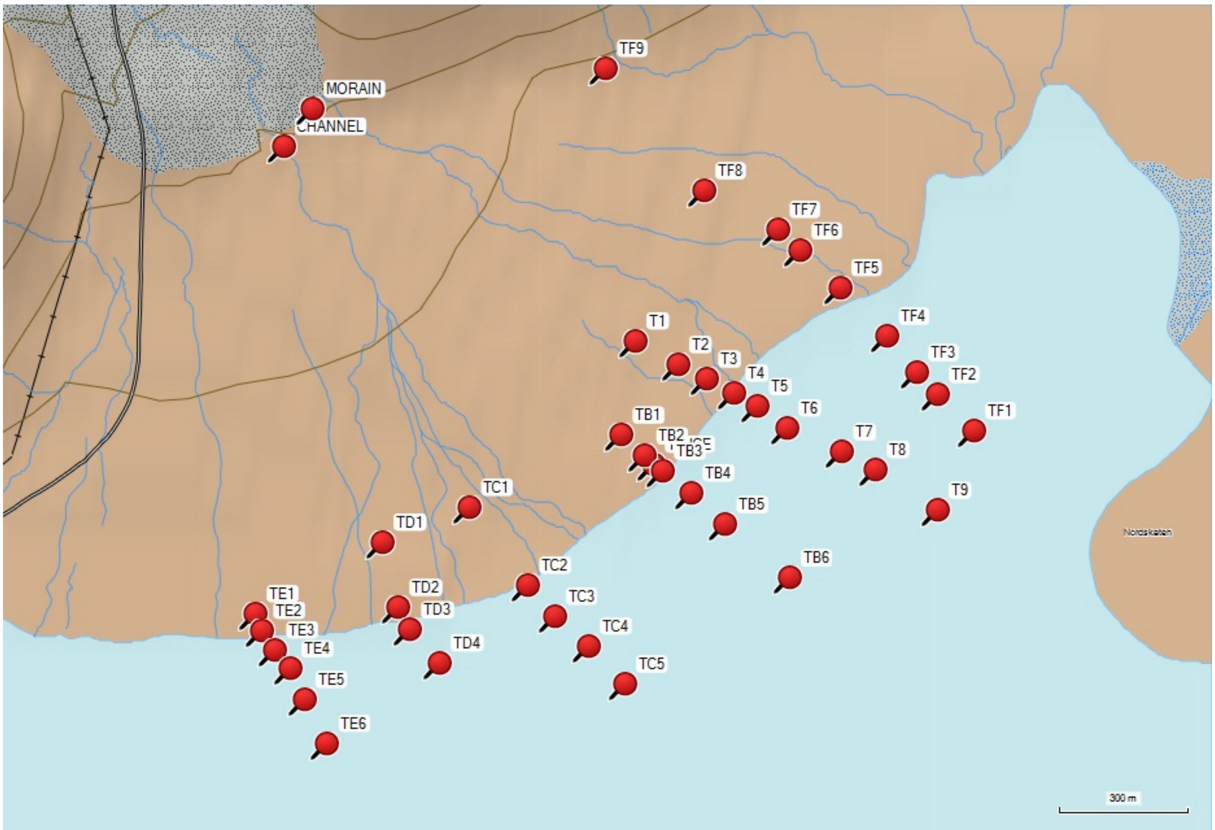

***Figure 18**: Map showing where the surface samples was collected during field season 2012 (modified from Topo Explorer Svalbard 2009)).*

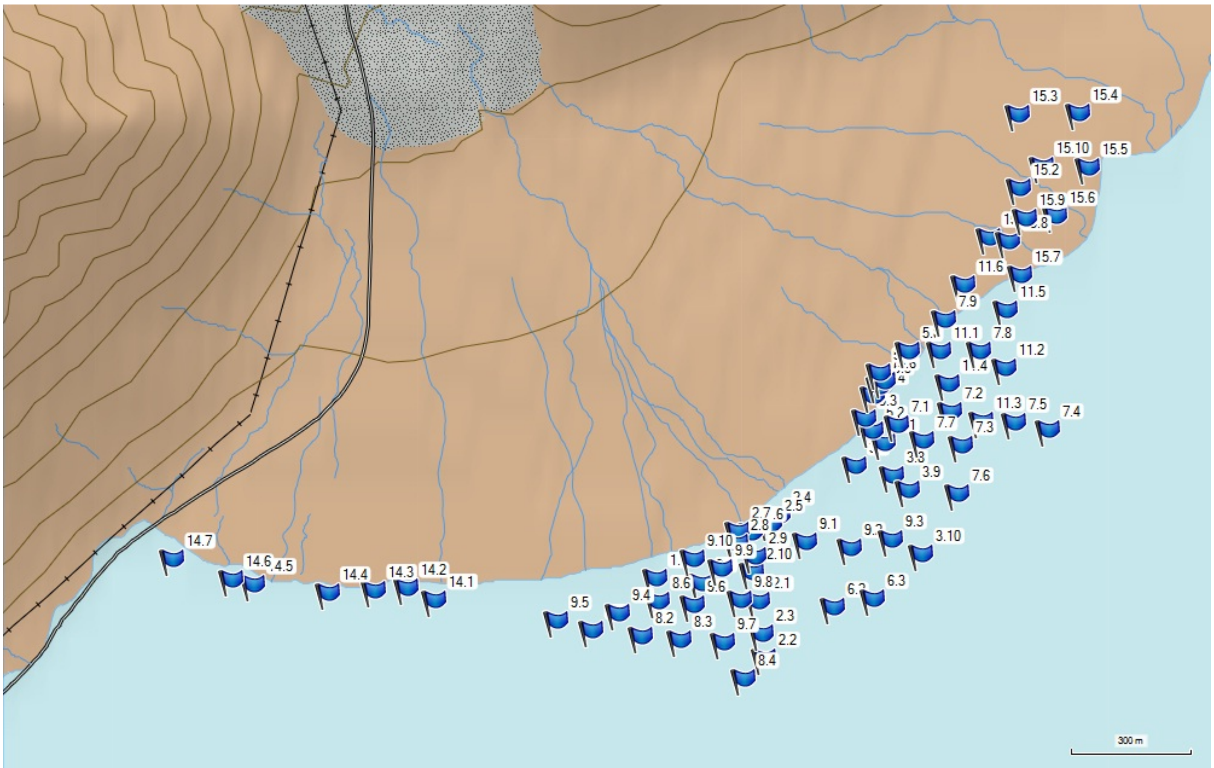

***Figure 19**: Map showing each location where logs and samples from field season 2011 was conducted, modified from Topo Explorer Svalbard 2009).*

4.2.1. Facies description

Based on logs made from field work during 2012, as seen in Appendix C, was possible to divide into four distinct facies. The facies are based on characteristics and similarities in each log compared with each other. Those four facies are as following:

Facies 1 is described as homogenous fine grained, as seen in Figure 20. One of the most apparent features with these logs is that they are relatively short compared to other logs that have the homogenous fine grain characteristics; they are 6-7 centimetres of length. Grain sizes are observed to be of clay and silt. This facies occurs closest to the fjord.

Facies 2: These logs contain bedding and have a larger variation in grain sizes as observed in Figure 21. In general they are fining upwards and have a range of grain sizes between coarse sand and silt. This facies is located in the area of the river mouth originated from the alluvial fan. This facies contained in some of the profiles different kinds bedding, e.g. wavy- and flaser-bedding.

Facies 3 consist of homogenous coarser material and are located in the more distal part of the river mouth, Figure 22. They range between 10 and 20 centimetres in length, and vary from coarse sand to fine sand in grain size.

Facies 4 are homogenous fine grained, as seen in Figure 23, and therefore similar to facies 1; the difference lies in the content of organic material found in facies 4. They consist of clay and silt, and are roughly 15 centimetres in length. These logs are situated furthest away from the fjord.

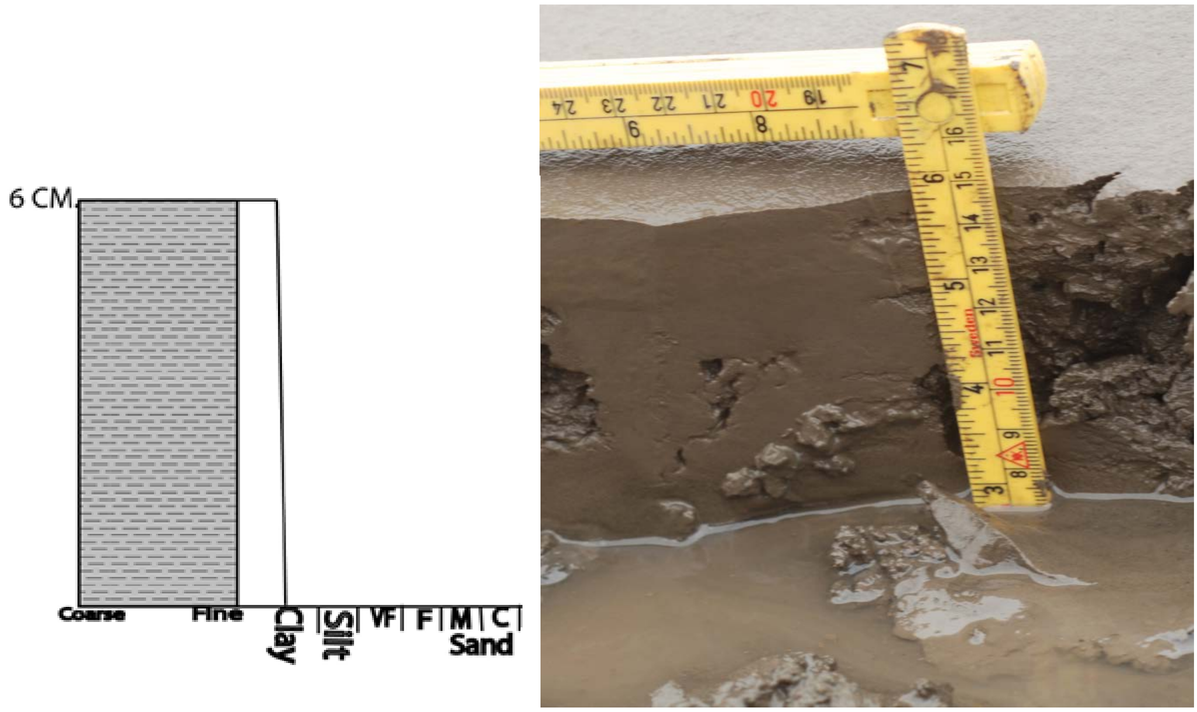

Figure 20*: Example for facies 1 is P20, location can be seen in Figure 17.*

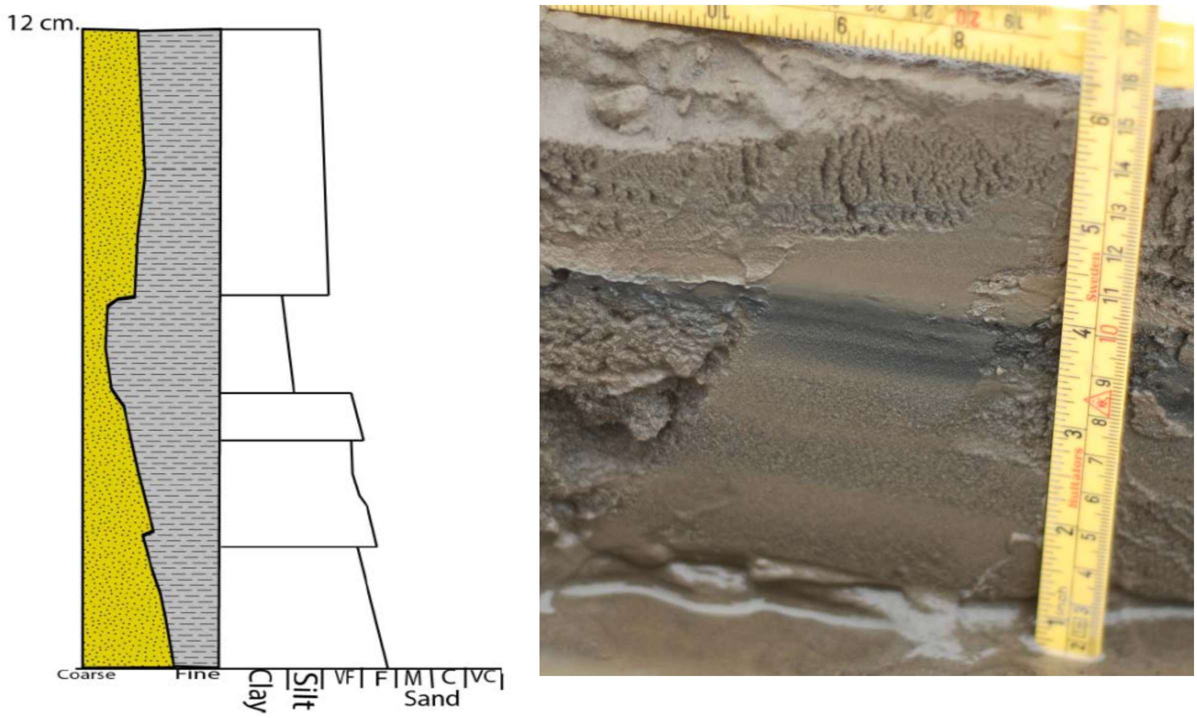

Figure 21*: Example for facies 2 is P6, location can be seen in Figure 17.*

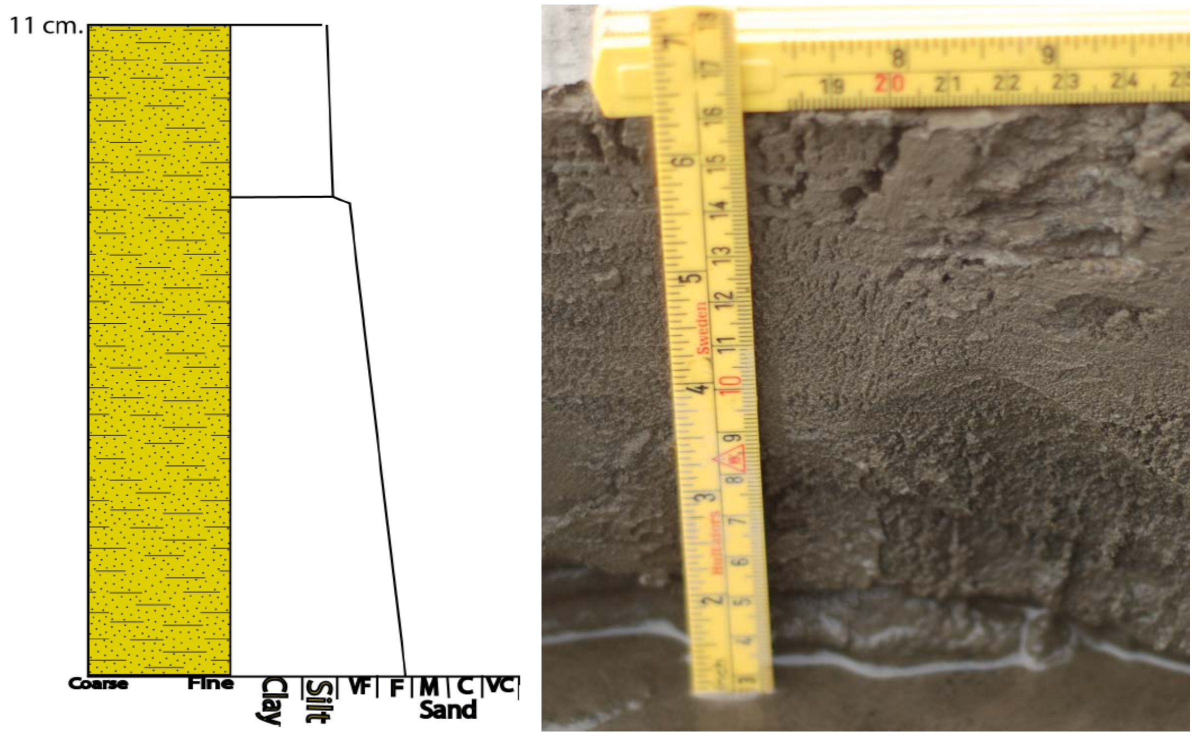

Figure 22*: Example for facies 3 is P14, location can be seen in Figure 17.*

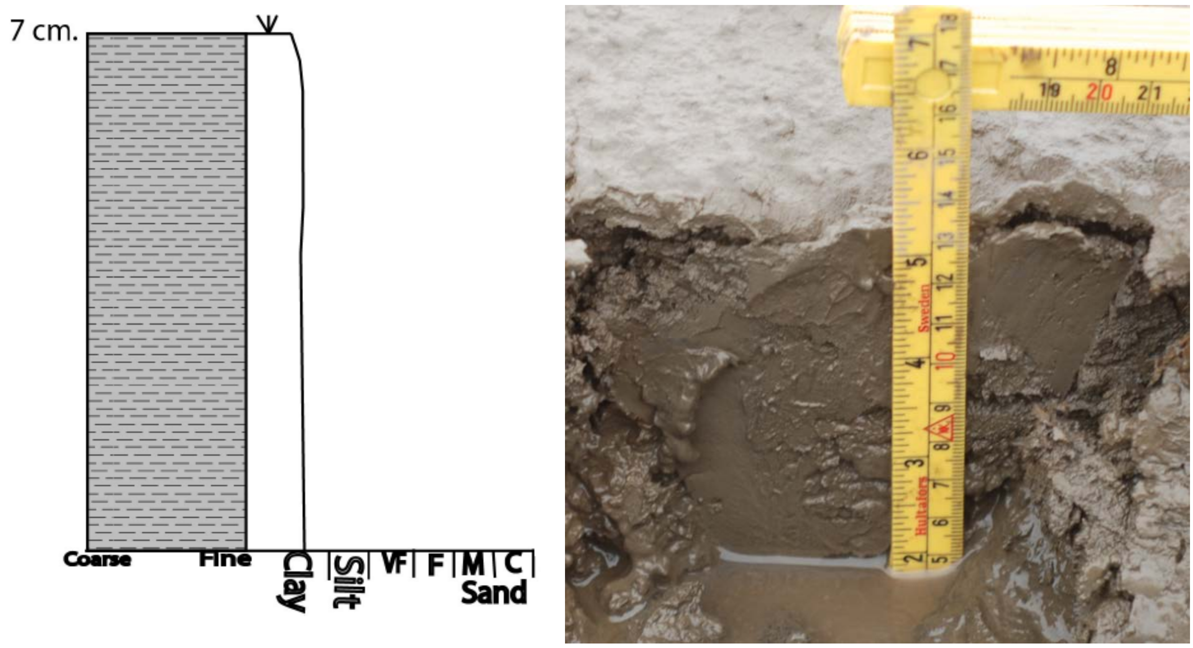

Figure 23*: Example for facies 4 is P22 where it is observed organic material at the top of the log, location can be seen in Figure 17.*

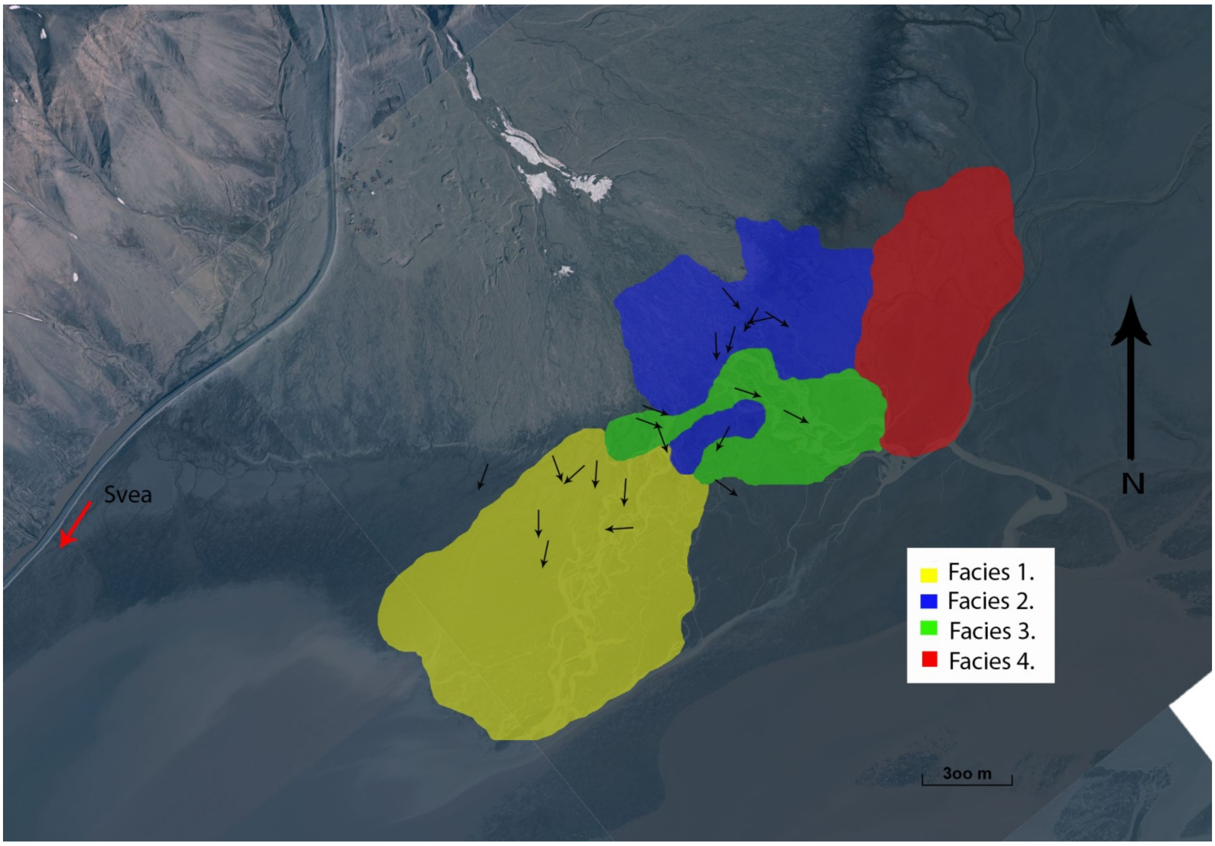

Figure 24*: Field area divided into four facies, facies 1 is tidally dominated, while facies 2 and 3 are mostly fluvial dominated. And facies 4 are reworked fluvial material and marsh. Arrows are showing the ripple direction on each location (modified from "Norsk Polarinstitutt").*

4.2.2. Ripples

Ripples that were measured are presented in Figure 25, showing the direction of the ripples, based on 20 measurements. Where each of those measurements is done can be seen in Figure 24. From this result it is possible to see how much these ripples vary in the studied area.

Seen from Figure 14, mostly there were asymmetrical ripples observed.

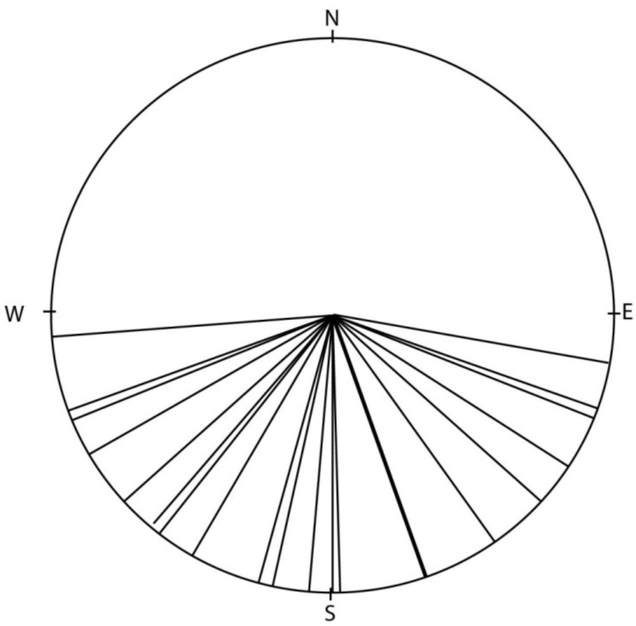

Figure 25*: Ripple directions measured in field during season 2011 and 2012.*

4.3. Lab results

Plots listed below are results from the grain size analysis done with Beckman Coulter LS 13 320, and some manually sieved samples. Further the calculation of mean grain size, skewness and sorting are the parameters used for making those plots. Results are presented in Appendix D and E. The *cumulative plots* made based on grain size analysis are presented in Appendix F and G. These different plots are divided into separate profiles, which have their own plot and each transect has its own plot.

Results from grain size analysis from 2012 are presented in Appendix E, here grain size, mean grain size, skewness and sorting are listed.

Based on the tables shown in Appendix E several plots are created. Presented here are the plots that have been divided into the four facies previously mentioned. The rest of the plots are presented in Appendix H. These plots have been separated into different groups based on facies, geographic location and the cumulative plots. The geographic location are separated into three different groups; *bay*, *river* and *inland.* Where *group bay* are profiles located closest to the bay, *group river* are the profiles that are situated nearby the area where the river from the alluvial fan flows out on the studied area. Last the *group inland* is located furthest away from the bay of Braganzavågen, where plots based on the similarities in the accumulation of grain size are shown in Appendix H.

Grain size analyses from 2011 are presented in Appendix D. As mentioned, data from field season 2011 will not be taken into much consideration due to the misfortunate sampling of the samples. They will however be presented here since they are results and make up the complete picture of the field area. Lab results from season 2011 have been put together without any separation of each sample. This was found to be unnecessary due to the sample quality.

4.3.1. Height vs. mean grain size

In the following four figures mean grain size distributions with height are presented, showing how the mean grain size changes by depth for the profiles. These plots are based on logs from field, seen in Appendix B and have been separated into the four facies. There have also been produced more similar plots presented in Appendix H.

Figure 26 show plot of facies 1, here mean grain size vary from 4 ϕ to 7,6 ϕ. Each log in the plot is represented with its own colour and symbol, making it easier to separate them from each other. Each symbol represents that specific depth from where the samples were gathered in field. Facies 2, in Figure 27, consist of profiles where bedding was observed in field. Here it is possible to see how the grain size changes with depth. These variations in mean grain size ranged from 3,1 ϕ up to 6,4 ϕ.

In Figure 28, logs that belong to facies 3 are plotted. Here the mean grain size range from 1,8 ϕ and up to 5,7 ϕ. Facies 3 consisted of the coarsest material. Figure 29 shows plot of facies 4. Mean grain size vary between 5,8 ϕ and 7,2 ϕ, showing that facies 4 have the least variation in grain size of these four facies. Facies 3 consist of logs profiles where the profiles where observed to be homogenous coarse grained. Here it is possible to see how the grain size changes with depth. These variations are of range from 1,8 up to 5,8 ϕ. It is also observed a larger span of mean grain size in facies 3 compared to the other three facies.

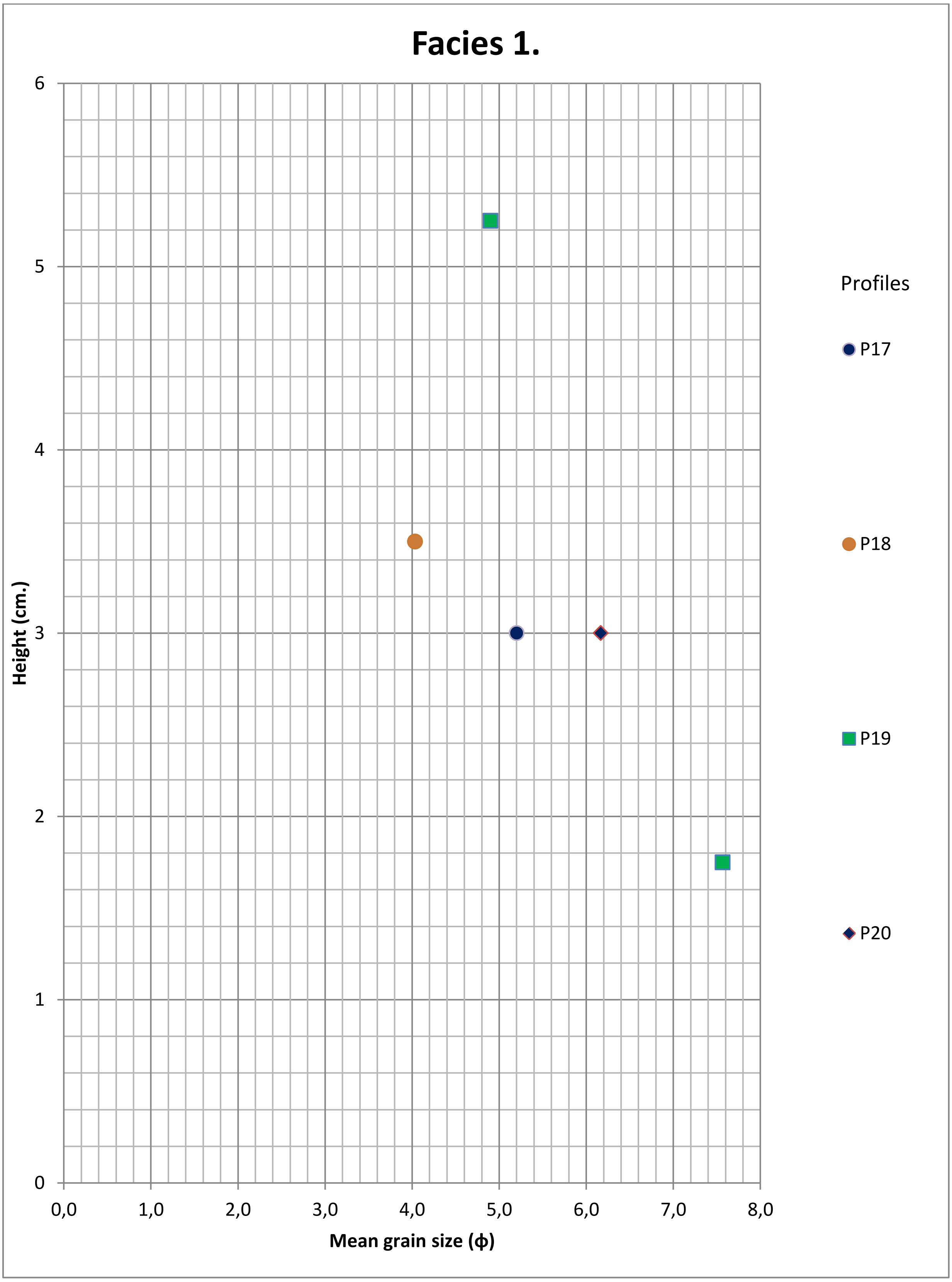

***Figure 26**: Mean grain size with height for facies 1.*

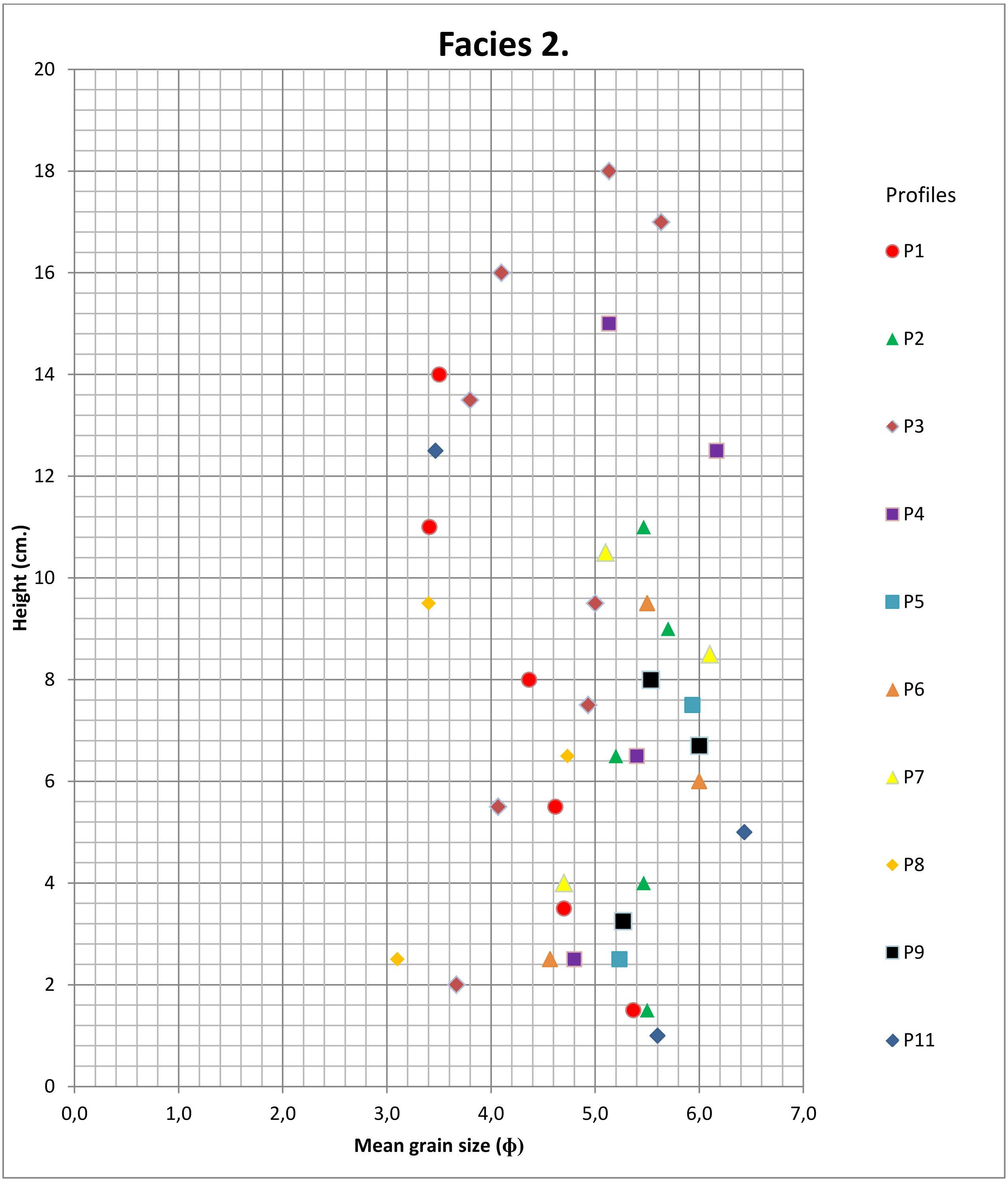

Figure 27*: Mean grain size with height for facies 2.*

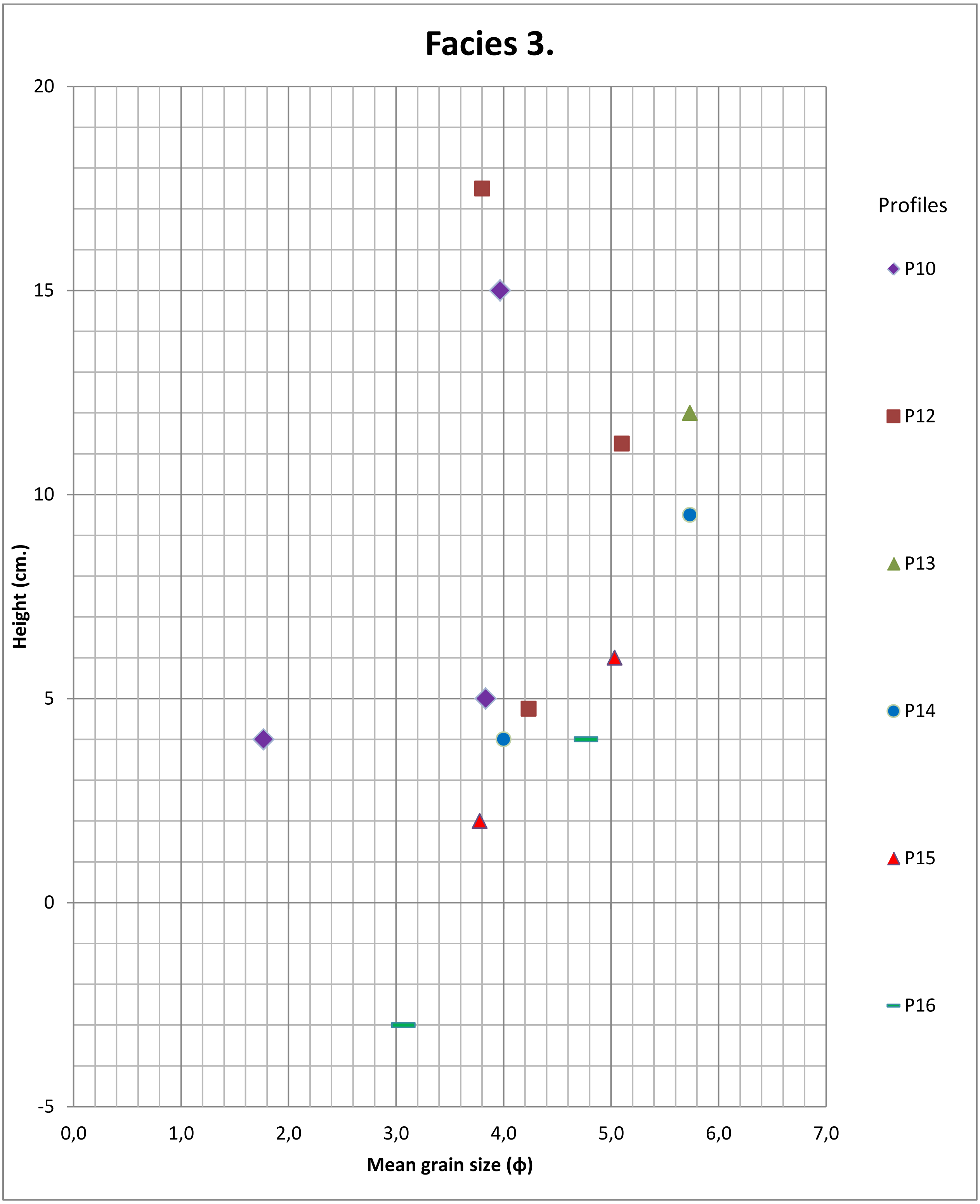

Figure 28: *Mean grain size with height for facies 3.*

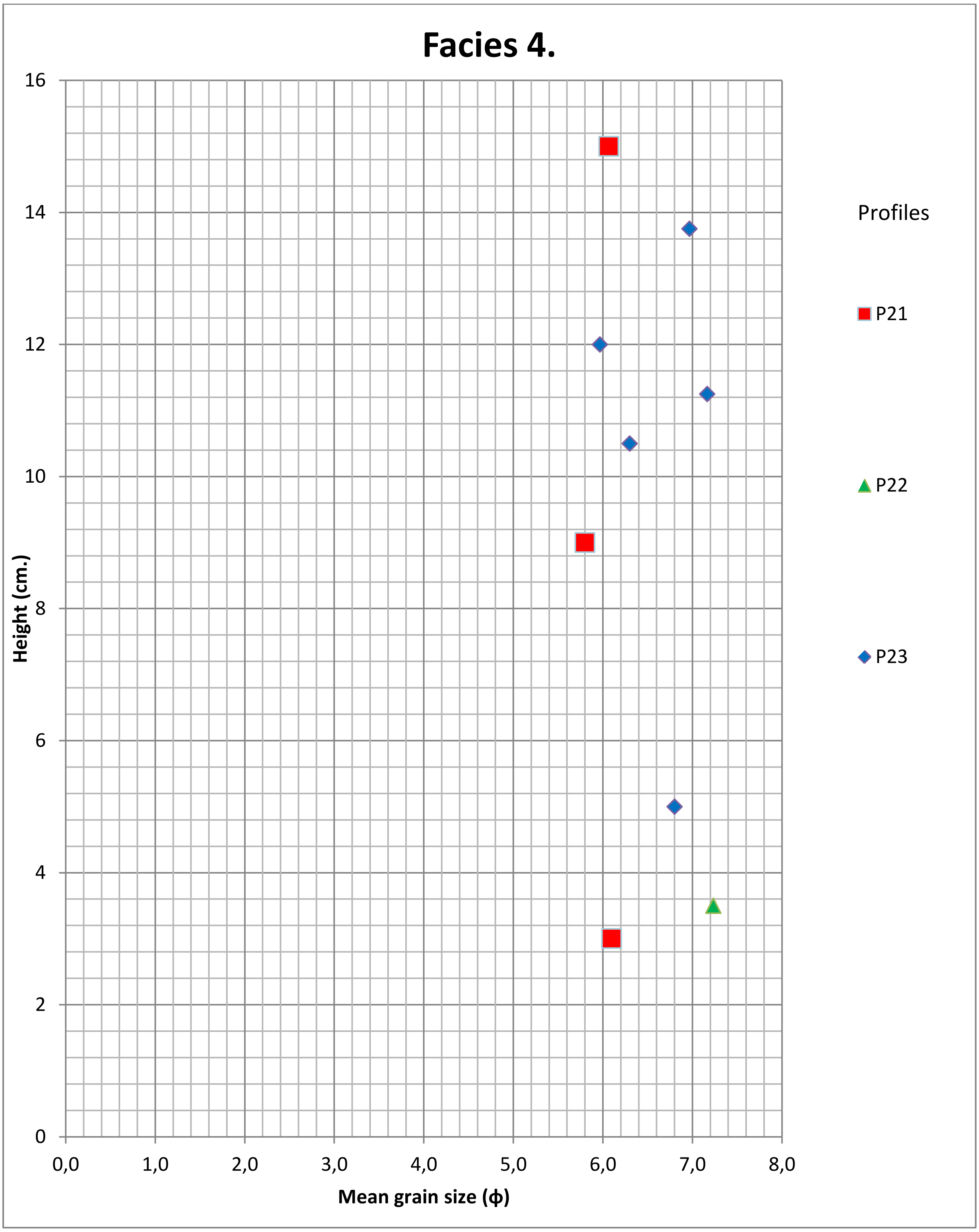

Figure 29*: Mean grain size with height for facies 4.*

4.3.2. Mean grain size vs. sorting

Figure 30 shows how the sorting is distributed accordingly to mean grain size for facies 1. It is noticeable that there is a very small variation in sorting that is in the range ‘very poorly sorted’ (Table 1), the mean grain size, however, has a somewhat large span.

Figure 31 shows how the sorting is distributed as a result of mean grain size for facies 2. It is observed that all the results are situated in a cluster rather than close to each other. They are in the range ‘poorly sorted’ to ‘very poorly sorted’ (Table 1). This facies share many similarities with facies 3, it looks more scattered, however facies 3 have less data points than facies 2.

Figure 32 shows how the sorting is distributed according to mean grain size for facies 3. It is observable that these results are more scattered than both facies 1 and 4. They are in the range ‘poorly sorted’ to ‘very poorly sorted’ (Table 1), showing how the sorting is distributed according to mean grain size for facies 3. Facies 3 also have the largest variation in mean grain size.

Facies 4 is presented in Figure 33, showing that the samples have a small mean grain size, and very poor sorting. This facies have many similarities with facies 1, except that facies 4 are more clustered than facies 1.

In Figure 34 results from season 2011 shows the relationship between mean grain size and sorting. Here it can be observed that the sorting becomes poorer as grain size decreases.

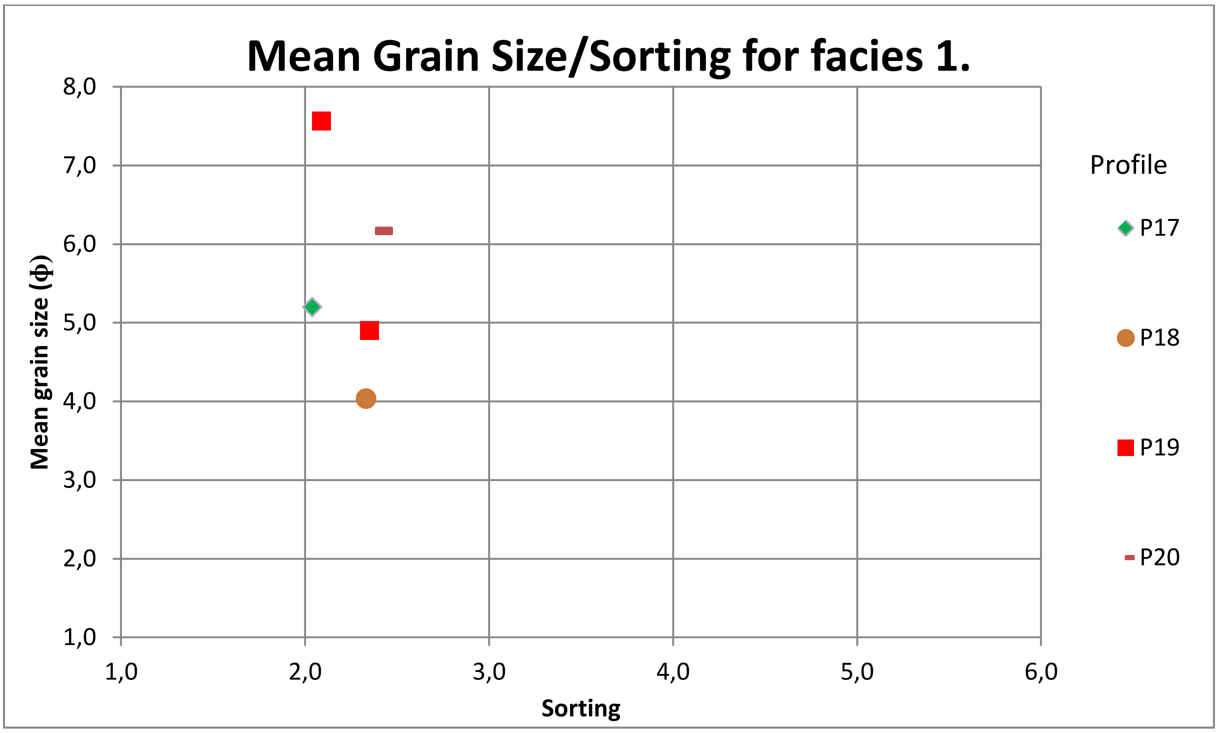

***Figure 30**: Relationship between mean grain size and sorting for facies 1.*

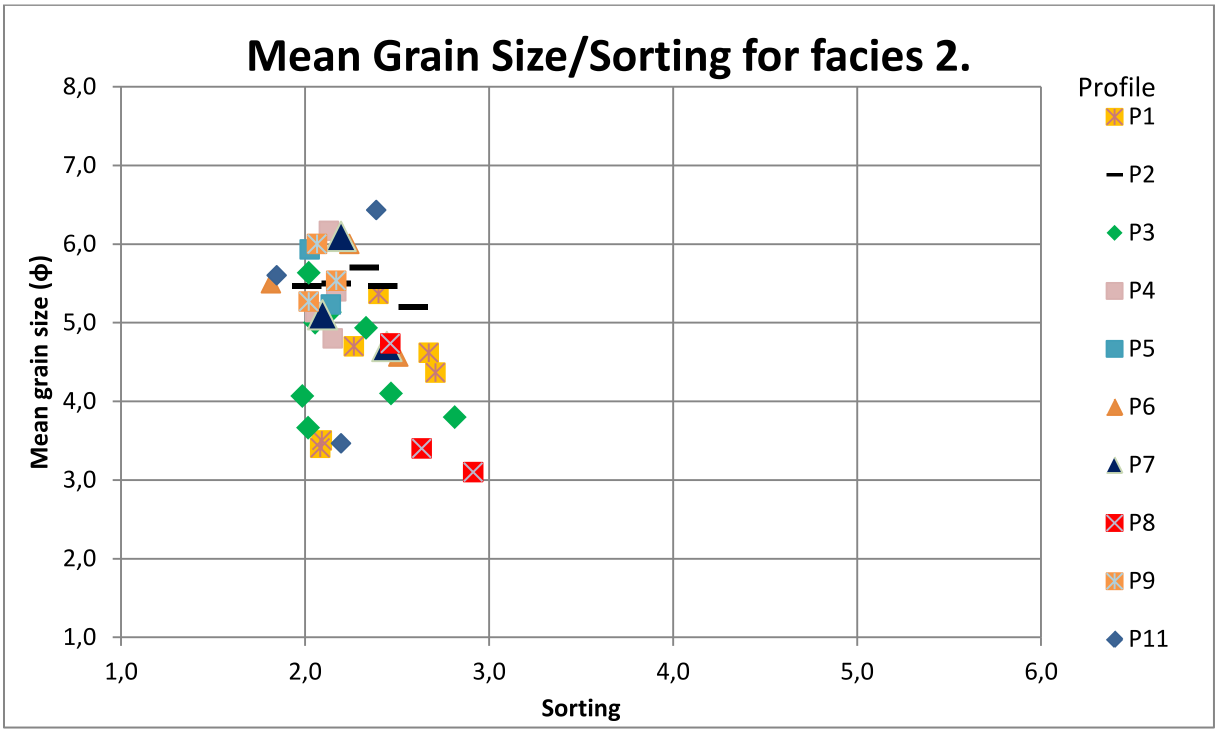

***Figure 31**: Relationship between mean grain size and sorting for facies 2.*

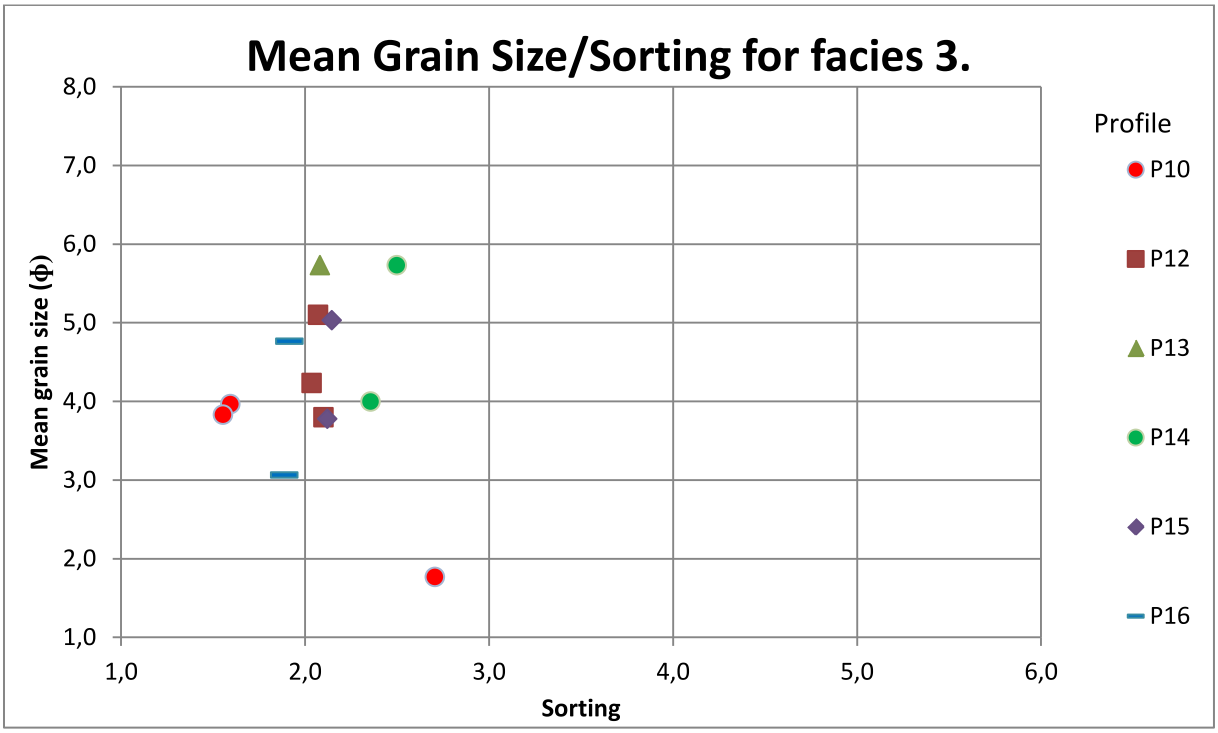

Figure 32*: Relationship between mean grain size and sorting for facies 3.*

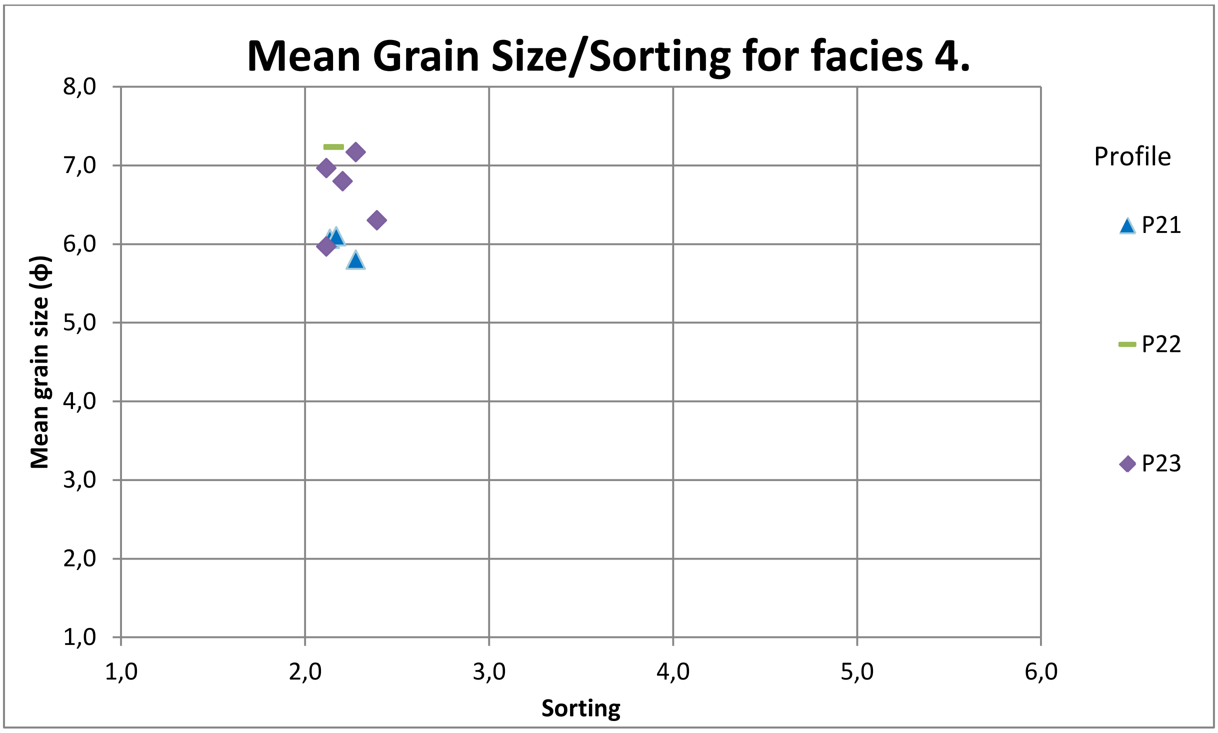

Figure 33*: Relationship between mean grain size and sorting for facies 4.*

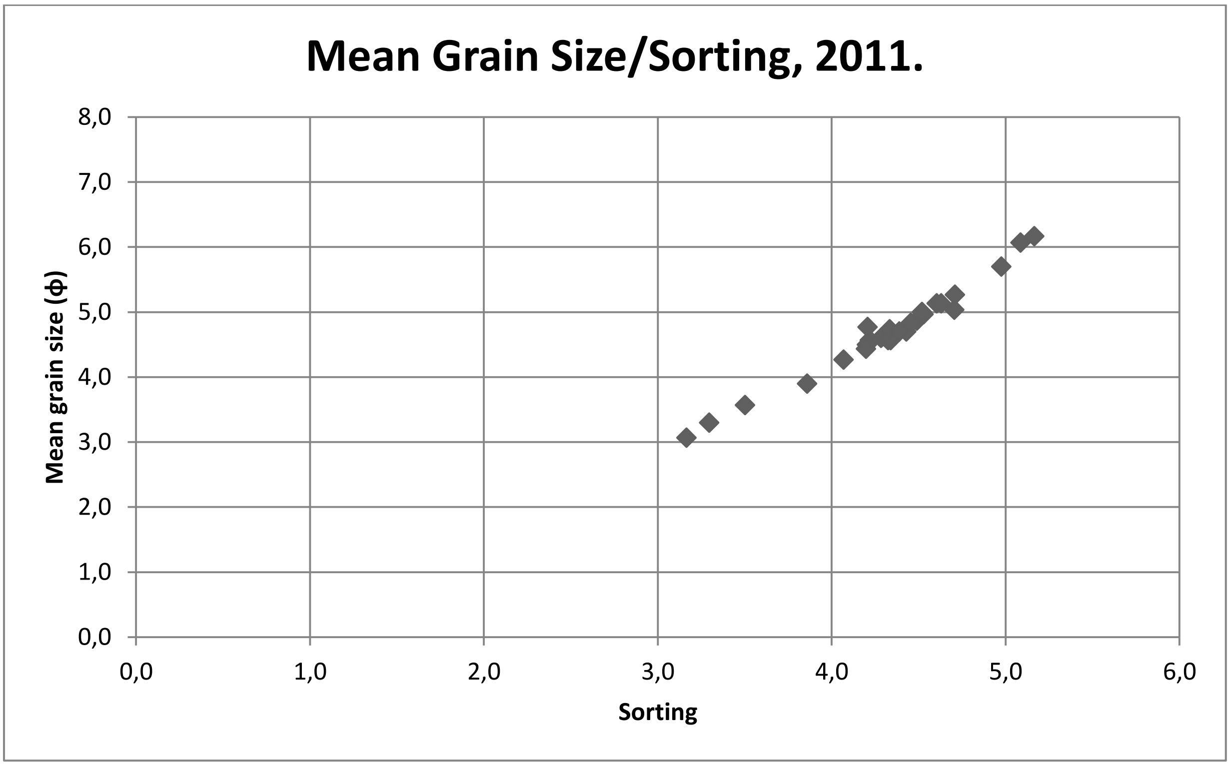

Figure 34*: Relationship between mean grain size and sorting.*

The rest of the plots that have been made are presented in Appendix H, it can here be observed that in the *group sea* it is apparent that the samples are scattered without any clear trend. Further in the *group river* the samples are more clustered together with a few exceptions. For *group land* the data set are clustered fairly well together, where the anomalies also can be observed as minor groups. The *cumulative plot* for *group 1* shows a cluster of the samples, except from P10 that are a little off compared to the rest of the groups. In *cumulative group 2* the plots are a little scattered from each other. In the last group, *cumulative group 3*, all of the samples are clustered nicely together.

4.3.3. Skewness vs. Mean grain size

Facies 1 are shown in Figure 35, here it is observed that the data set is scattered out in the lower right corner.

In Figure 36 facies 2 are presented. They are widely spread out in the plot, indicating a large span in both skewness and mean grain size.

Figure 37 shows facies 3, where the same pattern as in facies 2 are observed, with a large span of both skewness and mean grain size. In this plot a large portion of the data points are scattered out with only a few points centred closely together. However, facies 3 have some data points that stands out in a greater extent.

Facies 4 are presented in Figure 38. Most of this data set are situated in the lower right corner and have much in common with facies 1. They both have the same range in skewness as in mean grain size.

In Figure 39 the results from 2011 displays the relationship between skewness and mean grain size, showing that the grain size and skewness remain stable in almost all of the data points.

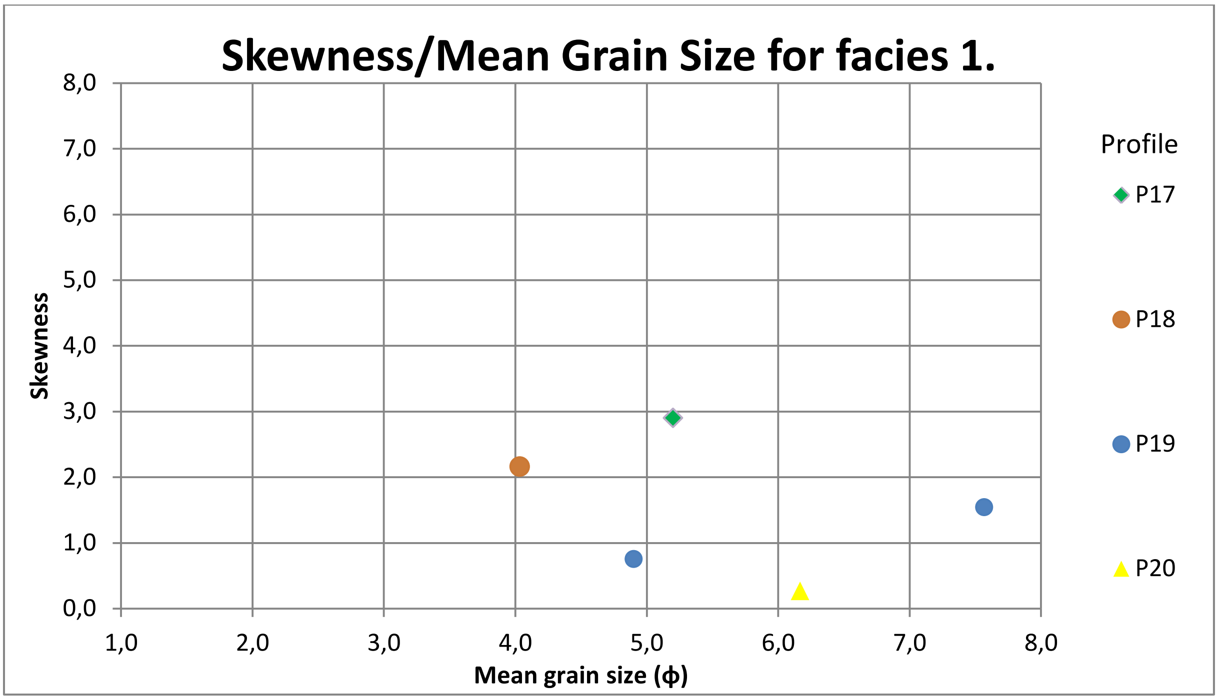

***Figure 35**: Relationship between skewness and mean grain size for facies 1.*

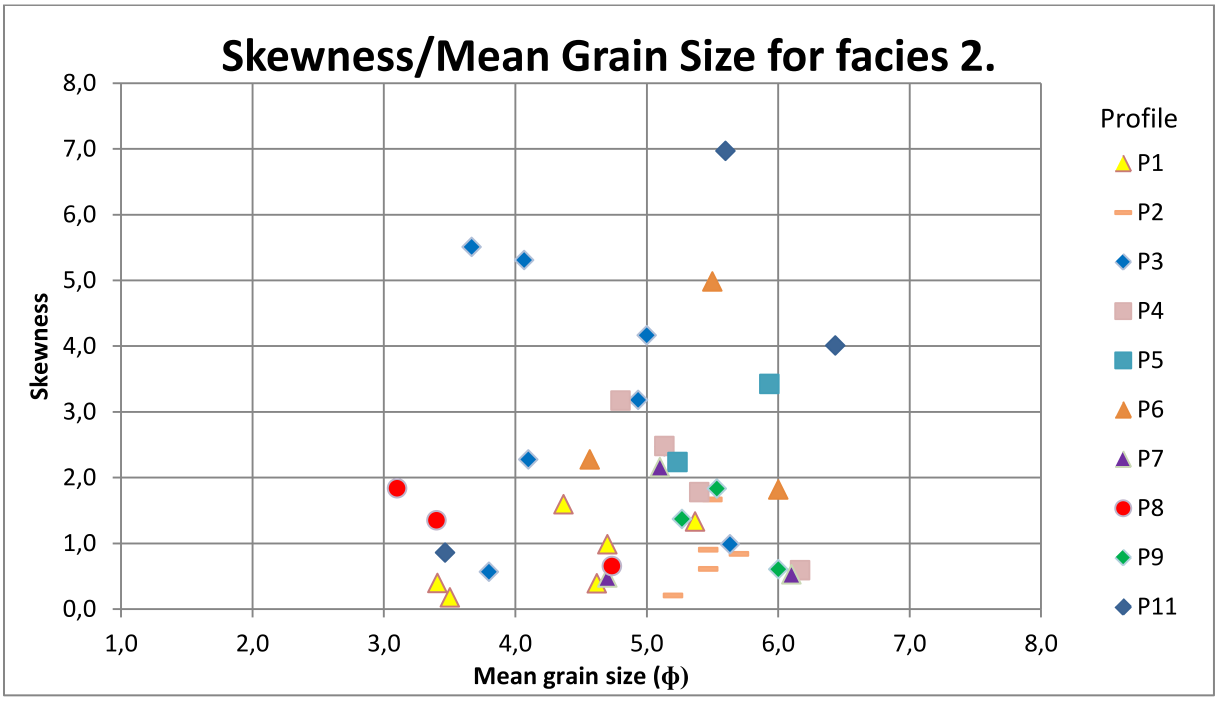

***Figure 36**: Relationship between skewness and mean grain size for facies 2.*

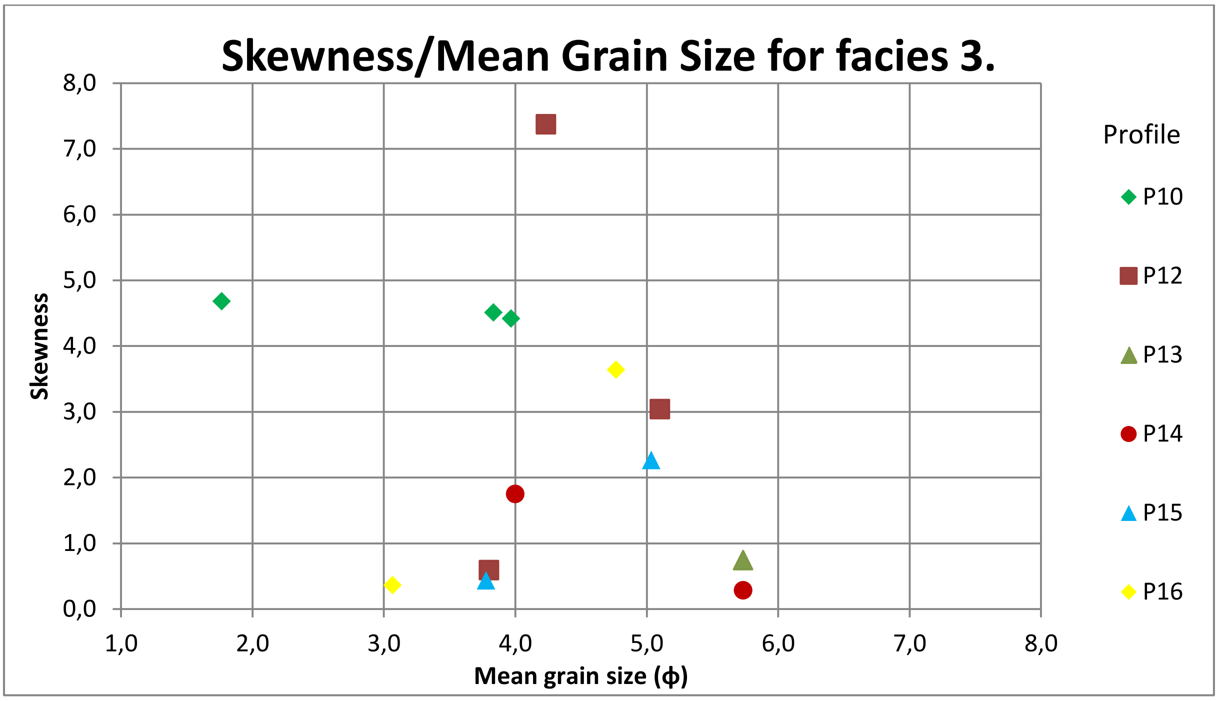

***Figure 37**: Relationship between skewness and mean grain size for facies 3.*

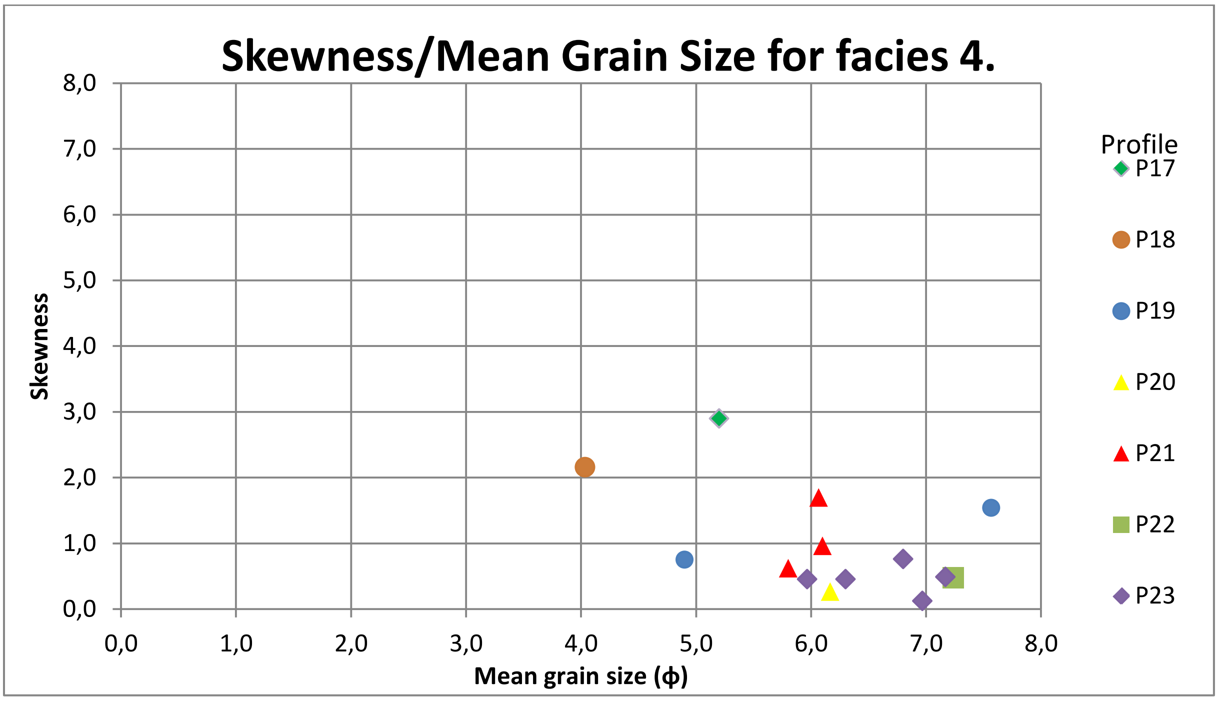

***Figure 38**: Relationship between skewness and mean grain size for facies 4.*

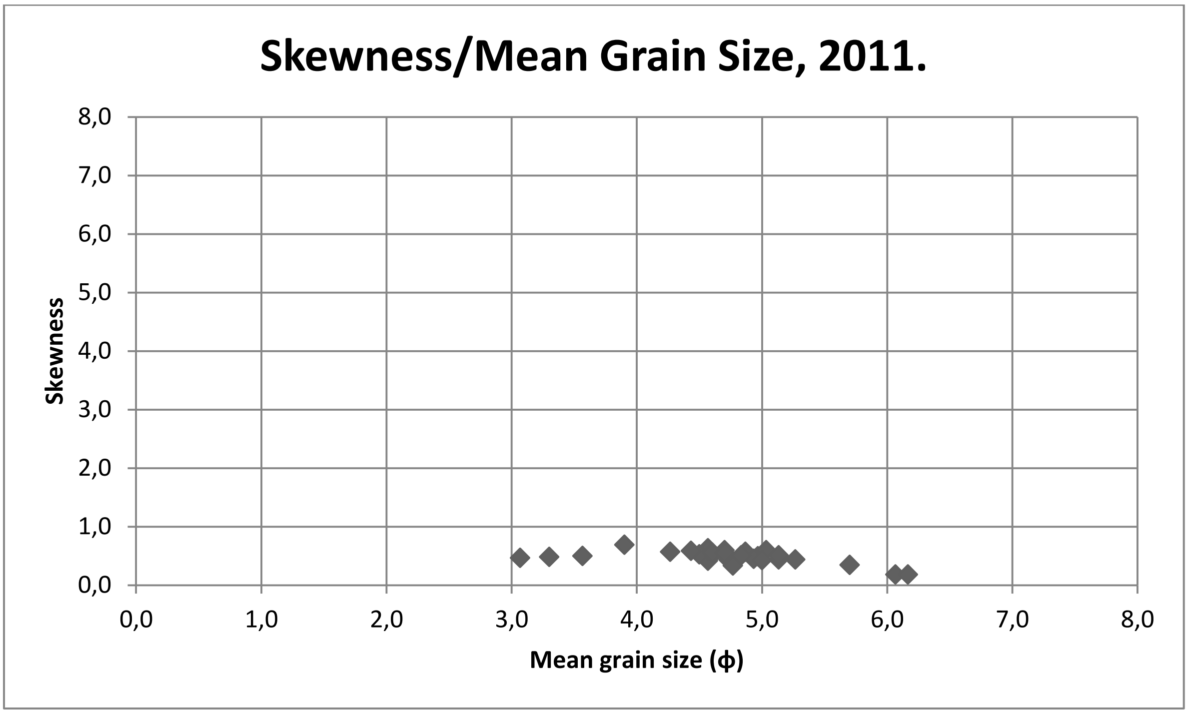

***Figure 39**: Relationship between skewness and mean grain size.*

For the next group that is called *sea*, all of the data points are scattered through the plot. With all of them having a skewness less than 5, it is also possible to observe that mean grain size is the main reason for the scatter of points. From the *group river*, the data points are scattered out, with skewness as the reason for the scattering of data points. In the *group land* the same trend is found as in the other two groups previously mentioned. Mean grain size is of equally importance when it comes to scattering of data points in both of the previously mentioned figures.

Plots based on similarities with *cumulative plots*, as seen in Appendix F, have been divided into *three groups*. In all three of the plots there have been observed that most of the data points are scattered through the plot, except for *group three,* where there can be observed a cluster of data points on the bottom right side of the plot.

4.3.4. Sorting vs. Skewness

Facies 1 are seen in Figure 40. Here low skewness are observed, and the sorting are ‘very poorly sorted’ (Table 1).

Figure 41 present facies 2. This data set is in the sorting range of 2-3, meaning that they are very poorly sorted. The skewness range is from 0 and up to 7, which indicates that they are very fine skewed.

In Figure 42 facies 3 are shown. Here a larger variation in sorting can be observed. Again the skewness has the greatest span.

Facies 4 are shown in Figure 43, here the lowest variations are observed. However, the same trend may be observed both in sorting and skewness. The sorting is ‘very poorly sorted’, and the skewness is very fine skewed.

The relationship between sorting and skewness from field season 2011 (Figure 44) shows that there are large variations in the sorting; all of the samples are extremely poorly sorted. While the skewness are from fine skewed to very fine skewed.

For the sorting vs. skewness type of plot, almost the same trend is observed in all of the groups that have been plotted. They all show that the sorting is fairly stable between 2,0 and 2,5, with some variation. In these cases it is the skewness that shows the largest variation in the spreading of data points. The rest of the plots (Appendix H) produced have the same pattern in both sorting and skewness, in all three groups (*sea, river and land*) and in all three groups for *cumulative plots*.

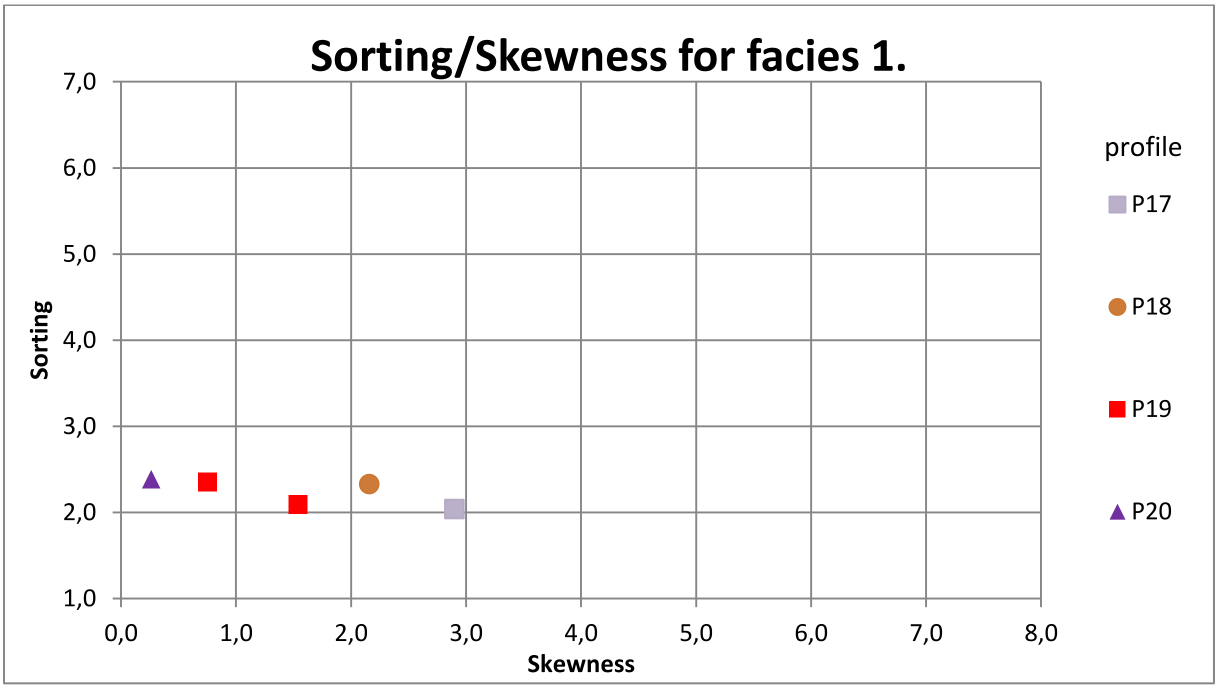

Figure 40: *Relationship between sorting and skewness for facies 1.*

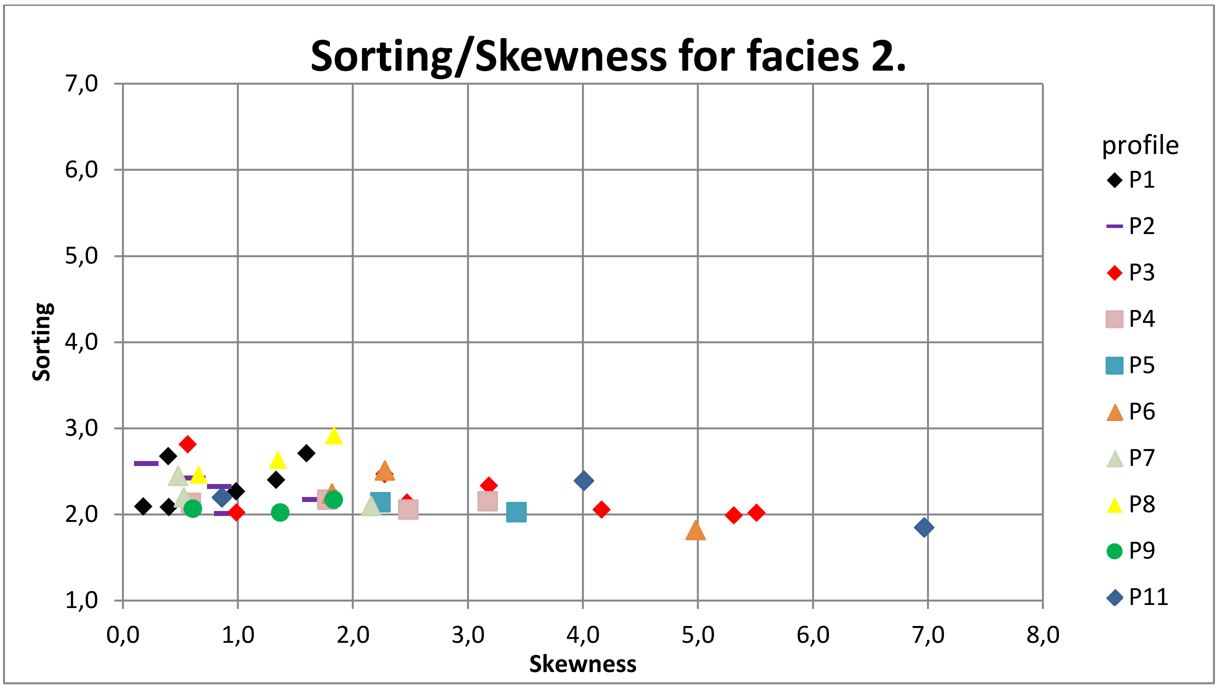

Figure 41: *Relationship between sorting and skewness for facies 2.*

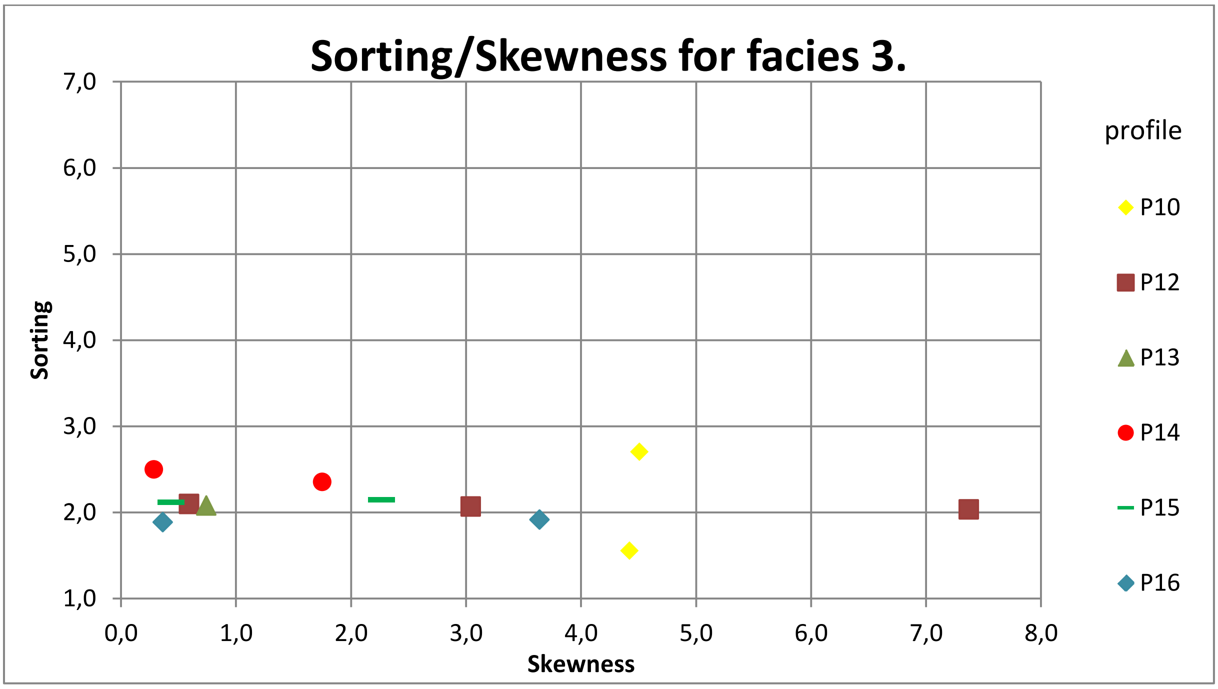

Figure 42*: Relationship between sorting and skewness for facies 3.*

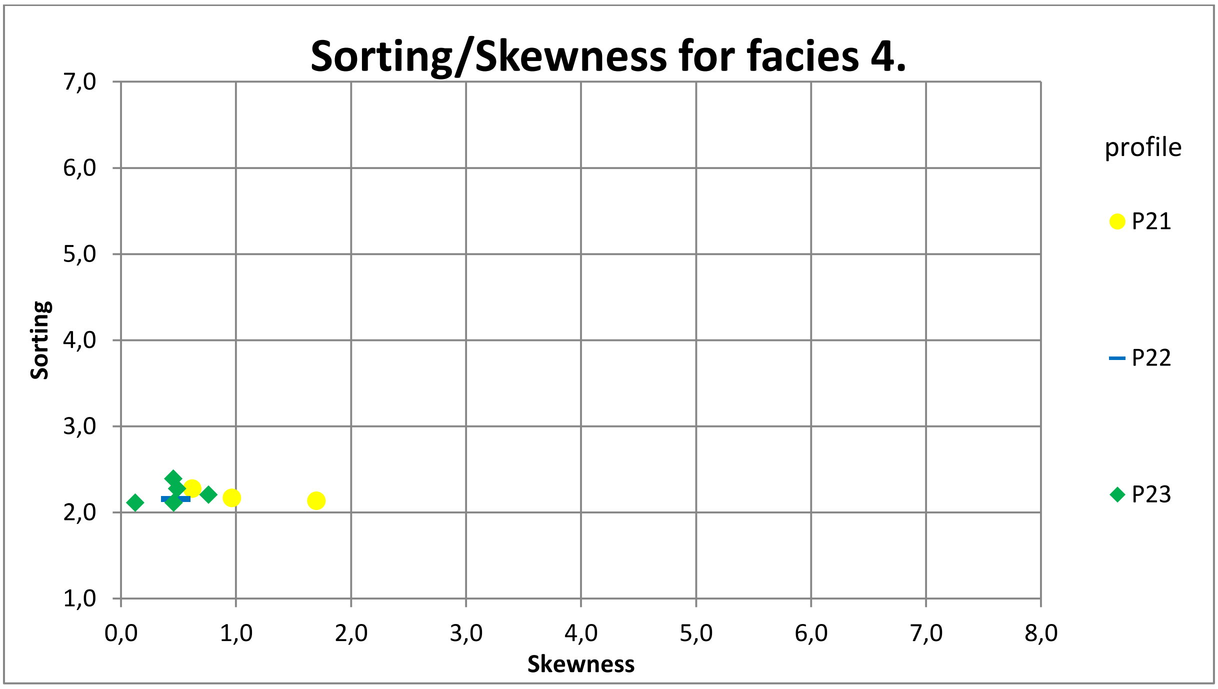

Figure 43*: Relationship between sorting and skewness for facies 4.*

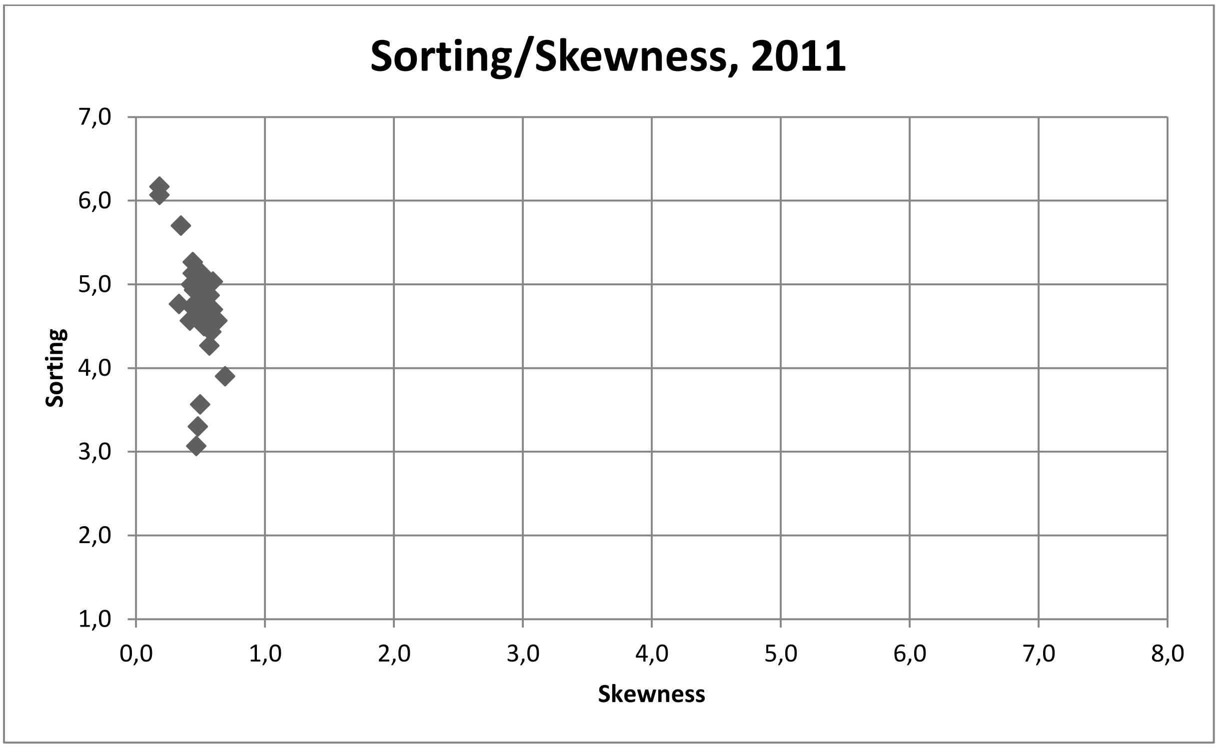

***Figure 44**: Relationship between sorting and skewness from field season 2011.*

With the grain size ranging from 4 – 6 ϕ, some anomalies up to 7,5 ϕ and down to 1,8 ϕ were observed, however they were rare. The same trend was observed in the parameter sorting, where the majority of the samples are within the range of 2 – 2,5 indicating that the sediments in the research area were 'very poorly sorted' as seen in Table 1. The parameter with the greatest variation is the skewness. Here most of the samples were within the range of 0 – 3, on the other hand values up to 8 were observed.

5. Discussion

To get an understanding of the processes going on in Braganzavågen, the observed and studied logs and morphology are crucial to gain the desired knowledge concerning this area. After two field seasons the first assumption that this area is a tidal flat, is not so obvious any more. This is based on observations done from the on-going alluvial fan and fluvial processes; it may seem that the studied area is more complex than just a tidal flat. This is mostly based on thorough observations done in field and the lab. Previously there has not been conducted much similar work on such sedimentation in arctic environments. The observations done will be compared to similar work at other latitudes (Dionne, 1970; Plater & Appleby, 2004;

Sisulak & Dashtgard, 2012; Yang et al., 2005). Several parameters are of importance for this study e.g. grain sizes, distribution of sediments, structures found in field and morphology; where logs are crucial for this work in gaining an understanding of the on-going processes. Further it is based on grain size parameters such as the mean grain size, sorting and skewness. All in all this can help identify what kind of depositional environment the studied area is.

All of the parameters above are crucial to understand the overall picture of how this environment behaves in sediment distribution and deposition. Is there an erosive or constructive tidal flat (Kirby, 2000; Yang et al., 2005), or even the possibility that this is not only a tidal flat. It could also be a prograding alluvial fan, or a small part of an estuary? The studied area is assumed to be highly active, possibly with a really high deposition rate.

Based on observations of an alluvial fan, a larger river, peninsula and lack of wave activity as the first and most apparent observations, the question is whether or not it really is a tidal flat. To increase the knowledge about this, the general tidal flat must be understood, and questions like how tidal flats are formed, where they are found, and what characterise them, are considered.

5.1. Importance of grain size distribution

When it comes to the distribution of sediments, they are most likely transported from the fluvial processes derived from the alluvial fan. Due to facies 1 and 4 that are of fine sediments in the marsh, and intertidal zones have probably been separated by the river system that comes from the alluvial fan (facies 2 and 3). This indicates that sediments deposited on the marsh most likely are older than sediments deposited on the intertidal zone, which also are being reworked frequently by tidal currents and meandering rivers.

From the facies it is possible to observe some pattern of distribution in the grain sizes (Figure 25, Figure 26, Figure 27 and Figure 28), where this pattern have an origin from the fluvial activity from the fan, suggesting that the sedimentation input are mainly coming from fluvial settings rather than tidal sedimentation. Tidal currents are of importance when it comes to reworking of the sediments. Because of the low velocity currents, only smaller grains can stay in suspension and they are deposited further out in the bay. One issue about this is that the sorting, profiles, like P14 taken more on the subtidal – intertidal zone, do not have any particular change in sorting (Figure 22). Even so they are emerging as more fine grained and homogenous in the field. When observing the mean grain size, it is possible to observe that the profiles from the subtidal – intertidal area are in fact a little more fine grained than the rest of the studied area, however, also very poorly sorted (Figure 30, Figure 31, Figure 32 and Figure 33).

When comparing the observations done in field and in lab there are some characteristic trends that may be witnessed when it comes to grain size and sorting. In some degree there is match between these two results. With this comparison it was possible to divide the studied area into four distinct facies as described earlier. Placement of these facies can fit in with the sedimentary history; moving from inland to the shoreline there is first marsh environment, going into possibly supratidal environment with high fluvial input, and then intertidal and subtidal environments. By Walther's law (Middleton, 1973) these facies would be possible to find lying on top of each other downwards if deeper cores would be made at a latter point, and could be of interest for any further study in this area.

Based on facies description from the logs and morphology observations done in field a facies distribution map is produced (Figure 24). Where the aerial image is the base; this would make it possible to see how the facies are spread out in the studied area. Since this is based on log description, this can be seen as a spatial distribution map.

Dispersal of the sediments in correlation with grain size distribution can be seen as going from coarse and mixed close to the front of the alluvial fan from the possible prograding fan, into being finer grained as moving away from this fan front. Scattering of these sediments gives the indication that the sediments are settling based on grain size distribution from energy differences in the stream. This may again indicate that the tidal currents are only contributing with reworking of the sediments, instead of deposition of a typical tidal environment where structures like tidal mud couplets would have been expected, since this is typical for tidal flat deposits.

Based sorting calculations it is possible to observe that the sorting generally is 'very well sorted' (Table 1) in the data set from 2012 and in the data set from 2011. Having a range from moderately- to very well sorted. This indicates either that the sampling was better in 2012 than in 2011, or that there have been some changes in the sorting. When observing data from Friedman (1967) in Figure 9 with data collected in Braganzavågen, they would be far off in the upper right corner compared to Friedman (1967) data set.

The grain size in general is largely dependent on local current strength and available particles. Sorting is in many ways dependent on grain size, and can be evaluated for example in a scatter plot of mean grain size and sorting (Folk, 1974), where the main trend is seen in Figure 45.

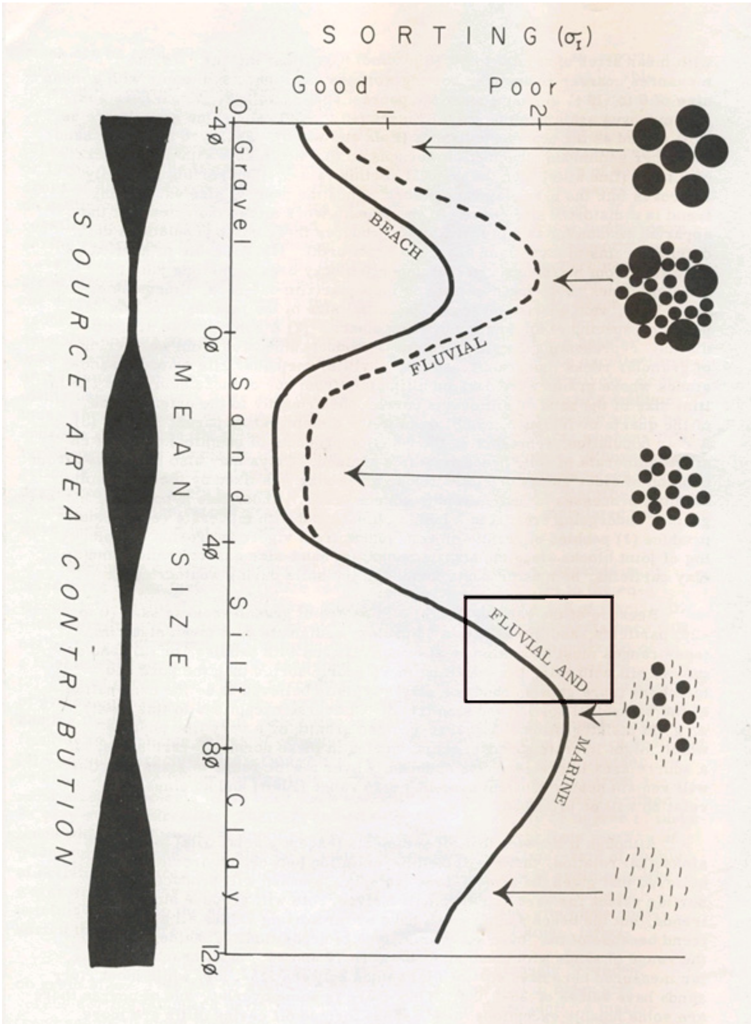

***Figure 45**: Showing typical environments based on the relationship between sorting and mean grain size (modified from Folk (1974)).*

5.2. Grain size plots

Grain size plots that were created were divided into four facies, further three groups that are based on geography and the cumulative plots. Based on these plots the homogeneity is apparent. Observation of these plots shows that skewness is the variable that changes the most. Where the skewness gives details about the symmetry in the samples, skewness between 0,1 and – 0,1 confirms that the samples are symmetrical (Folk & Ward, 1957). Most of the samples from Braganzavågen are in the range of very fine to exceptionally fine skewed. This explains that the larger grains are more numerous than the fine grains in the sample.

When it comes to the sorting most of the samples were between 2 and 2,5, with a few exceptions, i.e. most of the samples are very poorly sorted. Combinations of these plots can give an indication of in what kind of environment these sediments have been deposited, as mentioned above.

Based on Figure 45 from Folk (1974) where the relationship between sorting and mean size are presented, it is possible to conclude that the sediments collected from Braganzavågen are from a fluvial and marine environment (Figure 45). This fits well with the observations done in field, where it is apparent that fluvial processes are important factors when it comes to deposition. The marine part, described as facies 1, shows that the sedimentation is most likely based on tidal processes.

Surrounding formations may however, consist mainly of sandstone and siltstone units that most likely have been eroded by glacial activity and transported by melt water into the bay. In further work it would have been interesting to obtain knowledge about the mineral composition in the sediments that have been sampled in the bay of Braganzavågen; methods like C^{14}-dating would be of interest.

5.3. Logs

It is possible to observe some similarities e.g. between logs and morphology when comparing results from the two seasons done in field. They were divided into four main facies, based on the logs only. Facies 1was homogeneous with fine grains, facies 2 was a mix with bedding, facies 3 was homogeneous with coarse grain, and facies 4 was homogeneous with fine grains and organic material. When the facies are observed at as a whole, a relatively good overview of the distribution can be observed as a complete depositional system. It is possible to see that in areas around the river, outlets hold the largest variations in the profiles and morphology, and they have an overall coarser grain size than observed closer to the shoreline (Figure 21 and Figure 22).

Most of the samples with homogeneous fine grains were located close to the ocean and the Kjellströmriver. Logs with bedding in facies 2 and with coarser grained were situated in areas closer to the fan and where the river processes going on from the fan. The studied area is separated between facies 2 and 3. This trend was observed in both seasons when data were collected. The reason for the small variations are most likely caused by the high snow melting activity going on, that changes the river outlet frequently. Due to this erosion and deposition possibly happens over a relatively short time span. It can therefore be questioned whether or not the logs are complete, meaning that bottom and top is eroded away, giving an incomplete log. Areas where the homogenous fine grained logs are collected are in the more quiet parts of the studied area, and only the finer grains have high enough cohesion to be deposited there. The cause for this might be that the sediments on this flat are transported from the fluvial processes from the alluvial fan and Kjellströmelva, a large river that contain potential to bring huge amounts of sediments into the bay of Braganzavågen. Alternatively, the sediments are transported from the alluvial fan out into the bay, where the finest sediments are kept in suspension and deposited further away from the river outlet.

Another possibility is that tides do not have that much of an influence in this area as first expected. This field area appears to be more of an alluvial environment with minor tidal influence, as seen in the division of the study area. Most of the logs made in field where fining-upwards; this is a characteristic feature for fluvial deposits. Typical tidal deposits however, have characteristic features like double mud drapes, flaser bedding, wavy and lenticular bedding; which have not been observed in Braganzavågen. Another common feature for tidal depositions, are tidal bundles which are deposits of a single dominant tide that is bounded by reactivation surfaces or mud drapes (Visser, 1980).

From the structures that were observed in Braganzavågen, e.g. wavy bedding as observed in profile P13, is located in the active fluvial area (Figure 17). Wavy bedding itself is not only strictly found in tidal flat deposits, it can also be observed in storm-dominated shelves, lakes, inter-tidal areas, and environments where energy levels fluctuate significantly (Allaby, 2008). The on-going alluvial processes in Braganzavågen can possibly be responsible for the wavy bedding observed in field.

Bioturbation within the sediments were not observed during fieldwork, however, there were observed some few tracks and animals on the surface. These traces are most likely eroded away during high-tide over changing of sinuosity in the river system due to low amount of tracks from these animals/insects. The absent of bioturbation is uncertain, this could be in connection with the environment, with low level of nutrient and possibly high sedimentation rate, making it difficult for smaller reptiles to thrive in this particular site. As seen in examples from Lower Fraser River, Canada, bioturbation is a quite common view (Sisulak & Dashtgard, 2012) in similar alluvial-tidal settings.

In the four facies that has been described it is clear that they withhold different main processes. For facies 1 the main process are tidal influence. At this point the fluvial activity has widened out in such an extent that it is no longer the main contributor in the depositional environment. Facies 2 are mostly influenced by fluvial processes from the alluvial fan; also facies 3 consist of mainly fluvial processes. However facies 3 have less energy in the fluvial processes than what observed in facies 2. Facies 4 consist of little activity, besides anastomosing fluvial processes; this facies consist of organic rich marsh plain.

5.4. Ripples

The field area shows indications of being influenced by tidal currents. Similar types of ripples were observed in a paper from Sisulak and Dashtgard (2012). Here they are described as ebb-tidal ripples, meaning that those ripples are formed during the falling tide. There where almost none ripple structures observed within the profiles throughout the field area, suggesting that they were eroded from rising tide and from fluvial processes from the alluvial fan and the river coming from Kjellströmdalen. These asymmetrical ripples, interpreted as ebb-tidal ripples, are mostly found in areas between the alluvial processes from the fan and the bay of Bragazavågen. Close to the bay, the absent of ripples can be because of cohesion and the level of saturation in the silt. Beddings found within the profiles could also be wavy bedding or flaser bedding; both are found in areas of fluctuating flow. To obtain flaser bedding there would have to be a low-energy period after deposition of the ripples, so that the mud can drape the ripples. While wavy bedding are more characterized by interbedded rippled sand and mud layers, and they are commonly found on storm-dominated shelves. They are also found in other environments with appreciably fluctuating energy levels. Profiles made during this field work did not have much changing layers of sand and mud; they were mostly homogenous or parallel bedded as seen in Figure 46. The large variations in ripple direction (Figure 25) may also indicate several processes e.g. fluvial, when it comes to depositional environments in the studied area.

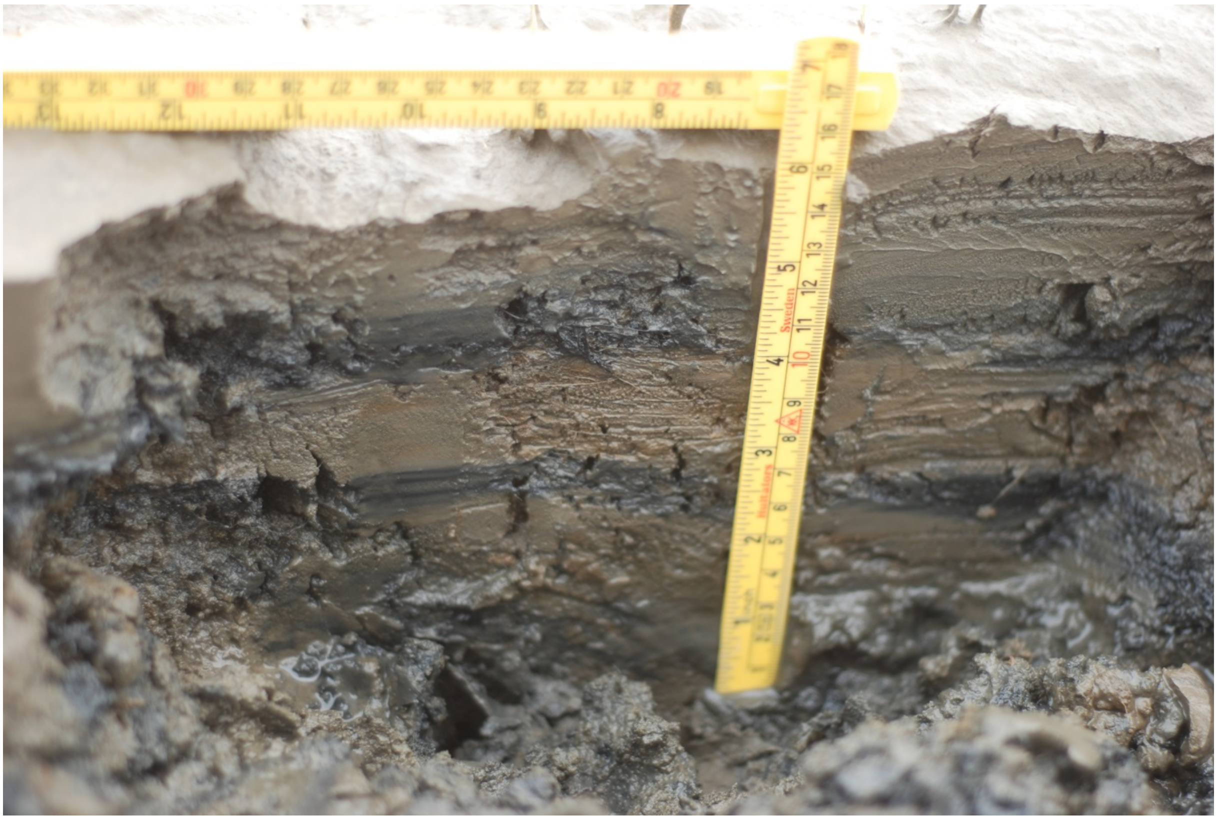

***Figure 46**: Picture from profile P2, where parallel bedding is observed.*

The direction of the ripples also indicates a wide variety of the current direction. The situation here is that there are several types of ripples observed based on their directions.

5.5. Braganzavågen

The peninsulas that are covering Braganzavågen from the fjord makes the bay in Braganzavågen a large depositional bay. Most of the sediments presumably originated from Kjellströmdalen (Figure 11). The rivers from nearby fans in the Kjellströmdalen also contribute by bringing large amounts of sediments into the bay. Fluvial processes from the alluvial fan were eroding channels, up to one meter in depth on the distal parts of the fan, thus distributing large amounts of sediments into the bay area. This is very different from the Wadden Sea, where the sediments are from the seafloor of the North Sea.

The valley Kjellströmdalen might be seen as a tide-dominated estuary, where the sediment dynamics in this tide-dominated estuary are dominated by tidal currents at the mouth of the estuary, as seen in Figure 47. Wave-dominated estuaries in comparison are predominantly at the mouth due to wave action (Tessier, 2012), where the wave-dominated estuaries consisting of wave-built coarse-grained coastal barrier scoured by a tidal inlet. That is sheltered from high-energy marine dynamics by the sand-dominated mouth body, most of the fine-grained sediments that comes from fluvial sources. Coarser fluvial sediments, on the other hand, concentrate at the head to the estuary, forming a prograding bay-head delta (Tessier, 2012). Based on this, it is not believed that the studied area is in direct connection with an estuary. There might be a possibility that it is a distal part of the mouth in an estuary formed by the Kjellströmelva based on morphology and location of the studied area. This makes the studied area a possible abandoned part of an older estuary in this valley.

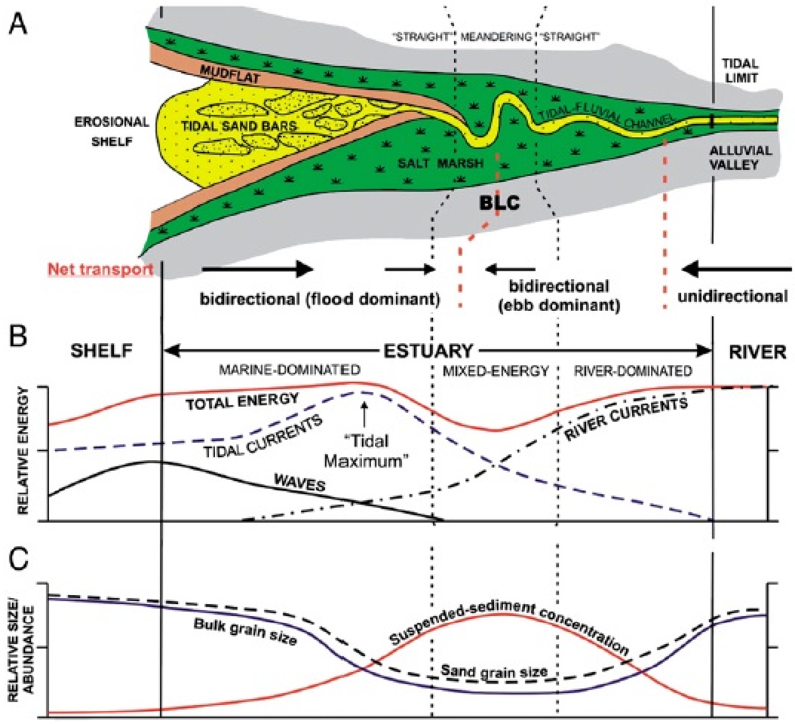

Figure 47: (A) Schematic map of a tide-dominated, estuary, where the tidal limit is marked. Further longitudinal variation in the intensity of river currents, tidal currents and waves, and the resulting directions of net sediment transport are shown in (B). (C) Longitudinal variation of the grain size of the sand fraction and suspended sedimentation concentration are the main parameters (Dalrymple & Choi, 2007).

5.6. Comparison of data

All in all, it does not seem to be any considerable difference between the results from the two field seasons. This can indicate that there have not been any vast changes in the area between those two time periods where data have been collected. Time taken into consideration it was not expected to be observed large variations in the area. Most of the data is based on grain size and logs where sedimentary structures are of importance. From Reineck and Wunderlich (1968) flaser and lenticular bedding are described as so-called tidal beddings. Ripples that were observed were mostly current ripples and laminas that are bipolar in the direction of the flood and ebb currents. The origin of these bedding types is related to the alternation of current wave action and slack water (Reineck & Wunderlich, 1968), and is described in an article from Reineck (1960). These studies however are based on tidal flats that consist of more sandy material. In what extent this matter in the comparison with Braganzavågen is uncertain. It can therefore be challenging to find any tidal signals in such a muddy environment as Braganzavågen.

Comparing these studies (Reineck, 1960; Reineck & Wunderlich, 1968) with gathered data for this thesis it is difficult to see any similarities. There might be several reasons for this. The studied area is located in an arctic environment or a different setting such as differences in grain sizes. It might also be a possibility that the studied area in fact is controlled by other factors than the tidal setting. In some of the logs, a number of structures were observed, e.g. bedding, coal seams and wavy bedding, usually there were homogenous layers without any visible signs of structures. Most of the layering observed was horizontal, occasionally there were some kind of wavy bedding (Figure 48) like in profile P13 (Appendix B).

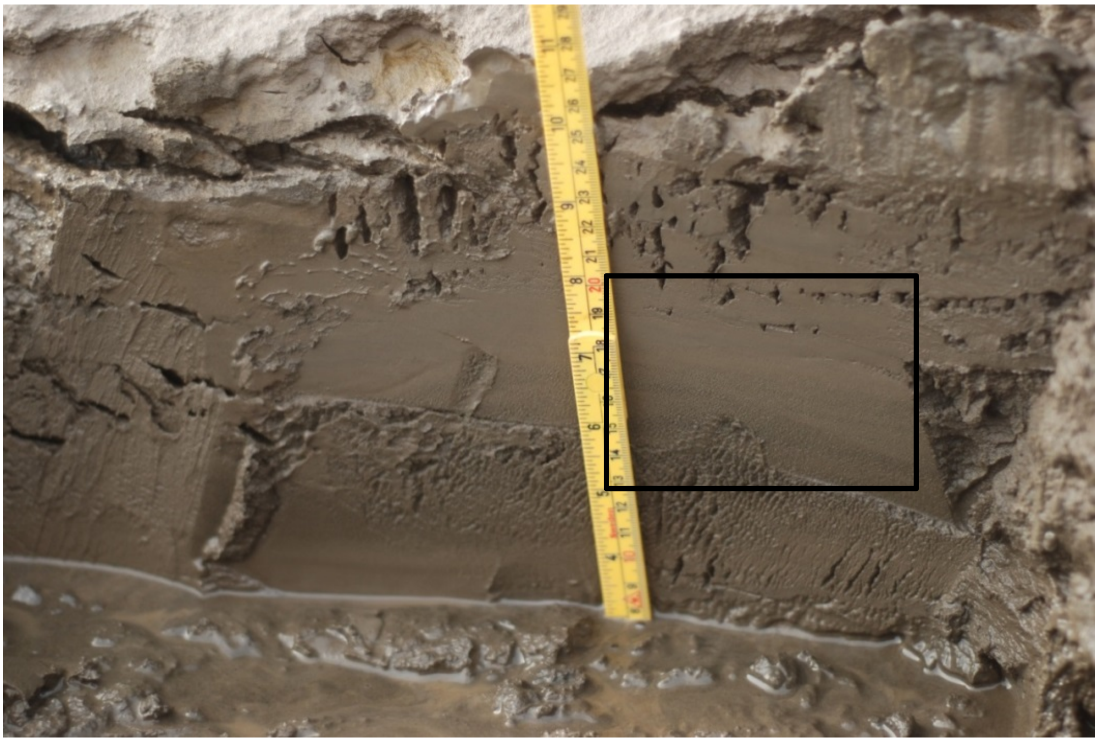

***Figure 48**: In the black box there are weak signs of some wavy bedding in profile P13, rest of the profile appears to be homogenous.*

During winter the area is covered by ice, therefore ice erosion plays a significant role in the forming and distribution of sediments. This has also been discussed by Dionne (1969), where erosion by ice was believed to have a large impact on the erosion of the tidal flat. Also when it comes to the transportation and sedimentation, ice movement is a factor that must be considered in the study of this field. During spring and summer many of the features made by ice have a tendency to be destroyed by waves and current processes (Dionne, 1969). This may explain why most of the studied area consists of homogenous layers. Also Sasseville and Anderson (1976) have studied the consequences of winter ice on a tidal flat. Similar to the study by Dionne (1969) they observed erosion as an important factor during ice cover. They made an observation in the clay size fraction, also structures created from ice such as drag scars, and small mud ridges were observed (Sasseville & Anderson, 1976). Furthermore it is stated by Dionne (1985) that frost and drift ice are important processes that create distinct features on tidal flats in cold regions.

One possibility is that the area is a distal part of a prograding alluvial fan. Here there are alternating pebbles and silt/clay layers that can help strengthen this theory or can be mistaken for being a part of the tidal flat, while it actually originates from the fan. A mix of distal fan and tidal flat makes it also possible that the alluvial fan is prograding onto the tidal flat.

Observations done in field indicate that most of the sediments in Braganzavågen are transported from rivers that culminate in the bay due to of lack of tidal energy.

5.7. Why tidal flat

In the field area it was observed several mud cracks in the marsh area. These are common in silt- and clay-rich sediments and found on tidal flats among many other environments (Dionne, 1969, 1973). Often in tidal flat deposits, tidal rhythmites are vertically accreted planar lamina that alternates between coarse and fine sediments, called tidal bundles (Coughenour et al., 2009). This has not been observed in field and do not support the theory that Braganzavågen is a tidal flat.

A standard definition states that a tidal flat is a tide-dominated environment with a gentle slope, negligible wave influence and with well-developed tidal creeks (Dalrymple, 1992; Steel et al., 1985; Yang et al., 2005). Some of the area in Braganzavågen consists of a gentle slope and with negligible wave activity. However, there was not observed any tidal creeks.

What we do know, is that Braganzavågen is tidally influenced. The main issue is whether it is a tidal flat or another environment that have tidal influence. Based on observations done in field, it seems like the environment is dominated by fluvial processes, and that the alluvial fan is prograding onto the studied area. This alluvial fan has an apparent trend of building outwards into the bay, and might therefore be classified as a prograding alluvial fan. It is only the lower part of the fan that has been studied, in association with the mapping of the tidal flat.

The theory that this alluvial fan progrades into the plain are substantiated with some coarsening upward profiles, mixed with fining upwards profiles can explain the meandering/braided streams on the plain (Le Roux & Elgueta, 2000). This is indicating that the coarsening upward profiles can substantiate the prograding fan theory. The fining upward trend explains the fluvial activity in the studied area.

5.8. General discussion on Braganzavågen

It is rather difficult to estimate if this area is a tide-dominated delta (Goodbred & Saito, 2012). There are several reasons for this; however the main reason being the high variation in the role of the fluvial system that defines the specific delta, and the high variation of these environments. The rivers on these systems have large variations when it comes to discharge, sediment load, seasonality and grain size. Also the scales of the tidal cycles and seasonal river discharge vary considerably. A consequence for this variation in transport energy is seen from the sedimentary successions formed in these tide dominated settings, and have a tendency to be heterolithic, with interbedded sands, silts, and clay, and with both fining and coarsening upwards trends. The greatest difference from tide-dominated alluvial fan and other tidally influenced settings are defined by cross- or along-shelf progradation of a clinofrom, or ‘S’–shaped, sedimentary deposit (Goodbred & Saito, 2012). This prograding clinoform is often separated into two distinct units, one associated with the subaerial deltaplain and one with an offshore subaqueous delta (Goodbred & Saito, 2012).

Regions that are exposed to flooding of tidal water develops into shallow areas that becomes flooded and retraction of flood water creates drainage channels. This leads to three major morphological components in the intertidal zone: i) unvegetated tidal flats or bars; ii) vegetated marsh platforms or mangroves; and iii) channels (Hughes, 2012). Based on this definition, the so called tidal flat area in Braganzavågen have morphological similarities with group i) in the intertidal zone based on the definition from Hughes (2012).

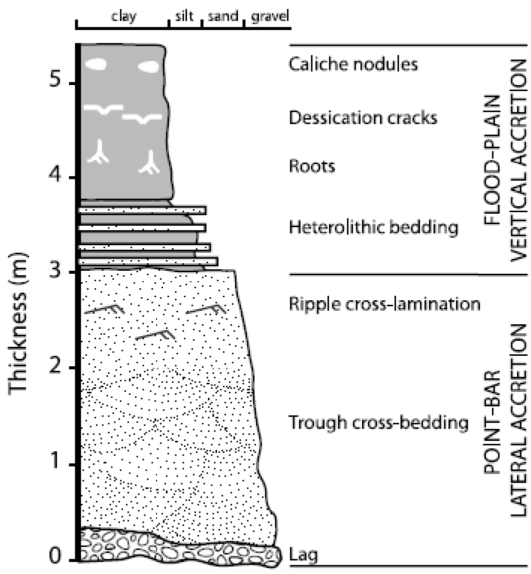

Figure 49: *Showing an classical vertical point-bar sequence, where the upper part have similarities with some of the profiles from Braganzavågen, indicating a possibility for the inland parts of the studied area to be a flood-plain (Donselaar & Overeem, 2008).*

In some of the logs it was observed some bedding, and most of this bedding is interpreted as heterolithic bedding and wavy bedding. Which may suggest that these profiles are in the upper part of a point-bar sequence, based on Figure 49 from Donselaar and Overeem (2008). However heterolithic bedding can also be deposited in storm-wave influenced marine environments, or delta-front settings where currents or sediments permits deposition of both sand and mud. The problem is the uncertainty of what is under the heterolithic bedding. Here it needs to be taken deeper cores, preferably one meter or deeper. Then it could be possible to see if there are more structures supporting the theory for this area to be mostly fluvial settings with point-bar and flood-plain deposits on this flat area below the alluvial fan. In Figure 50 the similarities is observed rather easily with the flood-plain example from Huesca fluvial fan, Ebro Basin, Spain done by Donselaar and Overeem (2008). Similarities like dessication cracks, roots and the heterolithic bedding are observed. Studies from the Huesca are in much of the same grain size range as observed in Braganzavågen.

Tidal channels tend to be ubiquitous and occurring across macro-, meso- and microtidal environments. Often these tidal channels form a dendritic network usually of low order (Hughes, 2012). However, most of the channels observed in the studied area derived from the fluvial activity from the fan (Figure 51). In this area tidal activity does not have much influence in the forming and shaping of these channels.

Salt marsh sedimentation can be separated into three different types: i) sedimentation associated with channel flow in the vicinity of salt marsh creeks, ii) sedimentation associated with sheet flow over vegetated salt marsh surface, and iii) sedimentation associated with exposed salt marsh edges (Bartholdy, 2012). The challenge is to separate those from sedimentation in fluvial systems, however; there are some differences in deposition between tidal dominated and fluvial dominated environments. It is the bidirectional flow that alter the morphology related to channels; compared to the unidirectional flow in fluvial systems. Based on this, the current velocity is at a minimum during the tide- dominated environment at high and low tide. This being in direct contrast to the fluvial systems (Bartholdy, 2012).

In the tidal depositional environment, some typical tidal depositional structures as previously mentioned would be expected to observe, e.g. mud droplets. A greater fluctuation in grain size would also have been expected to see e.g. tidal bundles, where the variation in sand and mud are much higher than what have been observed in Braganzavågen. However, these were not observed, suggesting that this might be something else than a tidal flat. Even though there are tidal currents present in Braganzavågen, these probably do not have much influence on the overall picture on this bay. A possibility is that the tidal currents do not sustain enough energy to break up the cohesion of the clay fragments that have already been deposited. The lack of structures are clearly seen in many of the logs e.g. P19 (Figure 52). Also accessibility of coarser material is crucial for e.g. tidal bundles to be present.

The depositional environments discussed will, when deposited, give some kind of structures. It is possible that these sediments have just been brought out into the bay and accumulated due to settling, this may explain the lack of structures to some degree. In this bay there probably is quite a high sedimentation rate, which is uncertain due to lack of data on this specific area. There are photos of larger vessels in the bay of Braganzavågen (Figure 53), showing that the bay of Braganzavågen had much deeper sea level in the beginning of the 20th century. The reason for this might be both tectonic uplift and deposits from Kjellströmdalen, since tectonic uplift alone is not a sufficient explanation in describing the depth of the bay at that time.

***Figure 50**: Picture from profile P1 showing heterolithic bedding and rootlets, which can be indicating flood-plain, as the upper part of a point-bar deposit.*

Figure 51*: Fluvial activity going from the alluvial fan into the tidal flat area, where channels where observed braiding out towards the bay*

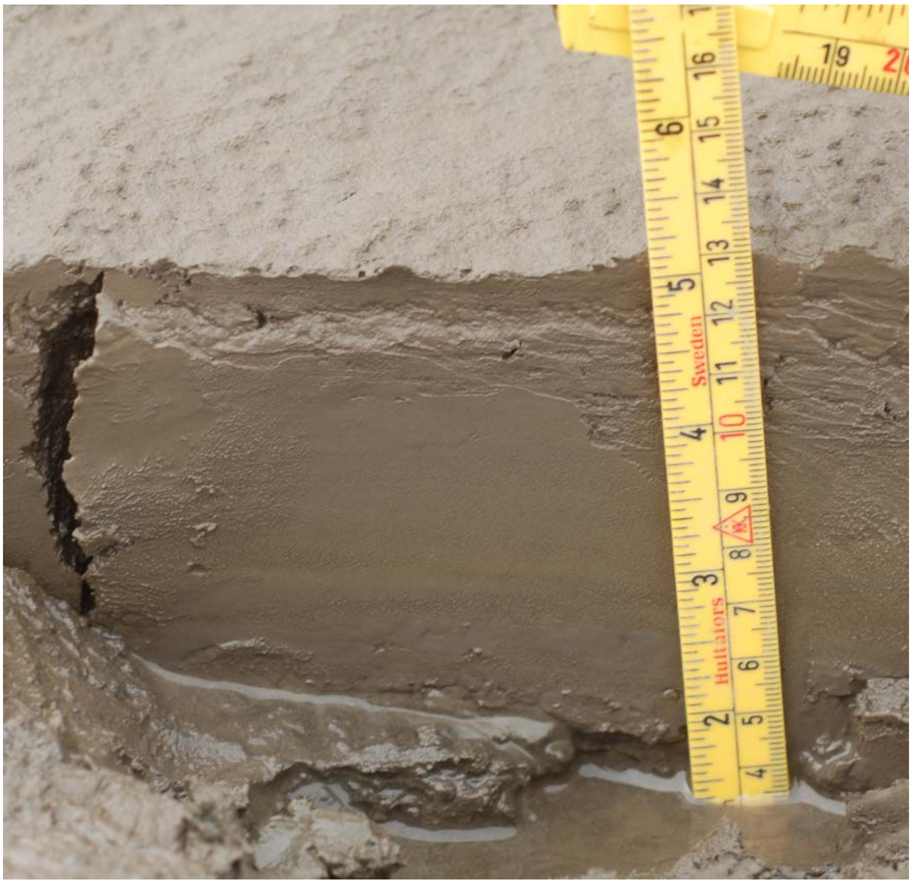

Figure 52*: A profile showing lack of structures, here P19 as an example.*

To manoeuvre vessels of that size in the bay today would not be possible, since the bay is almost completely filled with sediments, meaning that during less than 100 years ago the entire bay have almost been filled in with sediments. In Hald et al. (2001) it is stated that the depth of the fjord is about 30 meters deep in the Rindersbukta part of the fjord. Assuming that the depth in Braganzavågen could have been as deep as 20 meters in 1917, this will give a sedimentation rate of 200 millimetres each year. The actual depth is unknown, making the true sedimentation rate probably a bit lower than calculated here. Also the isostatic uplift is important when considering the sedimentation rate. Most likely the assumption of 200 millimetres is probably a much too high assumption, considering isostatic uplift and the uncertainty of the depth in this bay. The deposition rate is probably different throughout the field area.

Figure 53*: Photo of D/S Amsterdam in Braganzavågen, darker areas just to the right of the vessel are the peninsula; photo taken in 1917 by A. Reuterskiöld during a Swedish expedition to Svea (Humlum, 2007).*

However there is no doubt that the sedimentation rate in this particular area being relatively high, compared to e.g. a study by Hong et al. (2003) from the western coast of Korea, where sedimentation rate was in range of 61±4 mm yr^{-1}. Either because the sediments are transported strictly by fluvial processes or that some of the sediments have been transported in from Van Mijenfjorden. Furthermore it is stated that most of the fjord is surrounded by Paleogene sedimentary rocks, and that the innermost parts of the fjord are of Cretaceous sedimentary rocks (Hald et al., 2001). Another important feature when it comes to sediments is the catchment area of Van Mijenfjorden, approximately 2.8 x 103 km and roughly 50% of this area is covered by glaciers (Hagen et al., 1993), there is a possibility that large amounts of sediments are eroded by glaciers, for transport by fluvial activity out into the fjord.

Based upon this origin of sediments, it is possible that there are mostly marine deposits, where the sediments have been brought out in the bay mostly from the alluvial fan. Working as a prograding alluvial fan, this can explain most of the fluvial processes that have been observed in field, where sediments have gone through a reworking in the upper part of the sequence. These reworked sediments have probably been altered by basin processes like the streams going out in the bay. Coastal currents cannot be ruled out as a process for reworking of sediments in the bay. From the Sveabukta (Figure 11), large quantity of coastal water comes in to the bay of Braganzavågen where most likely coastal currents occur, in combination with fresh water from Kjellströmelva and fluvial activity on the alluvial fan. A typical tidal current consists of different energy regimes resulting in grain separation (Chang et al., 2006), producing typical tidal structures as mentioned e.g. mud drapes. The small tides that are present in this area indicate that the sediment supplied for typical tidal flat structures e.g. mud coplets are not present. This is indicating that the tidal flat holds mainly homogenous sediments, containing small quantum of structures in the deposited material.

Braganzavågen is sheltered from the fjord by the peninsula (Figure 11), meaning that typical tidal waves and waves in general do not have any impact on this apparent tidal flat. It is unknown if any currents are strong enough to bring sediments from the bay into suspension and transport them out into the fjord before they settle on the sea floor. Water temperatures have not been measured during this field study. It is possible that the density of the inflow water has a different density than the saltwater and does not get mixed before it reaches the strait between Braganzavågen and Sveasundet (Figure 11).

Other tidal flats often contain different types of typical structures that are commonly found in context within tidal flats (Dashtgard et al., 2009; Sisulak & Dashtgard, 2012; Yang et al., 2005). There have only been observed some ripples and a very few other structures in the profiles. Some structures that would be expected, like flaser bedding, lenticular bedding, interbedding and interlamination of mud and sand or silt, have not been observed during the field work in the extent that would be expected for this area to be mainly tidally influenced.

The most apparent sign of tidal currents are wavy bedding that have been observed, and ebb tidal ripples that are also often seen in tidal flat areas.

It could be that earlier studied tidal flats are located on more temperate latitudes of the world (Dashtgard et al., 2009; Dionne, 1969; Plater & Appleby, 2004; Yang et al., 2005), where Braganzavågen is located at about 78° north, and withholds a quite different climate than any other tidal flats that have been studied throughout the years. The arctic climate on Svalbard changes some parameters e.g. climate and physical differences. This makes the arctic tidal flats unique compared to other tidal flats.

The field area might be a more complex area than just a tidal flat. The fact that there are several parameters e.g. alluvial fan and fluvial input that are mixed in onto this tidal flat, makes it more difficult to analyse what it actually is. One factor that has not been discussed is the human impact. Larger areas of the tidal flat have been affected by human activity, mostly by moving sediments away from their natural position. This might have an impact further down in the environmental setting. It might be possible that this activity have influenced the natural sinuosity in the channels that transports large amounts of sediments each season, which again could have an impact on the sedimentation on the tidally influenced area on the edge on the distal part of the alluvial fan.

However, the channel on this fan is not modified significantly besides relocation of sediments, e.g. not been dammed or similar influence. Only the human impact decreases the possibility for this channel to flow freely. In the distal part of the fan the channel is seemingly braiding freely out onto the plain. According to this observation, the human impact in this case can be ignored in the sense of affecting the sedimentary environment in this particular area of interest. There might be a possibility that the human impact could interfere on the naturally braiding system of the river. This can also be seen where it flows out on the flat and where it erodes and later deposits sediments. Meaning that the most active area, as observed from the logs and in field, in fact could be on a different site than where it is located at present time if it were not for any human activity in this particular area.

The main interpretation is that the field area might be an alluvial fan that is prograding out on a tidal flat. Lack of typical tidal structures indicates that most of the sediments here are reworked, and that the main contributor for this rework is the river system coming from the alluvial fan. It is apparent that the coarsest material mostly where found in the proximity to the river outlet and the finest material where located closer to the shoreline; making the alluvial fan the main contributor for sediments to be deposition in the studied area. This distribution is observed clearly in Figure 54, where changing environment is most apparent in the areas around the river outlet. In this area the variations in grain size is more apparent. Also bedding can more clearly be observed in this area. The tide different In Ny-Ålesund, the tide difference have been measured to be about 100 centimeters between low- and high- tide, measured by Statens Kartverk (The Norwegian Mapping Authority). The fact that Braganzavågen bay is sheltered from most of the wave activity coming from the fjord, indicates that the tides are raising and lowering rather slowly compared to shorelines that are more exposed to tidal currents of higher energy. This indicates that tidal currents possibly contribute only in smaller portions.

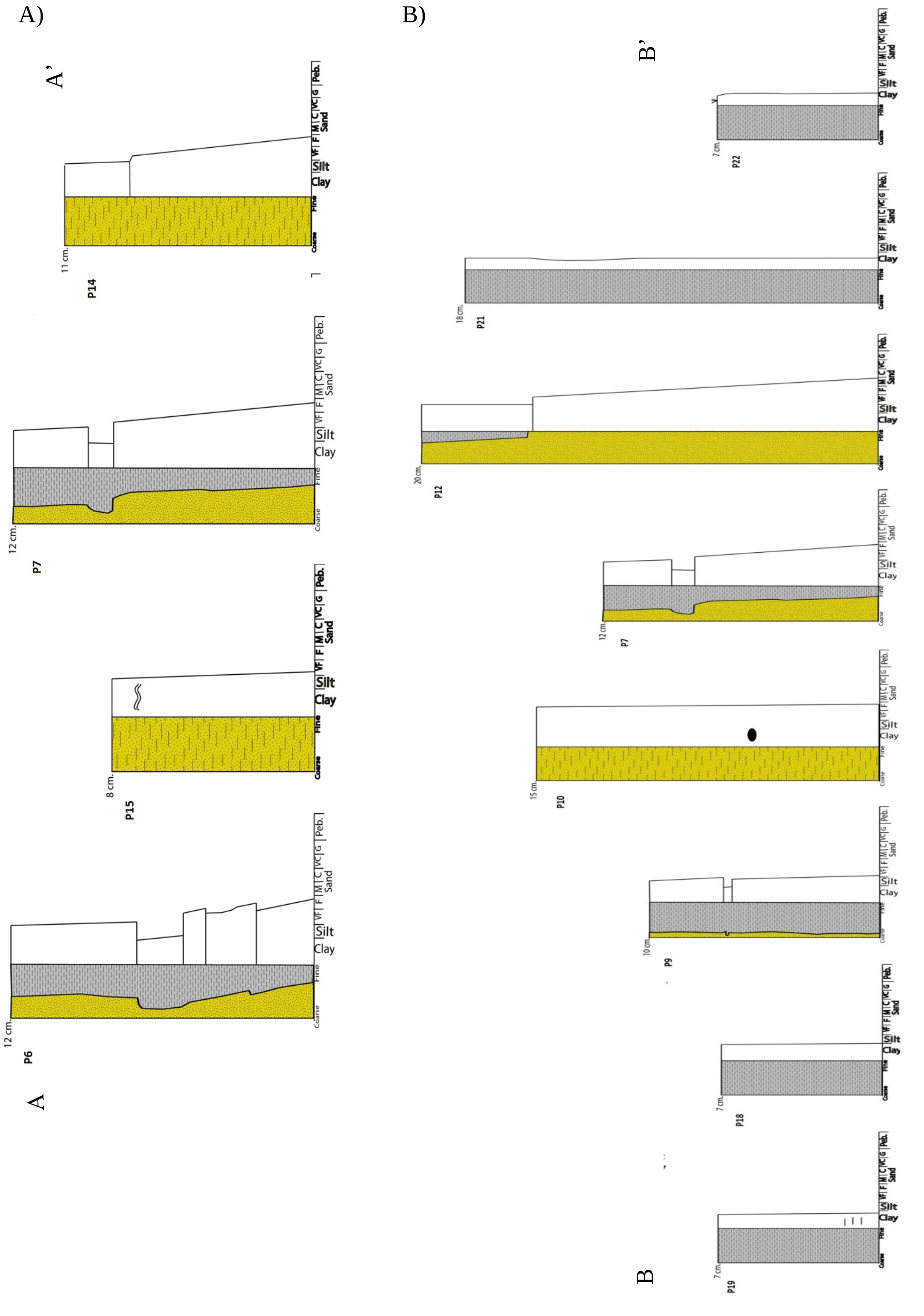

***Figure 54**: A) Illustrating changing environments downstream from the alluvial fan marked as cross-section A-A' in Figure 17. B) Shown here are the change in environment from the shoreline going inland, marked as cross-section B-B' in Figure 17.*

6. Conclusion

Based on the two field seasons it is concluded that the studied area in Braganzavågen is not a tidal flat, rather a tidal influenced distal alluvial plain, where the main contributor for the sediment influx in the studied area comes from fluvial activity related to the fan. Furthermore, the lack of expected structures in correlation with typical tidal sedimentation indicates that other processes e.g. fluvial are present. These processes are referred to as the fluvial activity that reworks sediments and erase any structures that might have been present. This fluvial activity is substantiated by Figure 45 where the sedimentary environment is put in relationship with sorting and mean grain size by Folk (1974). Based on this illustration most of the results show that the samples originate from fluvial sedimentation where sediments and channels originate from the alluvial fan. However tidal influence and input from Kjellströmelva are both crucial when it comes to the deposits and observations done in field. Not to mention that these processes can participate in reworking and redeposition of the same sediments and erase eachother's typical characteristics.

Profiles that have been studied showed the same pattern in distribution of grain size and have in general the same lack of visible structures, with some exceptions. Where those profiles which still contain some degree of bedding are situated mostly in the active fluvial areas, and to some degree in marsh areas, this again indicates that this is not mainly based on tidal current deposits. Little or none of the sediments are believed to be transported in from the fjord. This could be determined in further work where palynomorphs studies can be accompanied. Also XRD and several cores where X-ray images where taken and could contribute to the determination of arctic sedimentation in such environment, and possibly strengthen the work that already have been conducted in Braganzavågen.

Field observations indicate that the field of interest is a tidal influenced distal part of a prograding alluvial fan delta. Large amount of sediments are brought onto the tidally influenced plain by fluvial activity, giving this bay a high sedimentation rate; it is important not to forget that large amounts of these sediments also are brought into the bay from the river Kjellströmelva. That river is most likely a part of an estuary that probably expands onto the studied area. It could therefore be of interest to expand the study area; so that a larger area can be studied, and give a complete and overall understanding of the bay.

Possibly point-bar deposits can be found in context with fluvial activity from the alluvial fan, then again to confirm that more work needs to be done, preferably during winter where it is possible to collect deeper cores, and larger parts of an sequence can be obtained.

The studied area can be divided into four main depositional systems as seen in Figure 24, where facies 1 is interpreted as reworked fluvial deposits with tidally influence and facies 2 are mainly fluvial originating from the fan that behaves as a prograding delta. Facies 3 are of same type as facies 2 however, are more marine reworking, meaning that most of bedding and structures have been reworked. Facies 4 are the oldest deposited material in this area, consisting mainly of marsh with reworked fluvial material. Ripple directions also reinforces the statement that most of this are fluvial deposits. The reason for this being the large variations in ripple directions registered.

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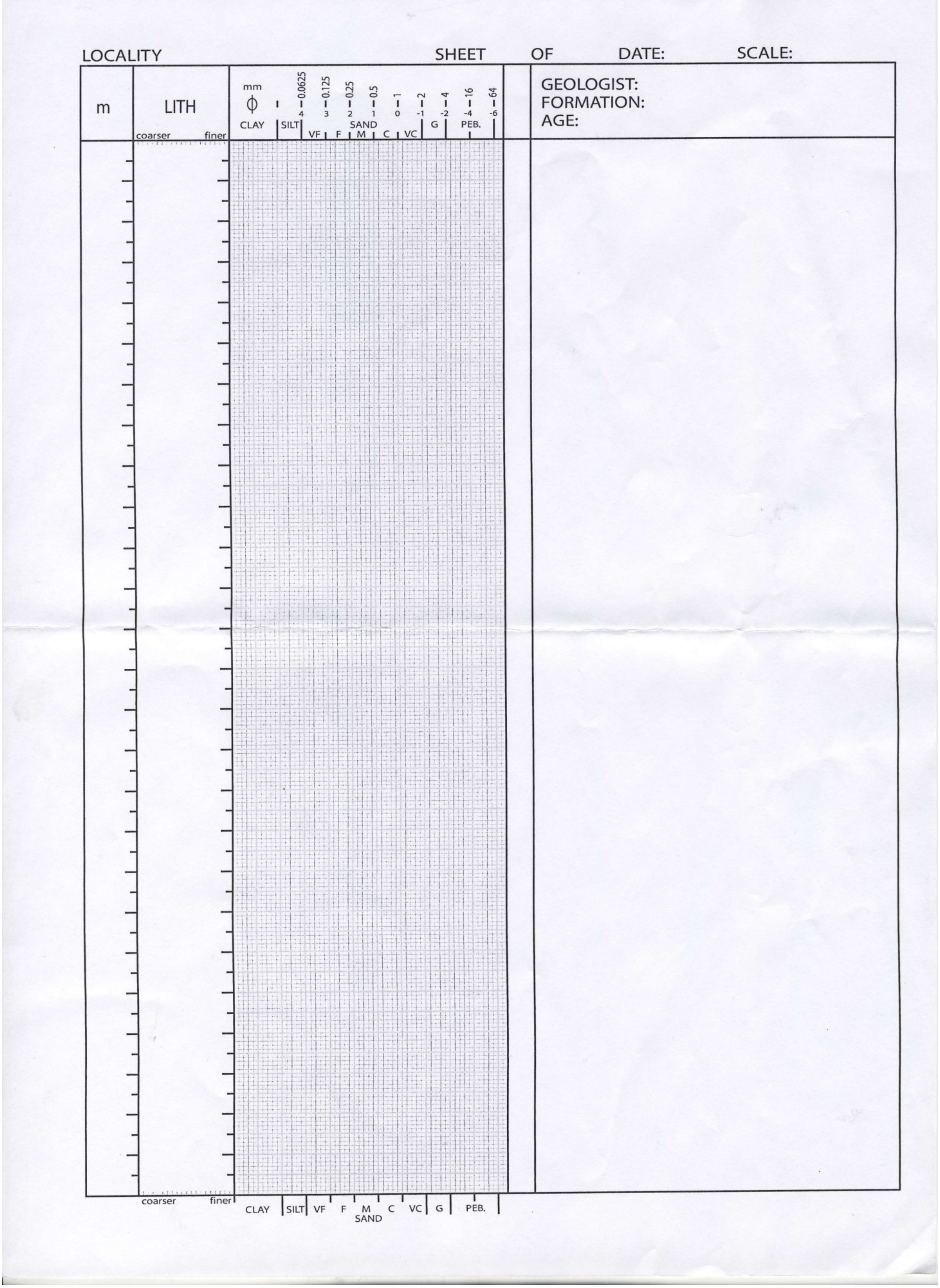
Appendix A:



LOCALITY SHEET OF DATE: SCALE:

m | LITH | mm 0.0625 0.125 0.25 0.5 1 2 4 16 64 | GEOLOGIST: FORMATION: AGE:

φ 4 3 2 1 0 -1 -2 -4 -6

CLAY | SILT | VF F M C VC (SAND) | G | PEB.

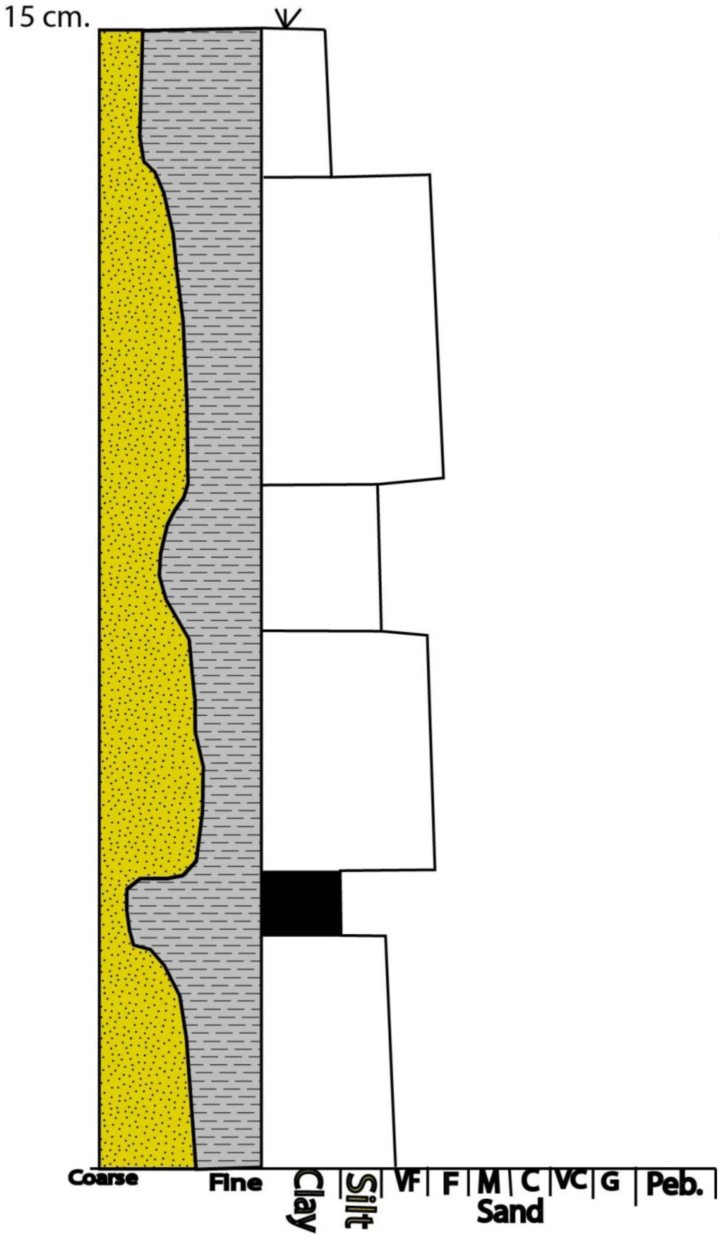
coarser finer

coarser finer

CLAY | SILT | VF F M C VC (SAND) | G | PEB.

Appendix B:

Logs from field season 2012.



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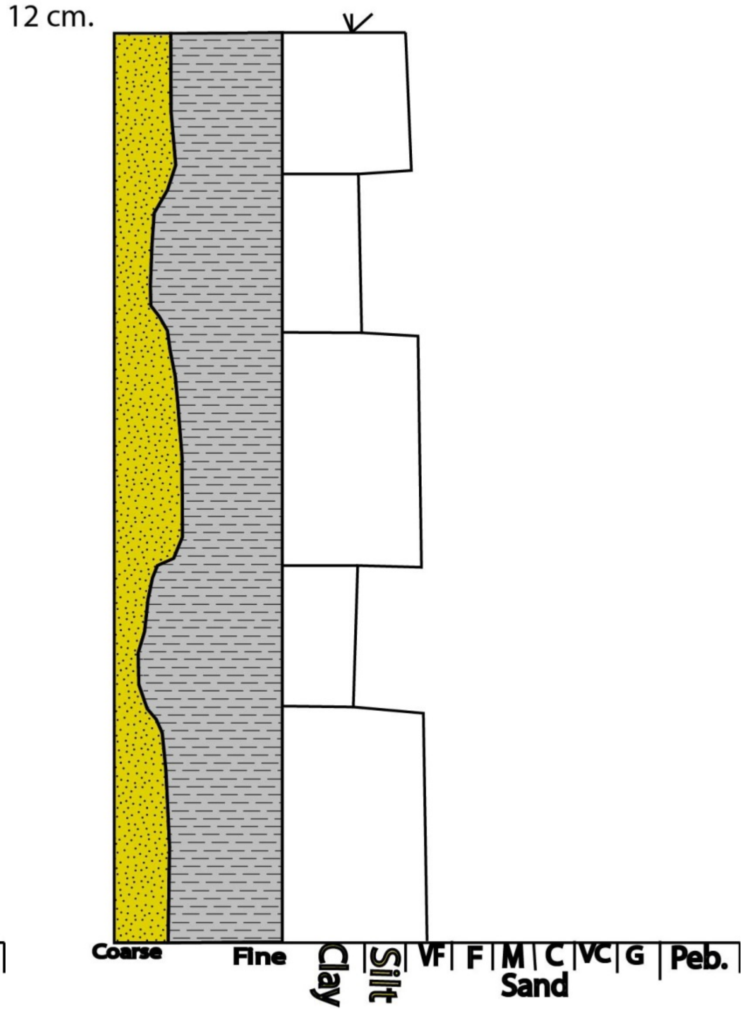

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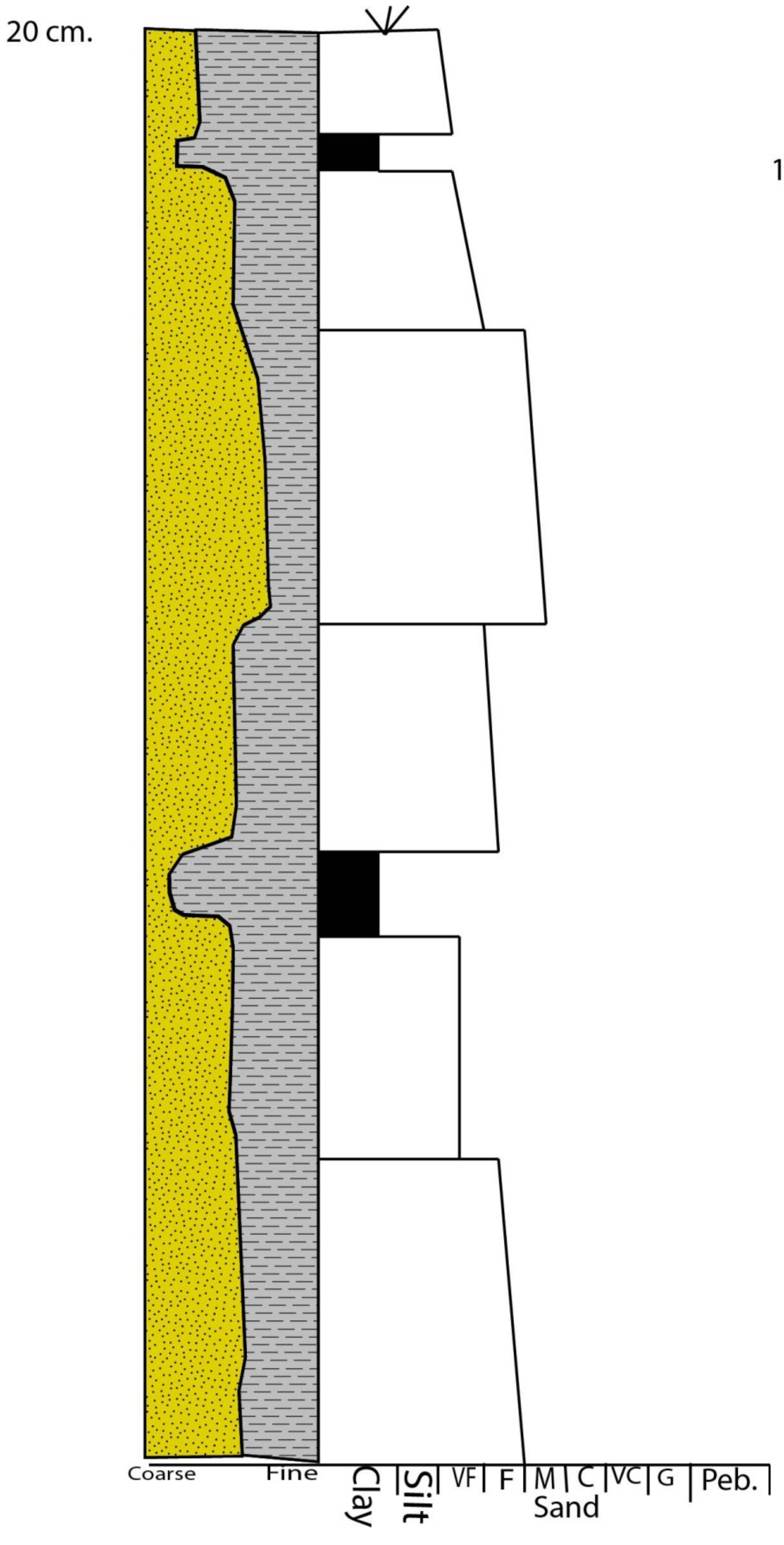
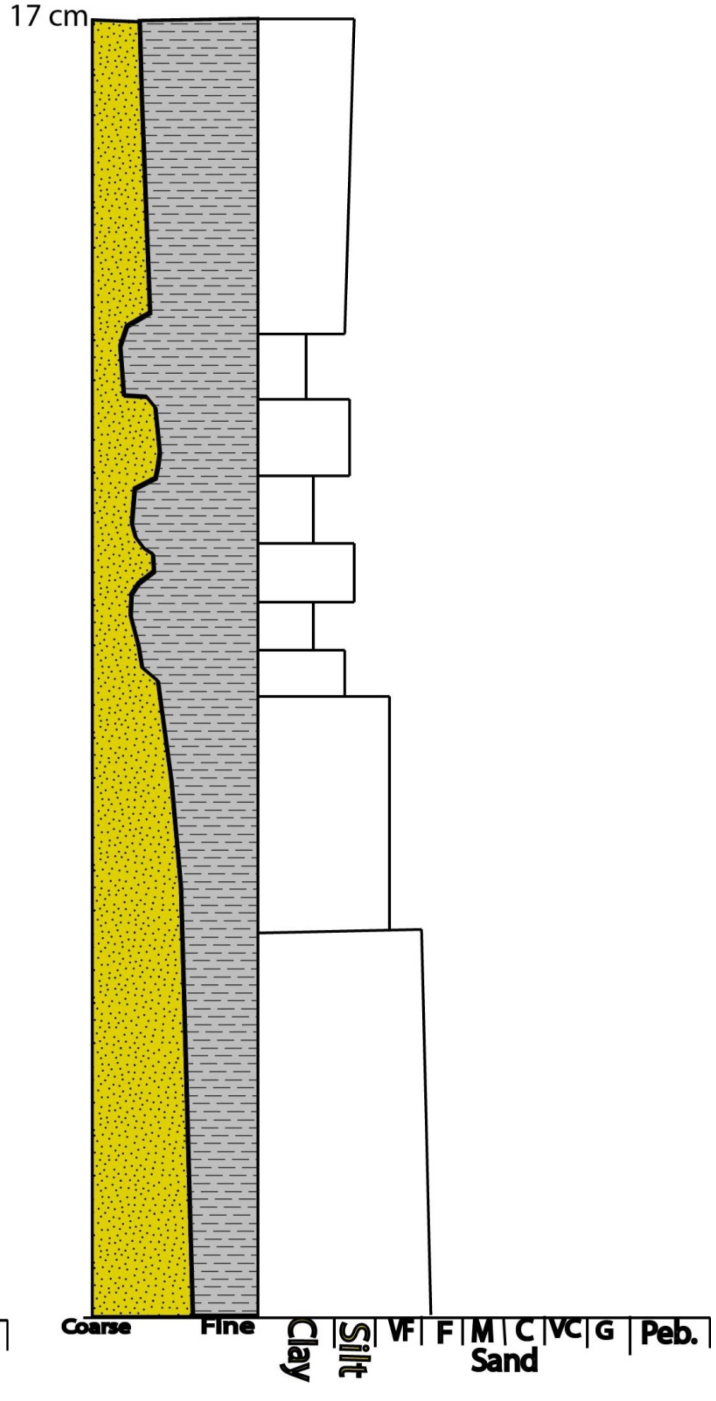
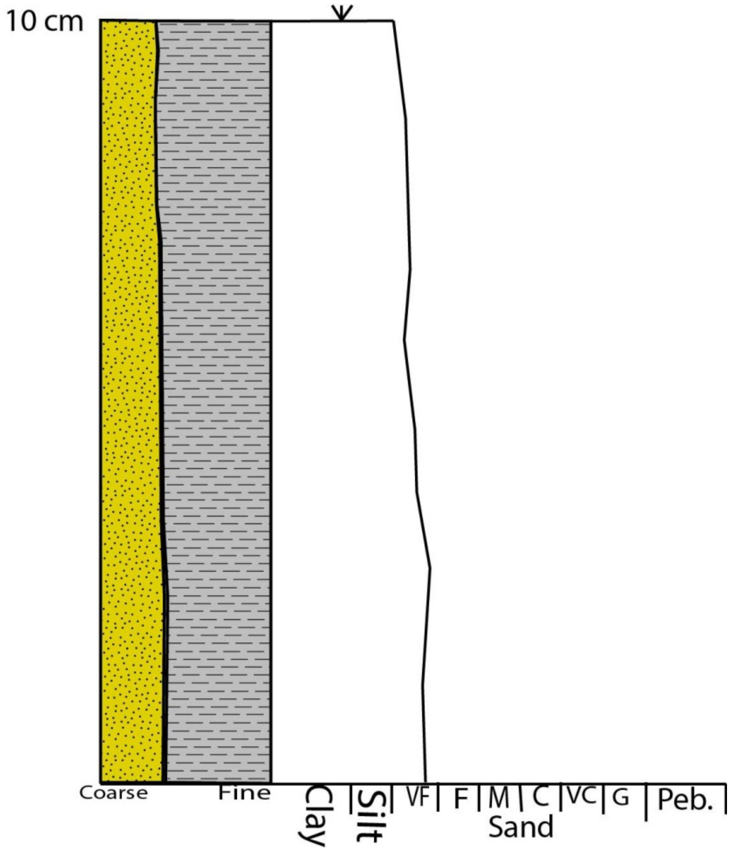

20 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

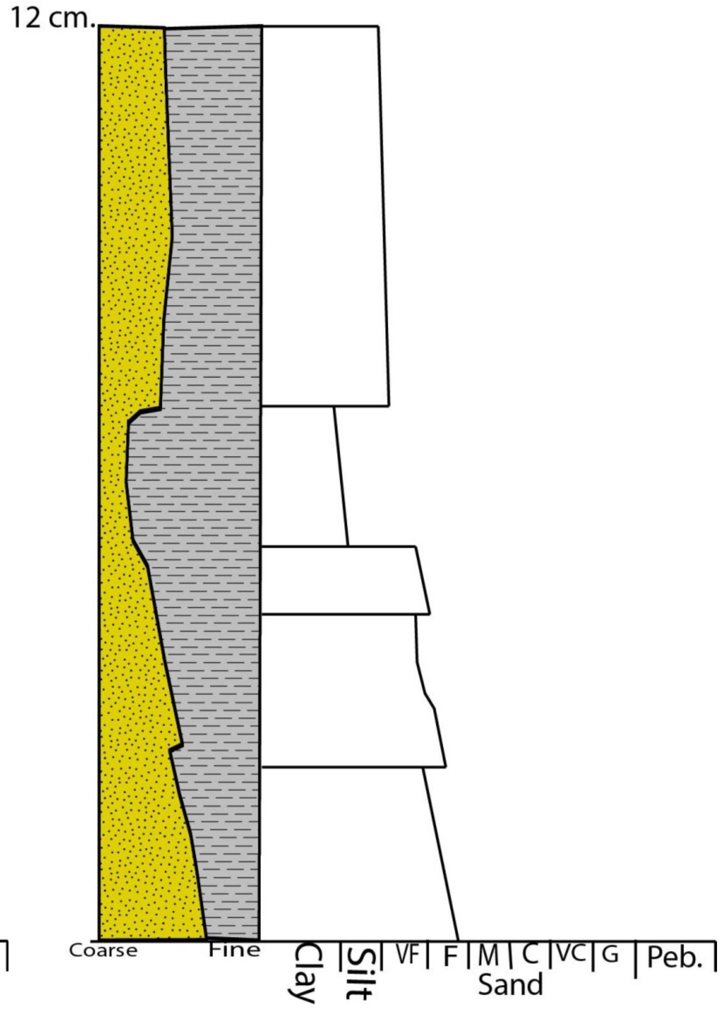
P3:


17 cm
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

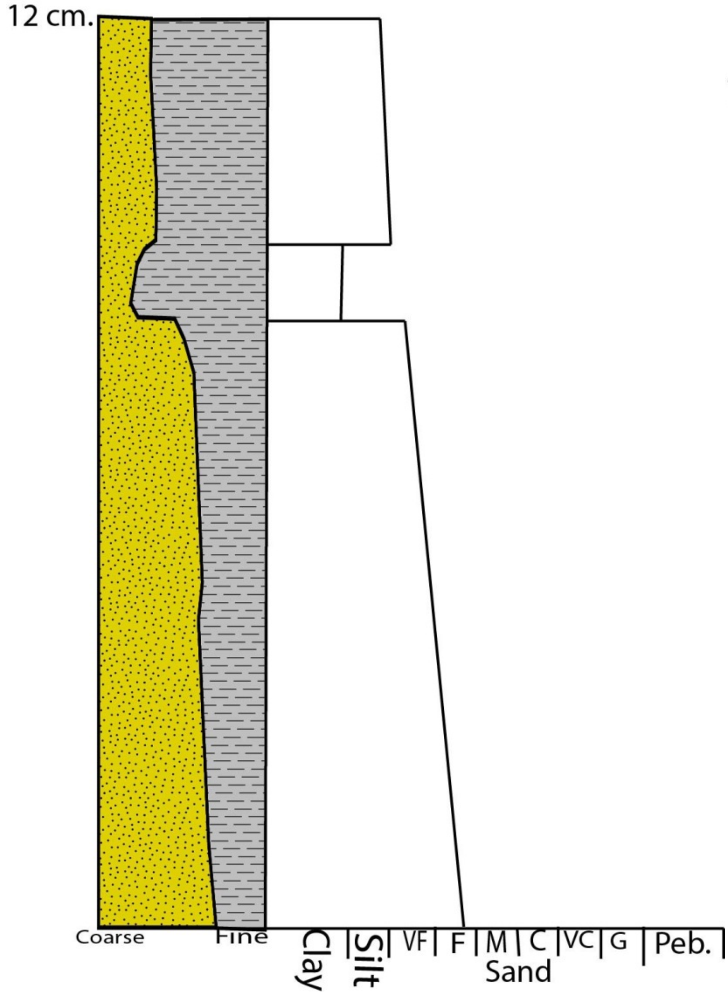
P4:


10 cm
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P5:

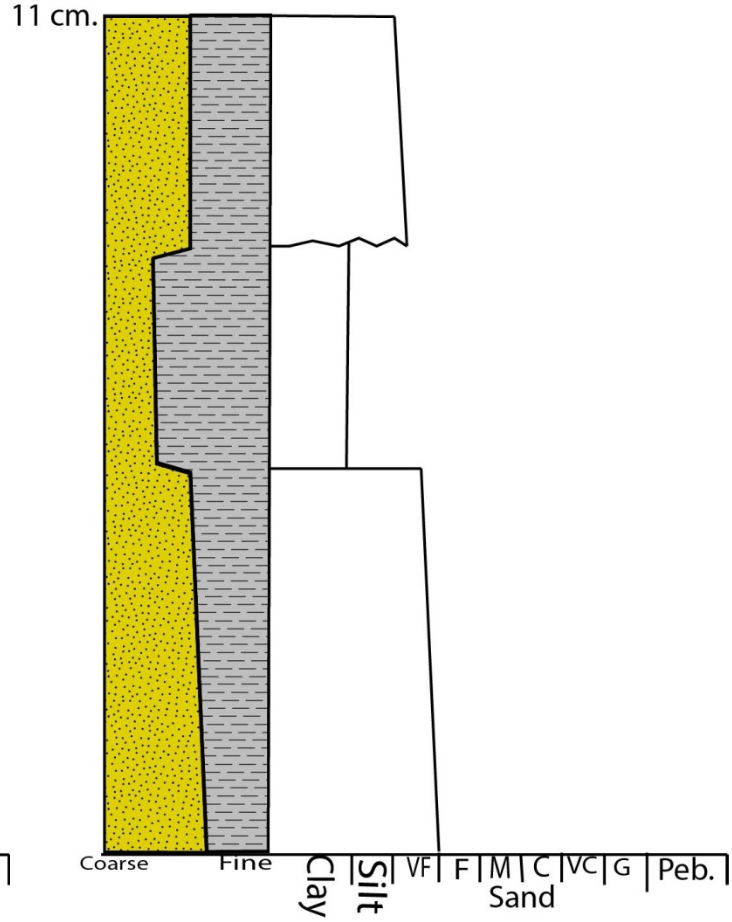

12 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P6:



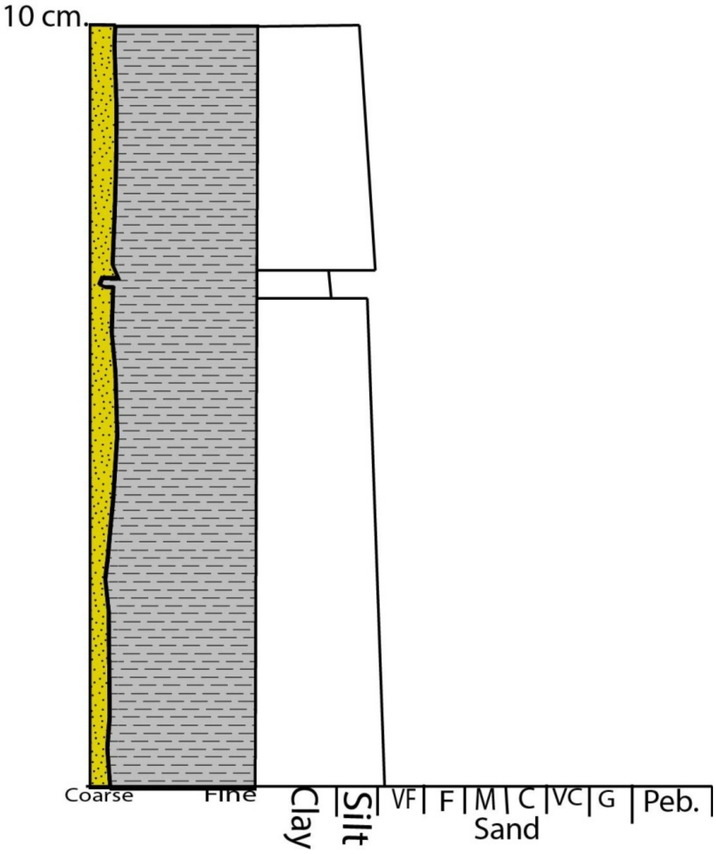
12 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P7:

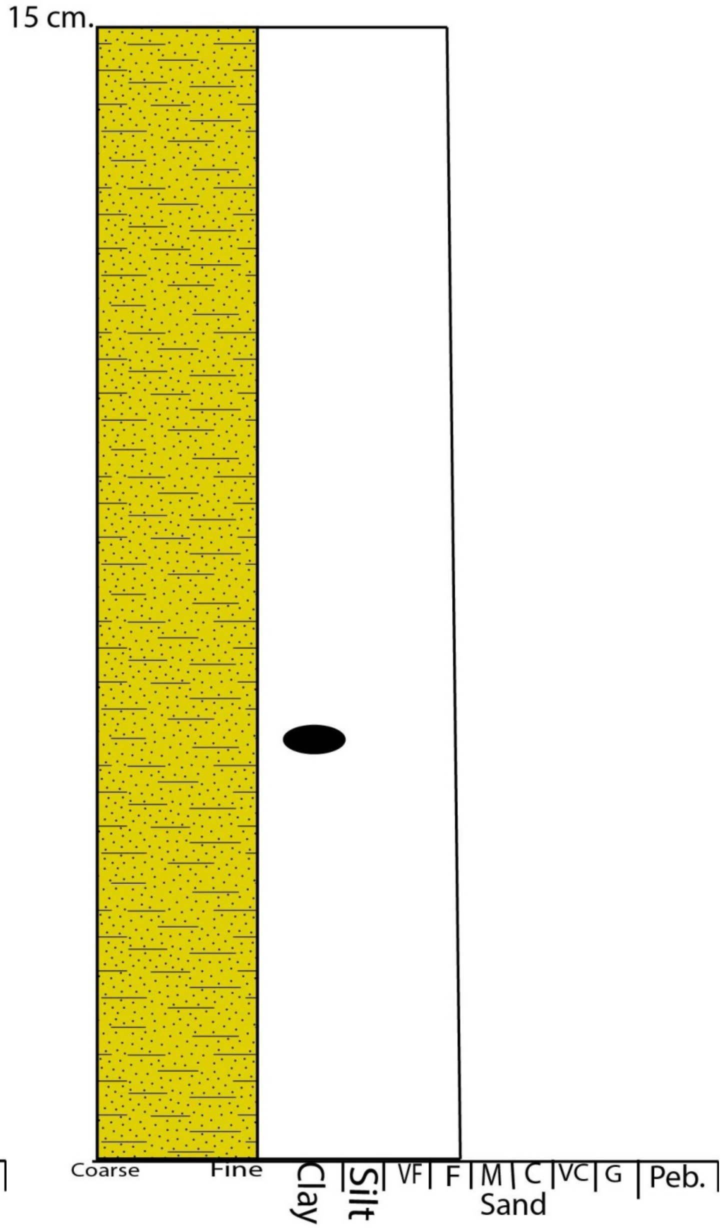


11 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P8:


10 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P9: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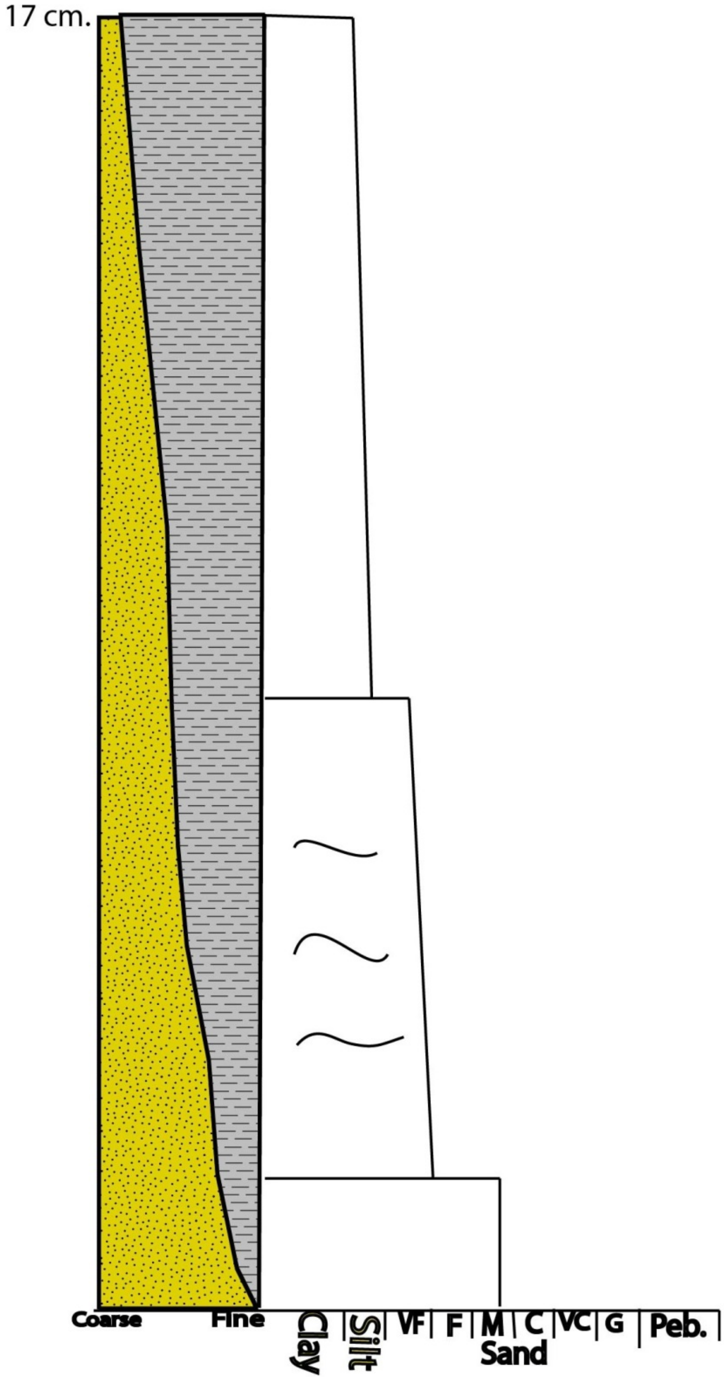
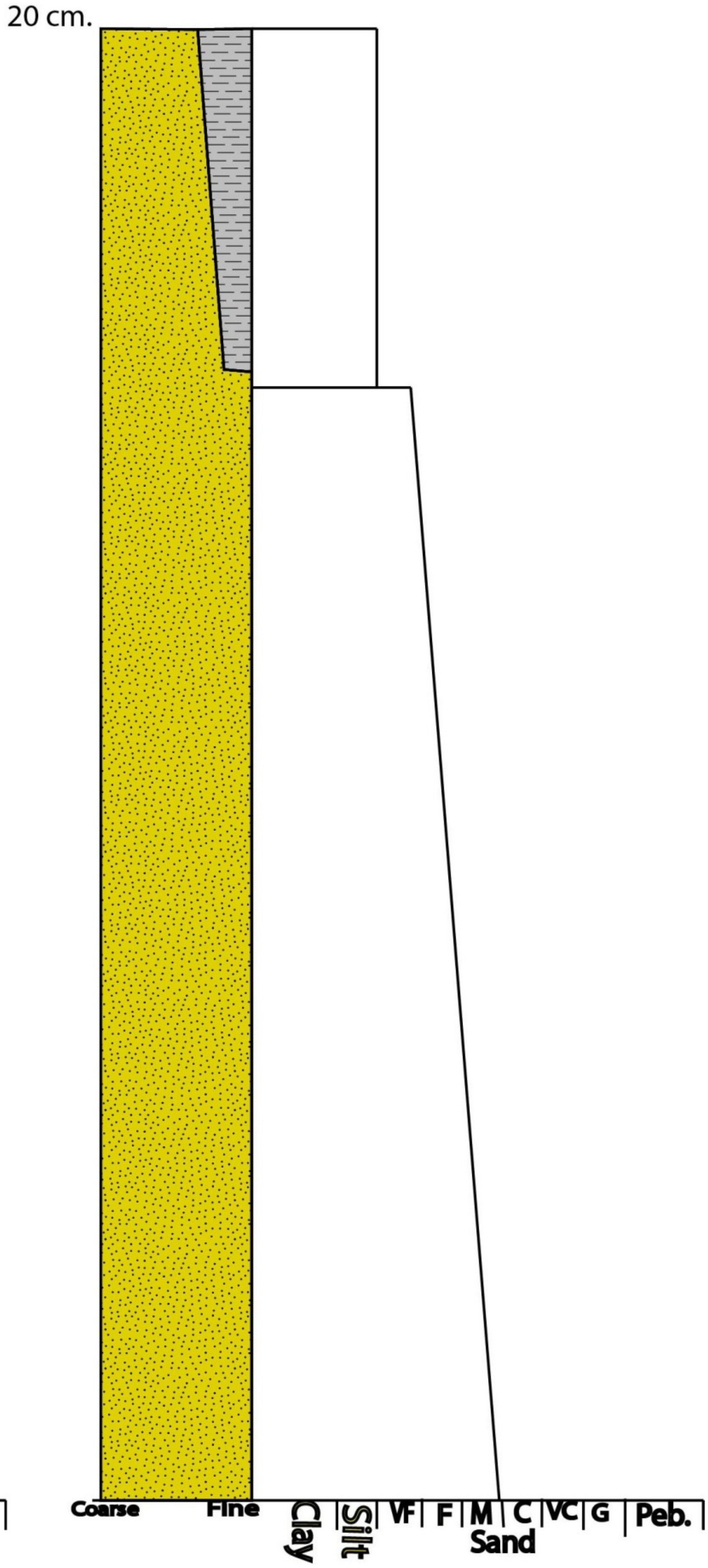
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

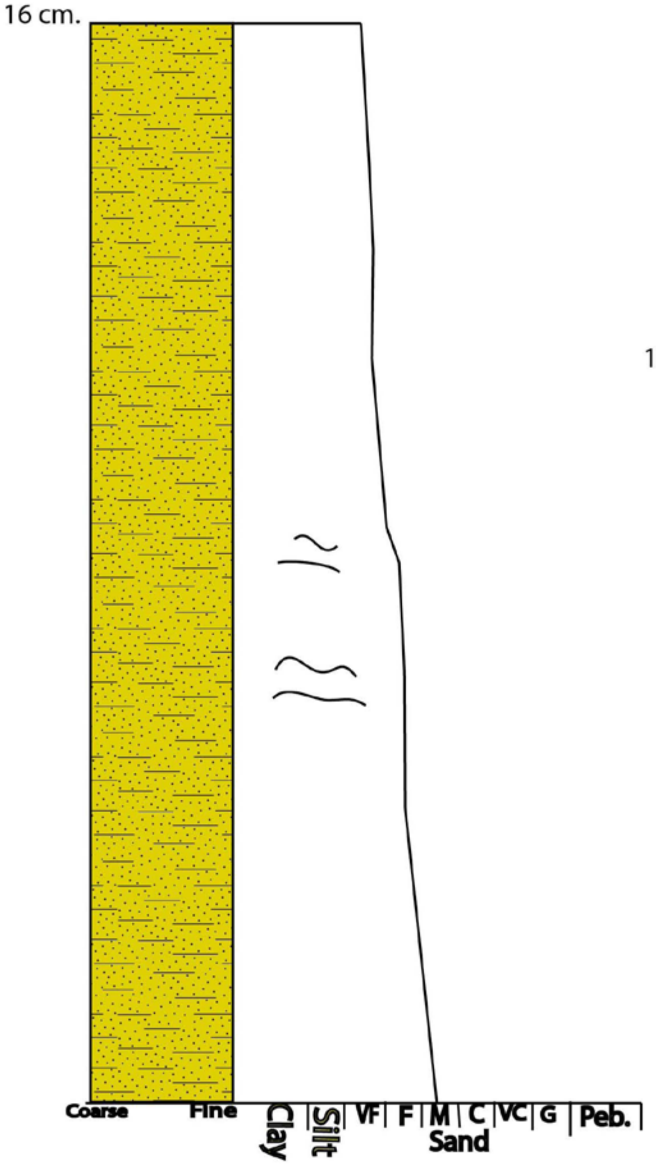
P10:


17 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

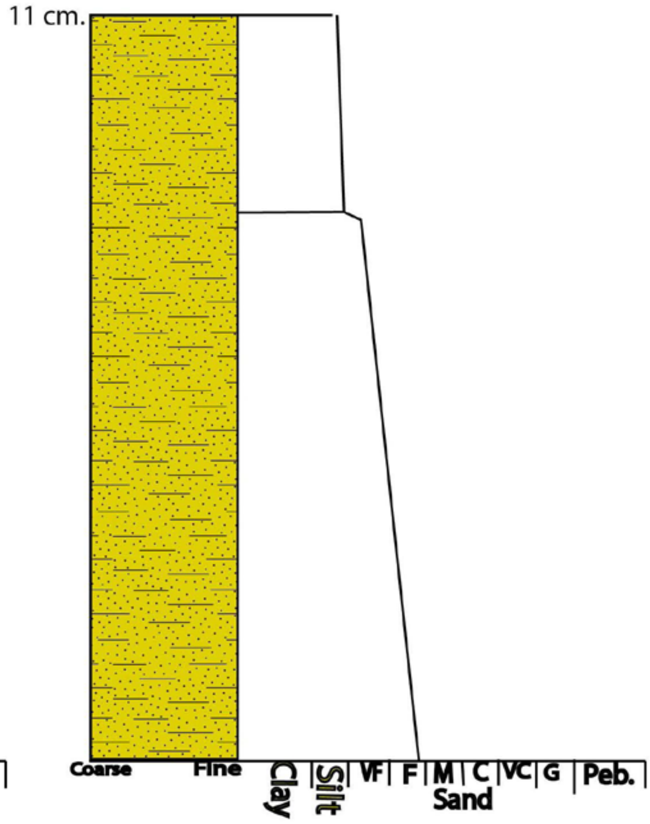
P11:


20 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

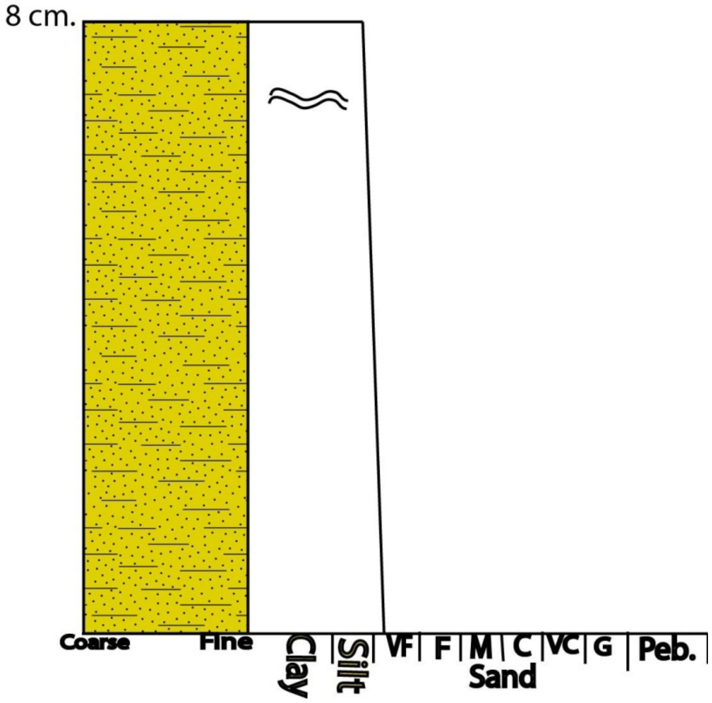
P12:

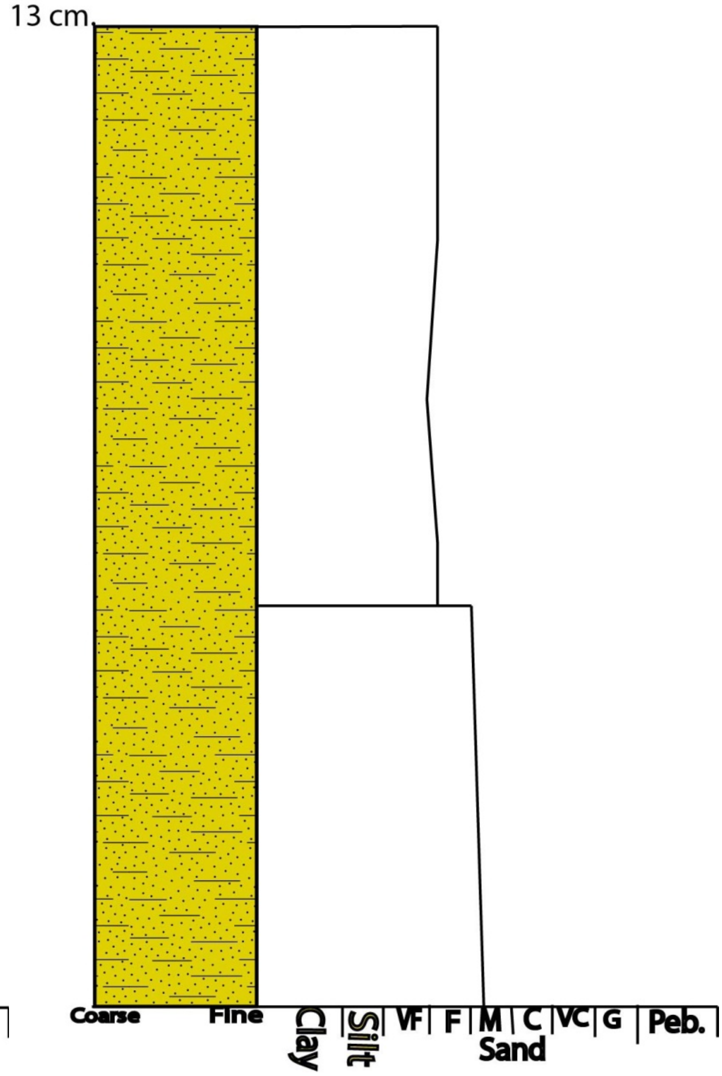

16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P13:


11 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

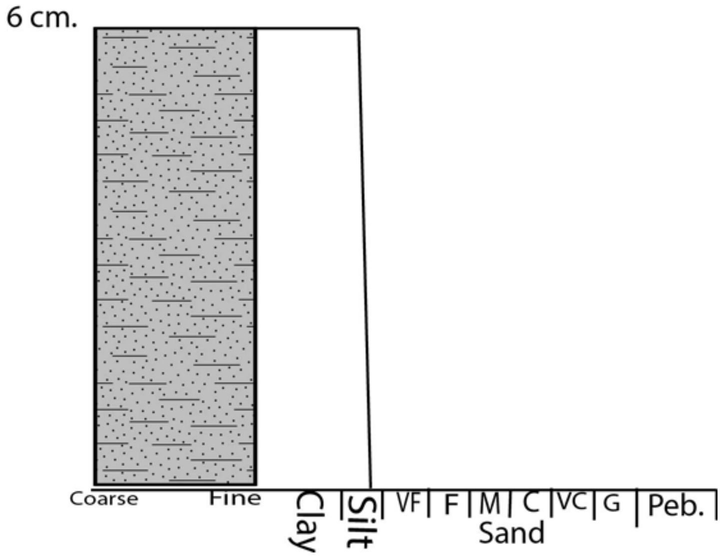
P14:

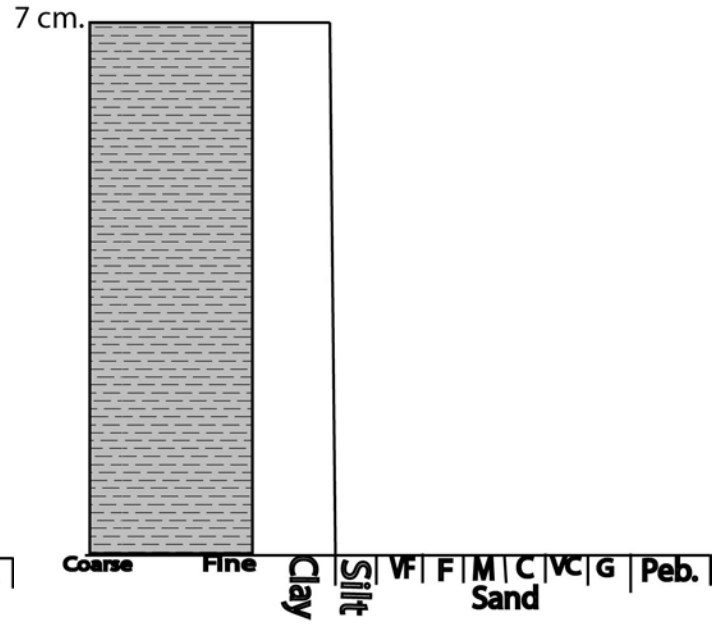

8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


13 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P15:

P16:





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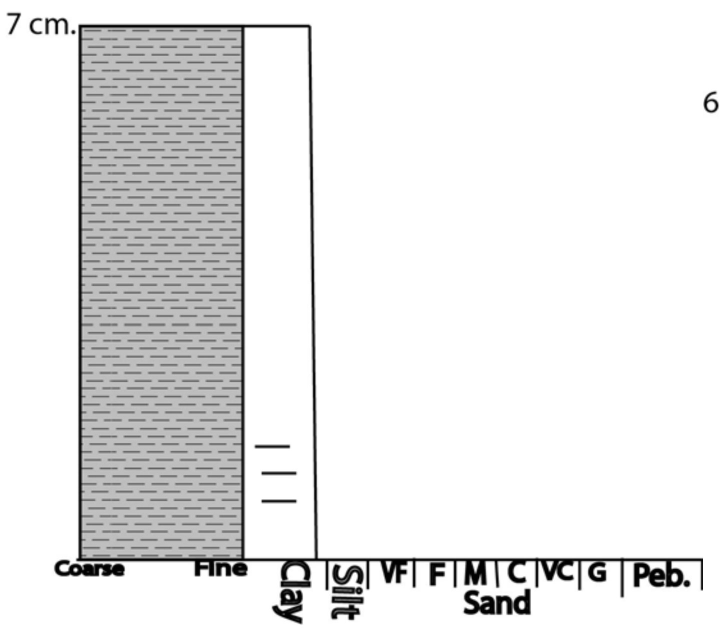
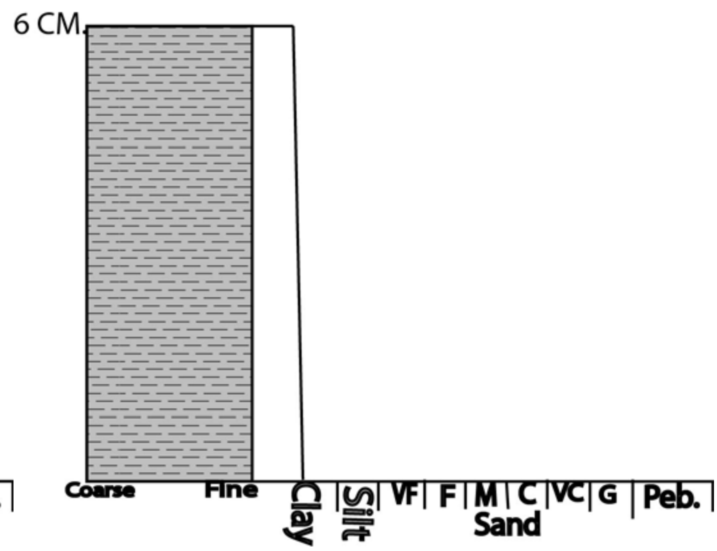
P18:





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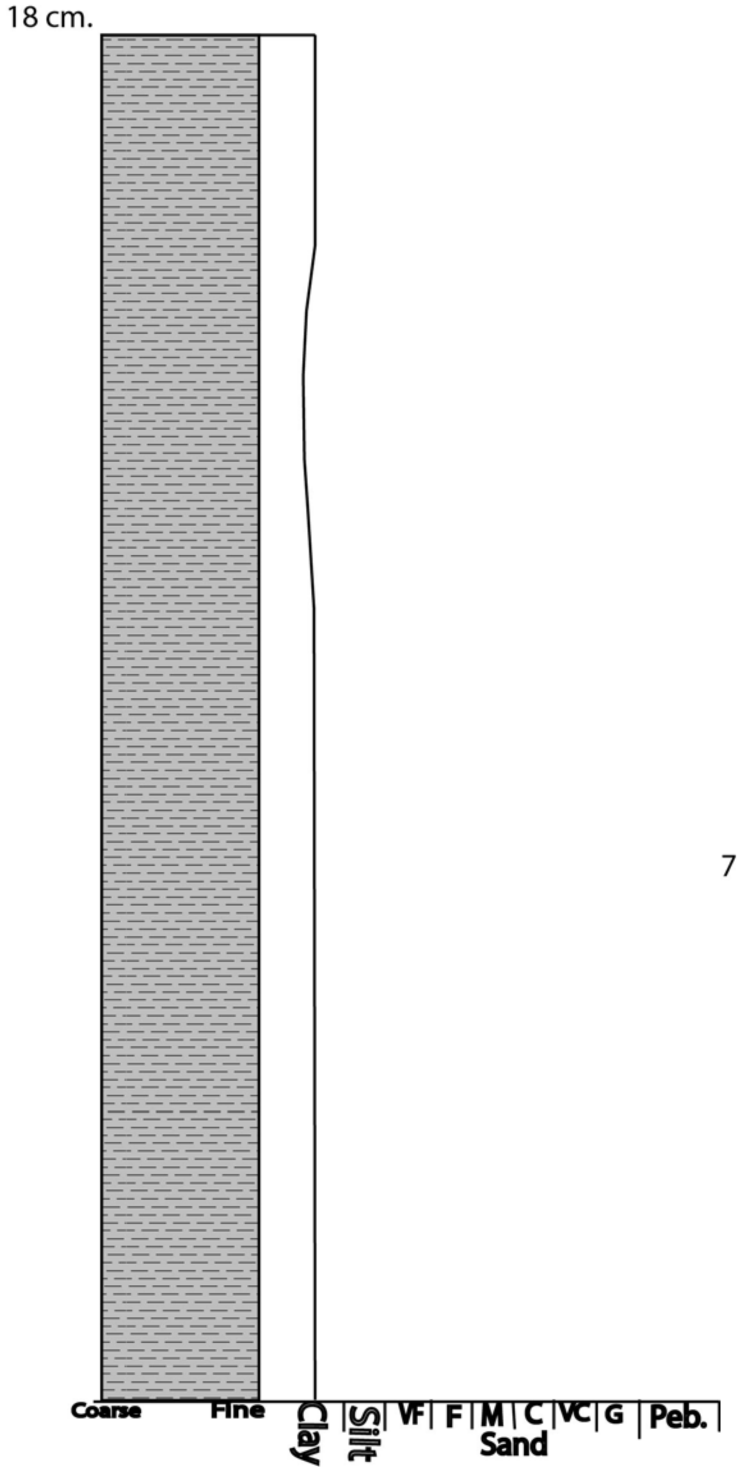
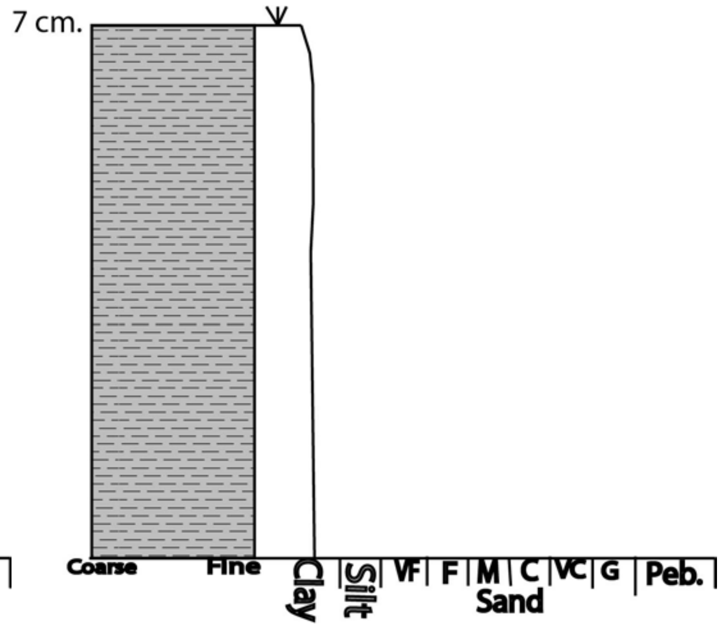
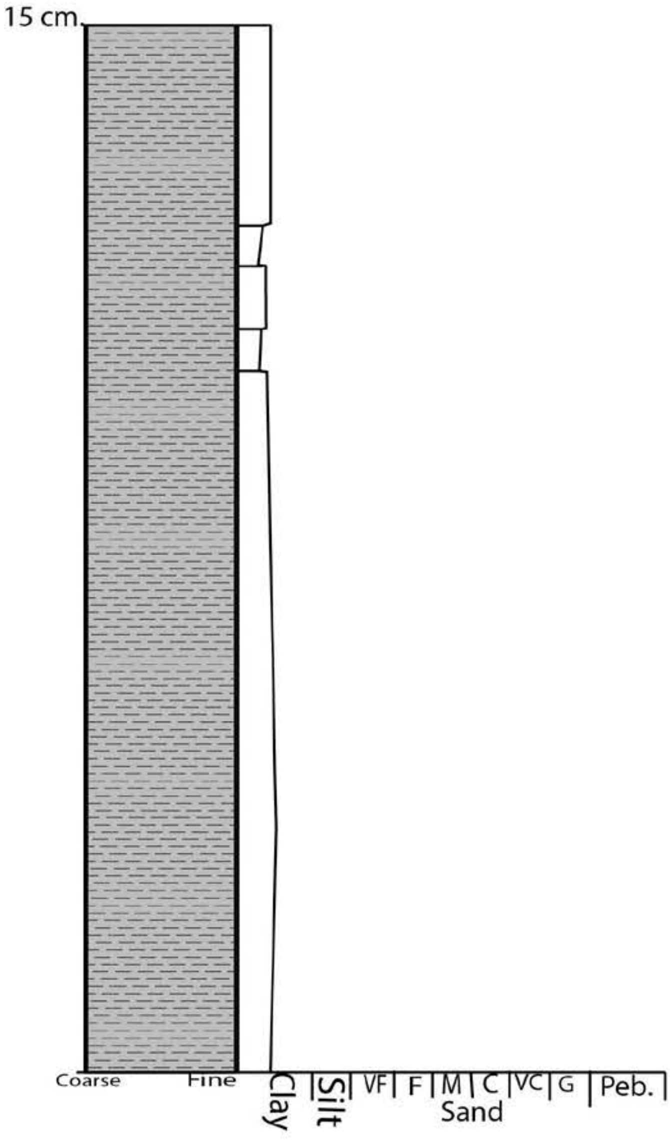

18 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

P21:


7 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

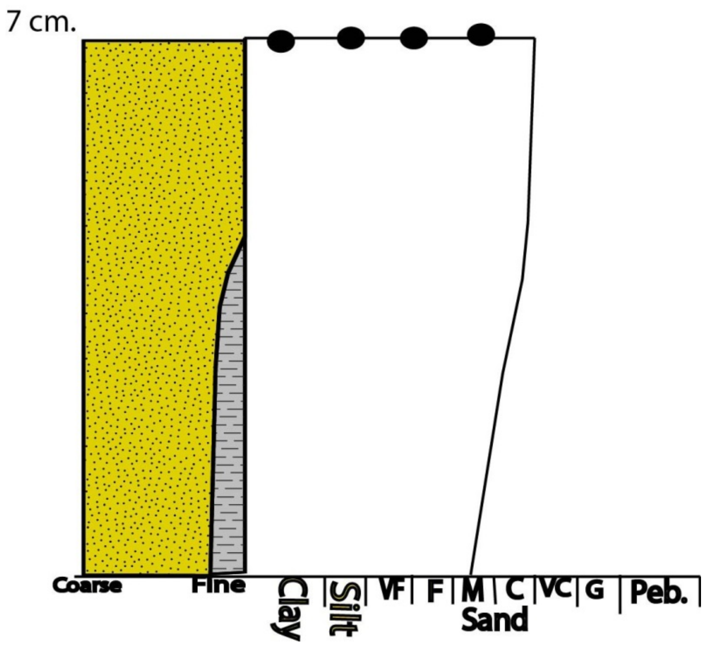
P22:



P23:

Appendix C:

Logs from field season 2011.



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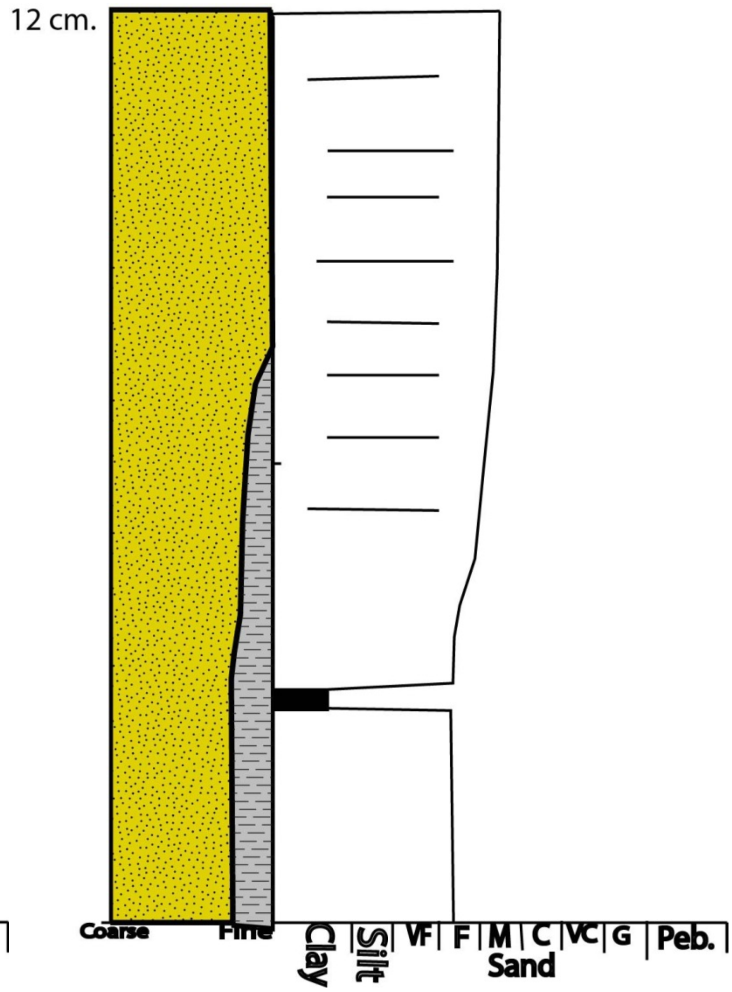

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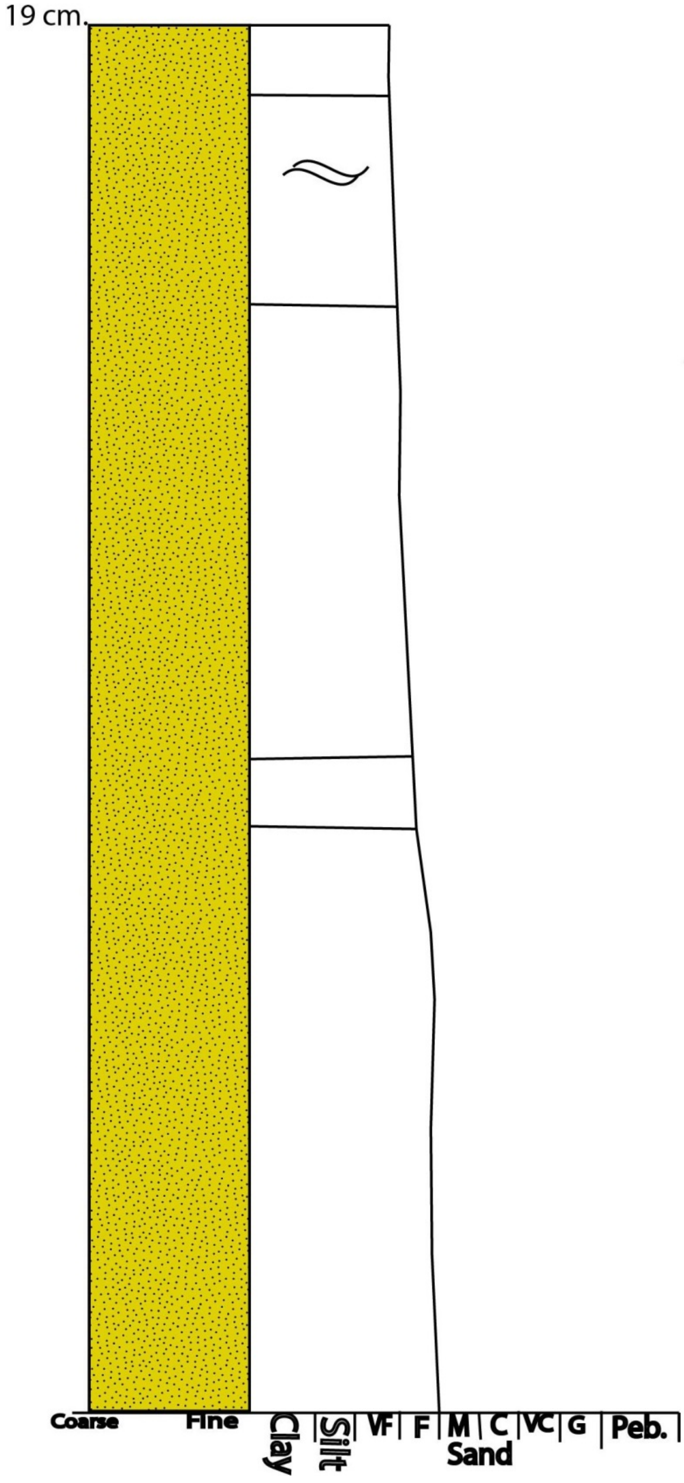
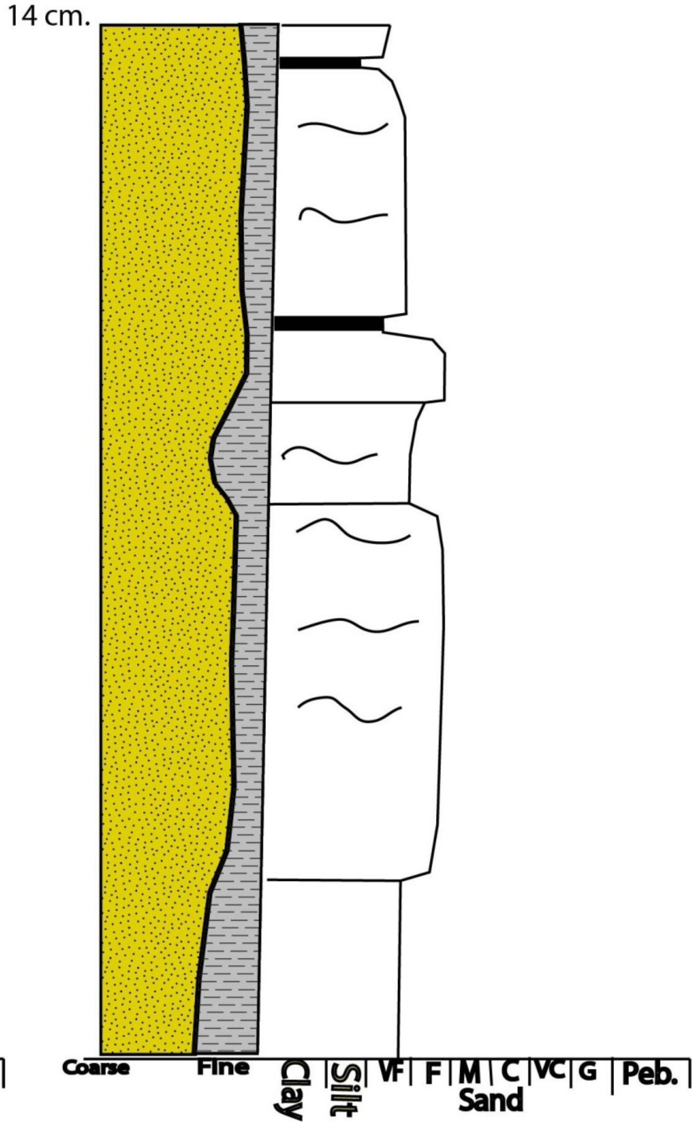
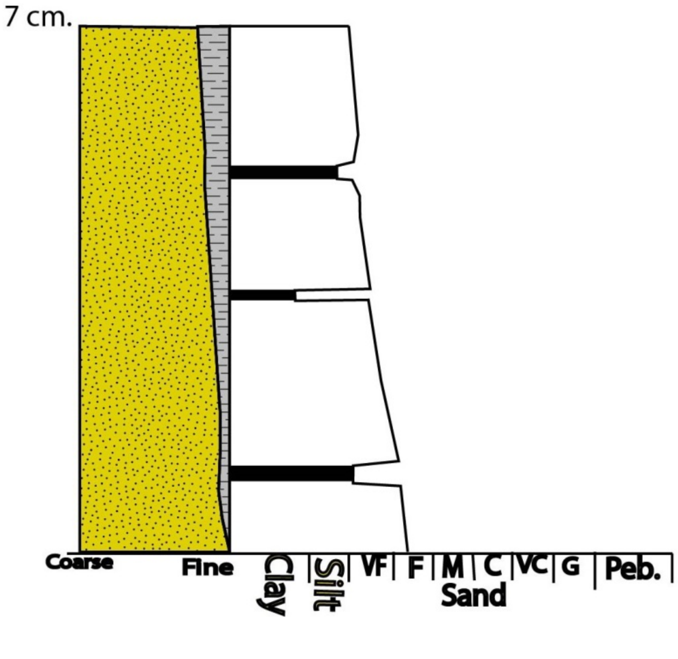

19 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

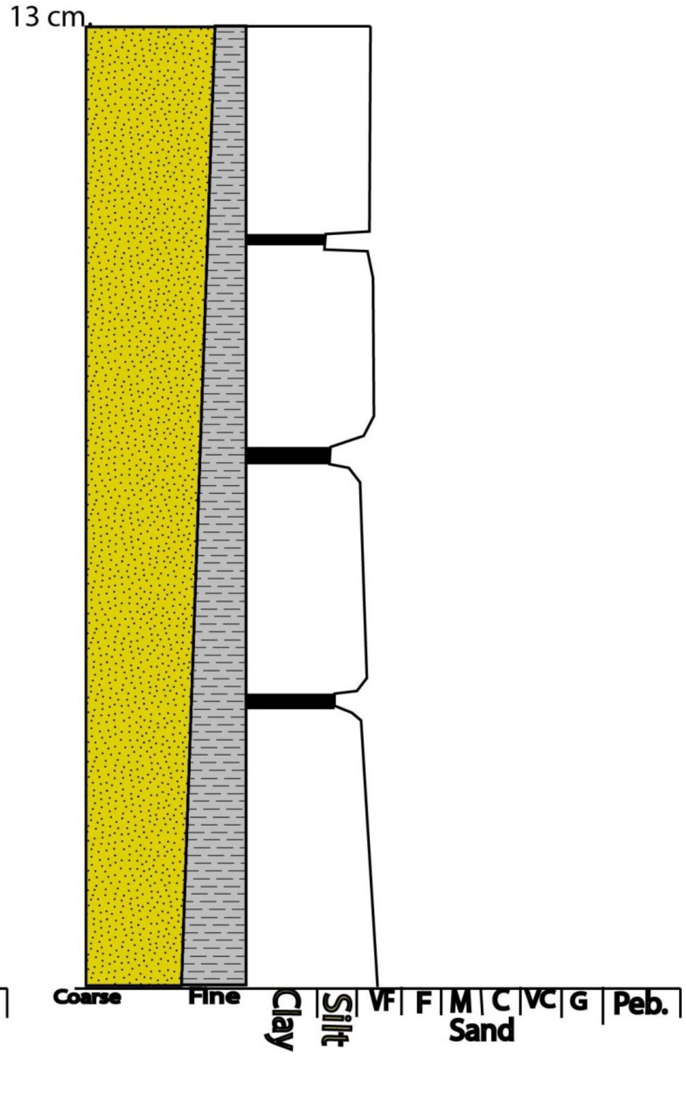

14 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

2.2:

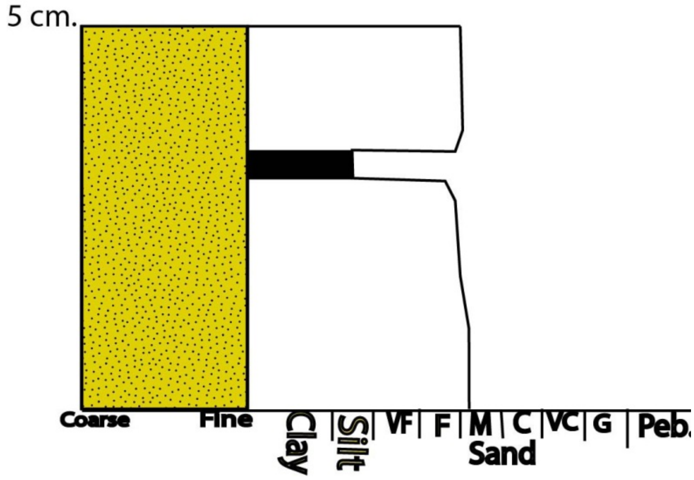
2.3:


7 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

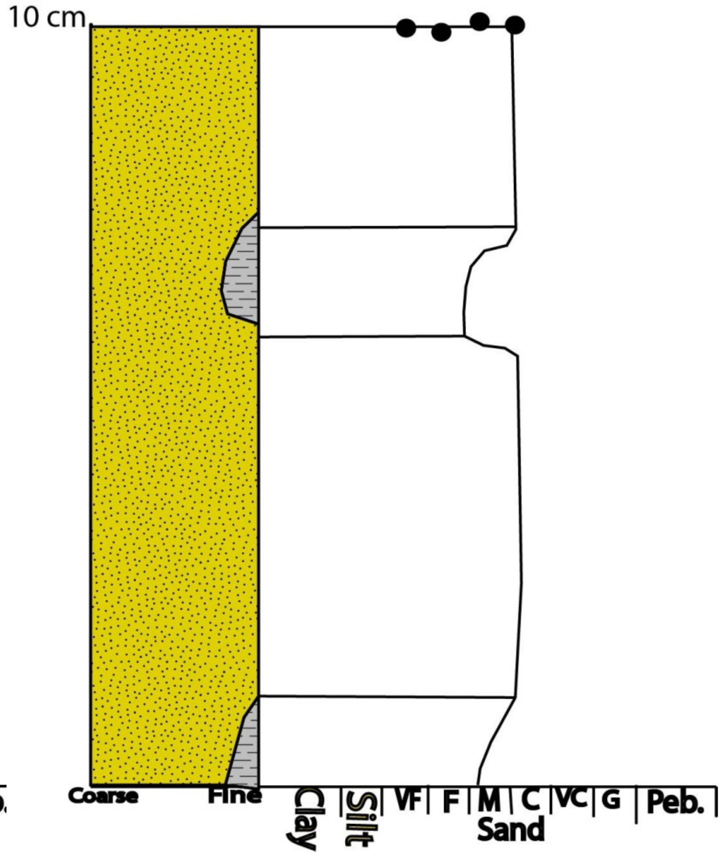
2.5:


13 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

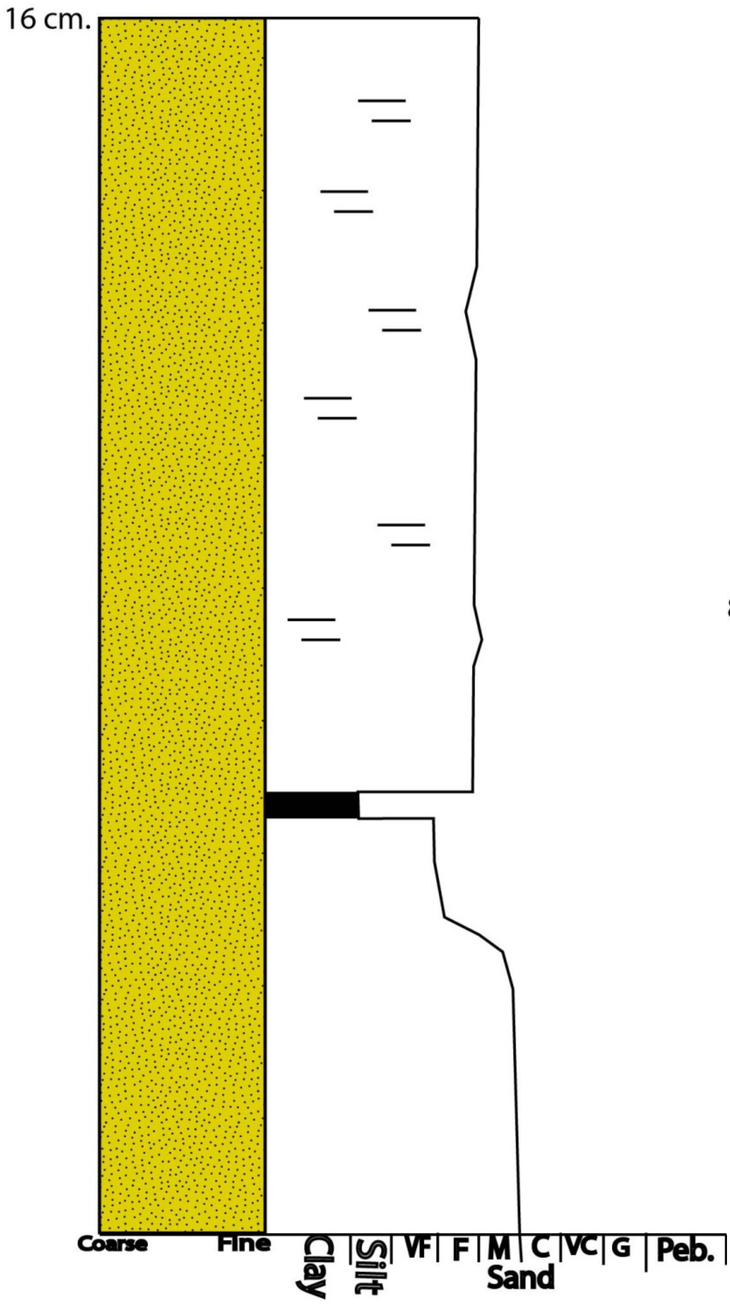
2.5:


5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

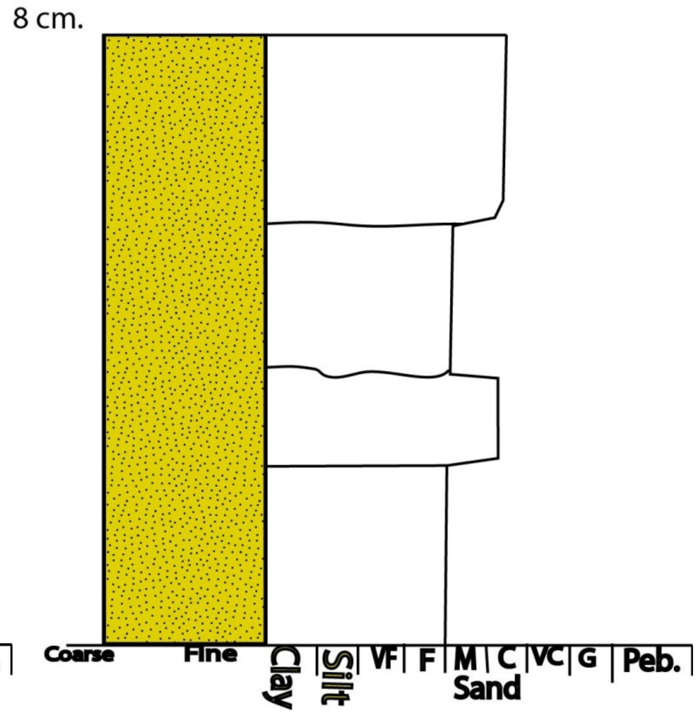
2.6:


10 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

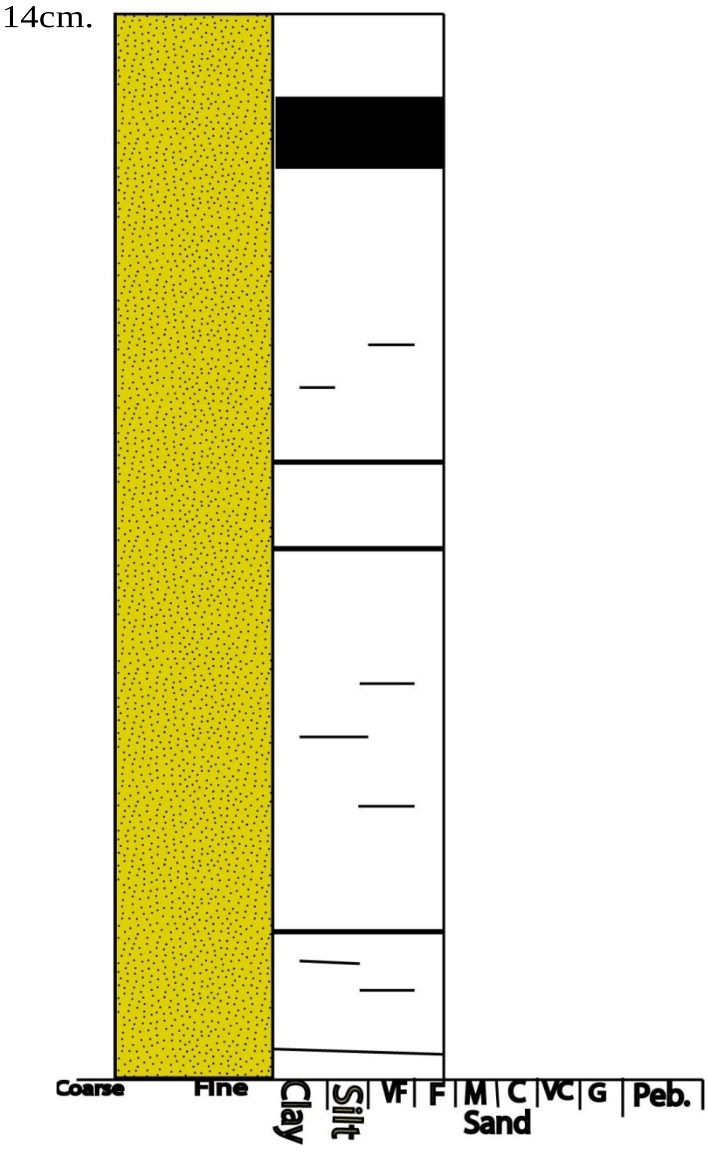
2.7:


16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

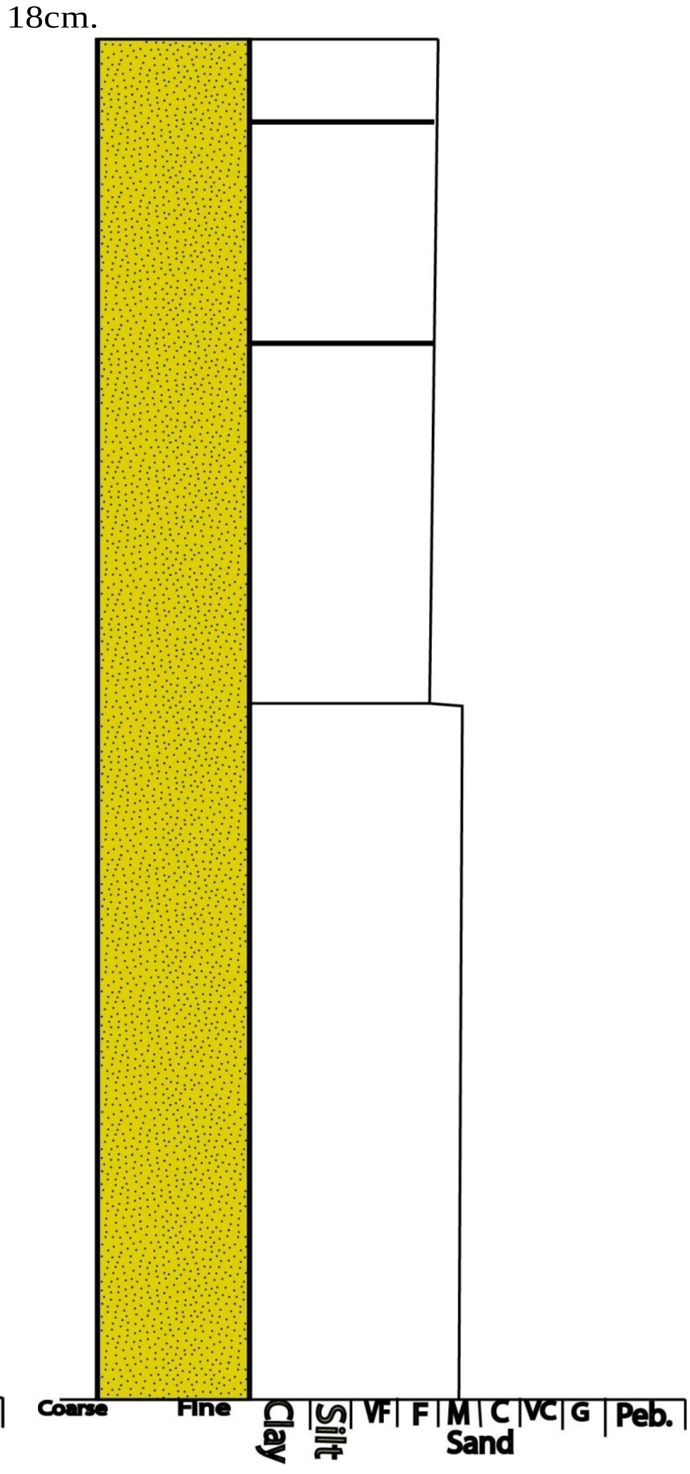
2.8:


8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

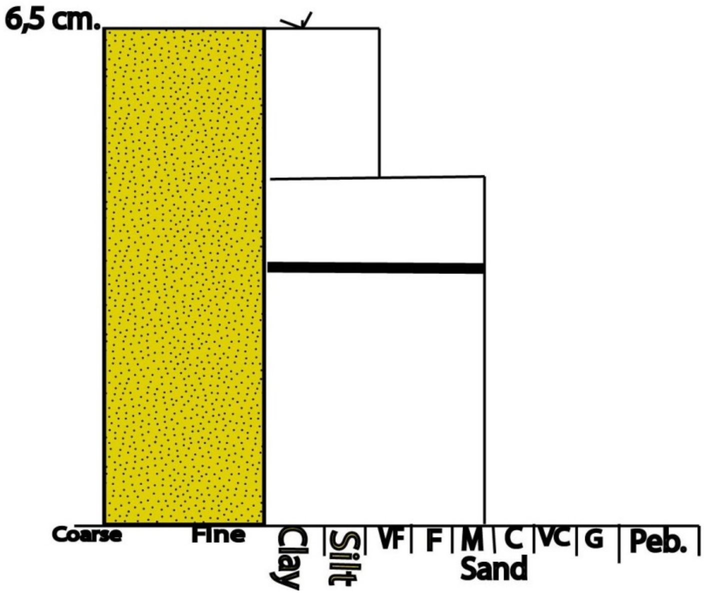
2.9:


14cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

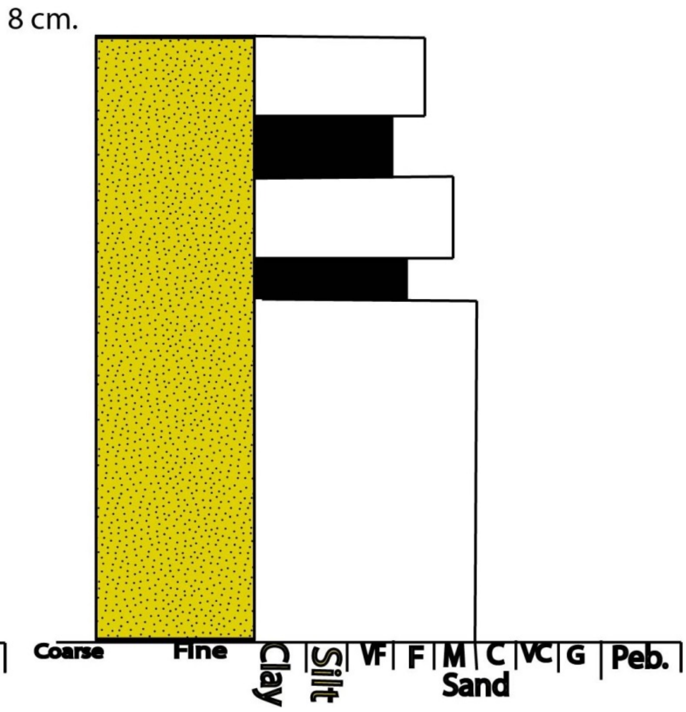
2.10:


18cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

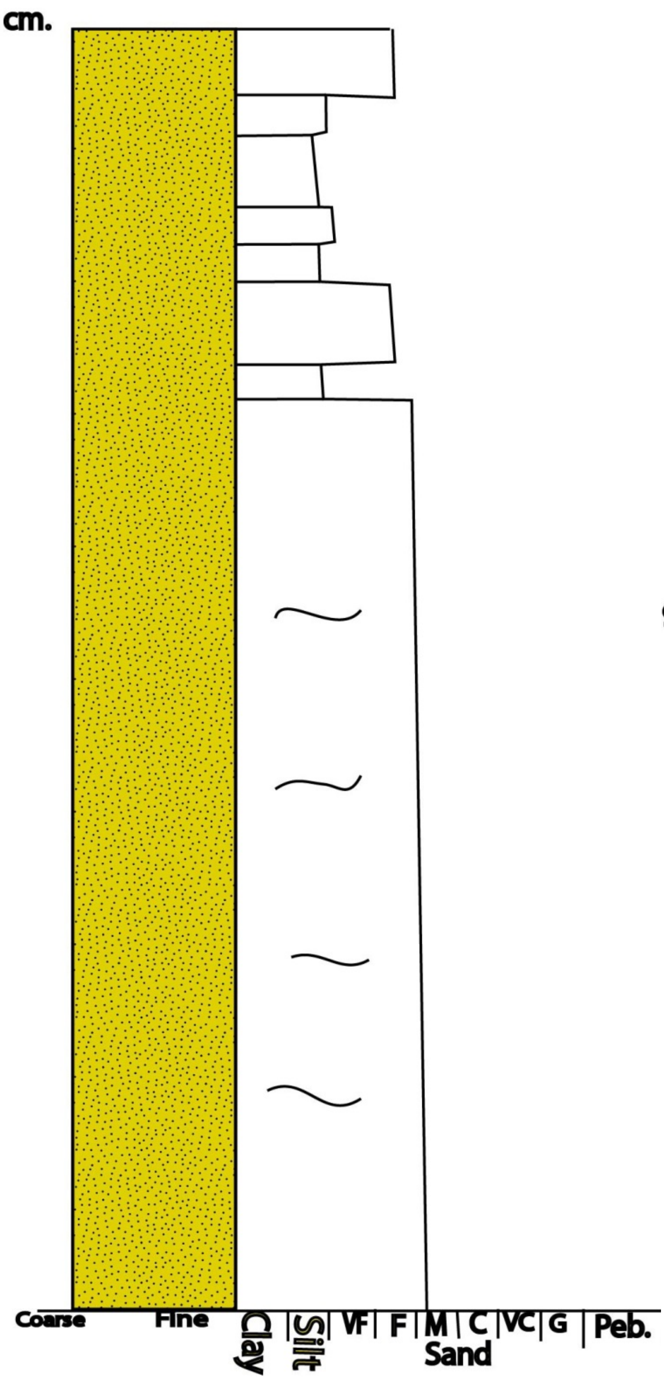
3.7:


6,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

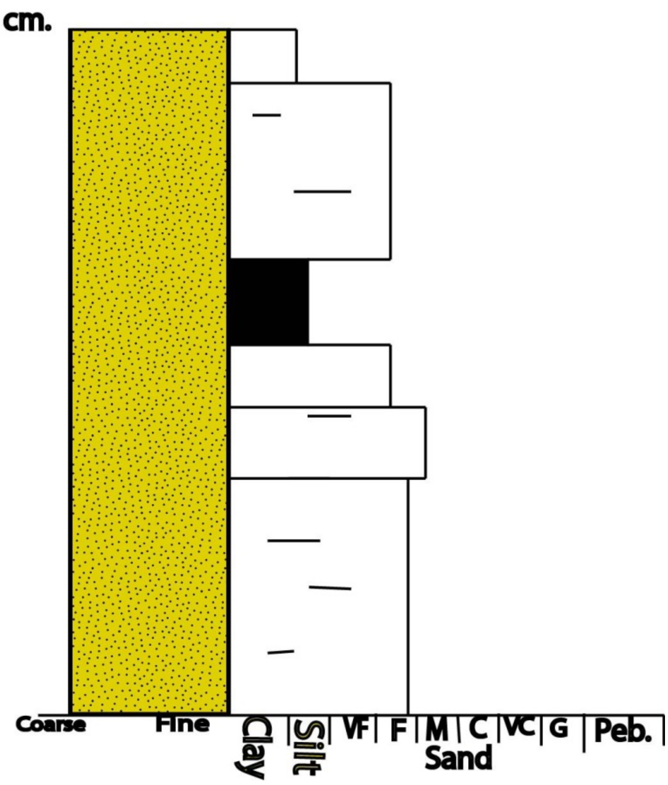
3.8:


8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

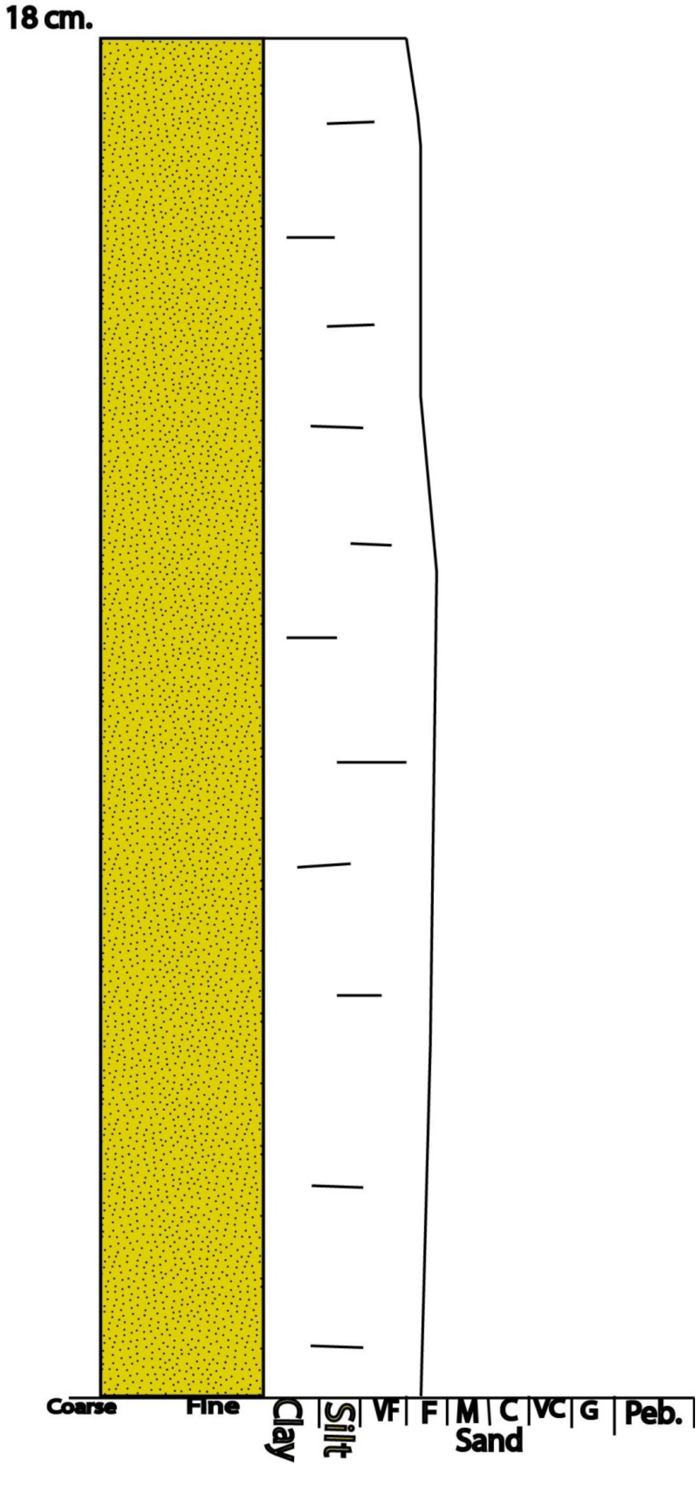
3.9:

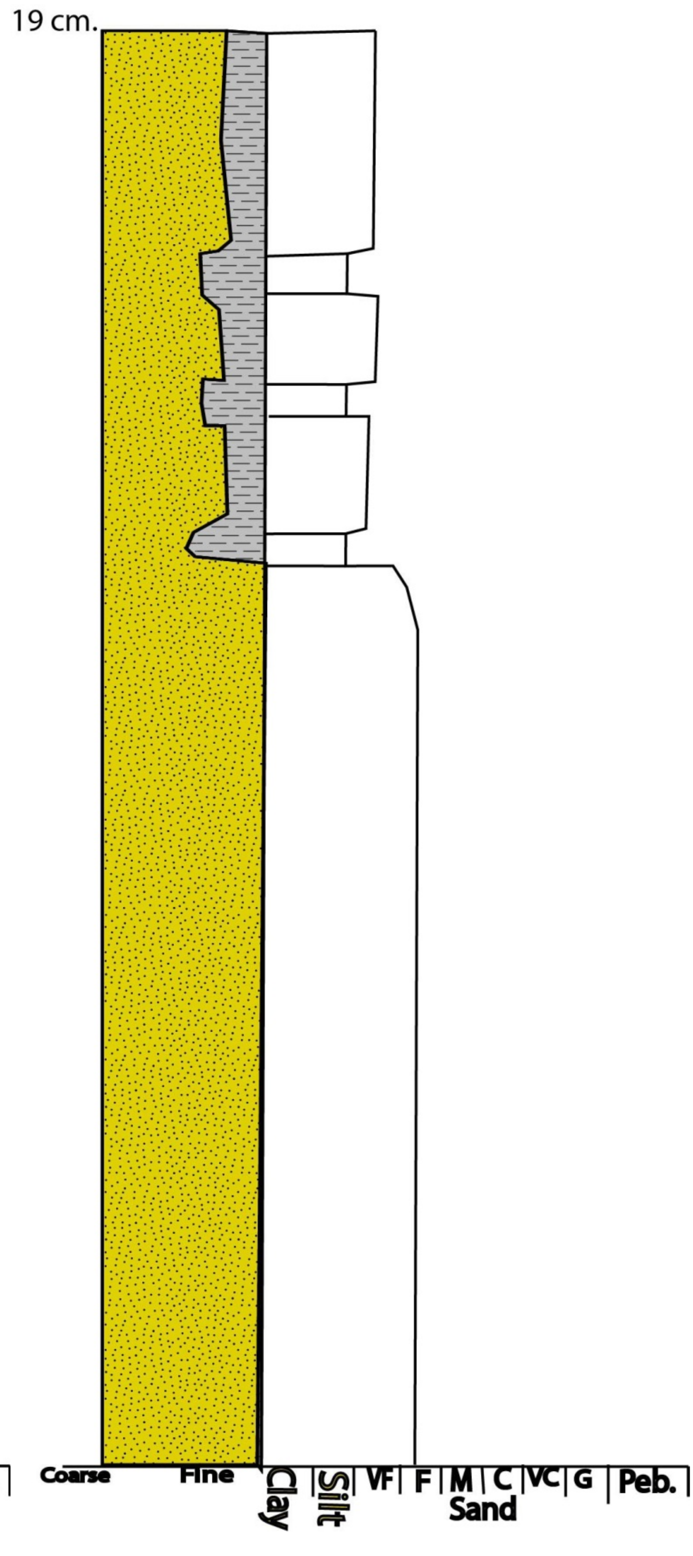

17 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

3.10:


9 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

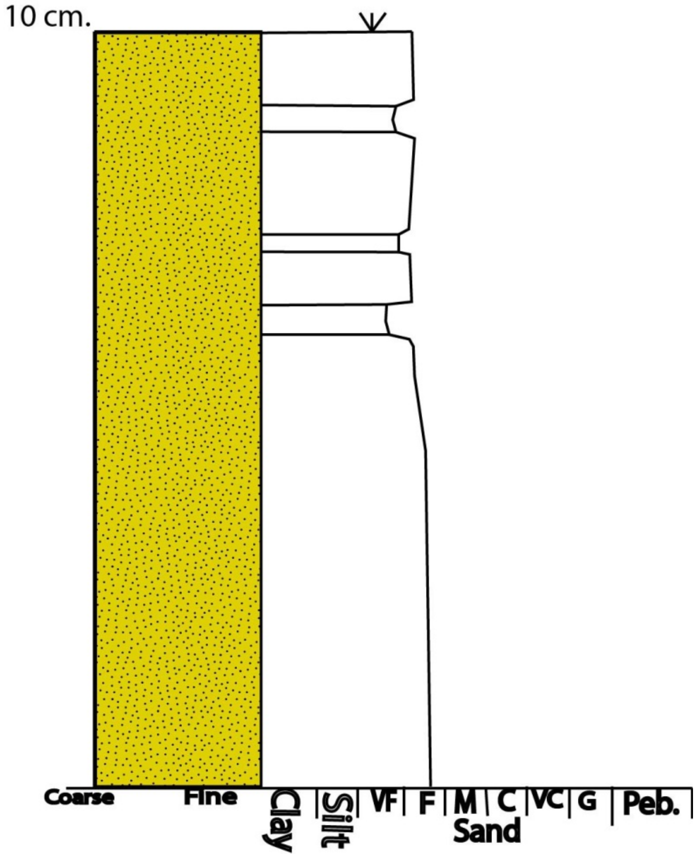
5.1:

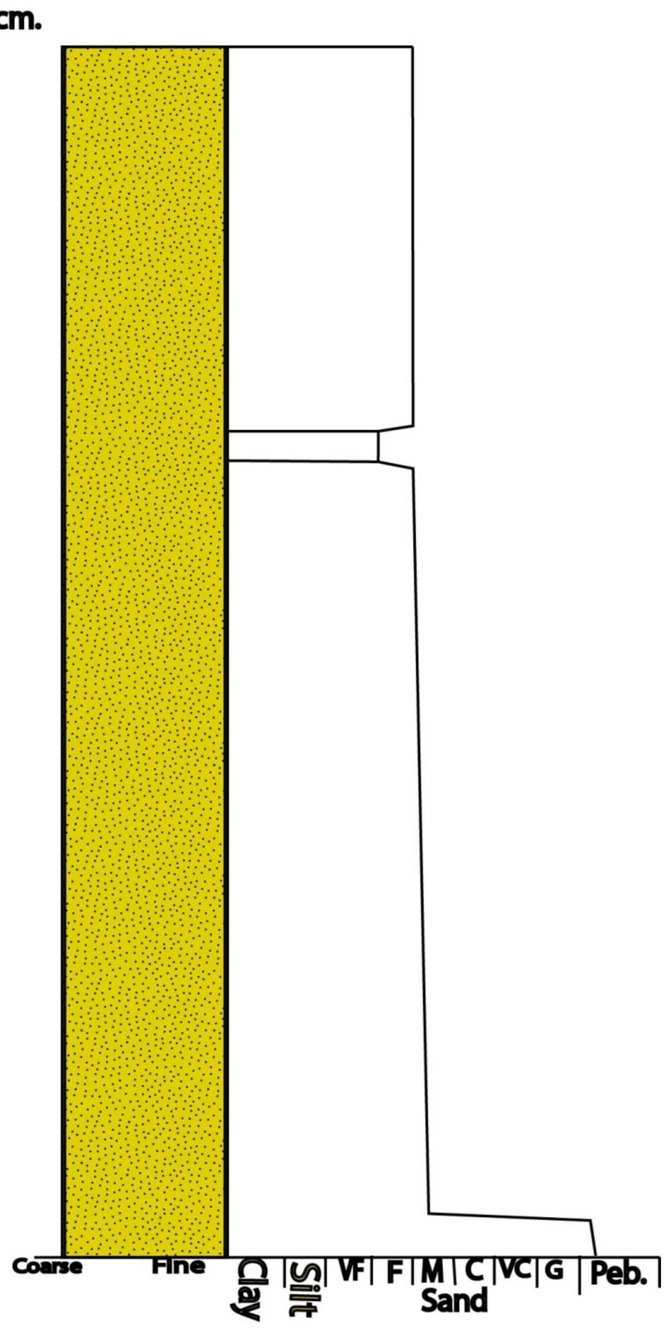

18 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


19 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

5.2:

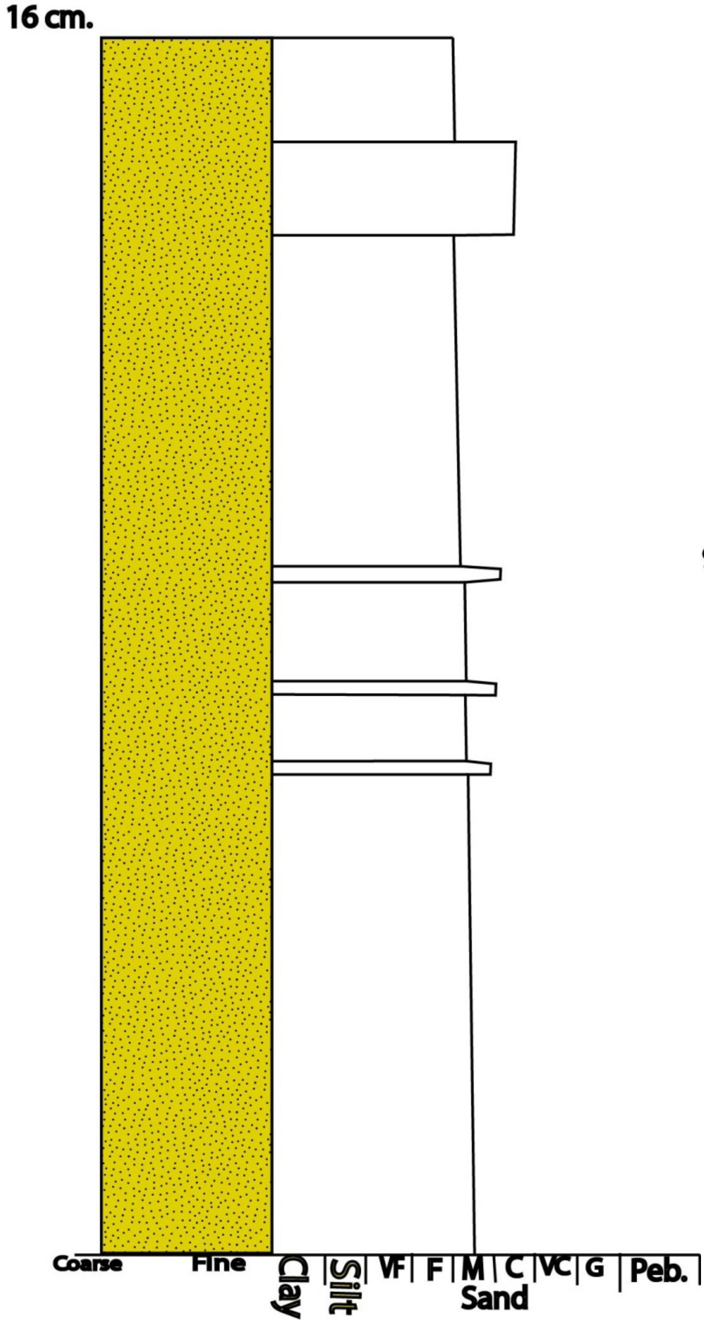
5.3:


10 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

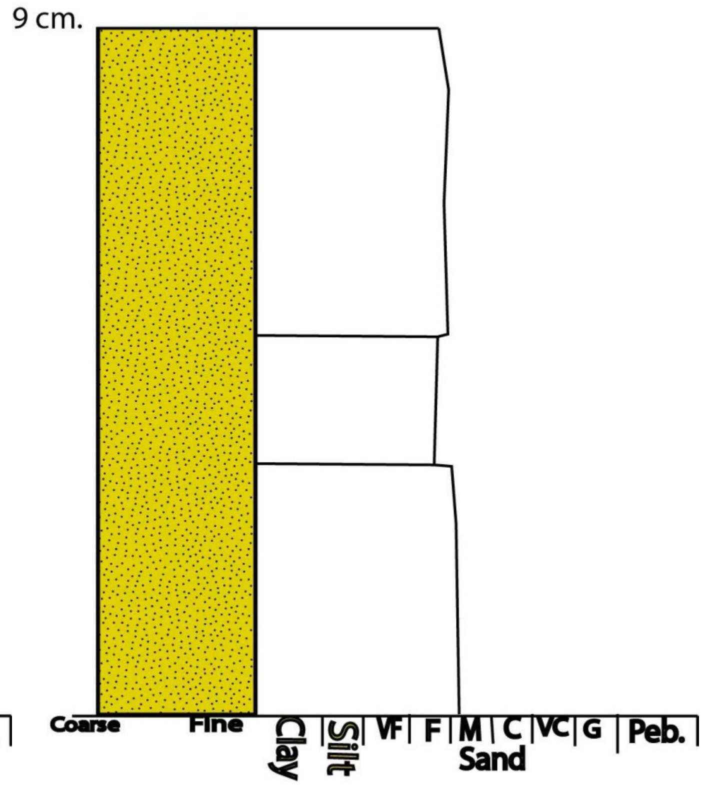

16cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

5.4:

5.5:



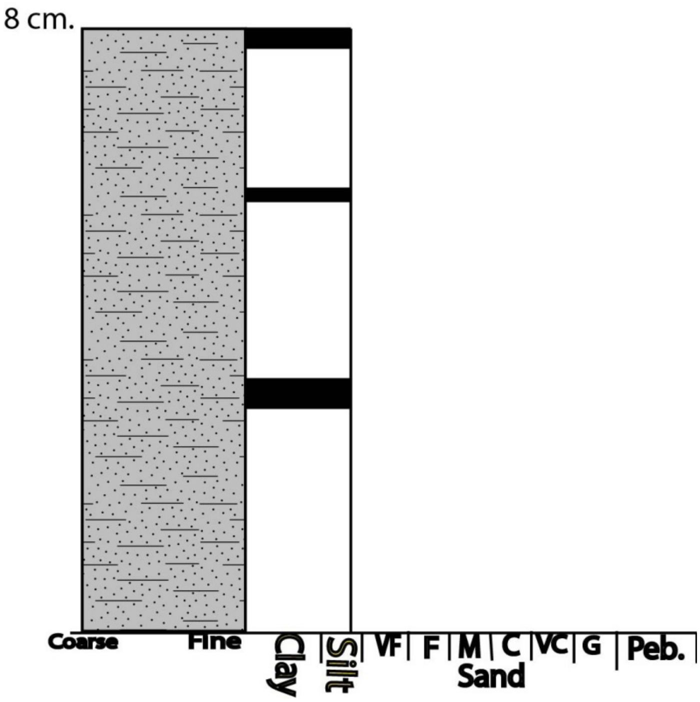
16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand



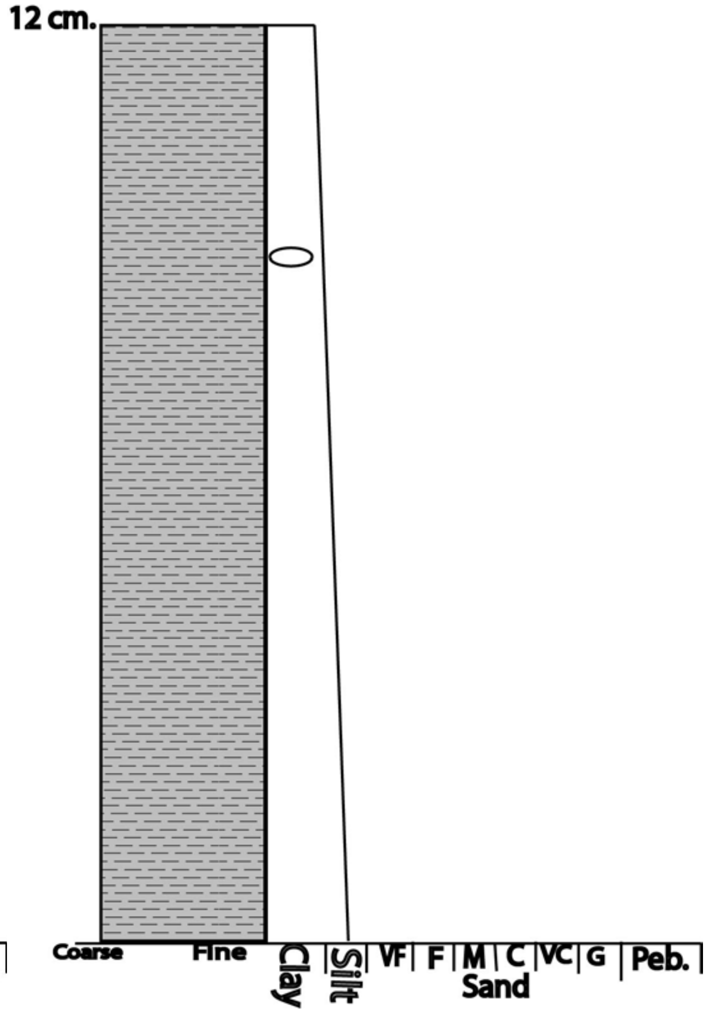
9 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

5.6:

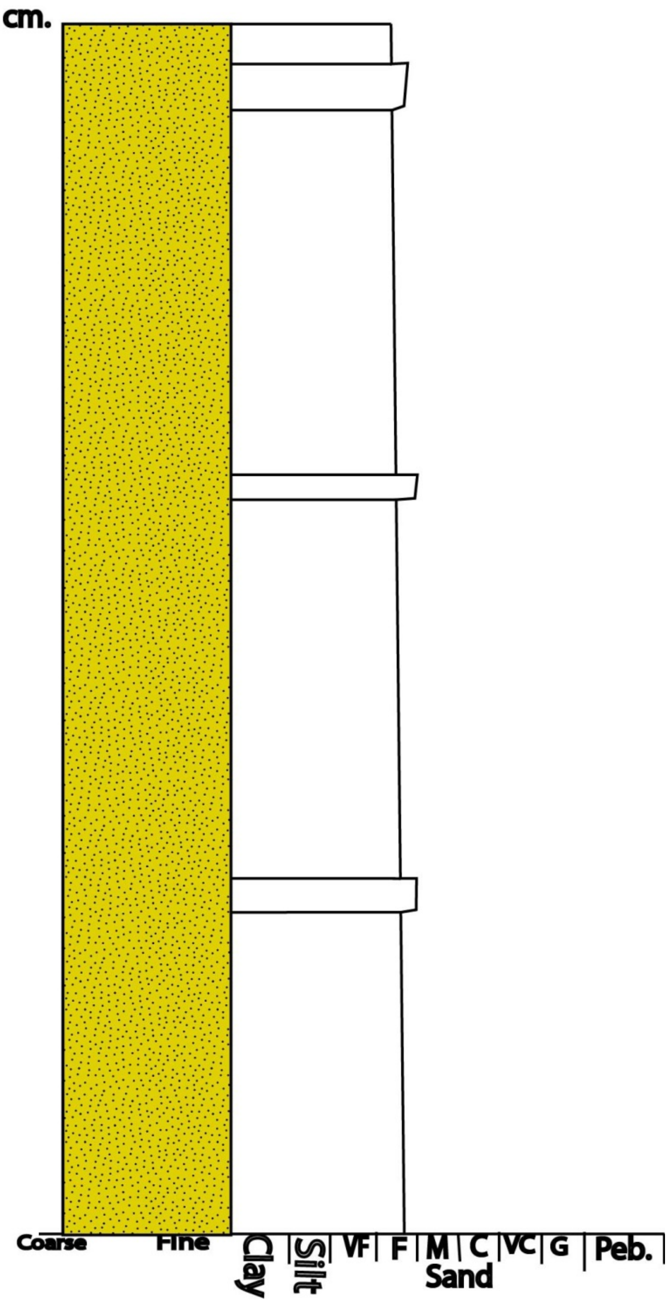
5.7:


8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

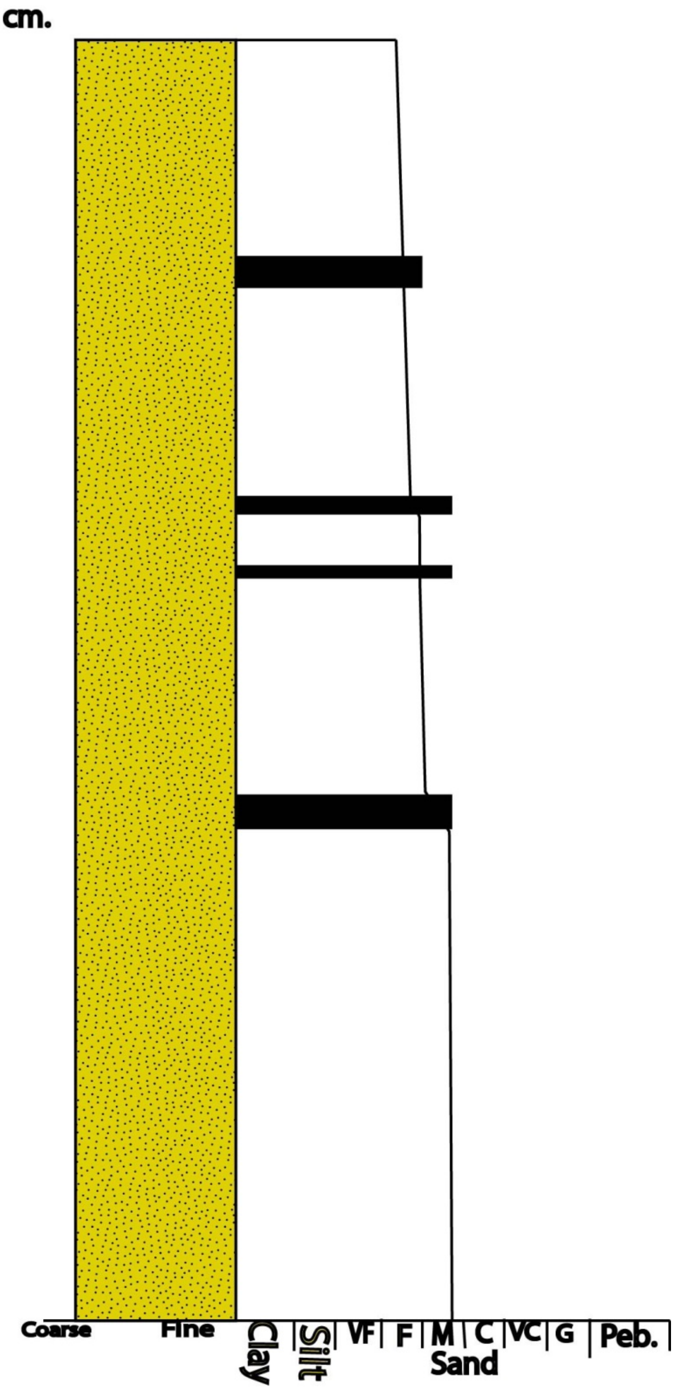
5.8:


12 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

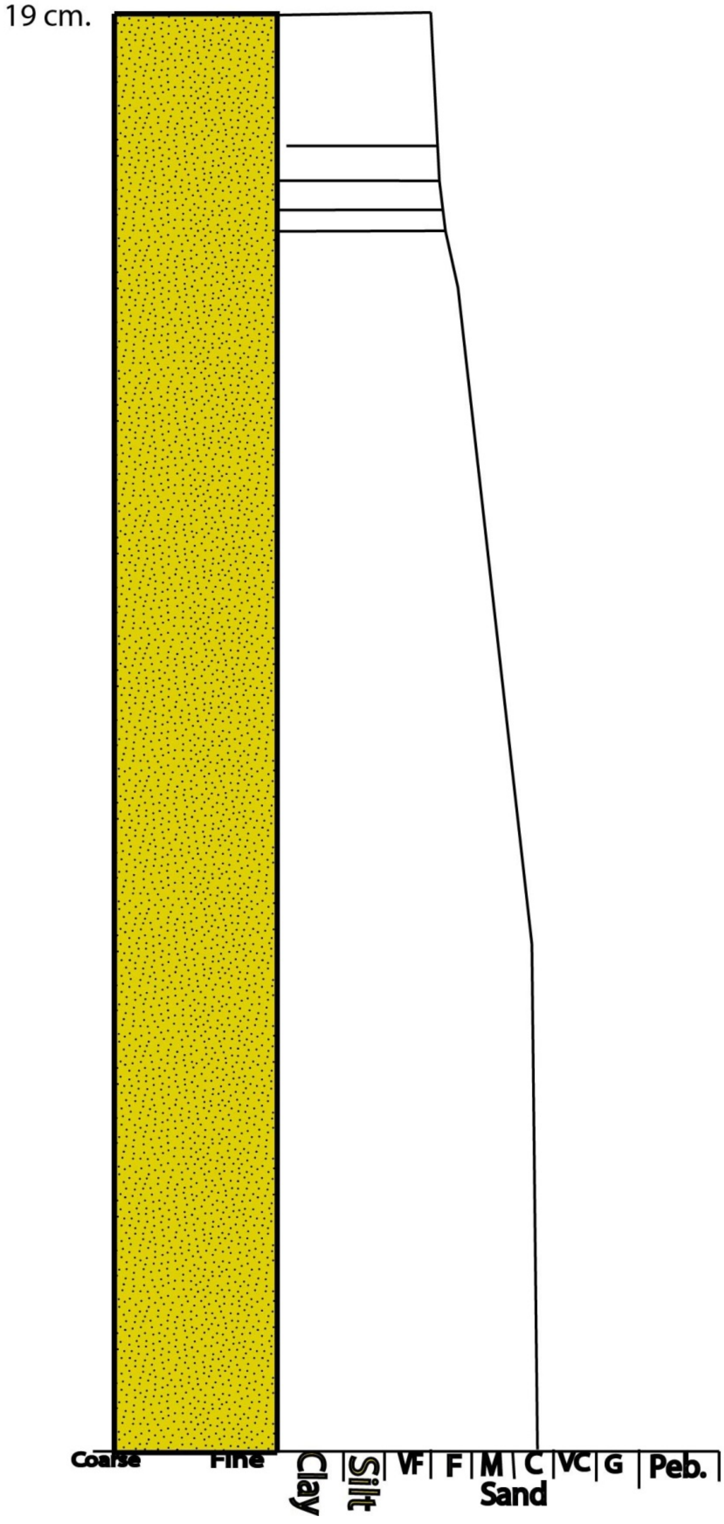
6.2:


16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

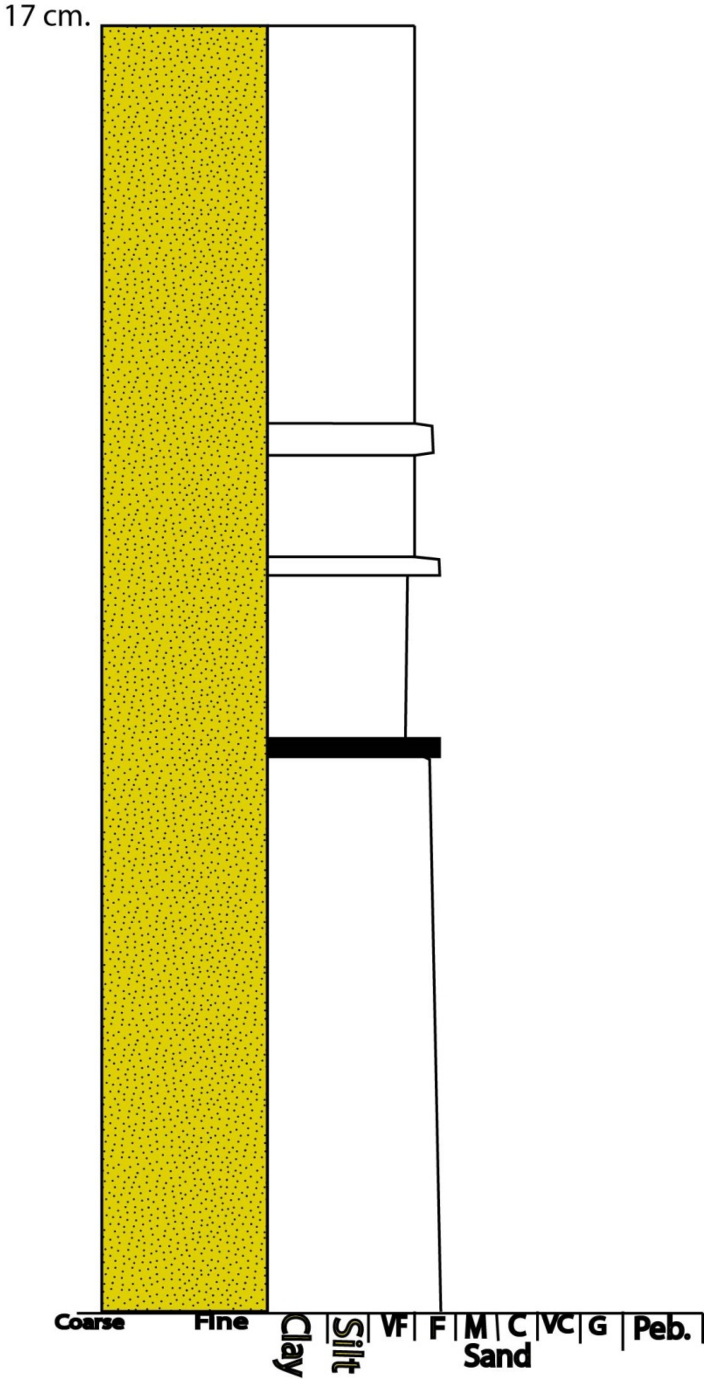
6.3:


17 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

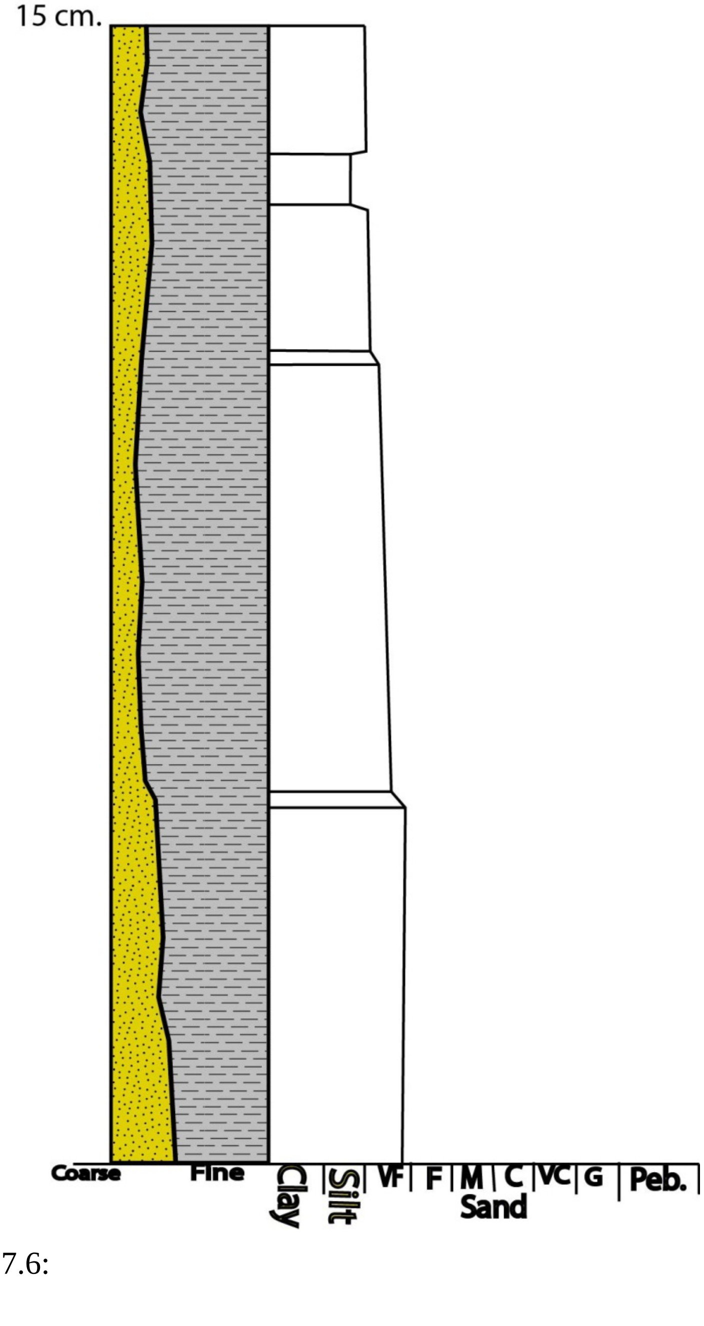
7.1:


19 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

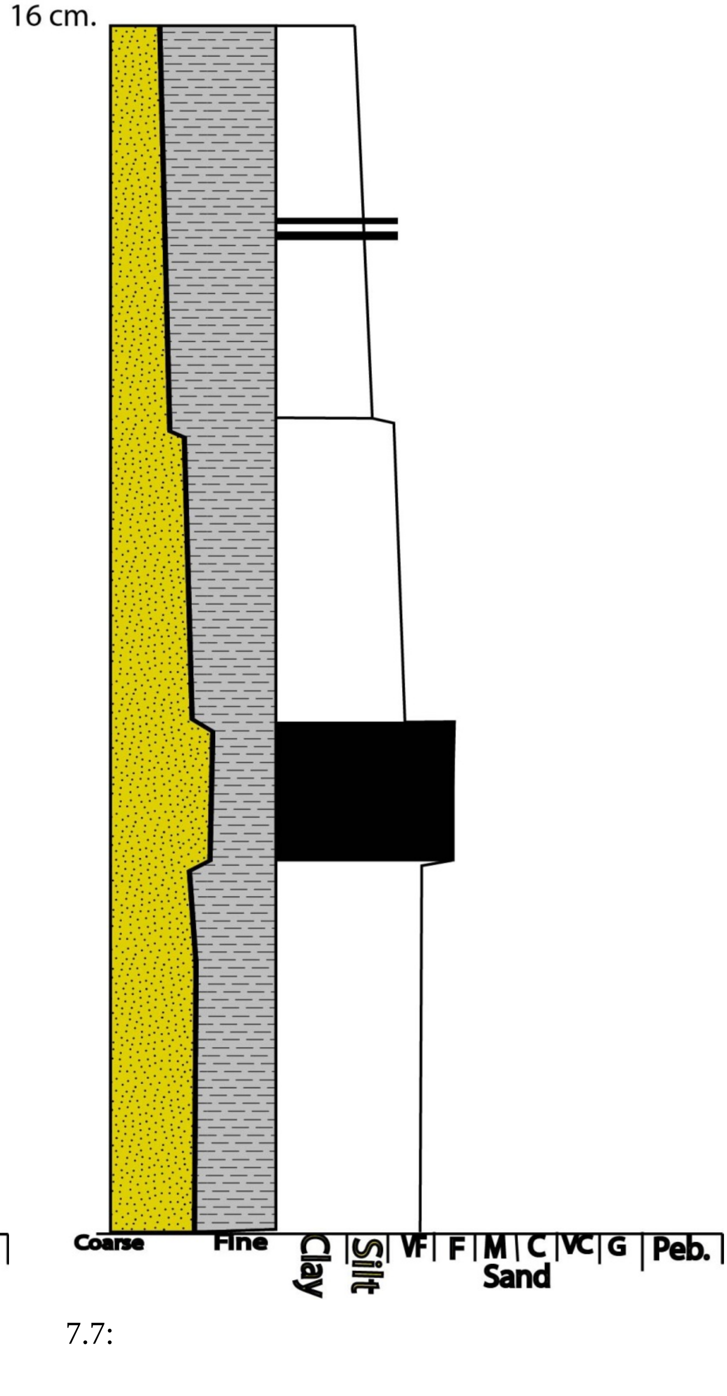
7.3:


17 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

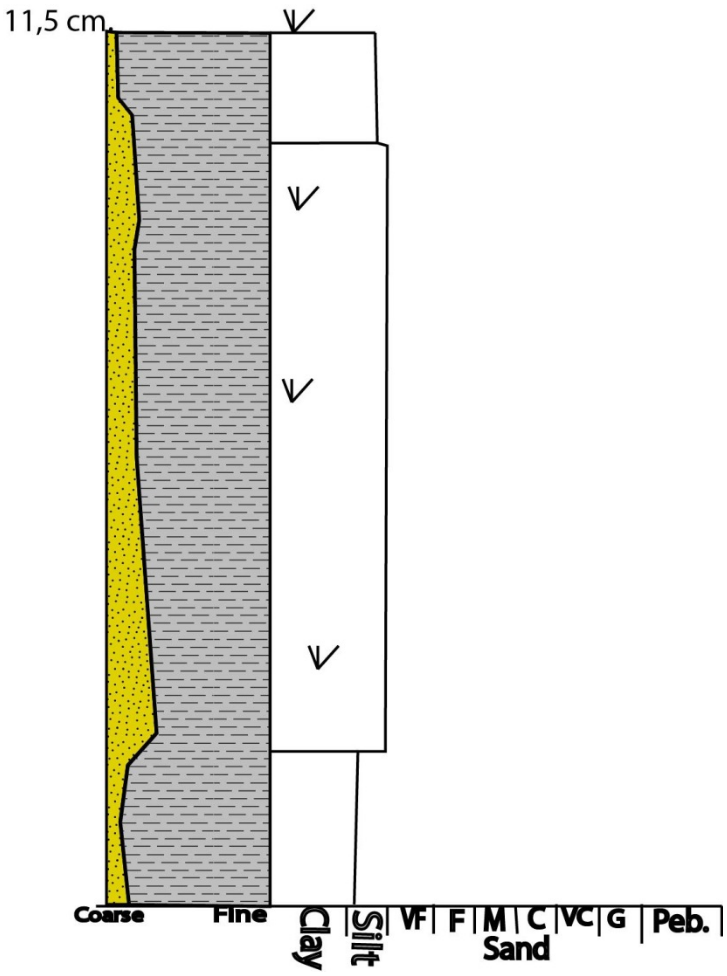
7.5:

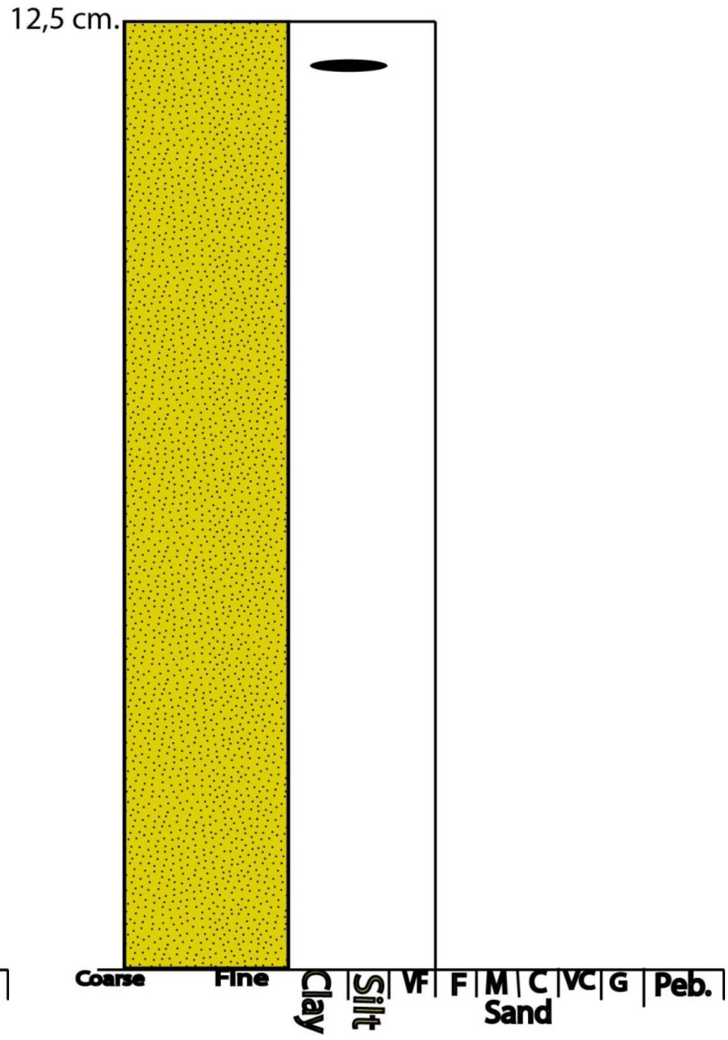

15 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

7.6:


16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

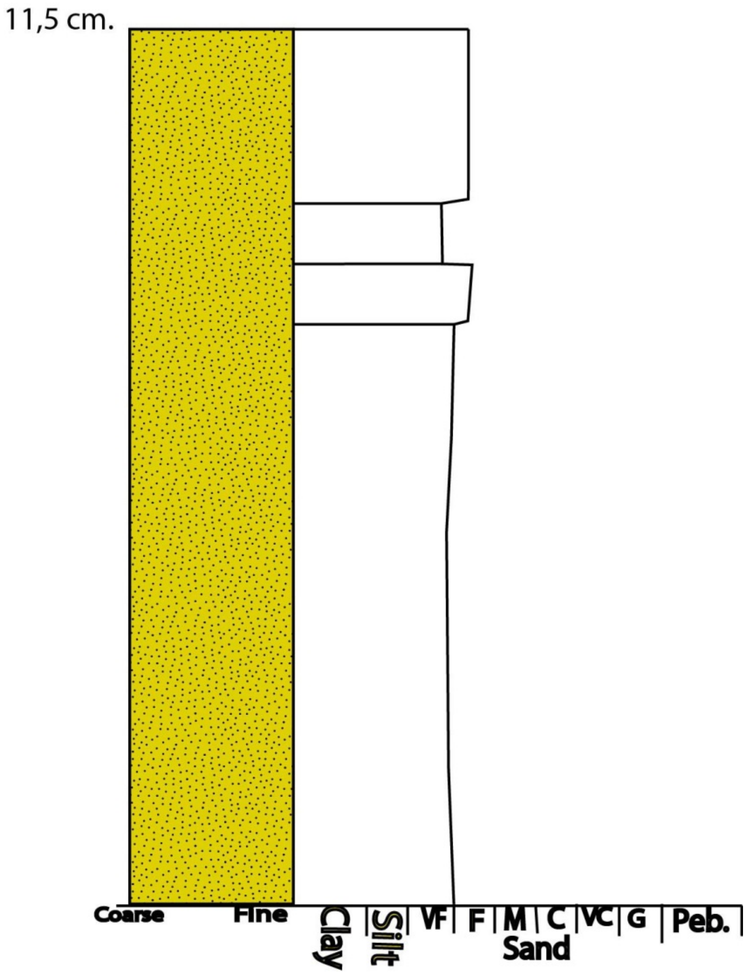
7.7:

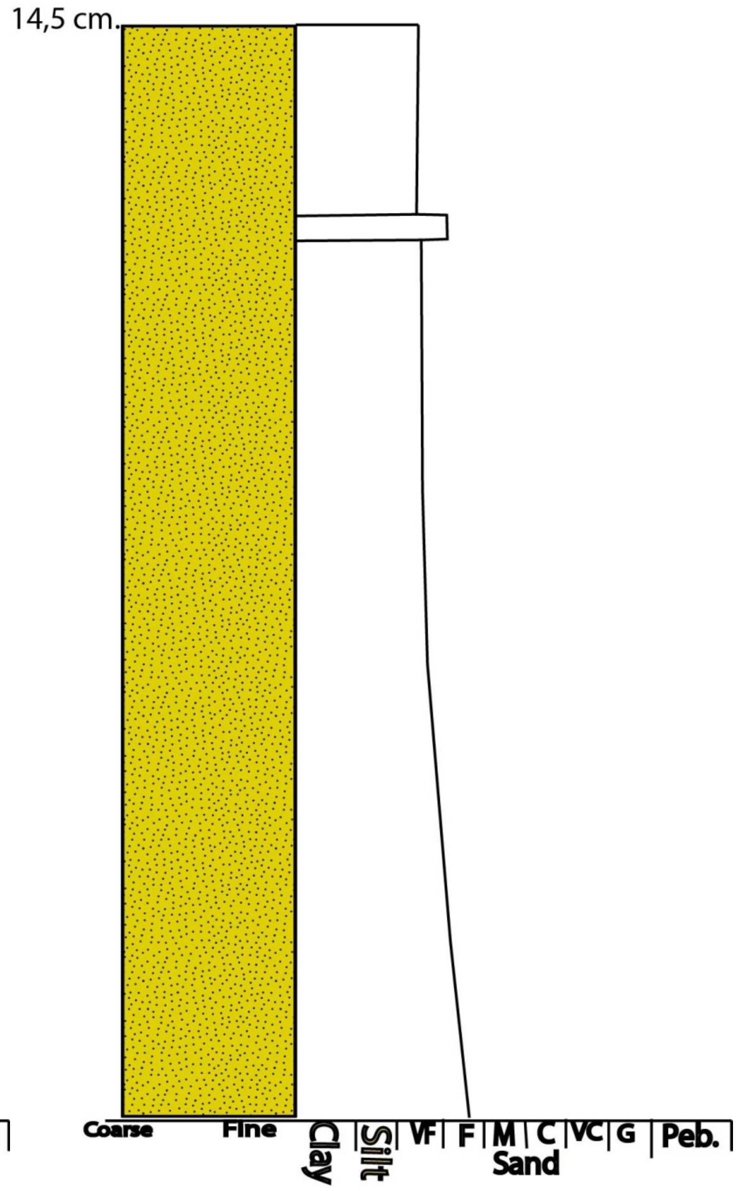

11,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


12,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

7.9:

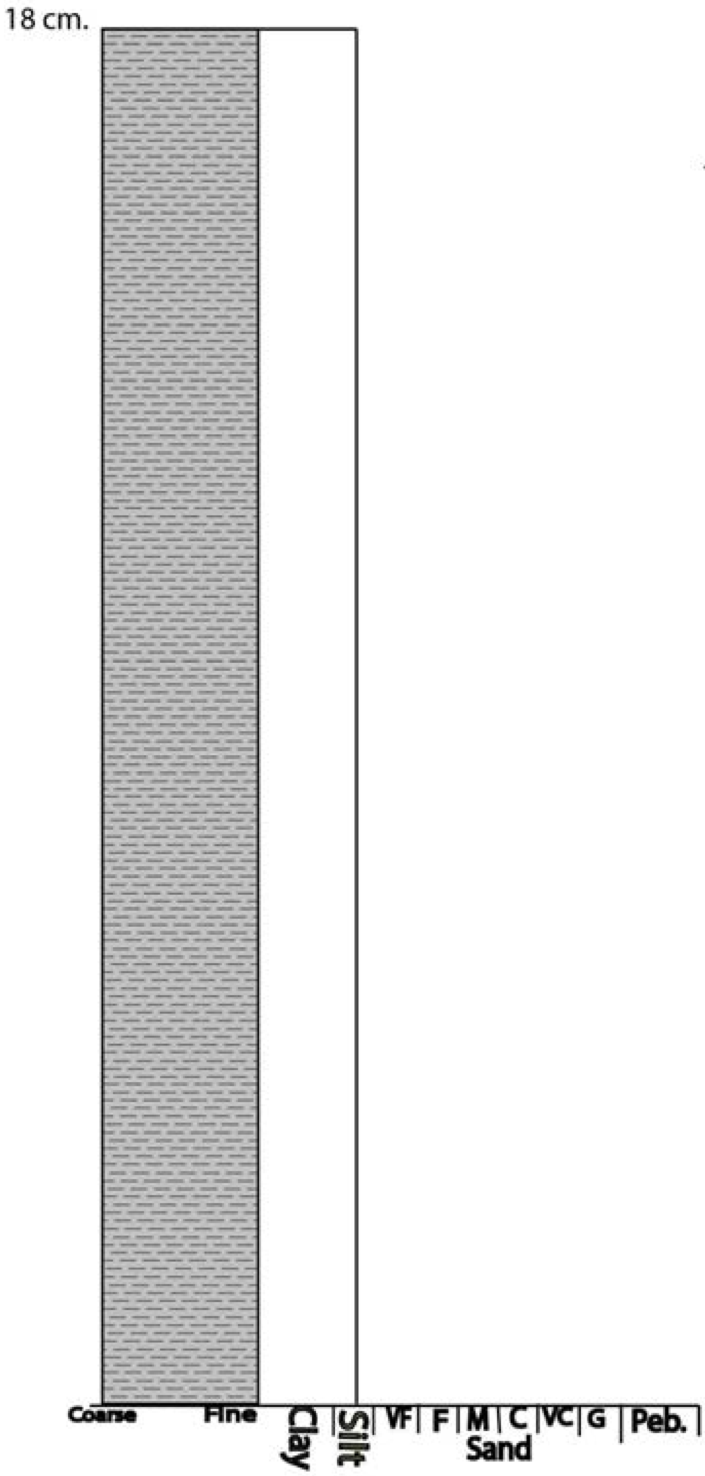
8.1:


11,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

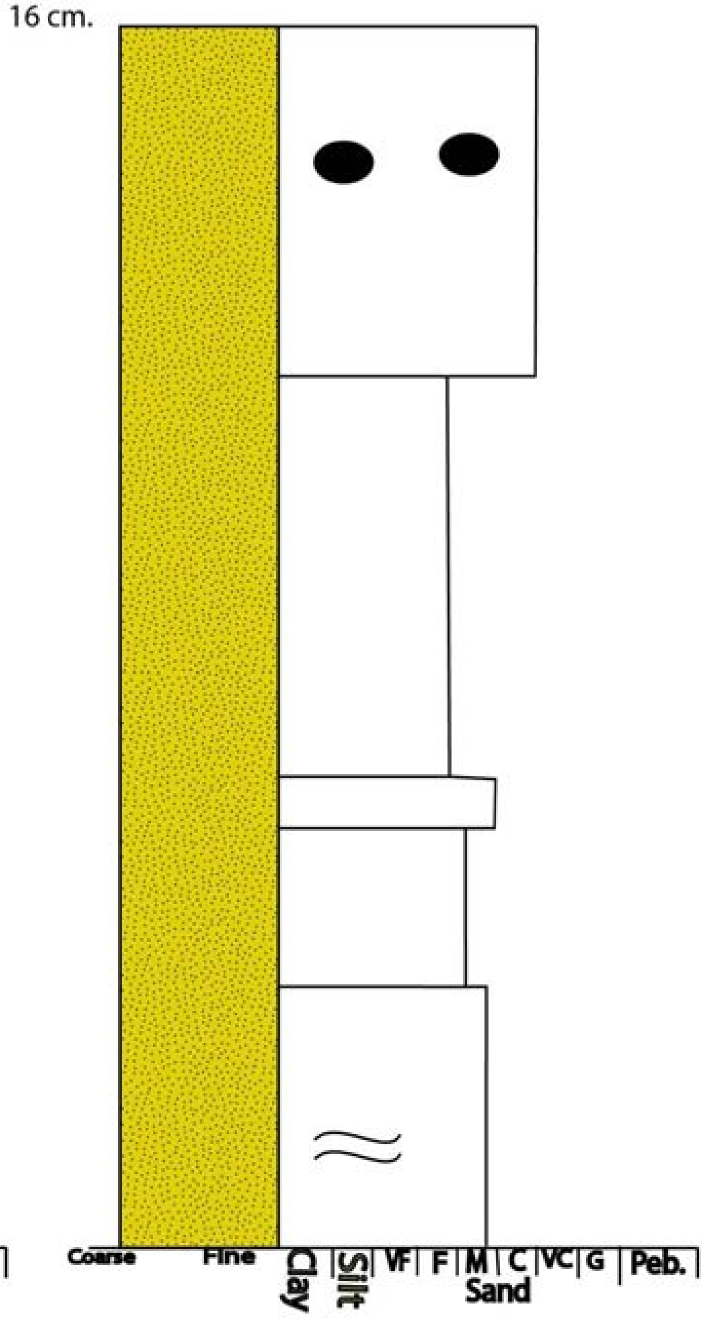

14,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

8.2:

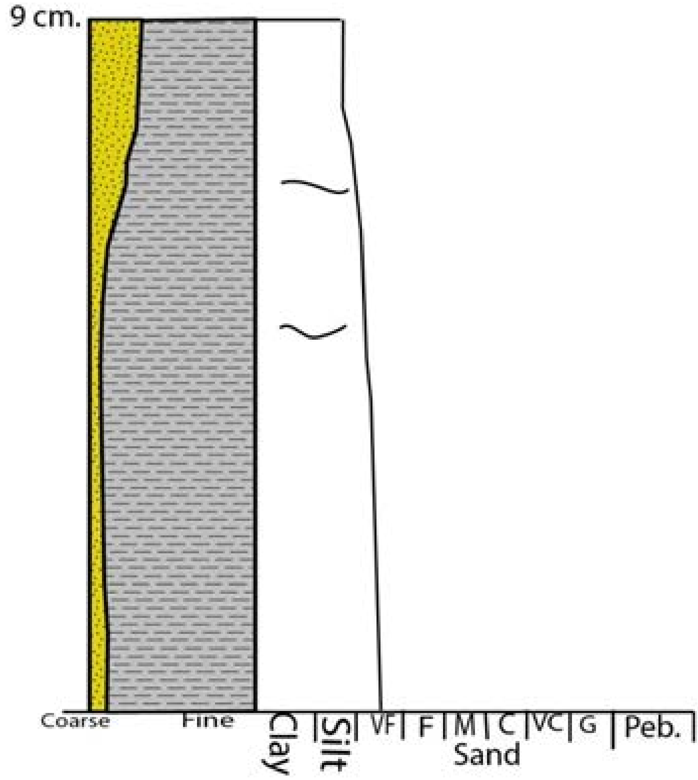
8.3:


18 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

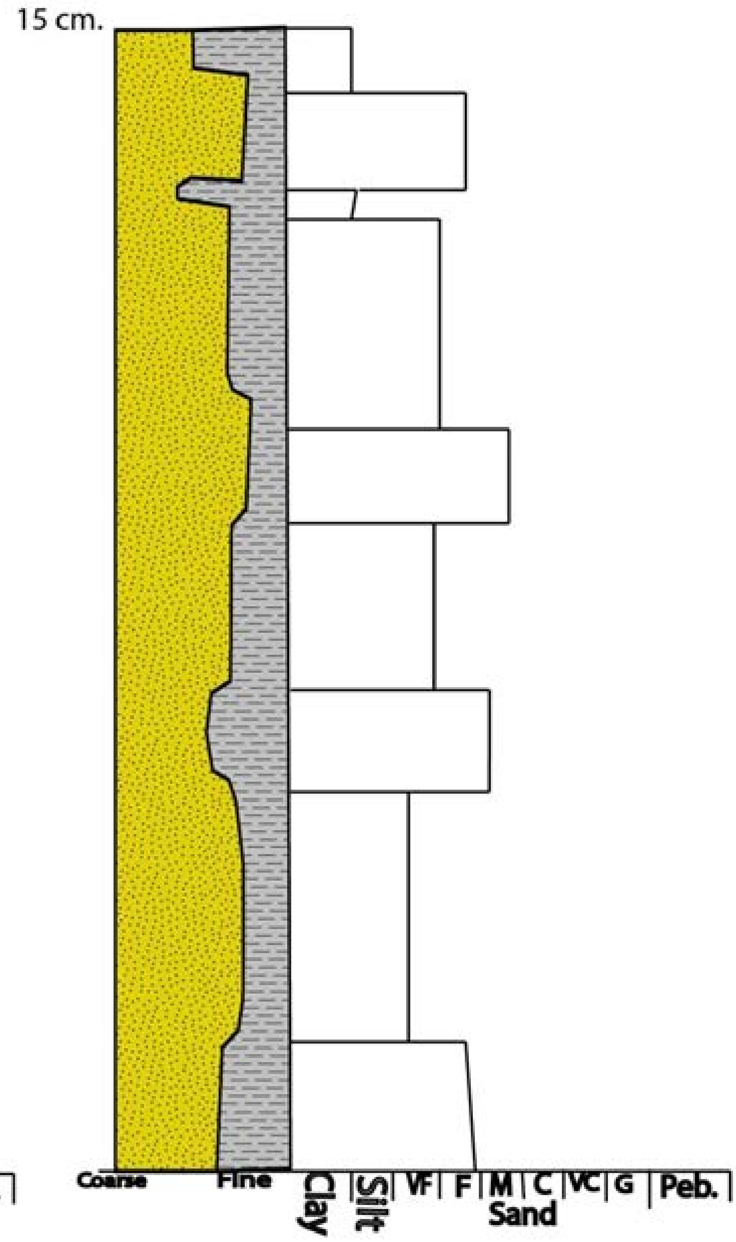
8.4:


16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

8.5:

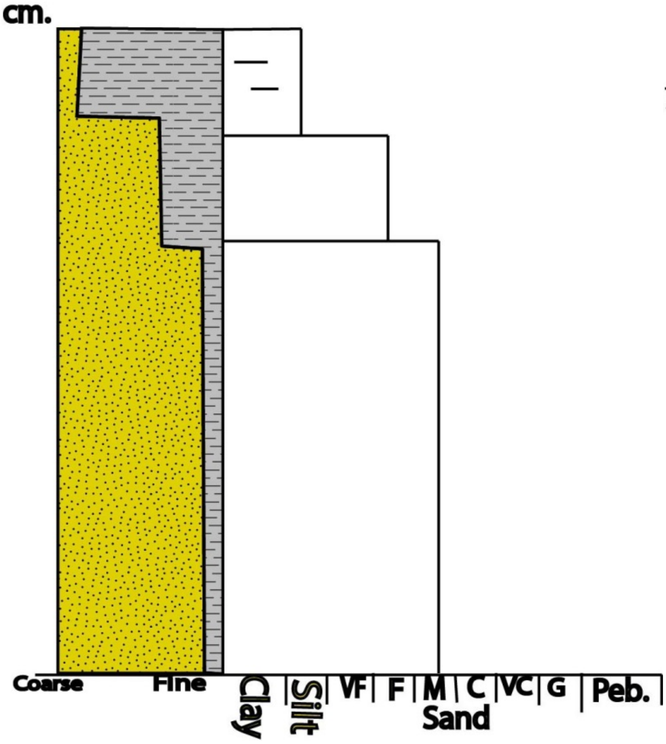

9 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

8.6:

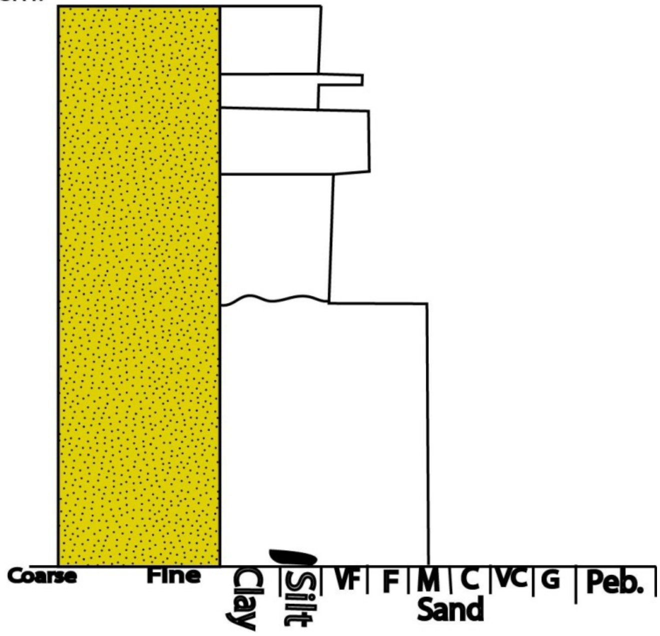

15 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

9.1:

8,5 cm.



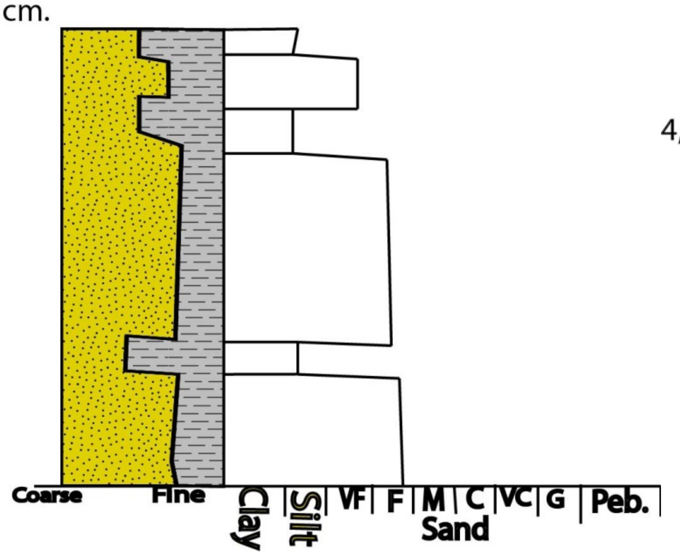
7,5 cm.



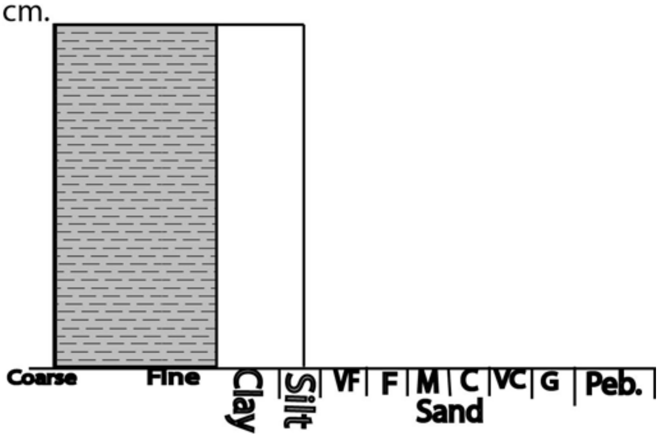
9.2:

9.3:

6 cm.

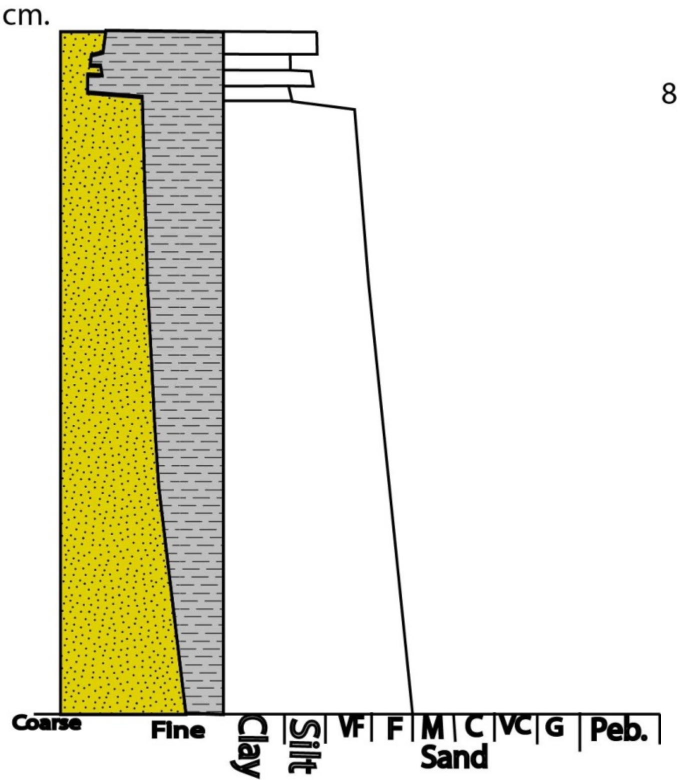


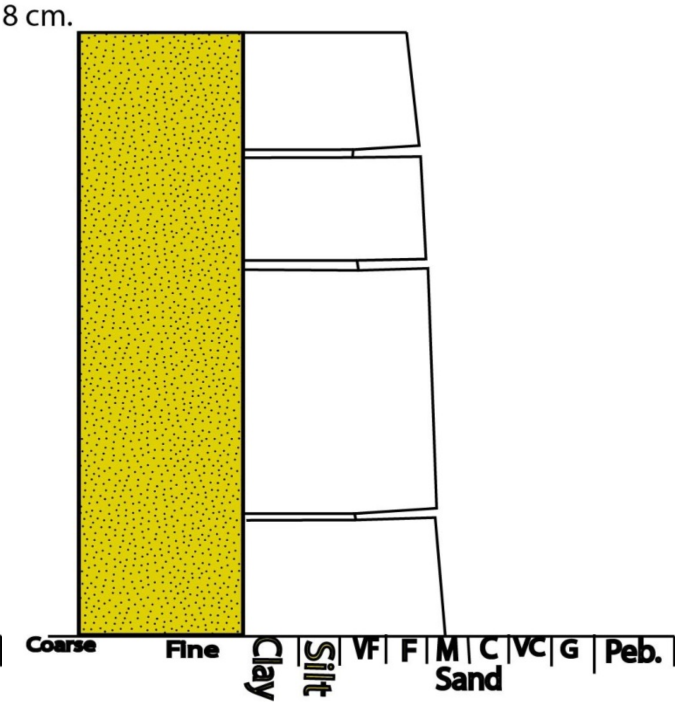
4,5 cm.



9.4:

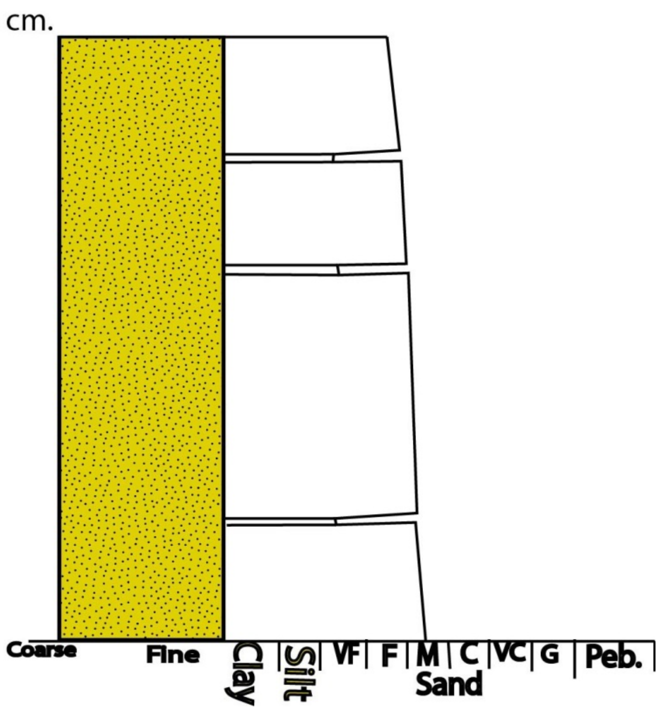
9.5:

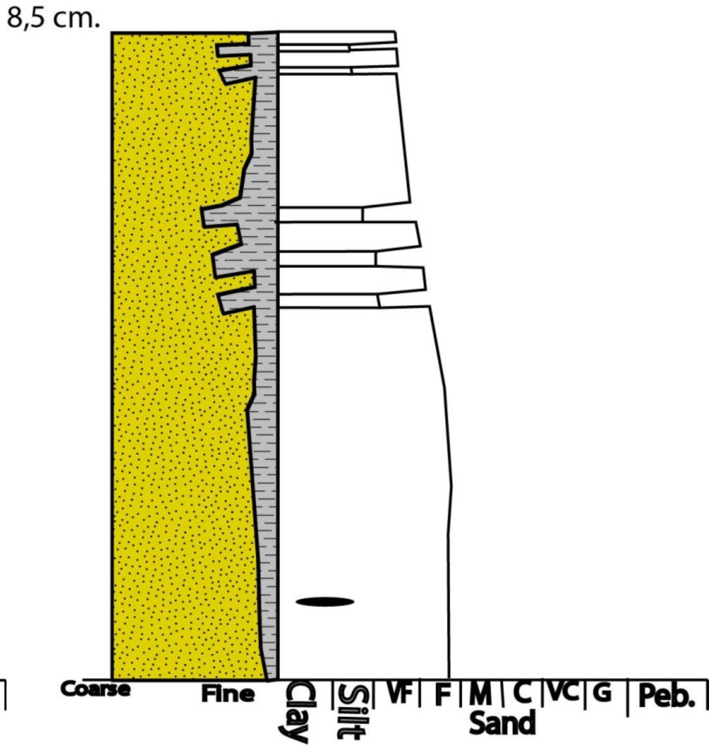

9 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

9.6:

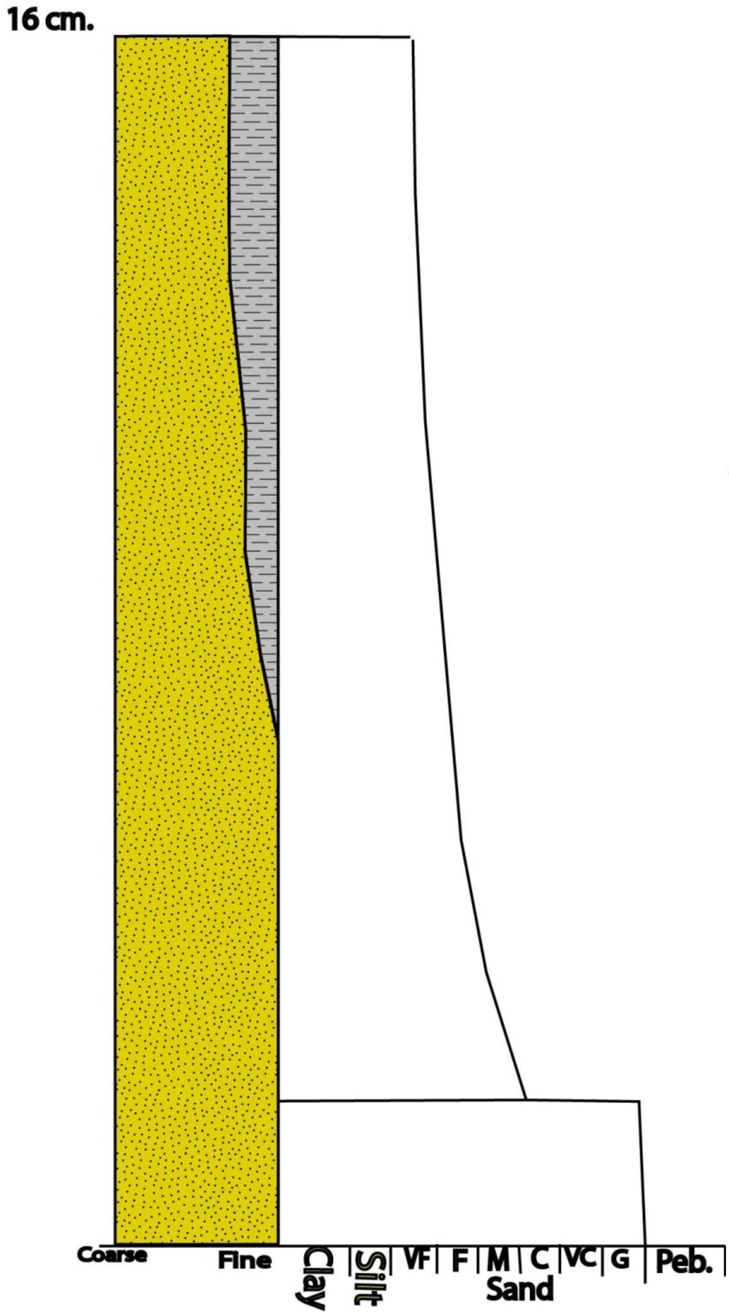
9.7:


8 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


8,5 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

9.8:

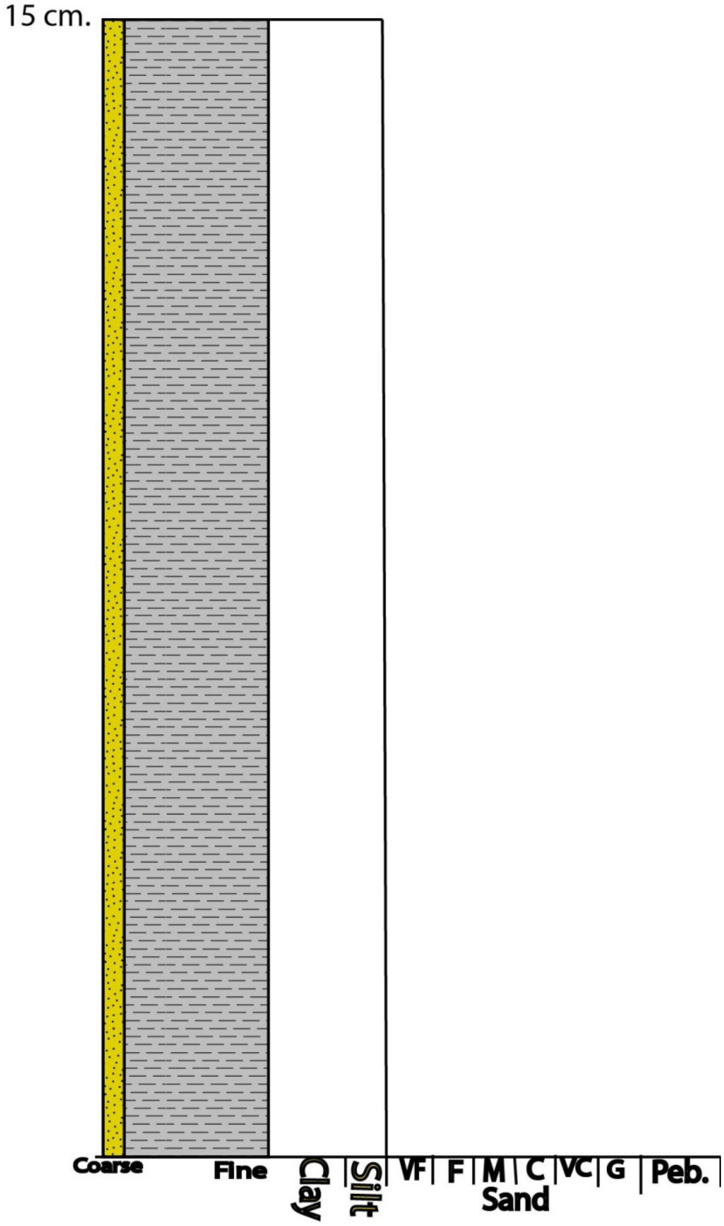
9.9:

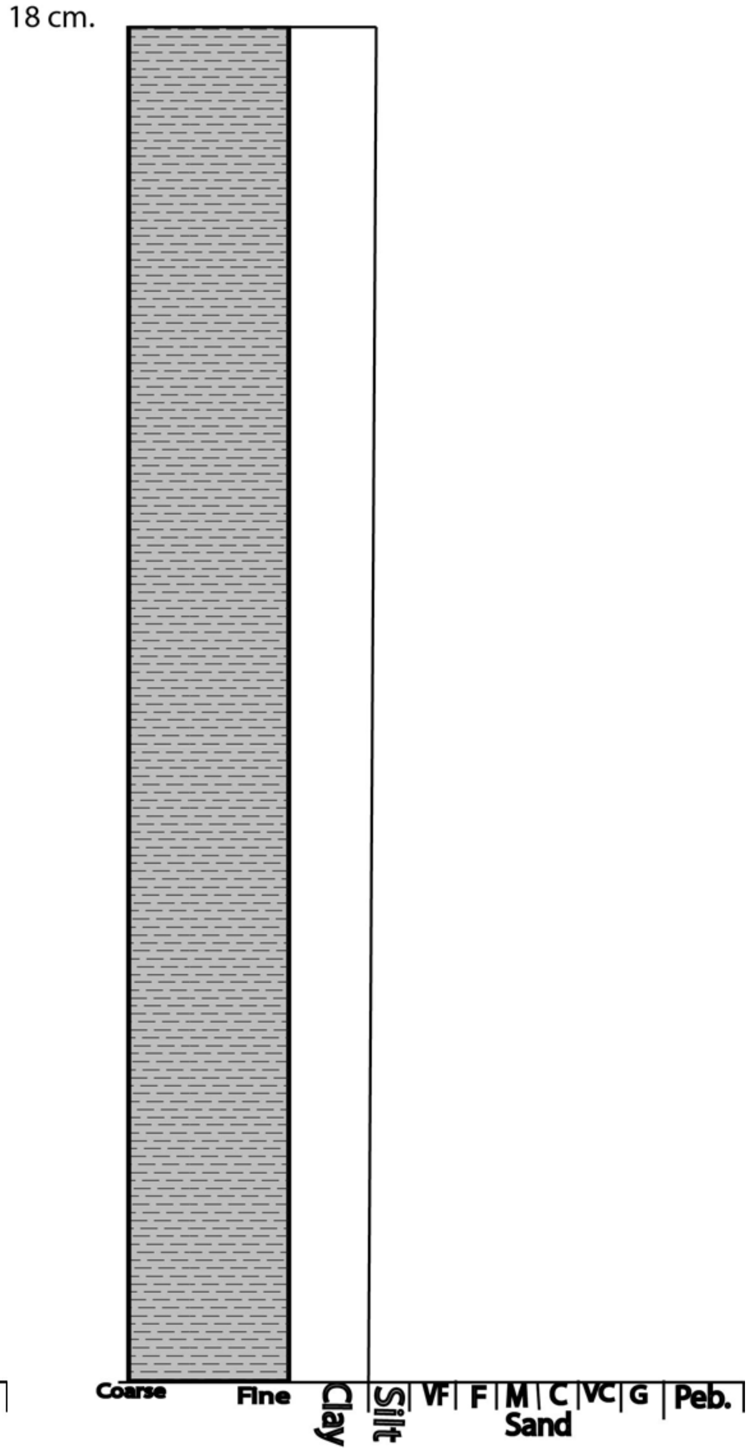

16 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

9.10:


10 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

11.1:

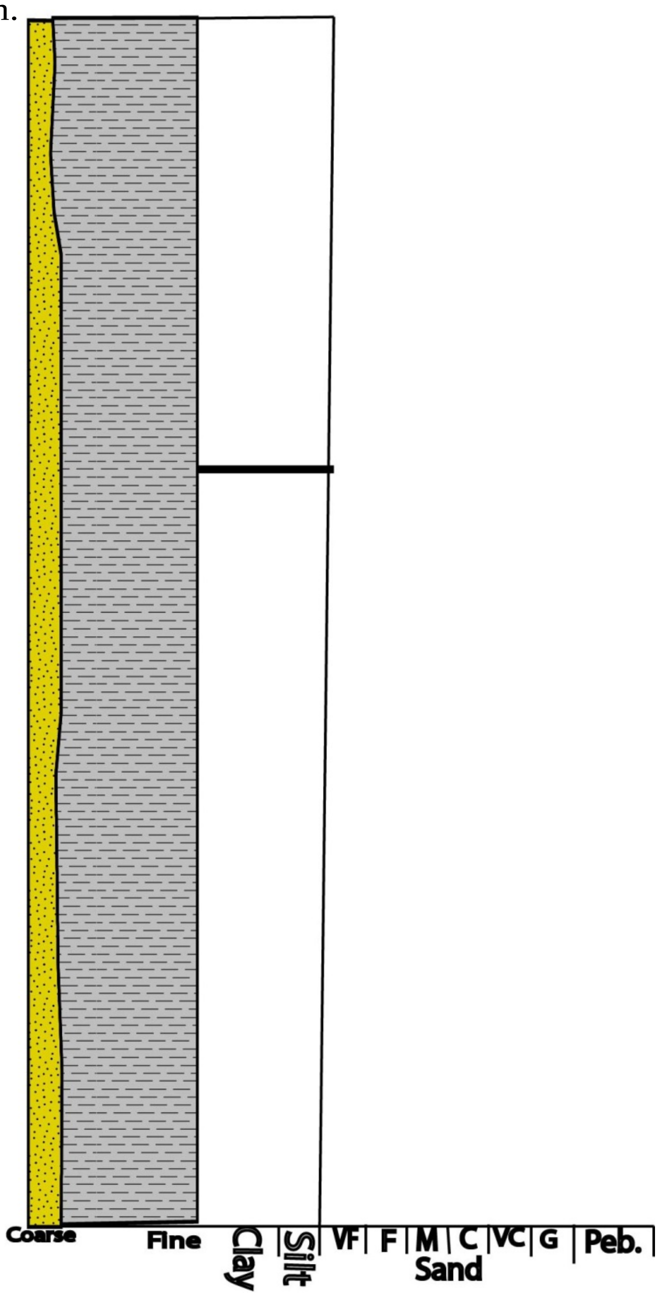

15 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


18 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

11.2:

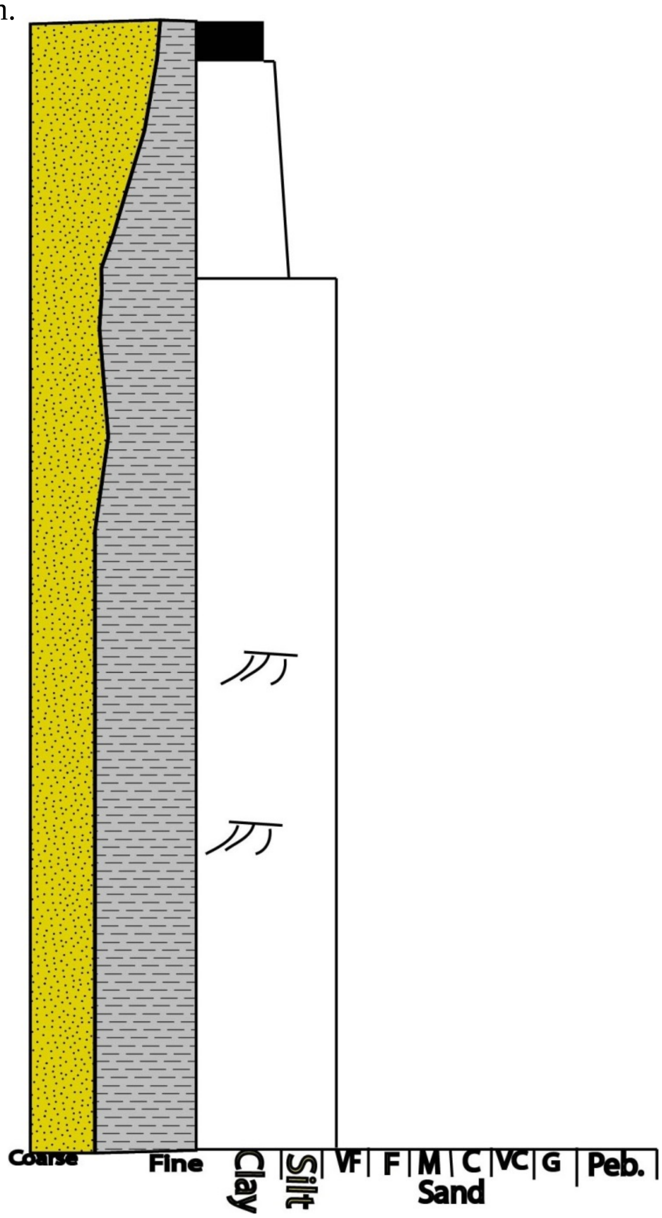
11.3:

16cm.



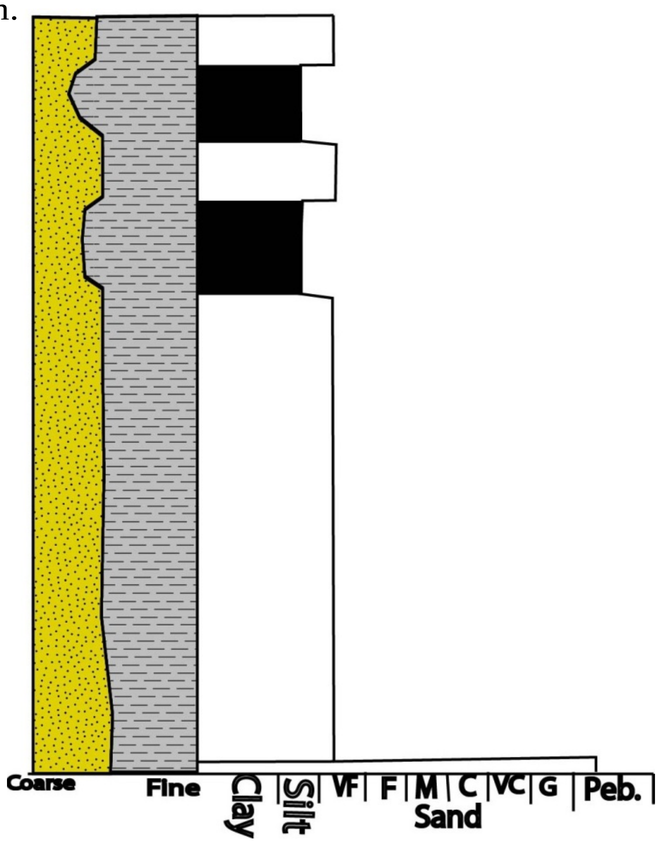
11.4:

15 cm.



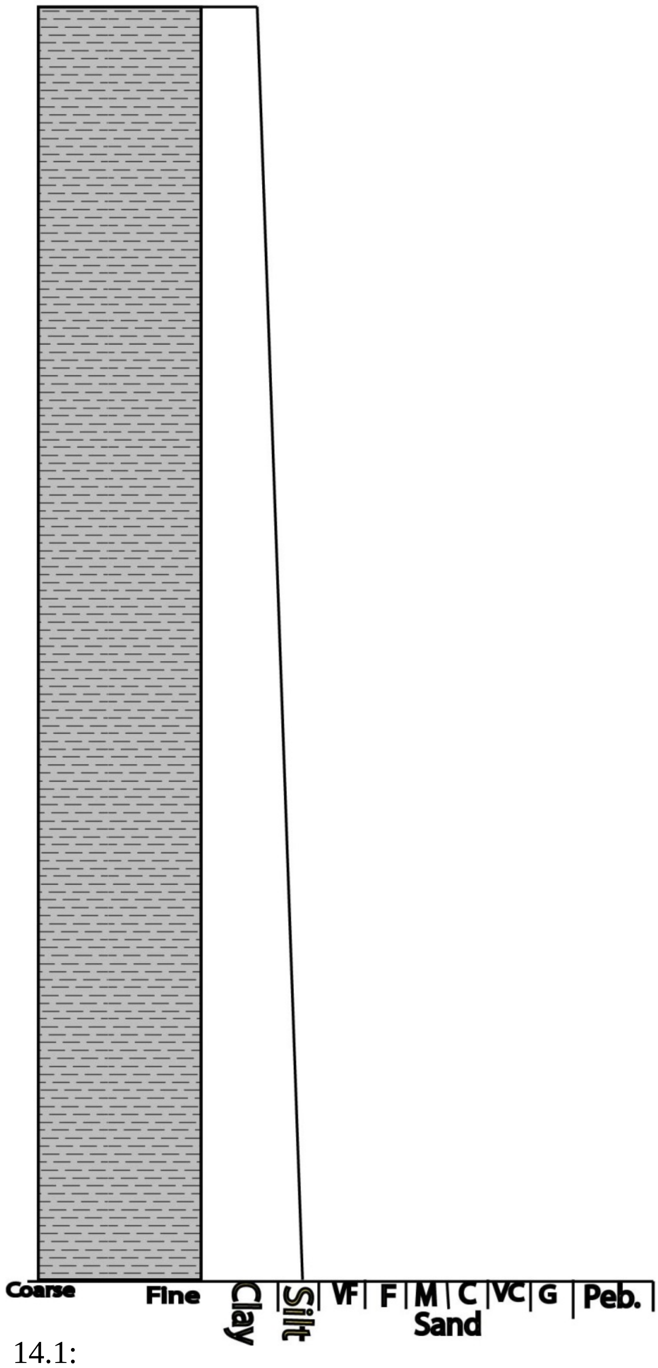
11.5:

10cm.



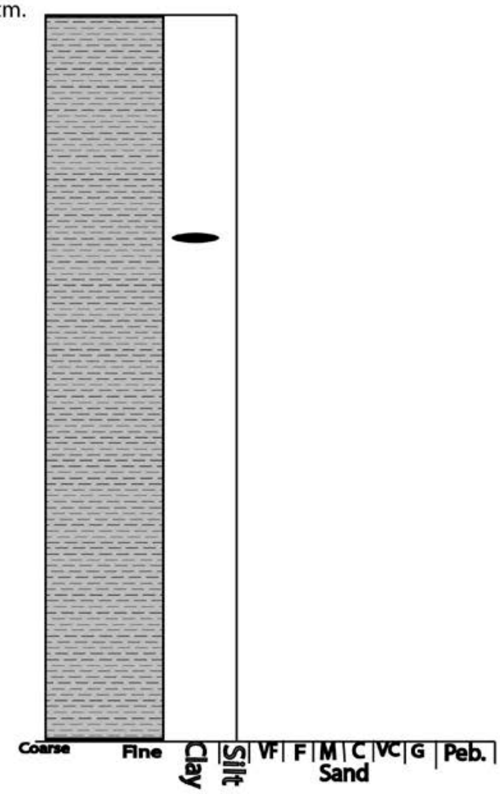
11.6:

17 cm.



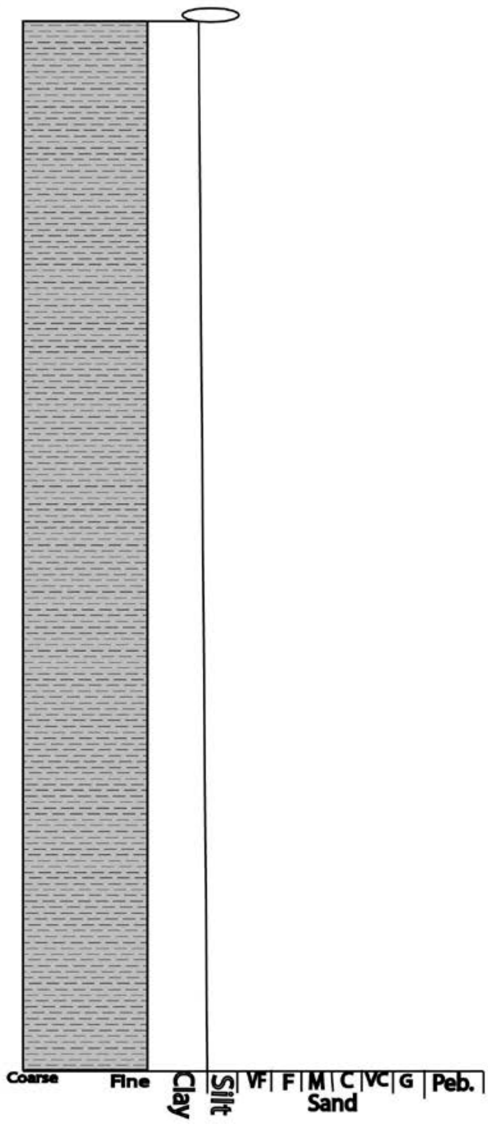
14.1:

13 cm.



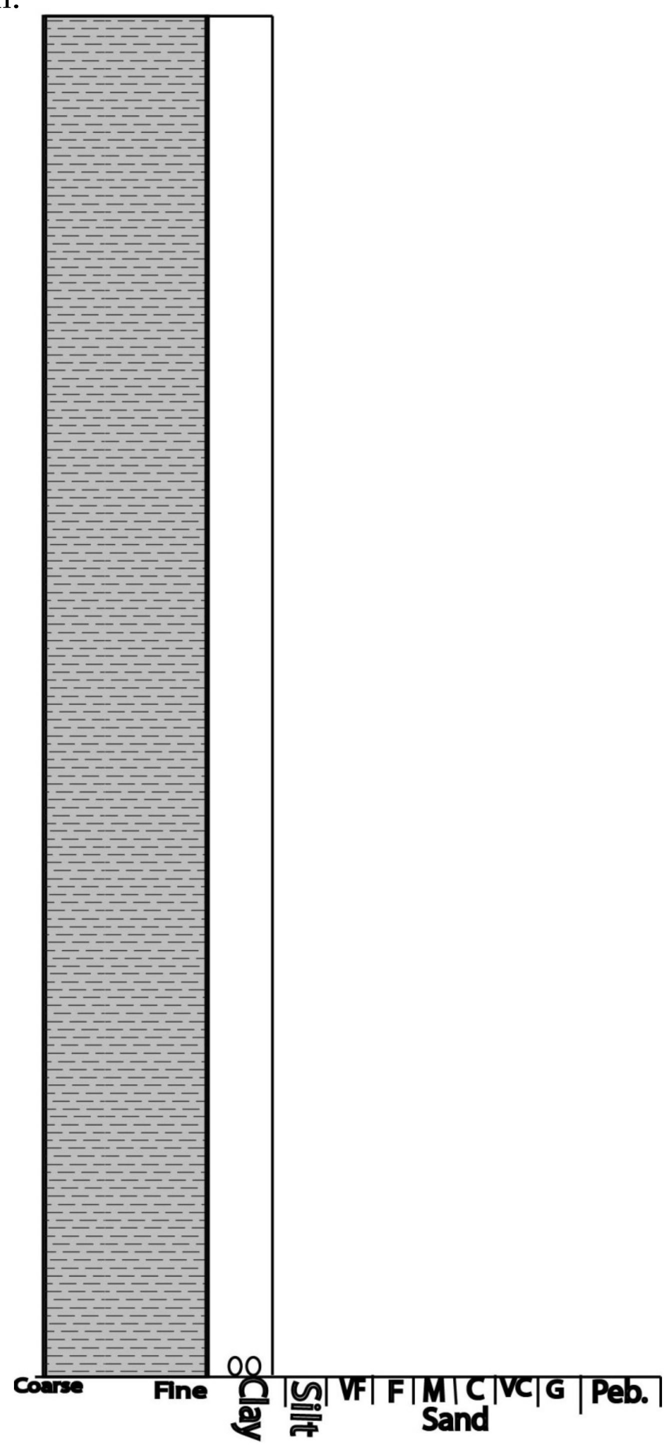
14.2:

19 cm.

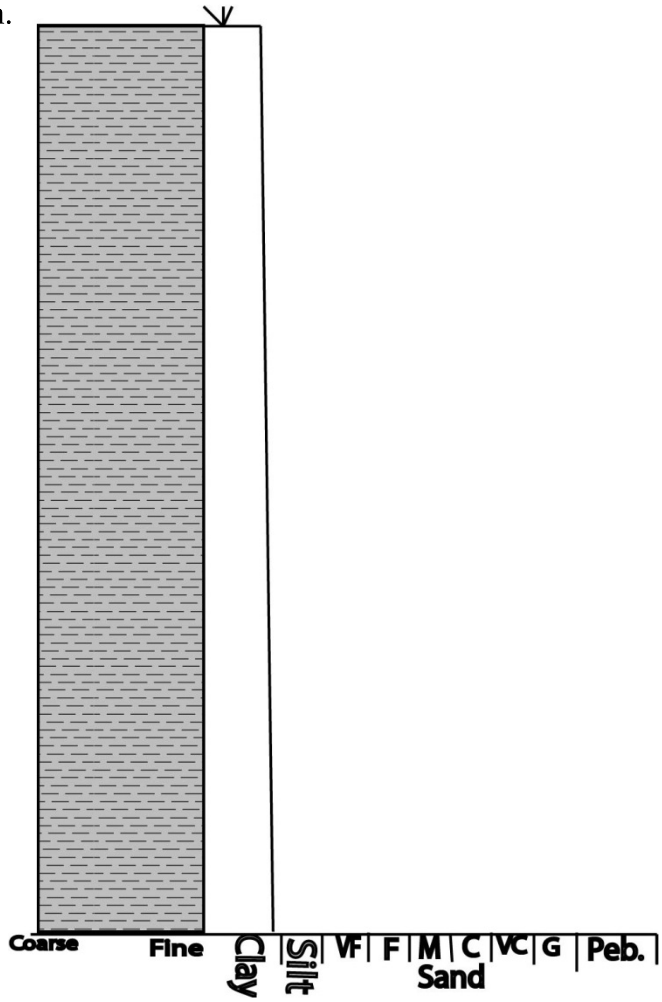


14.3:

18cm.

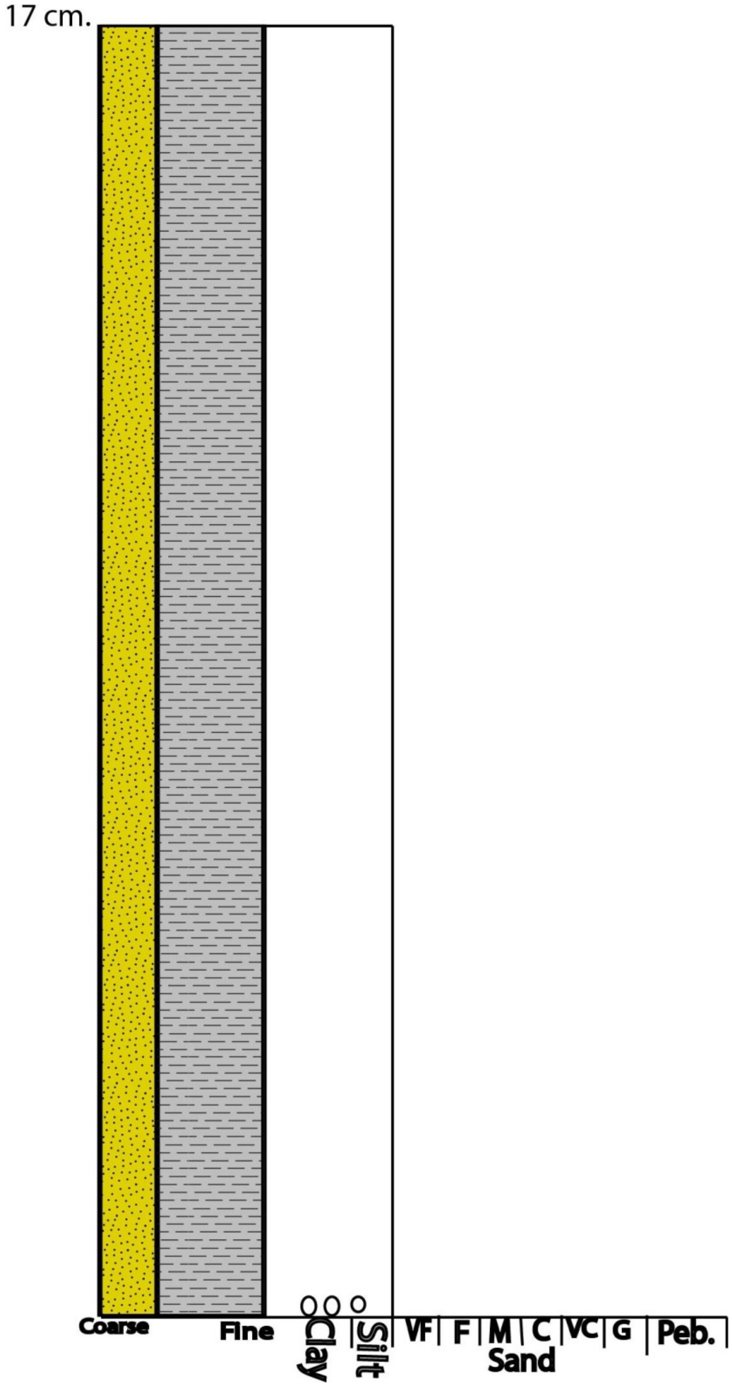


12 cm.

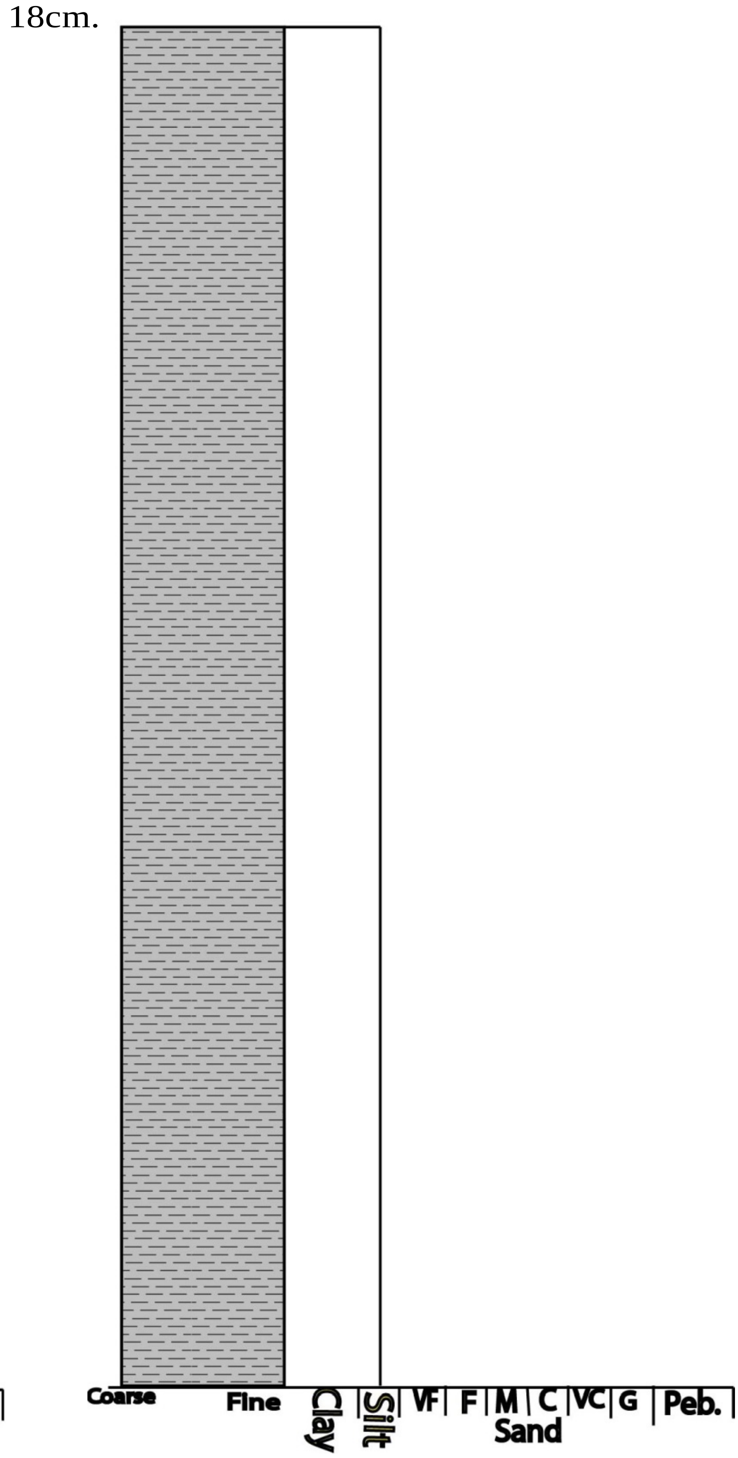


14.5:

14.4:

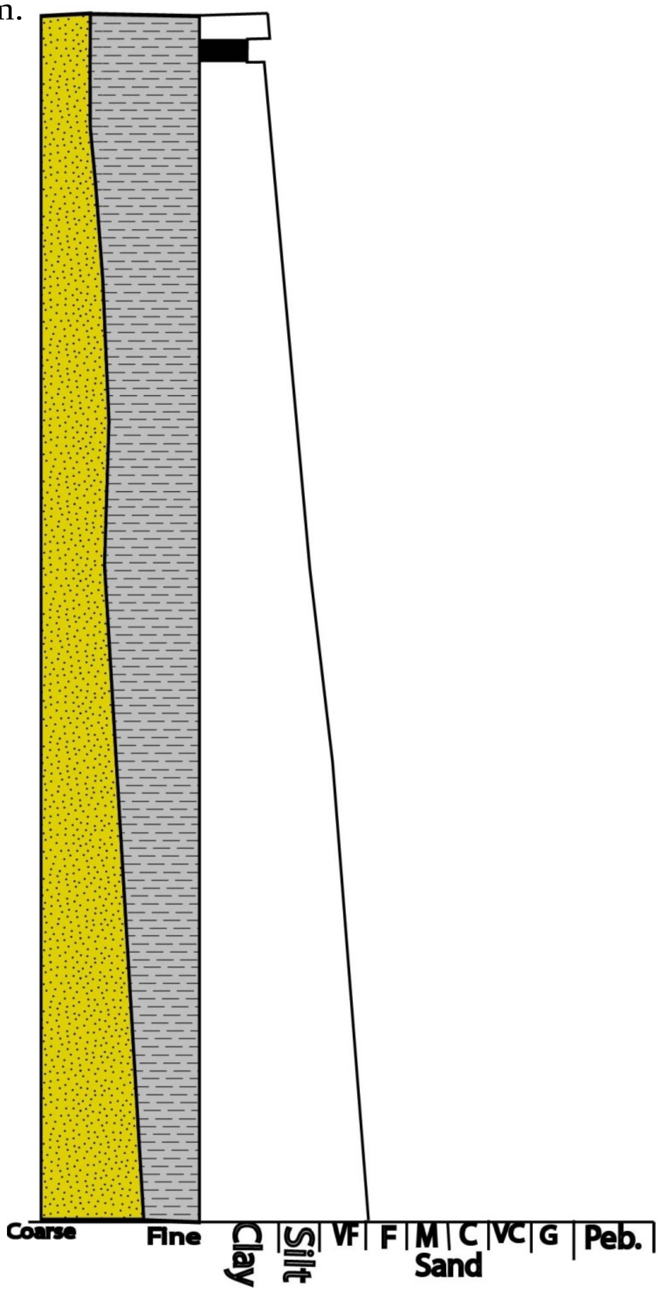

17 cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

14.6:


18cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

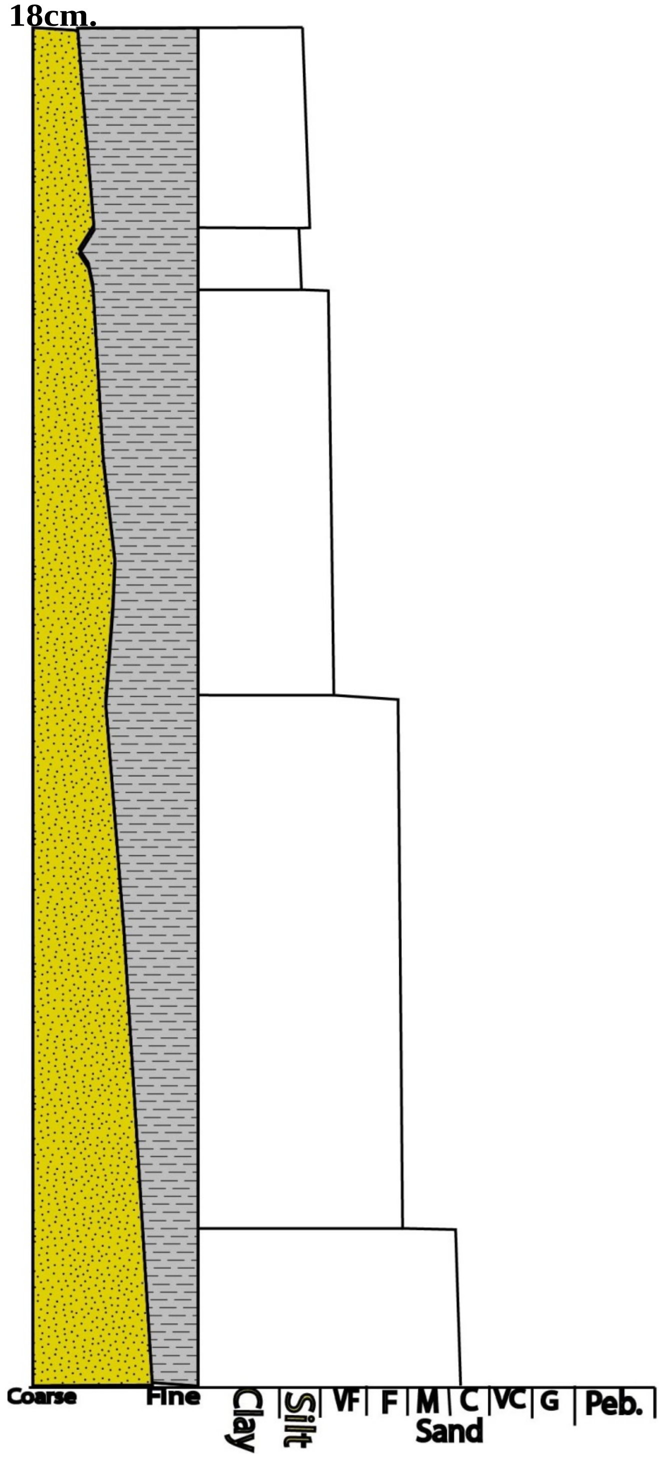
14.7:

16cm.



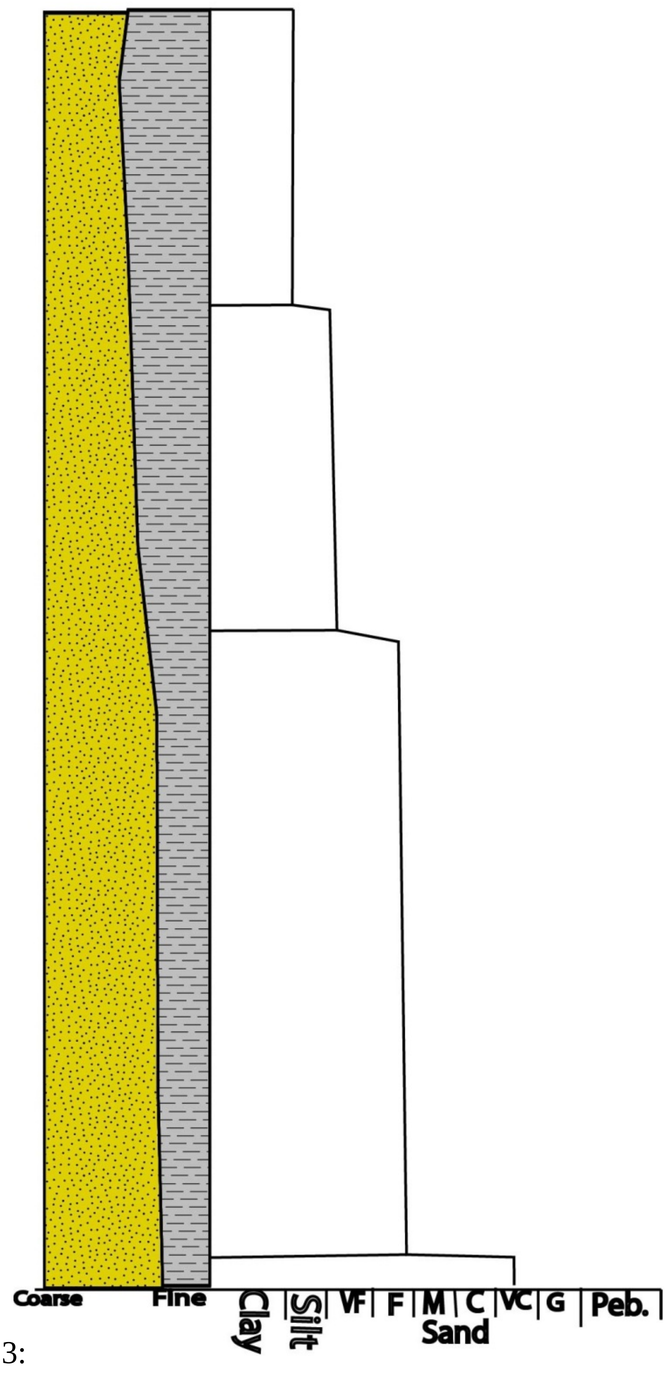
15.1:

18cm.



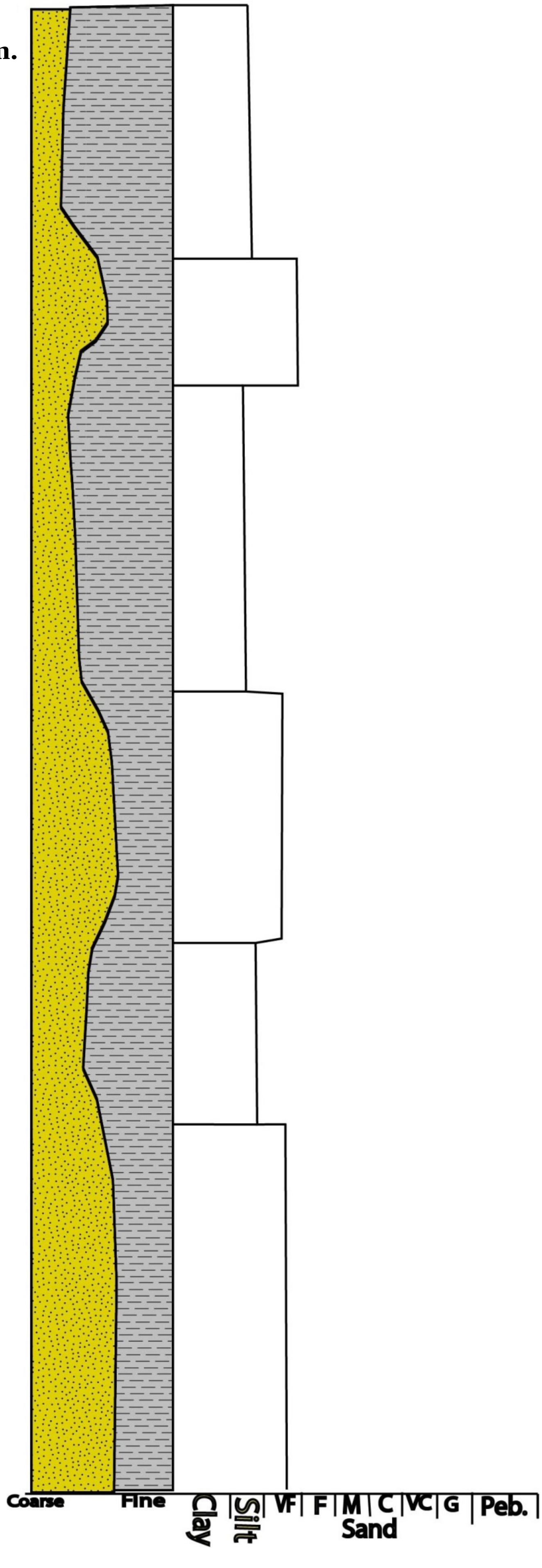
15.2:

17cm.



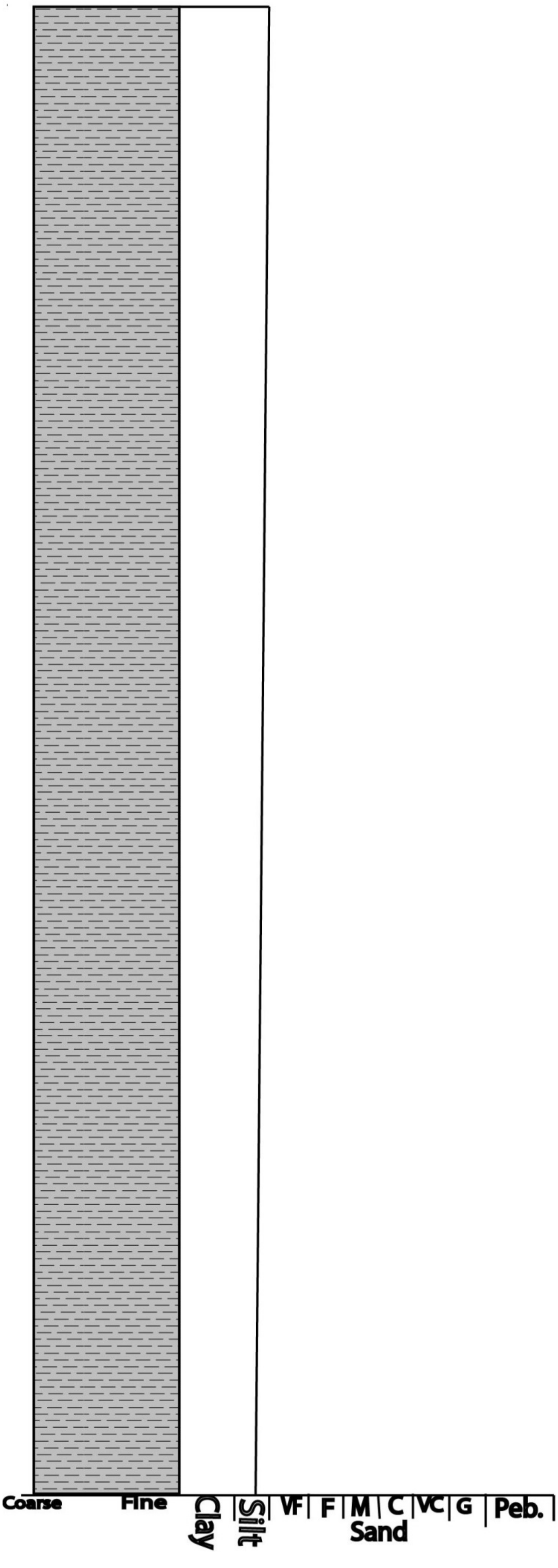
15.3:

24cm.



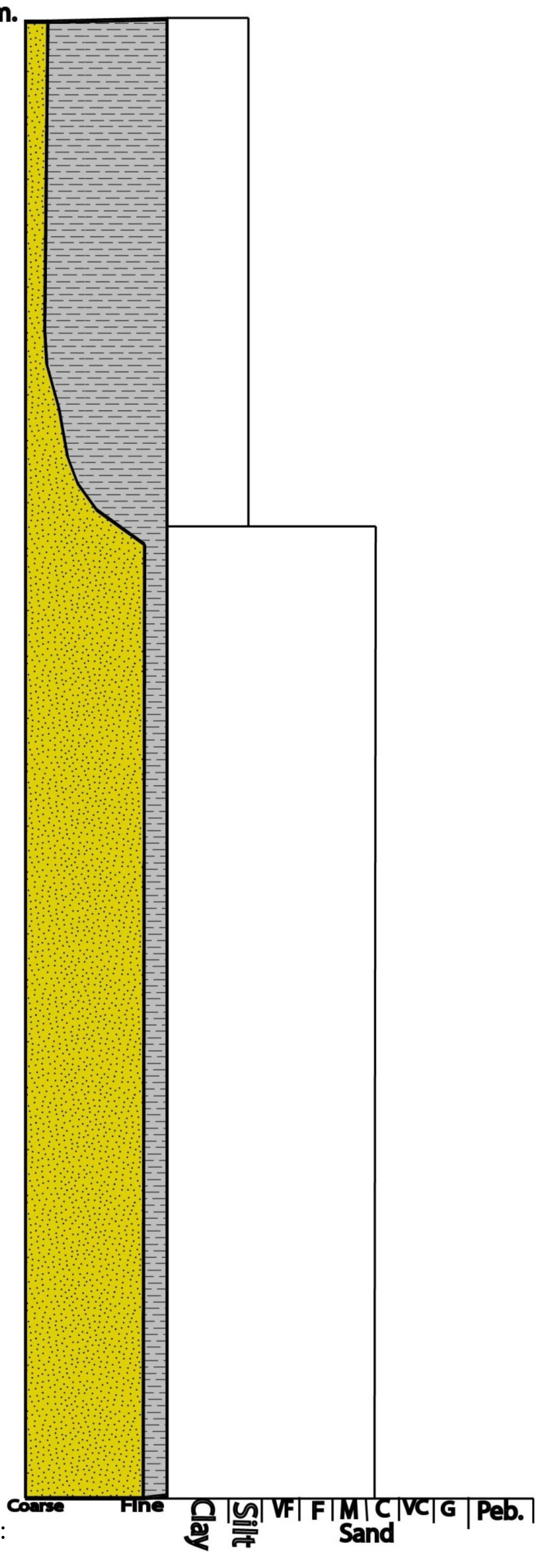
15.4:

23 cm.



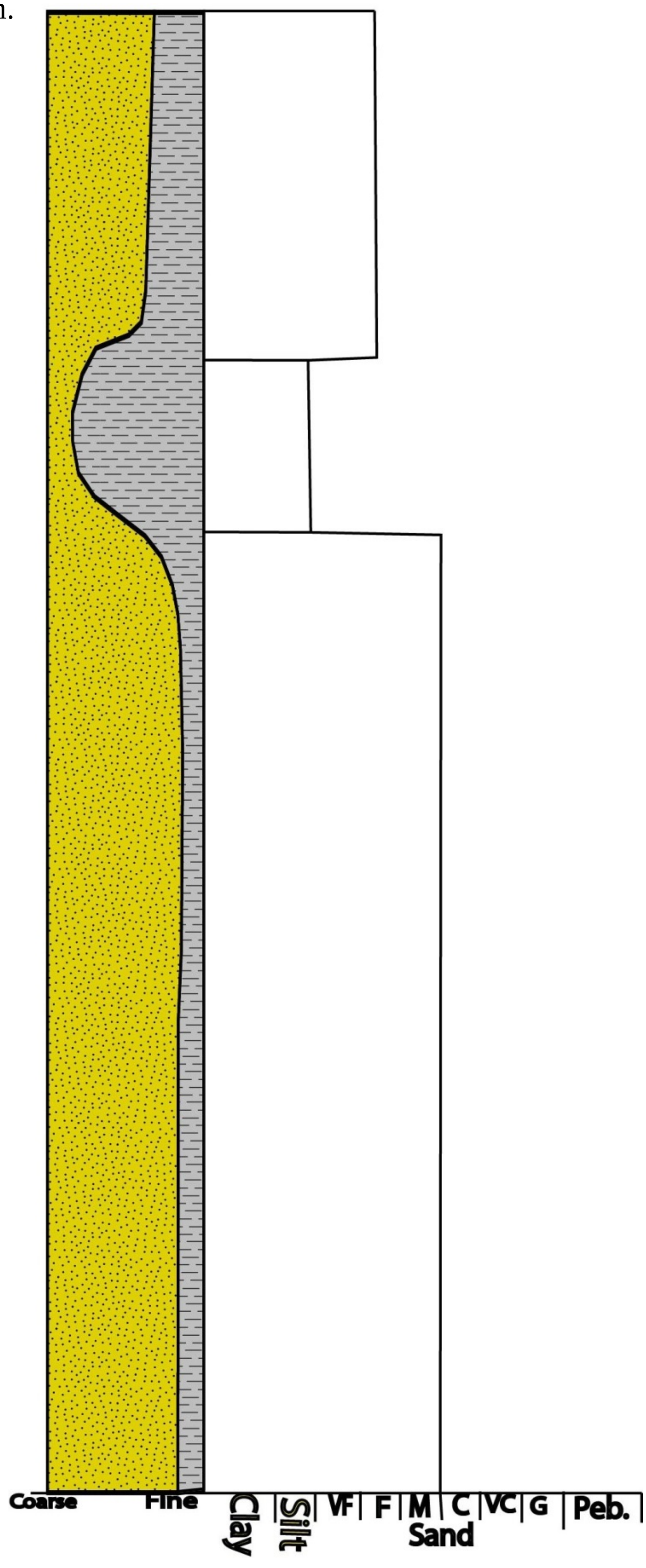
15.5:

24 cm.



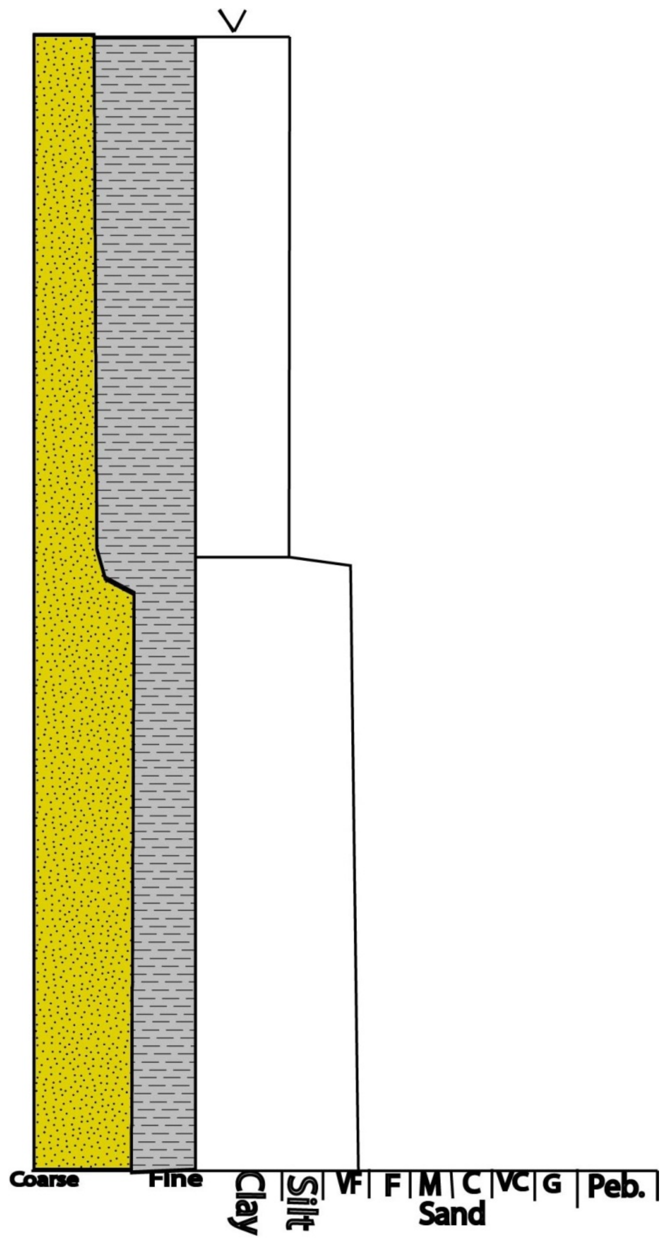
15.6:

20 (40) cm.

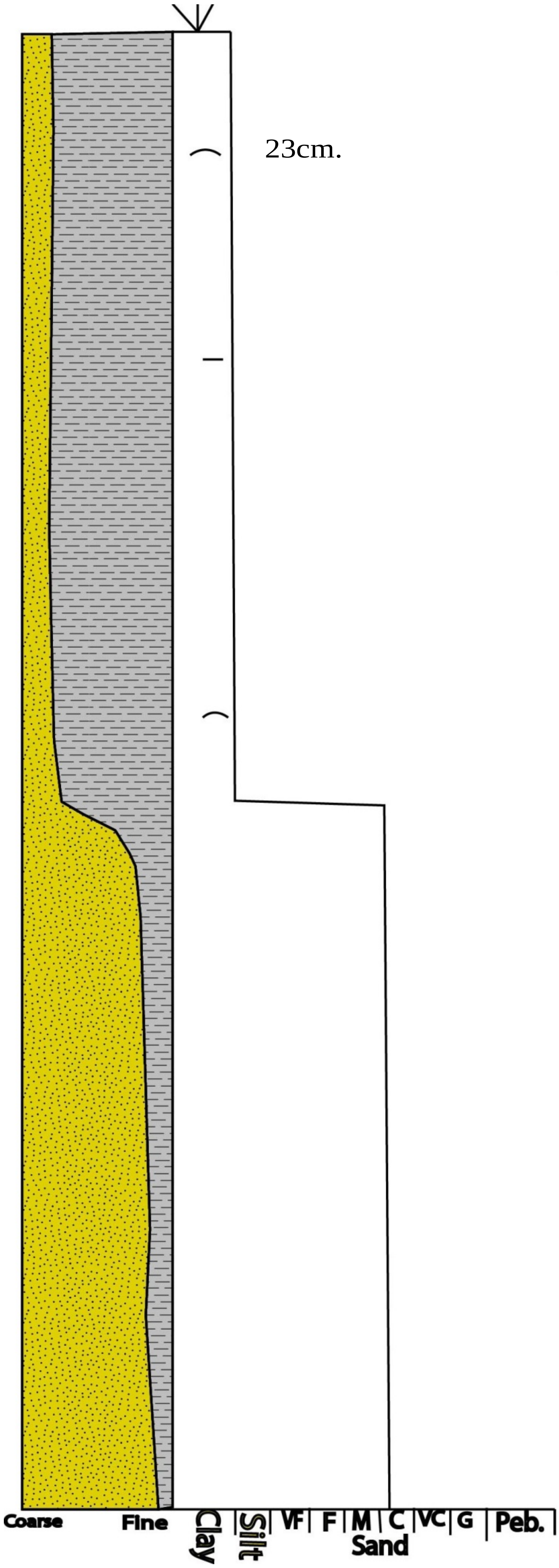


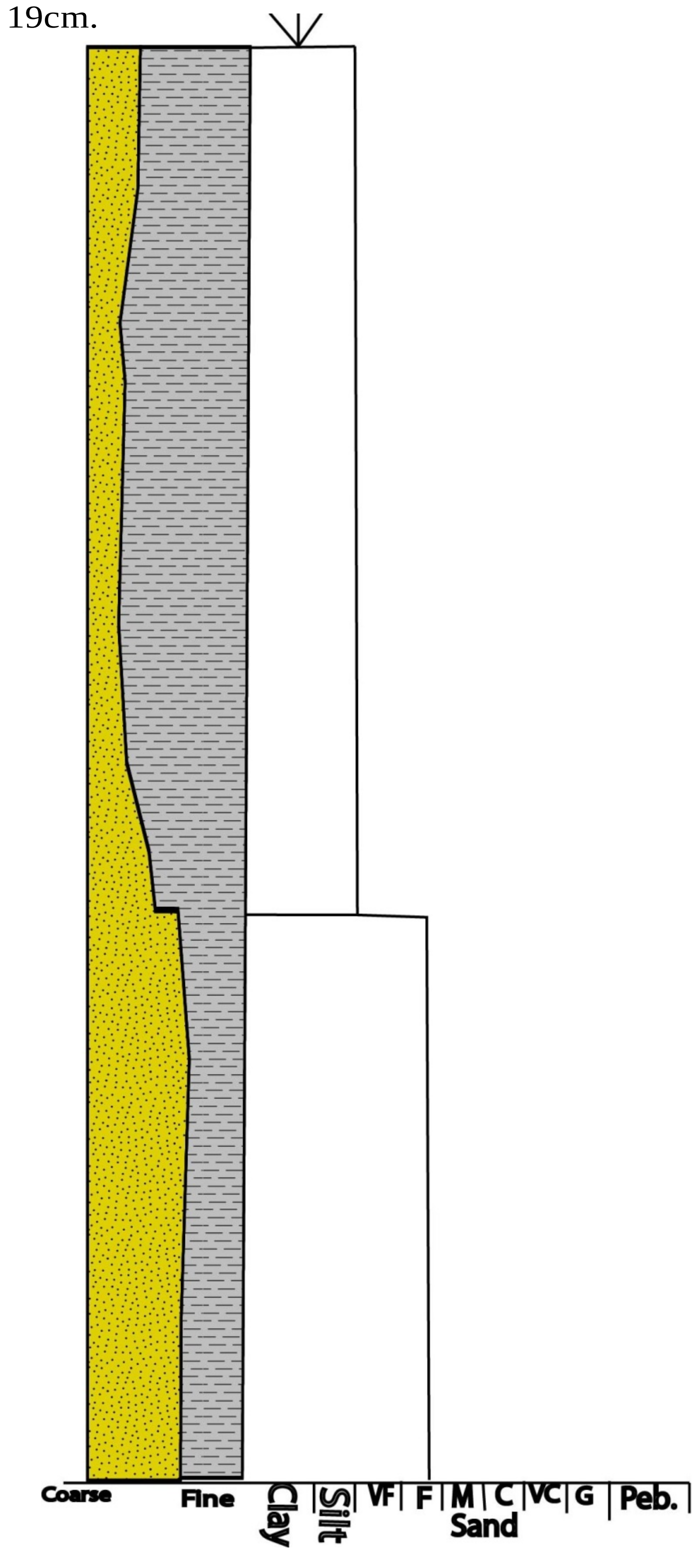
15.7:

15 cm.



15.8:


23cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand


19cm.
Coarse
Fine
Clay
Silt
VF
F
M
C
VC
G
Peb.
Sand

15.9:

15.10:

Appendix D:

Field season 2011:

Grain sizes gathered for analysis, season 2011.					
-	Values:	-	-	-	-
Loc.:	95 %	84 %	50 %	16 %	5 %
11.3	9,50	6,9	3,8	3	2,8
Sample 3.	9,8	7,9	4,6	3,3	2,8
Sample 1.	9,5	6,9	4	2,9	2,6
8.3	9,7	7,2	3,9	3	2,7
8.4	9,6	7,5	4,3	3,1	2,8
8.6	9,4	7,4	4,1	3,1	2,9
9.2	9,6	7	4,1	2,6	2,4
8.1	10,1	7,9	4,1	3,1	2,8
7.9	9,6	6,9	3,8	3	2,6
7.7	9,3	6,7	3,9	2,9	2,6
7.3	9,7	7,2	3,8	2,8	2,4
6.3	9,8	7,3	4,4	3,1	2,8
6.2	10,1	8,2	5,2	3,7	3,1
5.3	9,6	7,2	4,2	2,8	2,5
5.1	9,4	7	3,6	2,7	2,3
3.8-2 (3.9)	9,6	7,8	4,5	3,1	2,8
3.10	10	8,6	5,8	3,8	3,1
3.8	9,6	7,4	4,5	3,1	2,9
8.5	9	5,6	3,3	2,8	2,6
7.1	9,3	7,4	4,2	2,7	1,8
7.5	10,1	8,8	5,9	3,8	3,2
3.7	9,6	7,2	4,2	3,1	2,8
2.10	9,2	5,9	3,8	3,1	2,8
2.5	9,6	7,1	4	3	2,7
2.2	9,5	7,6	4,4	3,4	2,9
1.5	9	5,5	3	2,2	1,4
2.9	8,9	6	2,6	1,3	0,8
2.7	9	5,2	2,6	1,4	1

Mean:	Skewness:	Sorting:
5,2	1,407	0,900
5,68	1,343	1,600
5,18	1,420	1,550
5,3	1,371	1,350
5,46	1,345	1,350
5,38	1,323	1,300
5,14	1,362	1,400
5,6	1,293	1,400
5,18	1,432	1,050
5,08	1,444	1,000
5,18	1,343	1,400
5,48	1,419	1,200
6,06	1,413	1,500
5,26	1,363	1,450
5	1,330	1,150
5,56	1,296	1,500
6,26	1,368	1,450
5,5	1,375	1,350
4,66	1,663	0,650
5,08	1,334	1,350
6,36	1,325	1,650
5,38	1,407	1,000
4,96	1,763	0,750
5,28	1,396	1,050
5,56	1,381	1,250
4,22	1,514	0,800
3,92	1,232	1,450
3,84	1,359	0,900

Appendix E:

Field season 2012:

Lab samples, from field season 2012.					
-	Values:	-	-		
Loc.:	95 %	84 %	50 %	16 %	5 %
CHANNEL	9,6	7,3	3,8	2,7	0,3
P11-1	10	8,5	5,6	3,9	3,1
P11-2	9,7	7,5	3,7	2,5	2,2
P11-3	8,9	5,5	2,8	2,3	2
P12-1	10	8,6	6	4,2	3,4
P12-2	9,6	7,3	4,2	3,2	2,7
P12-3	9,2	6,3	2,9	2,4	2,2
P13-1	10	8,4	5,7	4,2	3,2
P15-1	9,8	7,8	4,7	3,4	2,9
P15-2	9,2	6	3,2	2,3	1,1
P16-1	9,3	6,5	3,9	2,9	2,6
P16-2	8,9	5,2	2,9	2	0,5
P18-1	9,9	8	4,5	3,1	2,6
P19-1	10,2	8,8	5,9	3,7	3,1
P19-2	9,9	8,1	5,3	3,8	3,2
P20-1	10,2	9	6,4	3,7	3,2
P22-1	10,1	8,7	6,1	4,2	3,3
P23-1	10,3	9,2	6,8	4,8	3,6
P23-2	10,2	8,9	6,3	4,5	3,5
P23-3	10,1	8,7	5,9	3,9	3
P23-4	10,1	8,8	6	3,6	2,9
P23-5	10,2	8,8	6	4,1	3,4
P5-1	9,7	7,6	4,5	3,5	3,1
P5-2	9,9	8,1	5,1	3,6	3,2
P6-1	9,1	5,9	3,4	2,7	2,4
P6-2	9,8	7,7	4,7	3,1	2,6
P6-3	9,5	7,1	3	2,1	1,2
T1	9,7	7,7	2,3	0,4	0
T6	10,1	8,8	6,2	4,3	3,4
T9	10	8,4	5,1	3,3	2,9
TB1	9,5	6,9	3,3	1,2	0,2
TB2	9,7	7,5	4,6	3,2	2,6
TB3	9,5	6,8	3,3	2,6	2,1
TB4	9,9	8,1	5,3	3,8	3,2
TB5	9,6	7,5	4,3	3,3	2,9
TB6	10	8,5	5,8	4,2	3,5
TC3	9,6	7	4,1	3,2	2,7

TD1	9,5	6,8	3,5	2,5	2,1
TD4	9,5	7,3	3	1,8	1,1
TE1	9,8	7,8	4,1	2,8	2,3
TE2	10,5	9,6	7,5	5,6	3,9
TE3	10,2	8,8	6,1	3,6	2,8
TE4	10,3	9,4	7,1	5,2	3,8
TE5	10,2	9,2	6,9	4,8	3,5
TE6	10,1	8,5	5,6	3,8	3,1
TF-1	10,3	9,2	7	5,3	4,1
TF-2	10,1	8,6	6	4,3	3,5
TF3	10,2	9	6,7	4,7	3,3
TF4	10,1	8,7	5,7	3,4	2,8
TF-5	9,8	7,9	4,9	2,9	1,2
TF-7	9,9	8,2	4,9	3,4	2,9

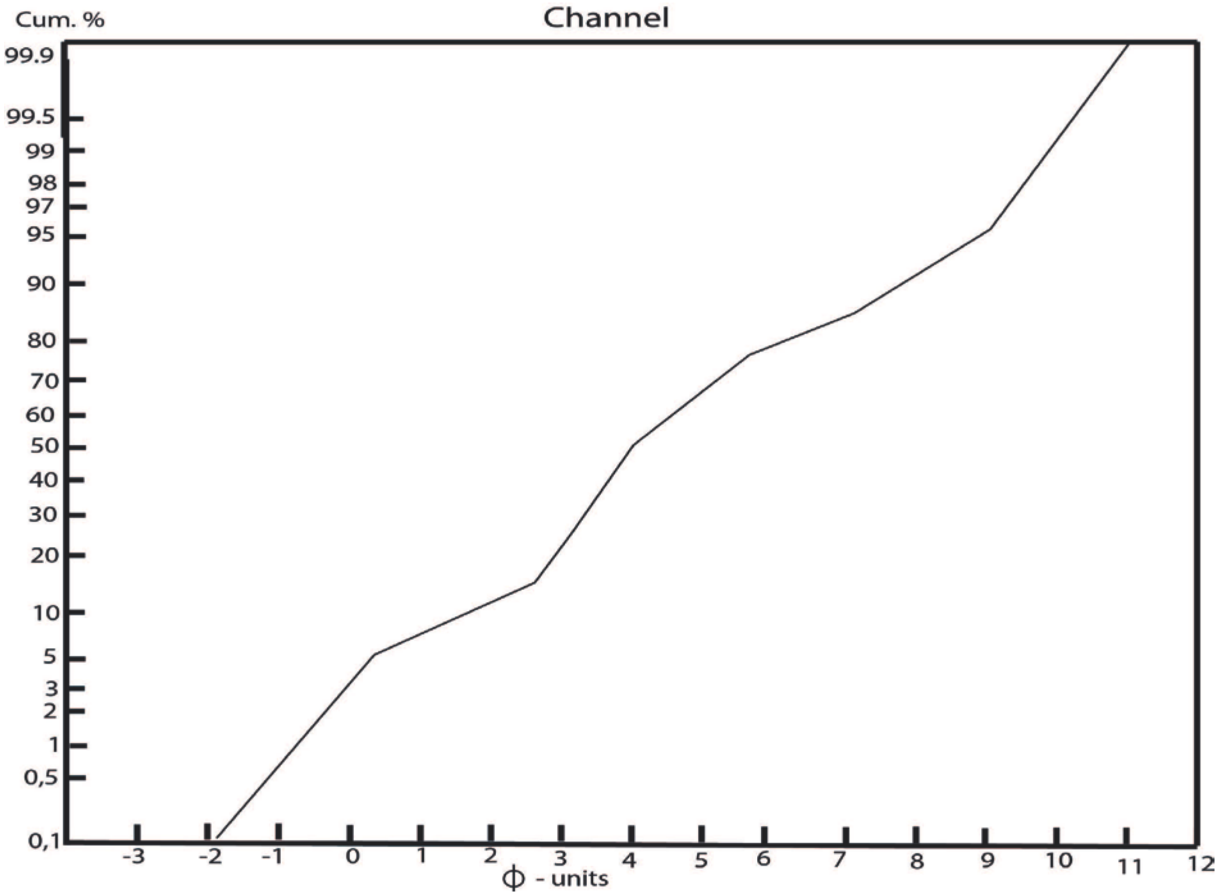
Results 2012 in ϕ:				
Loc.:	Hight in cm:	Mean:	Skewness:	Sorting:
P11-1	12,5	3,5	0,9	2,2
P11-2	5	6,4	4,0	2,4
P11-3	1	5,6	7,0	1,8
P12-1	17,5	3,8	0,6	2,1
P12-2	11,25	5,1	3,0	2,1
P12-3	4,75	4,2	7,4	2,0
P13-1	12	5,7	0,7	2,1
P15-1	6	5,0	2,3	2,1
P15-2	2	3,8	0,4	2,1
P16-1	4	4,8	3,6	1,9
P16-2	-3	3,1	0,4	1,9
P18-1	3,5	4,0	2,2	2,3
P19-1	5,25	4,9	0,8	2,4
P19-2	1,75	7,6	1,5	2,1
P20-1	3	6,2	0,3	2,4
P22-1	3,5	7,2	0,5	2,2
P23-1	13,75	7,0	0,1	2,1
P23-2	12	6,0	0,5	2,1
P23-3	11,25	7,2	0,5	2,3
P23-4	10,5	6,3	0,5	2,4
P23-5	5	6,8	0,8	2,2
P5-1	7,5	5,9	3,4	2,0
P5-2	2,5	5,2	2,2	2,1
P6-1	9,5	5,5	5,0	1,8

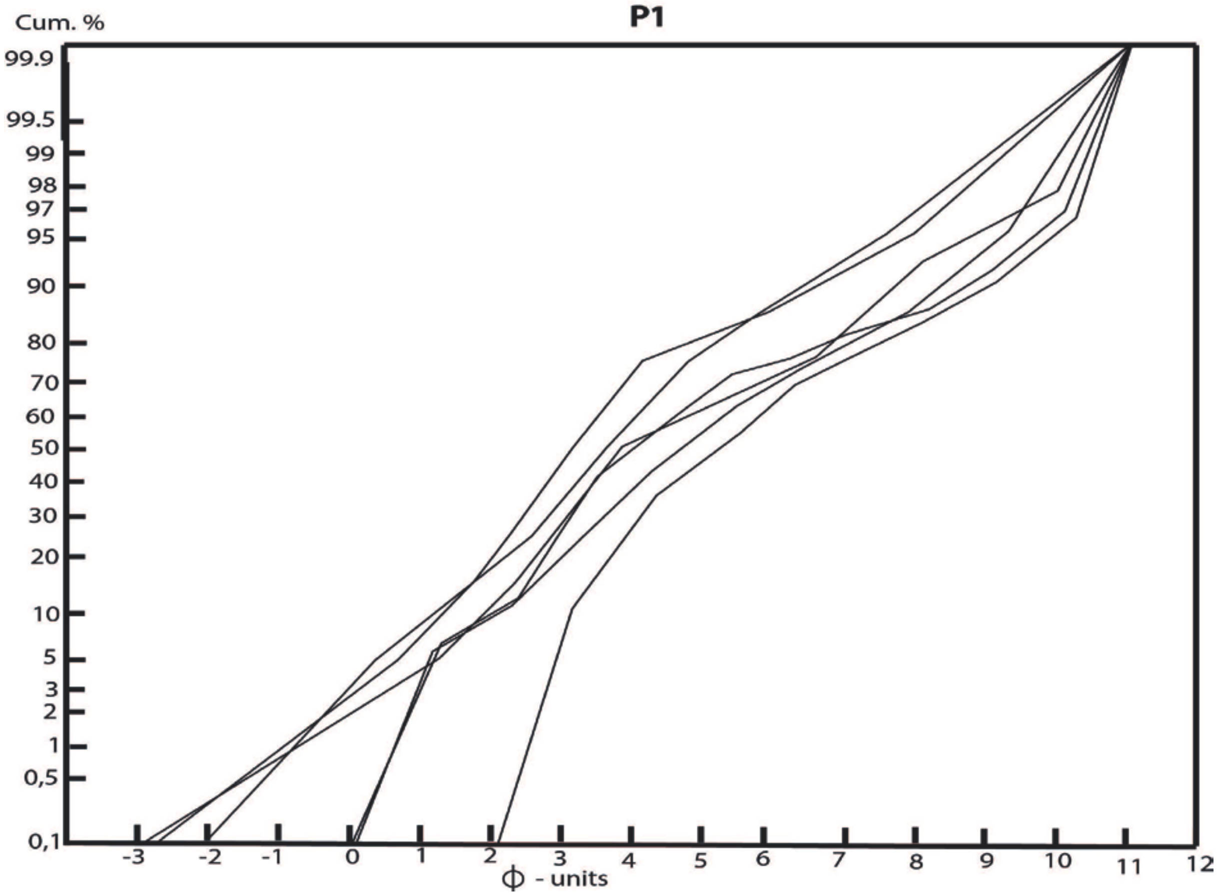
P6-2	6	6,0	1,8	2,2
P6-3	2,5	4,6	2,3	2,5
P10-1	15	4,0	4,4	1,6
P10-2	5	3,8	4,5	1,6
P10-3	4	1,8	4,7	2,7
P1-1	14	3,5	0,2	2,1
P1-2	11	3,4	0,4	2,1
P1-3	8	4,4	1,6	2,7
P1-4	5,5	4,6	0,4	2,7
P1-5	3,5	4,7	1,0	2,3
P1-6	1,5	5,4	1,3	2,4
P14-1	9,5	5,7	0,3	2,5
P14-2	4	4,0	1,8	2,4
P17-1	3	5,2	2,9	2,0
P21-1	15	6,1	1,7	2,1
P21-2	9	5,8	0,6	2,3
P21-3	3	6,1	1,0	2,2
P2-1	11	5,5	0,9	2,0
P2-2	9	5,7	0,8	2,3
P2-3	6,5	5,2	0,2	2,6
P2-4	4	5,5	0,6	2,4
P2-5	1,5	5,5	1,7	2,2
P3-1	18	5,1	2,5	2,1
P3-2	17	5,6	1,0	2,0
P3-3	16	4,1	2,3	2,5
P3-4	13,5	3,8	0,6	2,8
P3-5	9,5	5,0	4,2	2,1
P3-6	7,5	4,9	3,2	2,3
P3-7	5,5	4,1	5,3	2,0
P3-8	2	3,7	5,5	2,0
P4-1	15	5,1	2,5	2,1
P4-2	12,5	6,2	0,6	2,1
P4-3	6,5	5,4	1,8	2,2
P4-4	2,5	4,8	3,2	2,2
P7-1	10,5	5,1	2,2	2,1
P7-2	8,5	6,1	0,5	2,2
P7-3	4	4,7	0,5	2,4
P8-1	9,5	3,4	1,3	2,6
P8-2	6,5	4,7	0,7	2,5
P8-3	2,5	3,1	1,8	2,9
P9-1	8	5,5	1,8	2,2
P9-2	6,7	6,0	0,6	2,1
P9-3	3,25	5,3	1,4	2,0
T1	Surface	2,6	0,5	2,5
T6	Surface	6,3	0,5	2,1

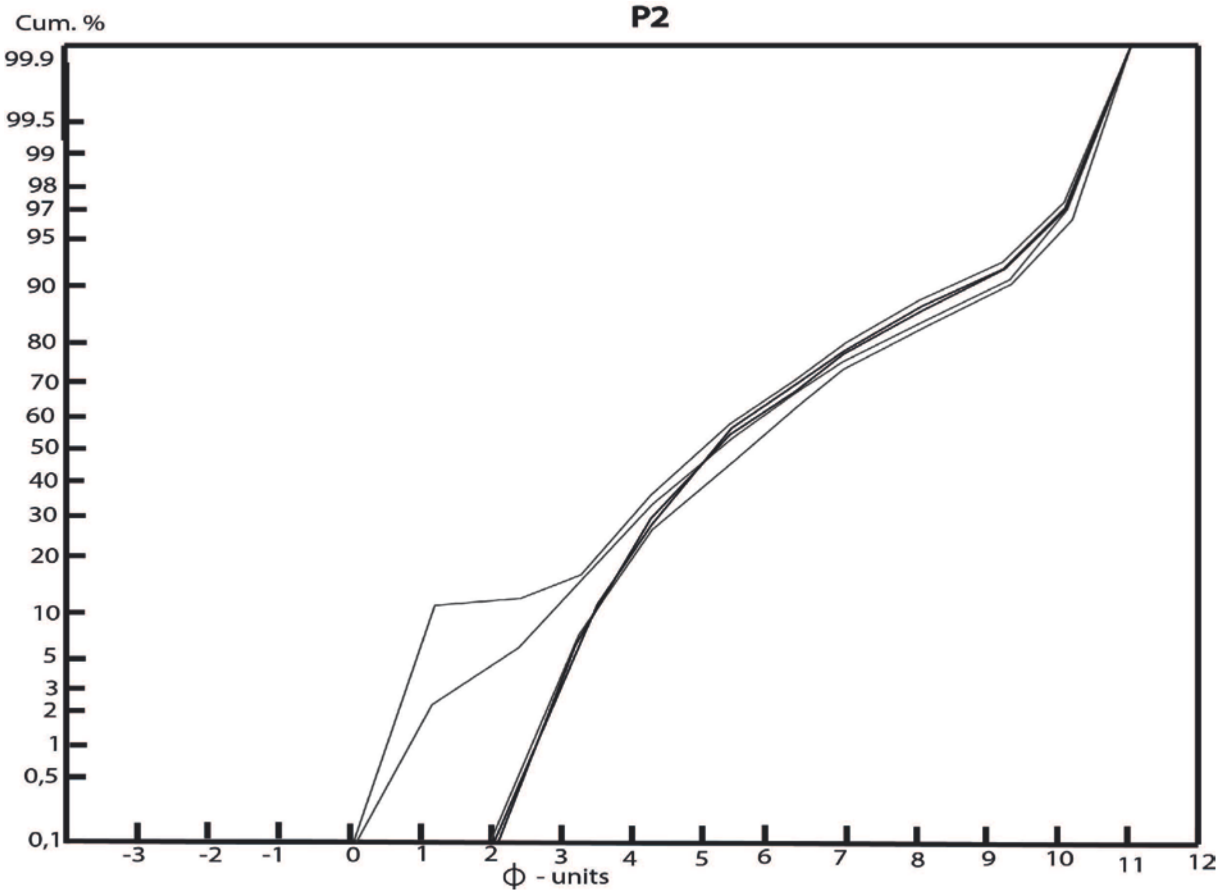
T9	Surface	4,9	2,4	2,4
TB1	Surface	3,2	0,3	2,4
TB2	Surface	6,1	1,9	2,2
TB3	Surface	5,3	3,5	2,2
TB4	Surface	3,8	1,3	2,1
TB5	Surface	4,4	3,0	2,1
TB6	Surface	3,4	1,0	2,1
TC3	Surface	5,2	2,8	2,0
TD1	Surface	6,1	3,6	2,2
TD4	Surface	5,7	2,6	2,6
TE1	Surface	6,4	2,4	2,4
TE2	Surface	6,3	-0,1	2,0
TE3	Surface	6,9	0,3	2,4
TE4	Surface	6,6	0,0	2,0
TE5	Surface	6,2	0,0	2,1
TE6	Surface	6,1	1,0	2,2
TF-1	Surface	6,3	0,2	1,9
TF-2	Surface	5,2	0,7	2,1
TF3	Surface	5,6	0,1	2,1
TF4	Surface	4,0	0,8	2,4
TF-5	Surface	5,2	0,4	2,6
TF-7	Surface	4,1	2,1	2,3
CHANNEL	Surface	4,5	0,3	2,5

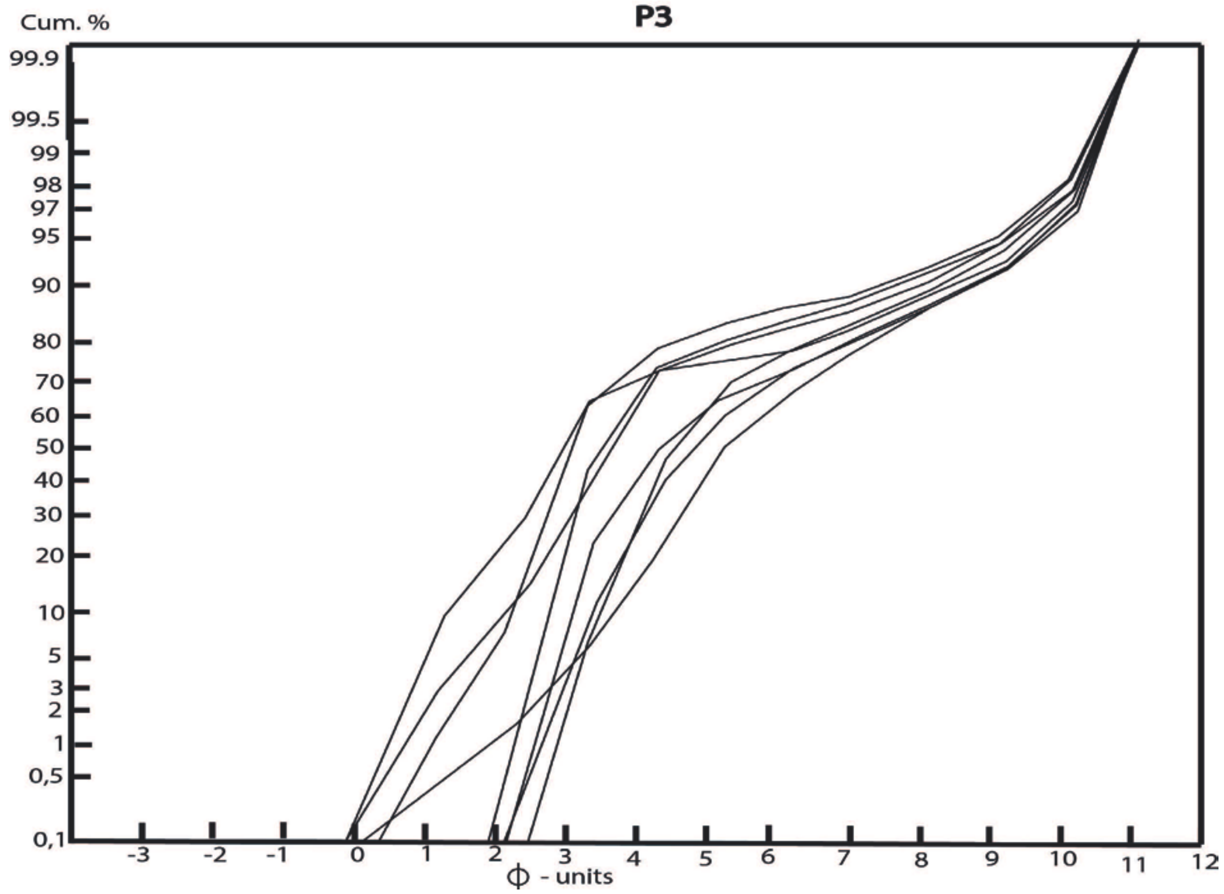
Appendix F:

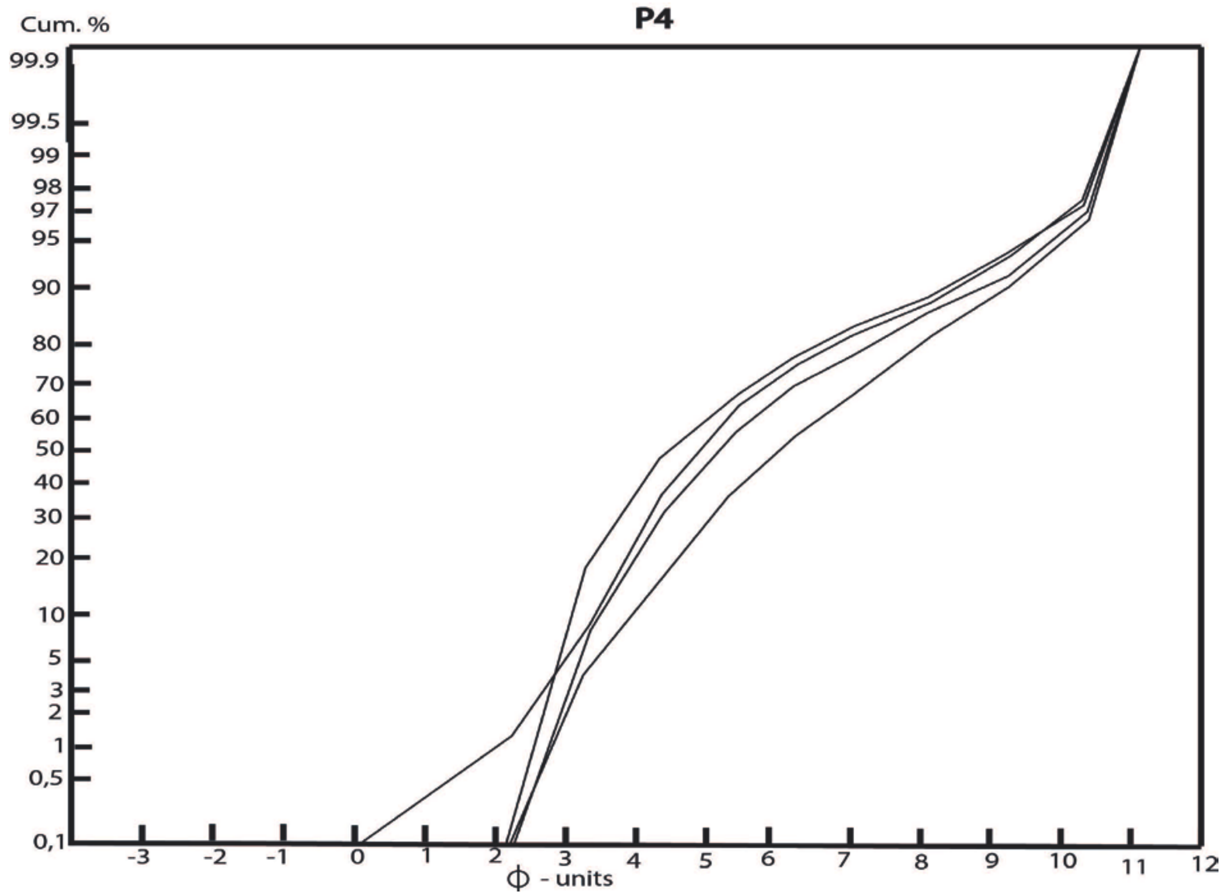
Below are cumulative grain size plots based on grain size analysis done in lab; for each profile and surface sample from field.

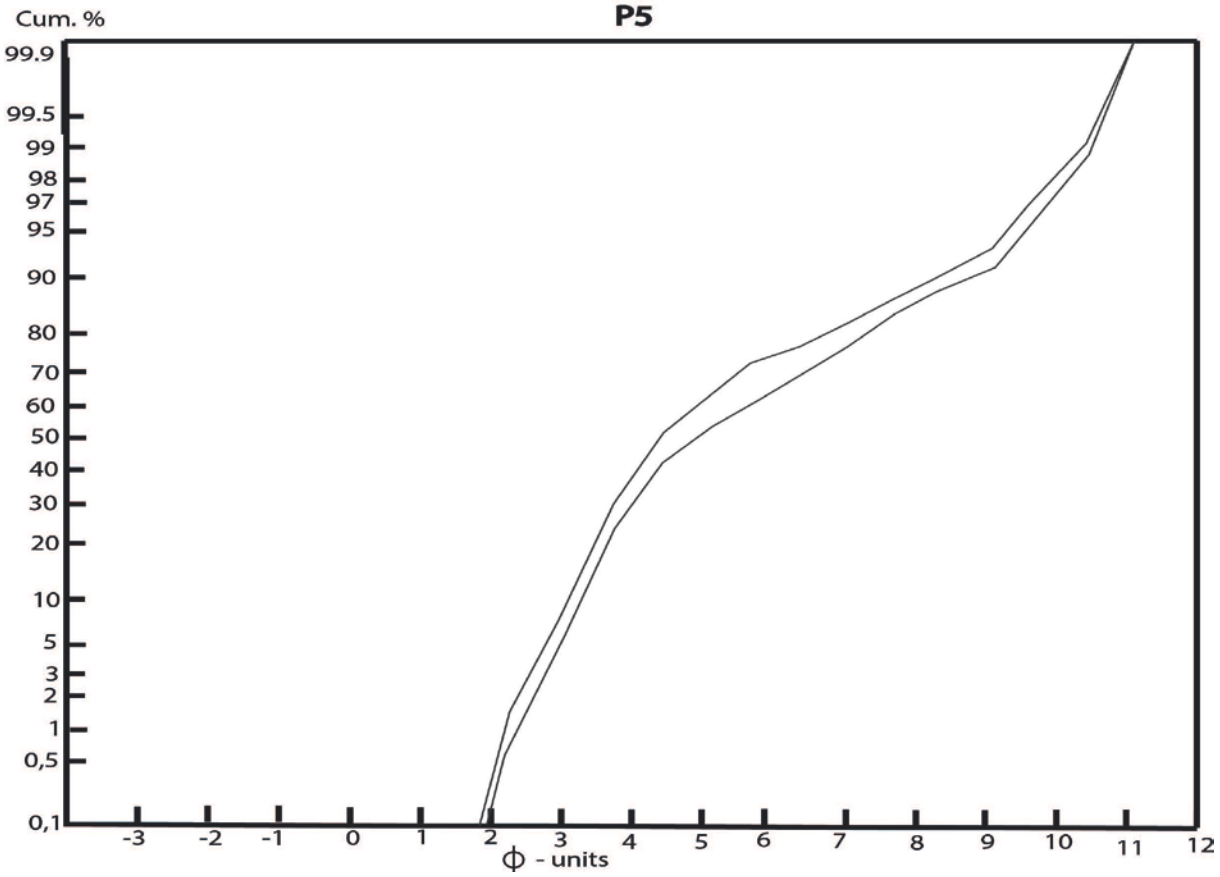


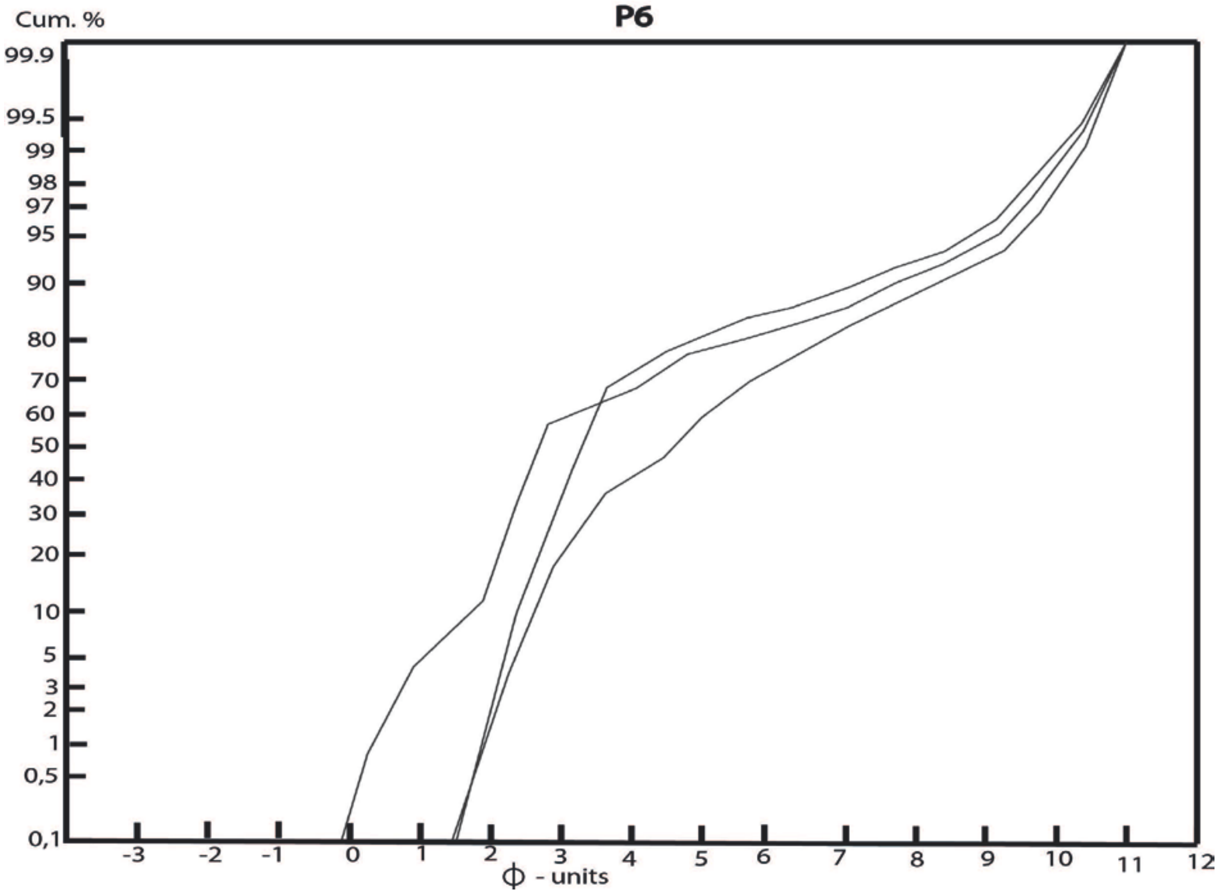

P1
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units

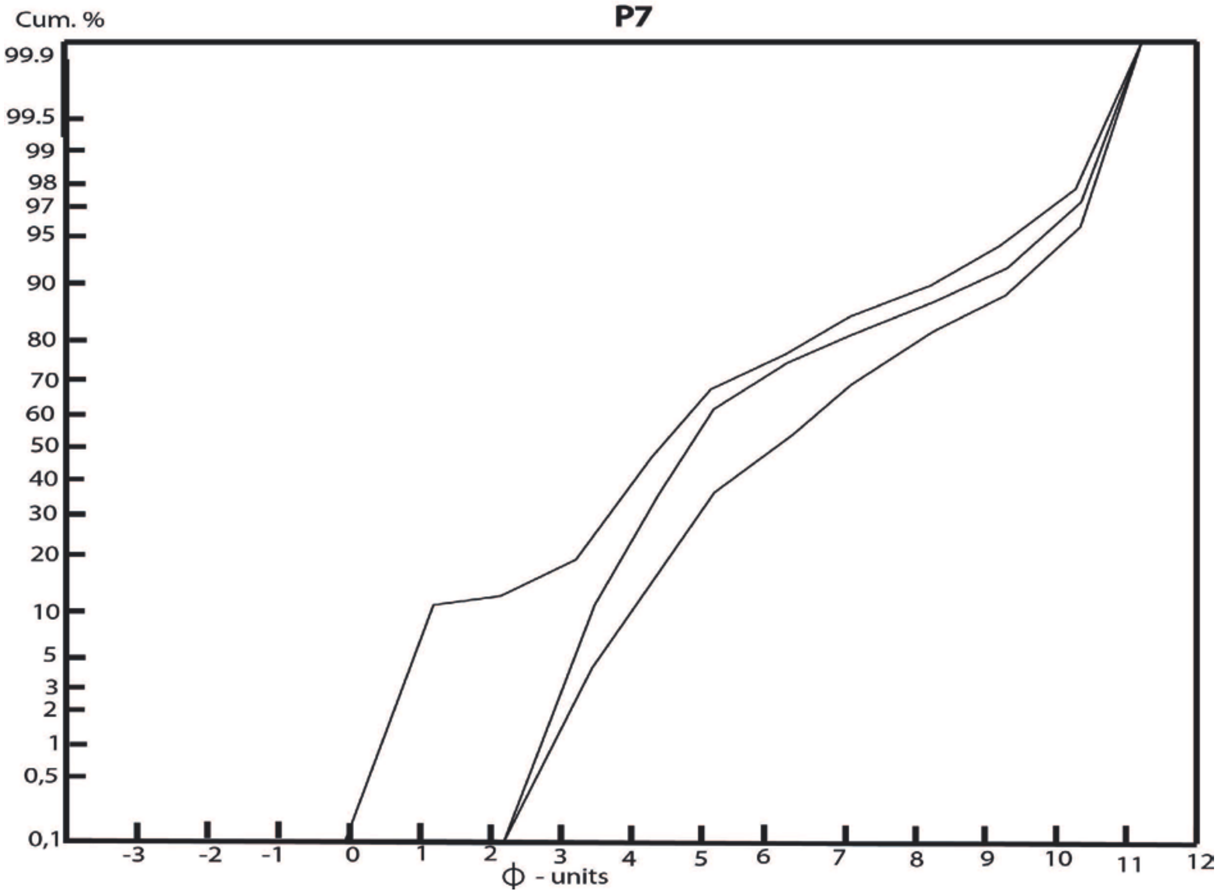

P2
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units

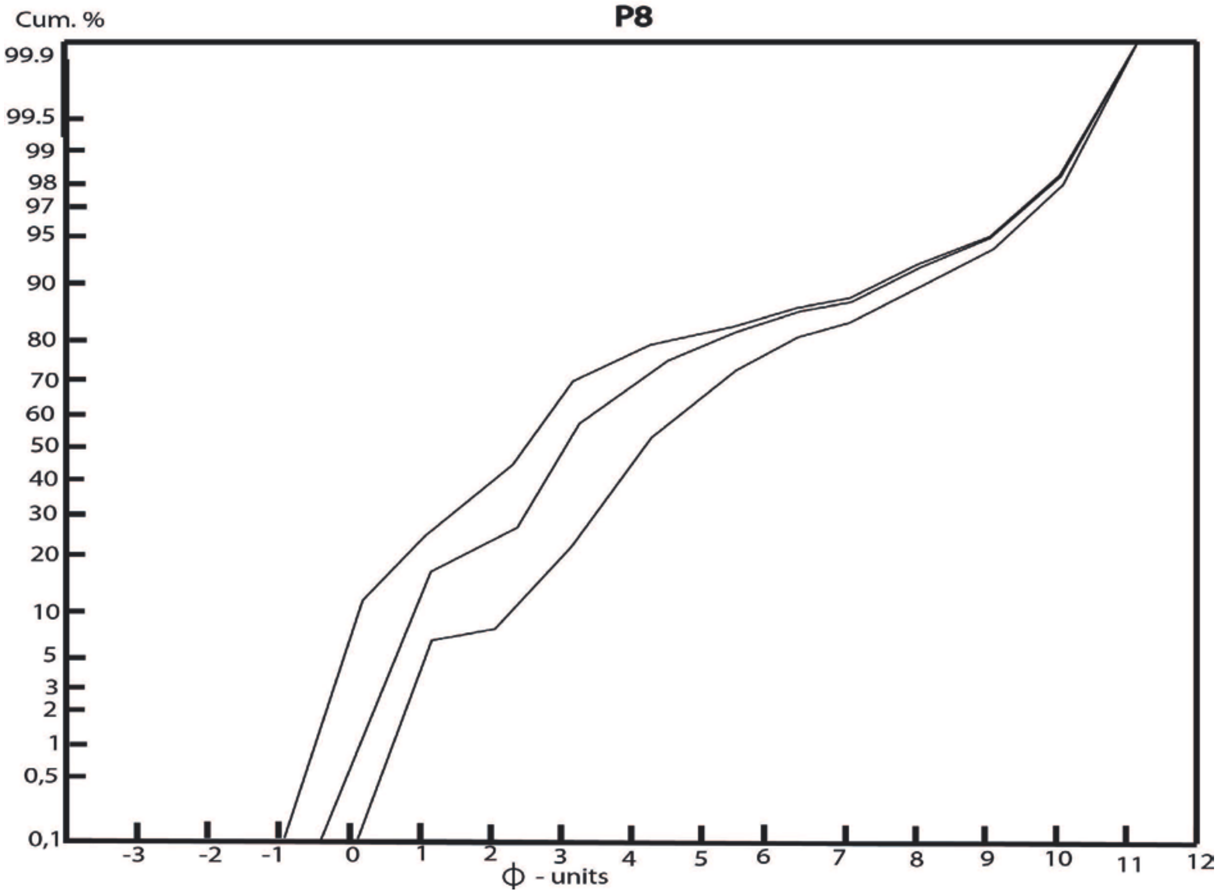

P3
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

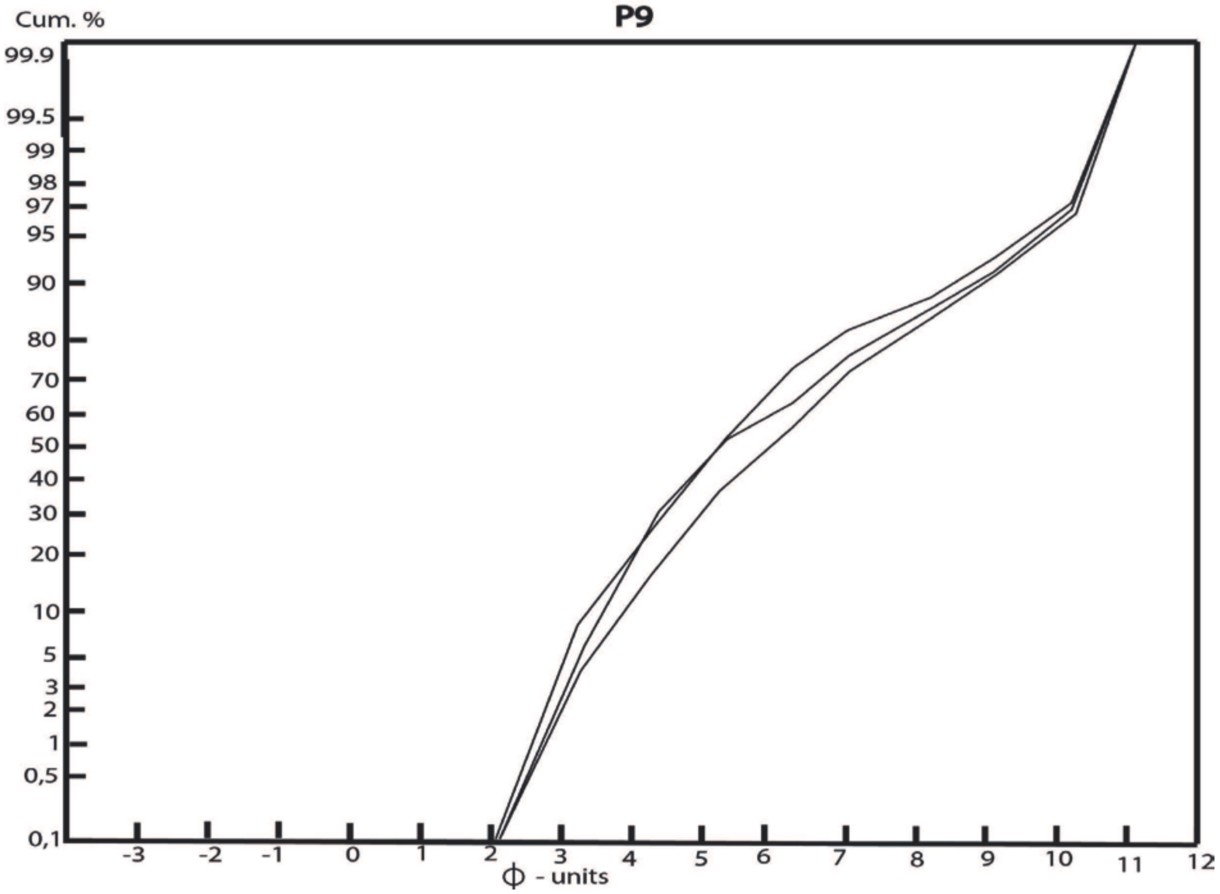

P4
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

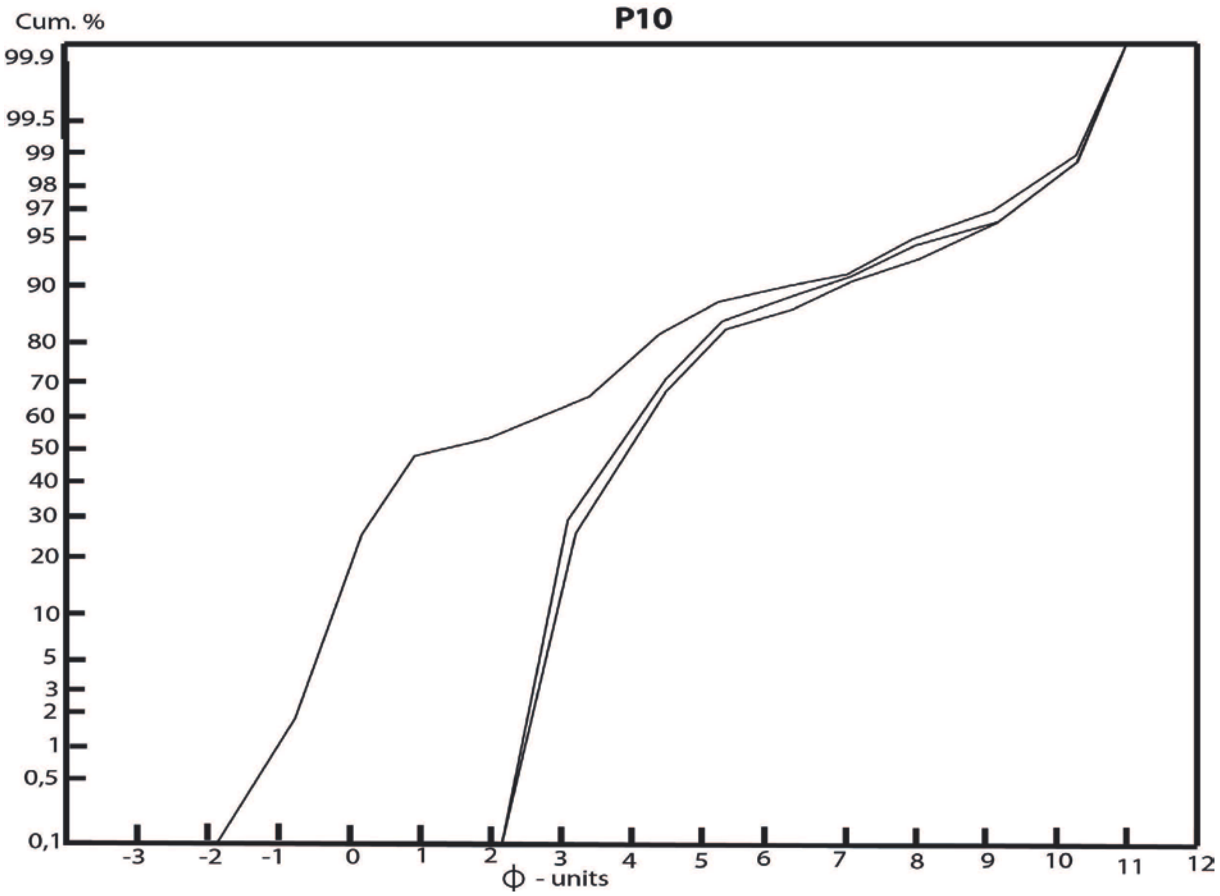

Cum. %
P5
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


Cum. %
P6
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

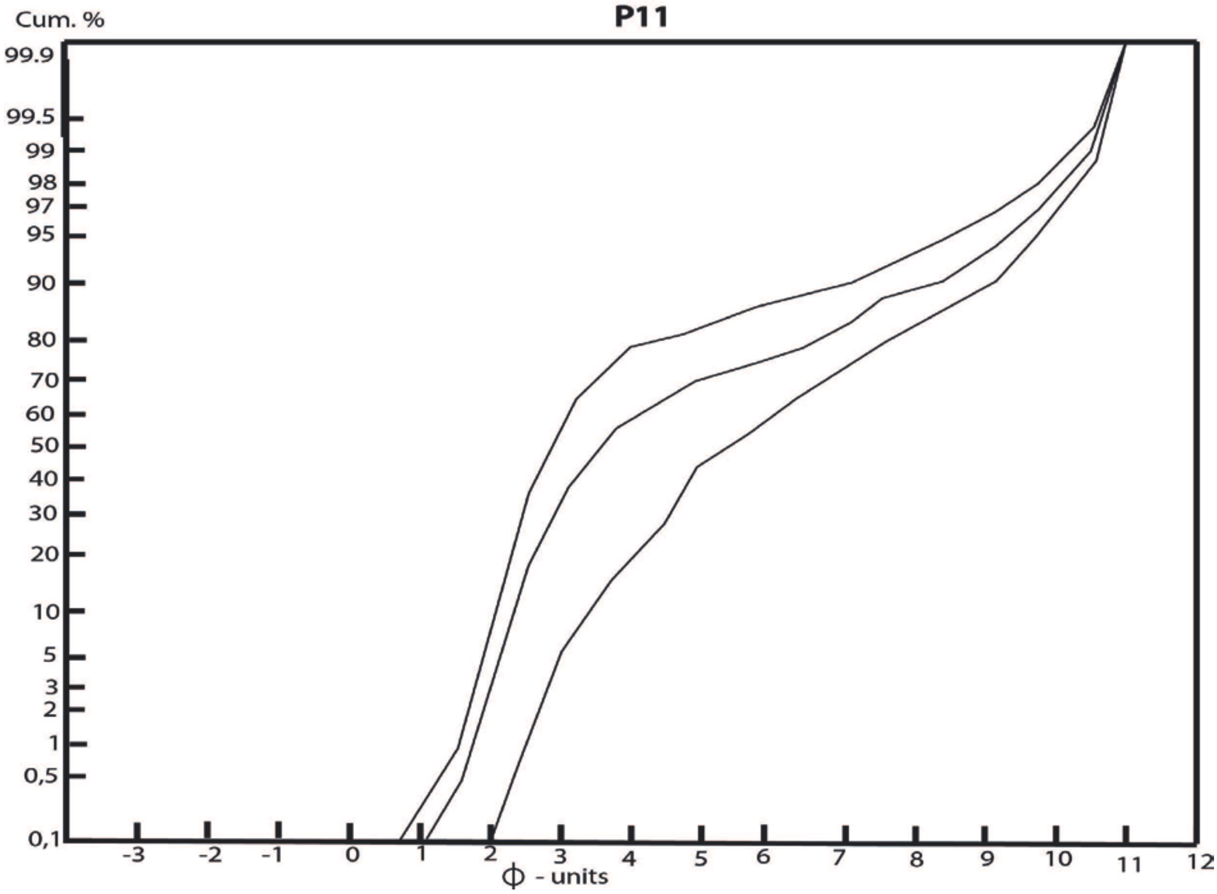

Cum. %
P7
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units


Cum. %
P8
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units

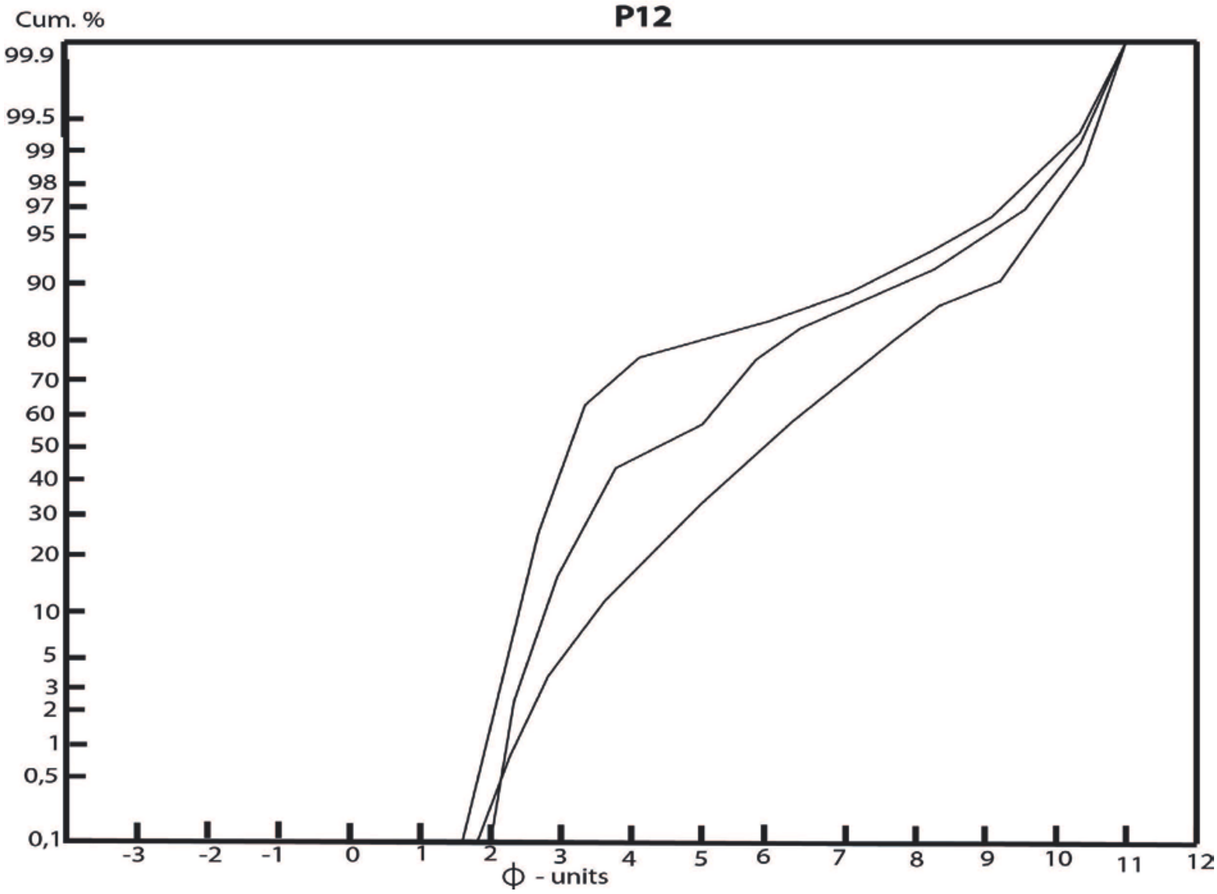

Cum. %
P9
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

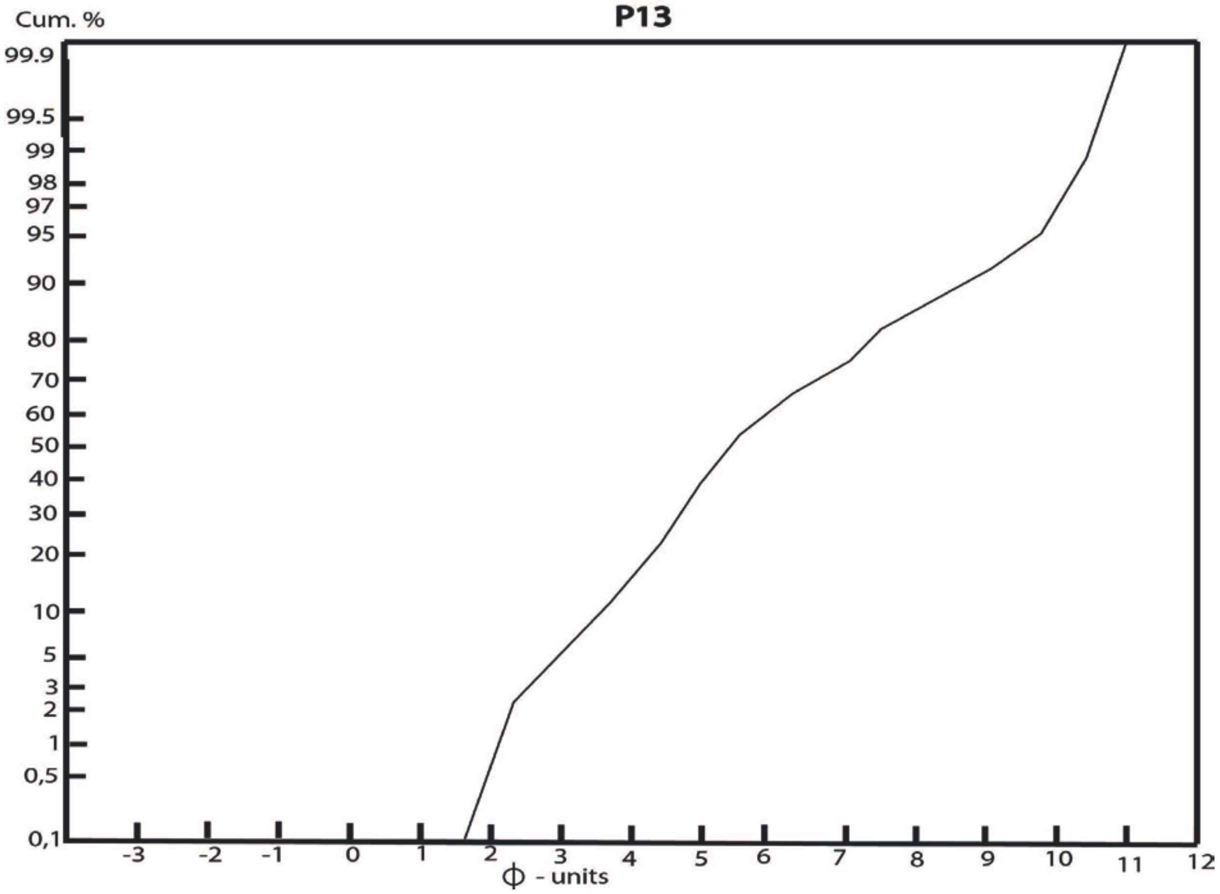

Cum. %
P10
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

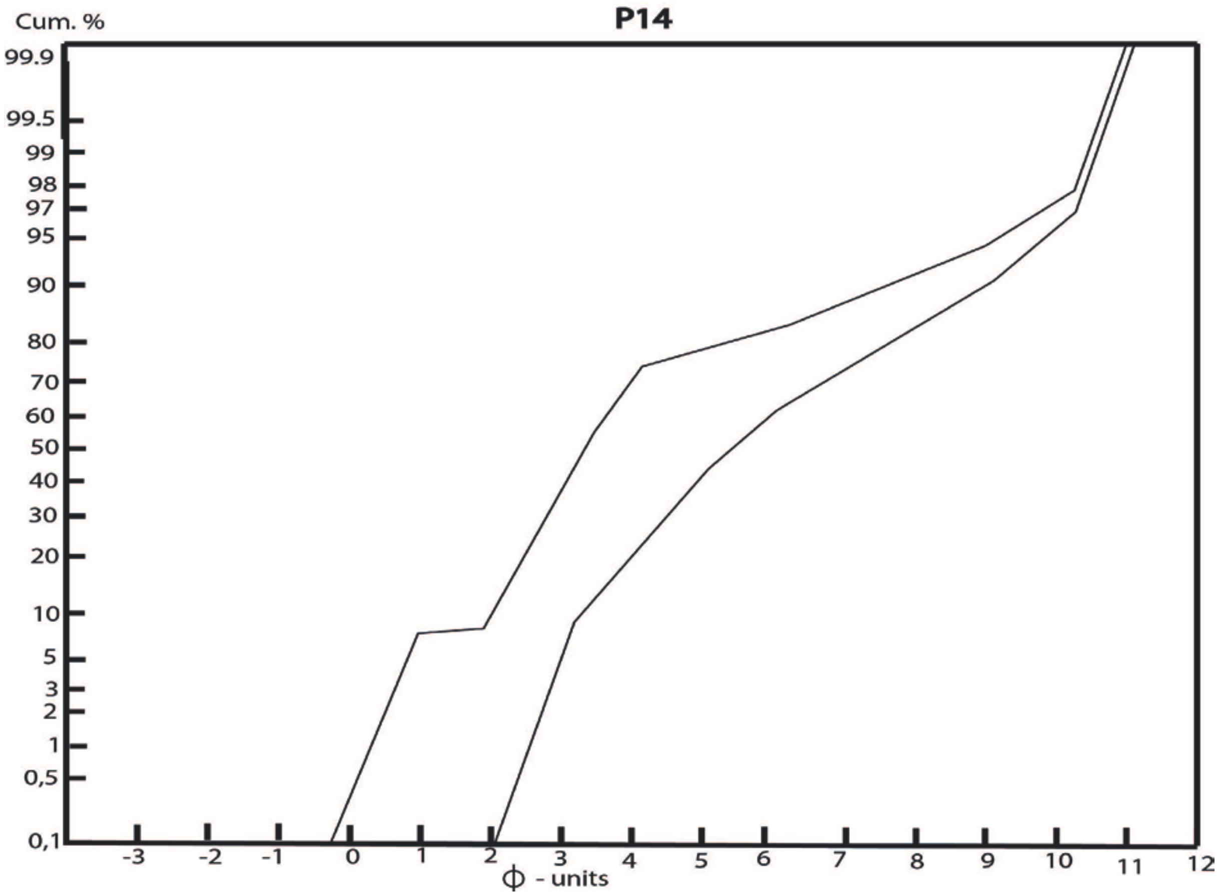
P11

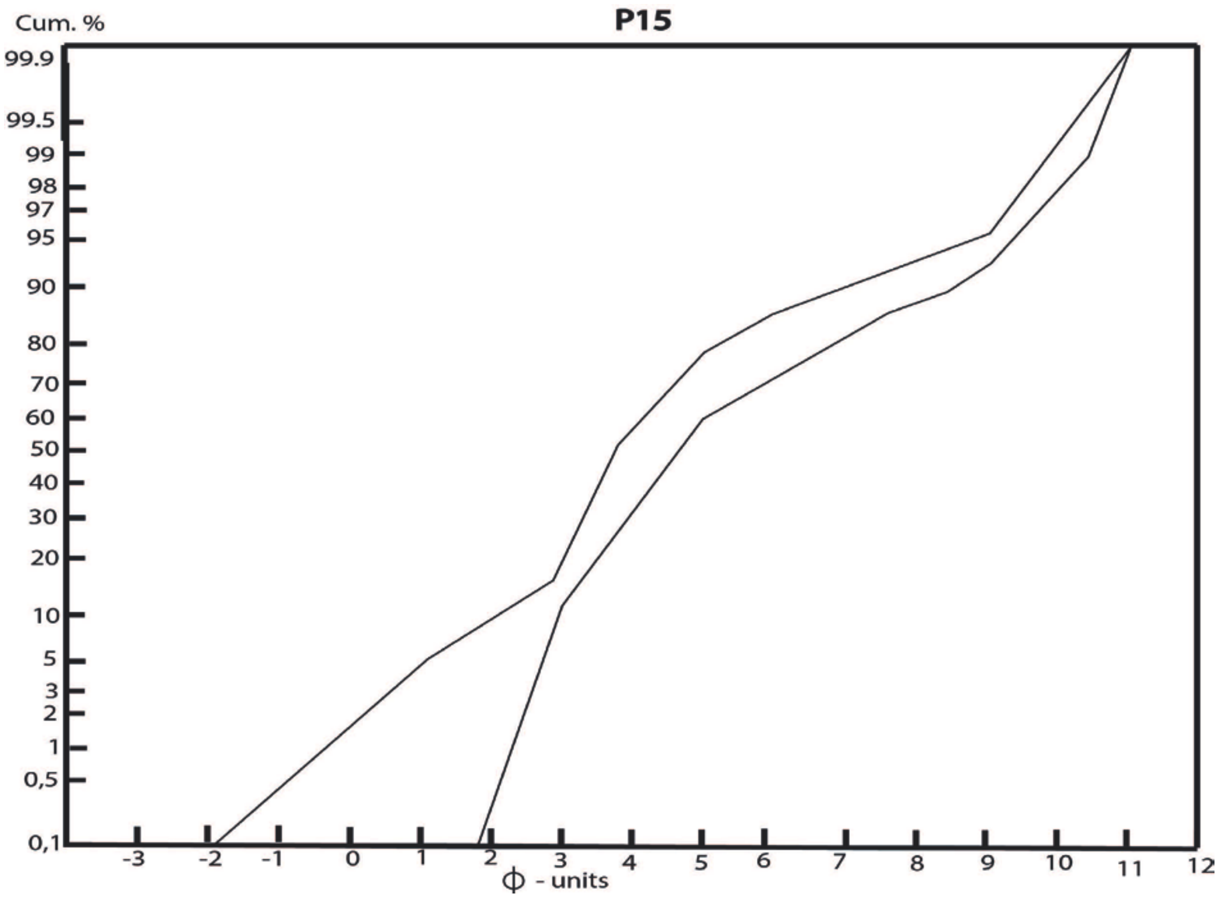

Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
ϕ - units

P12


Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
ϕ - units


Cum. %
P13
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


Cum. %
P14
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units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Cum. %
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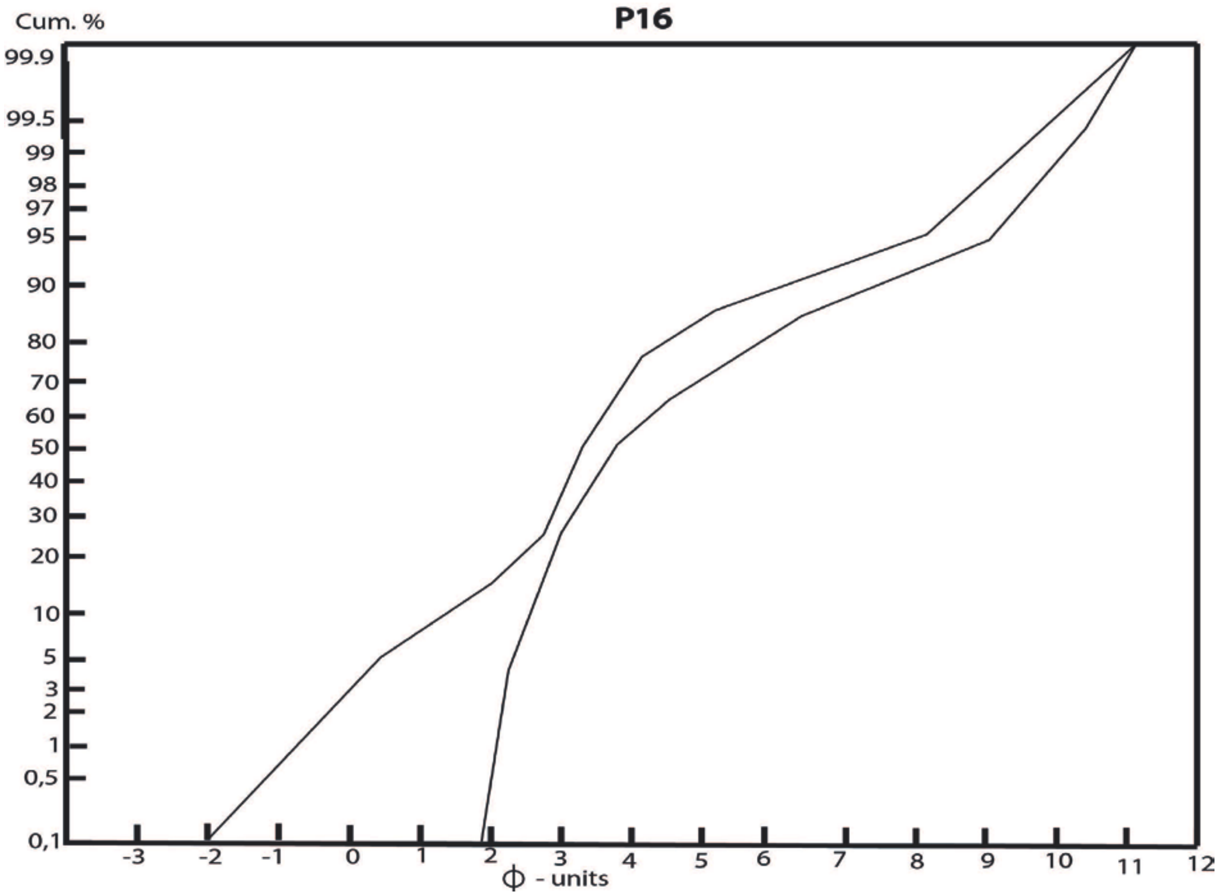
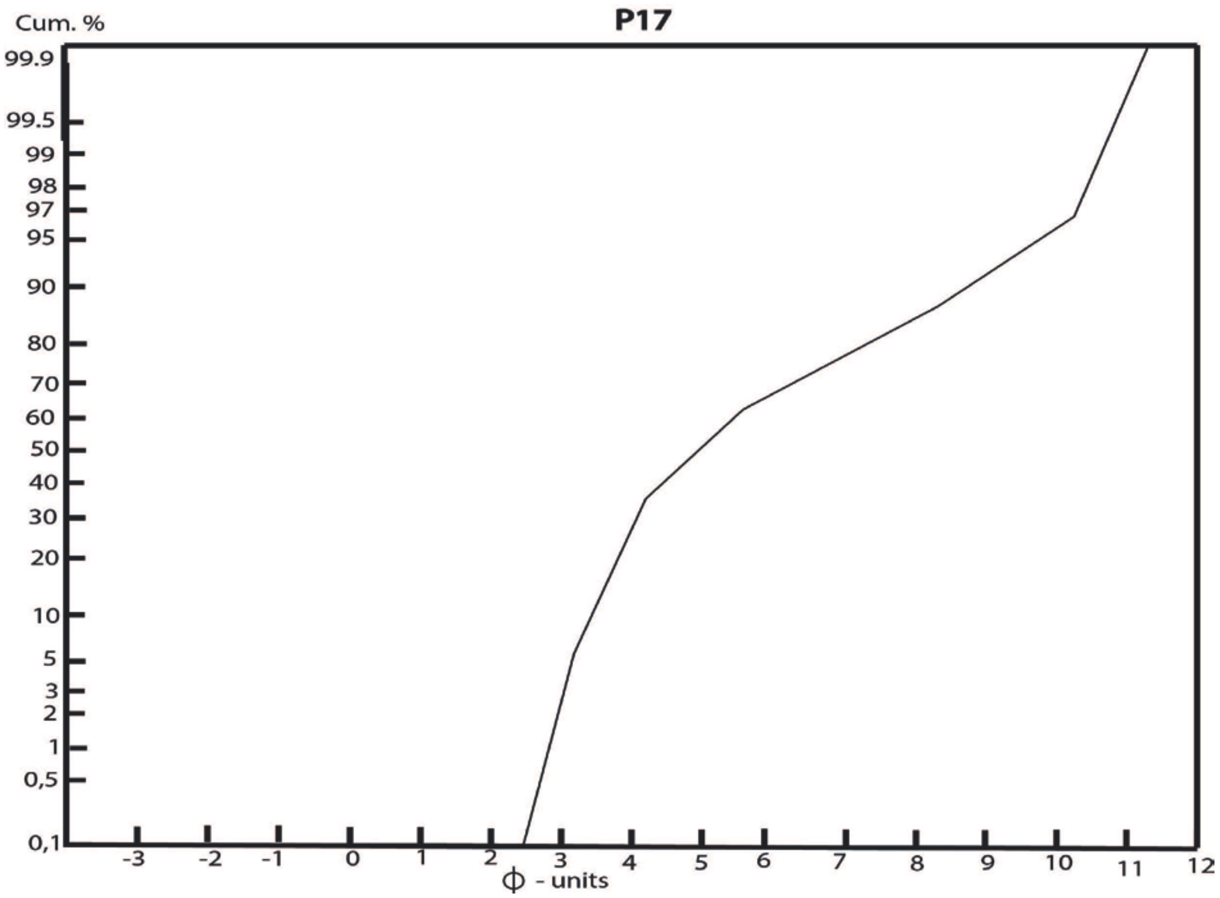
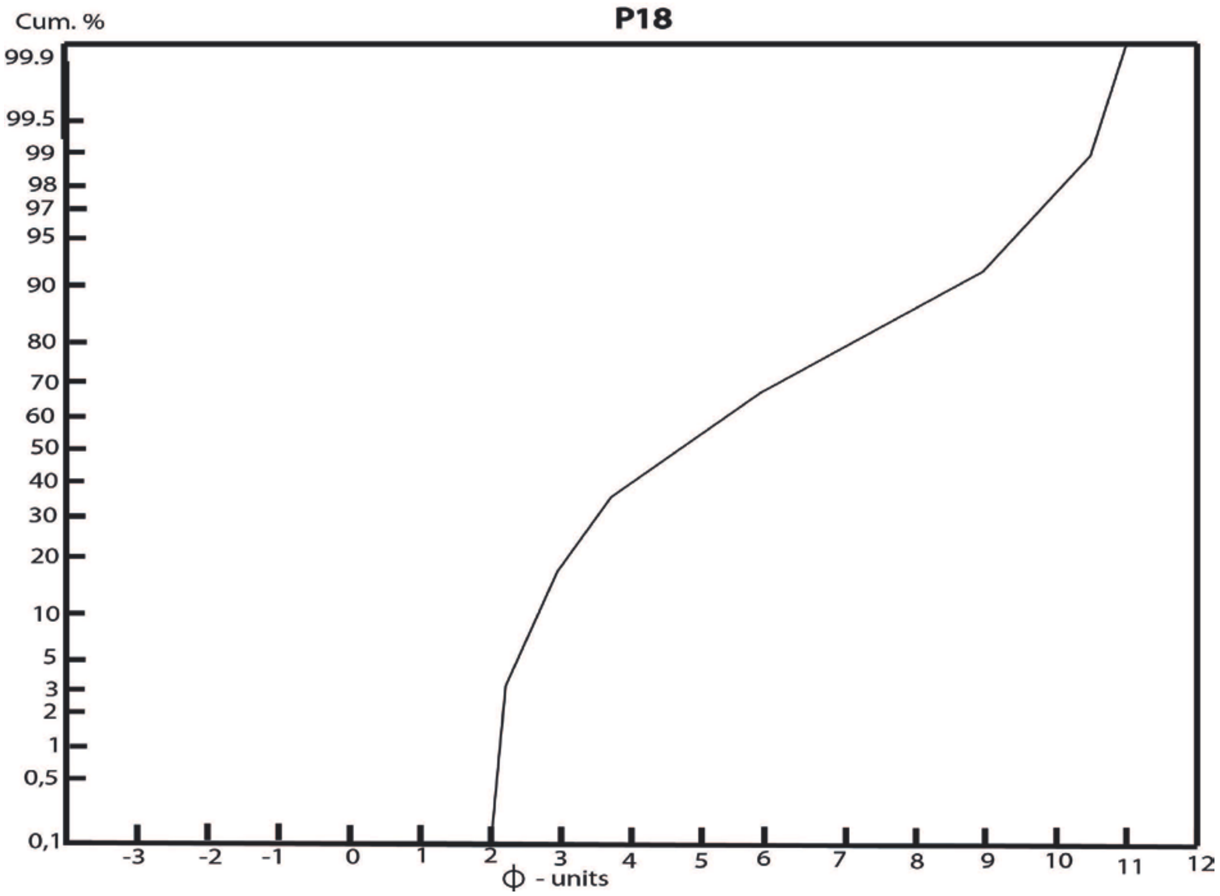
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


P16
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


Cum. %
P17
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


Cum. %
P18
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units

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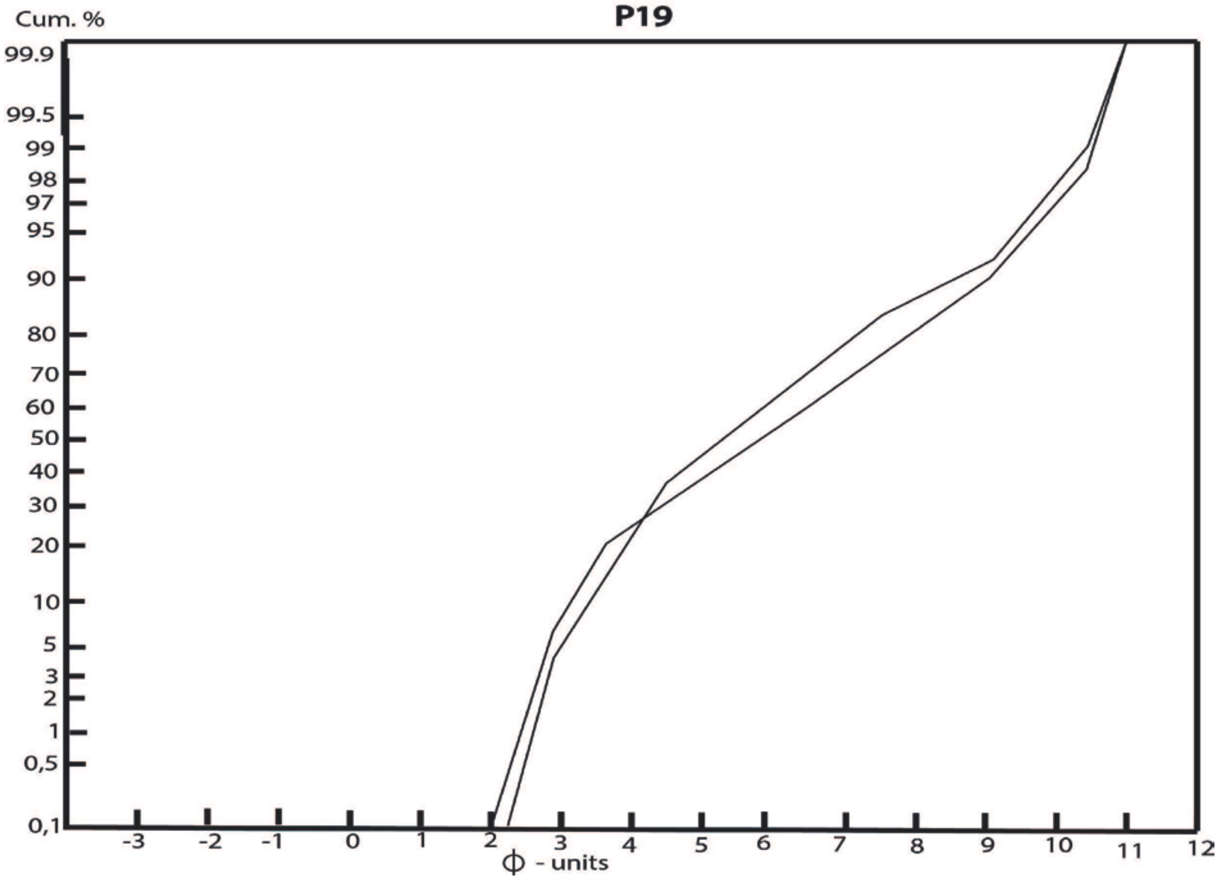
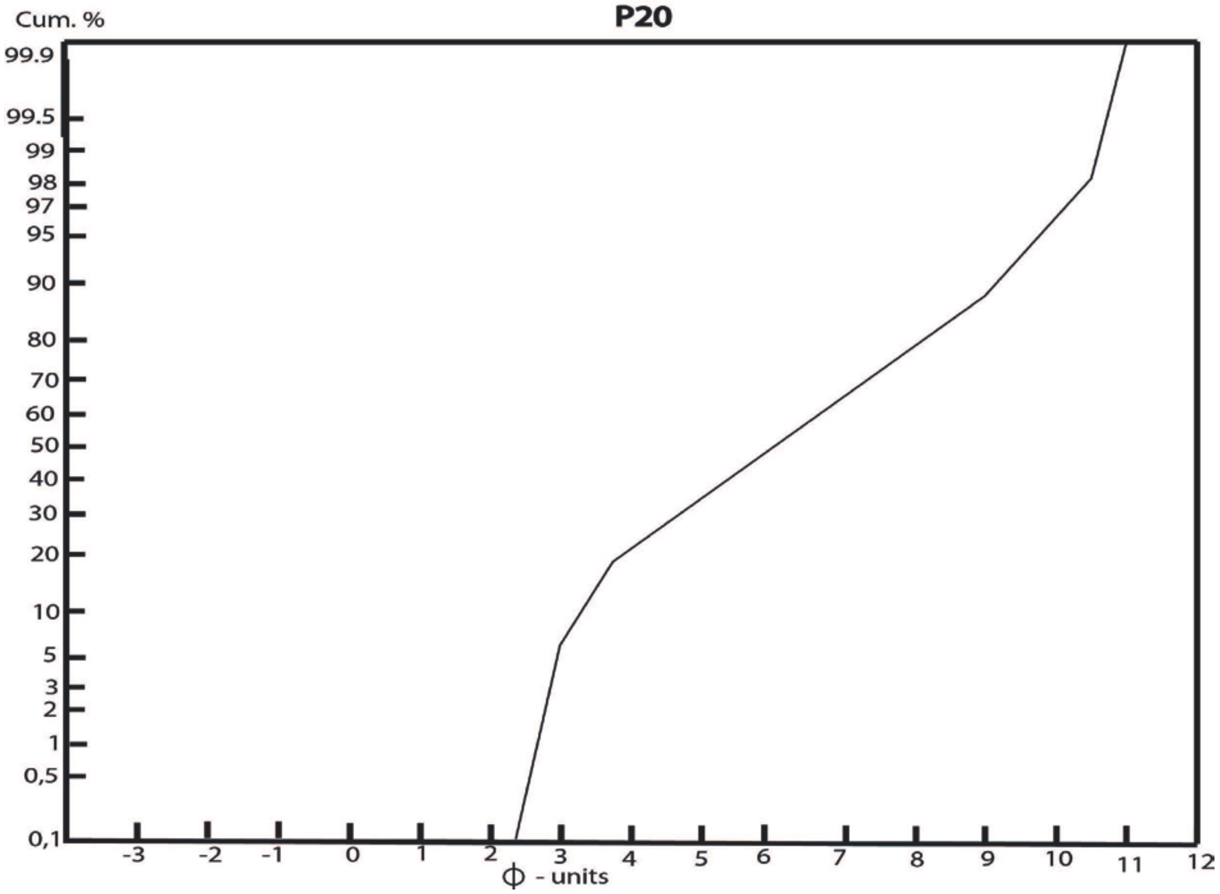

Cum. %
P19
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units


Cum. %
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99.5
99
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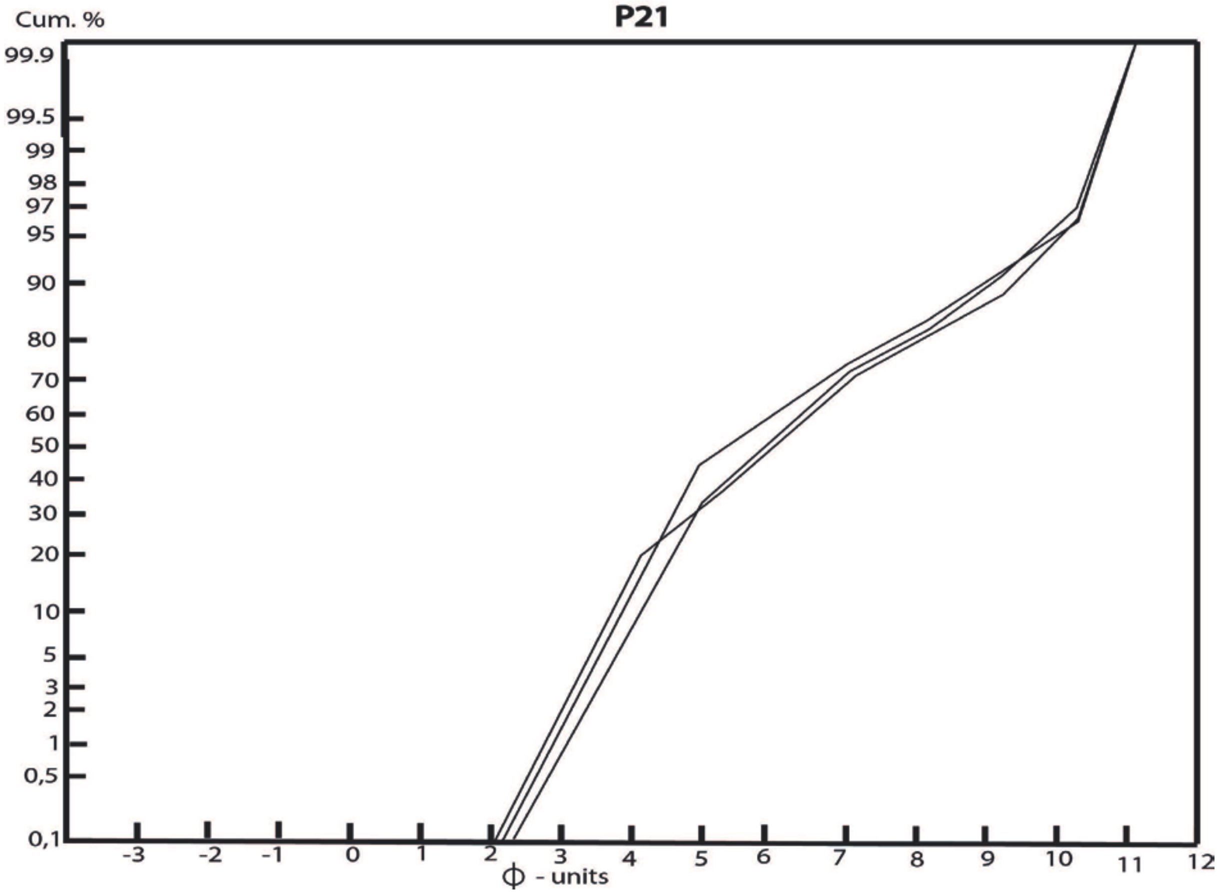
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units


Cum. %
P21
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
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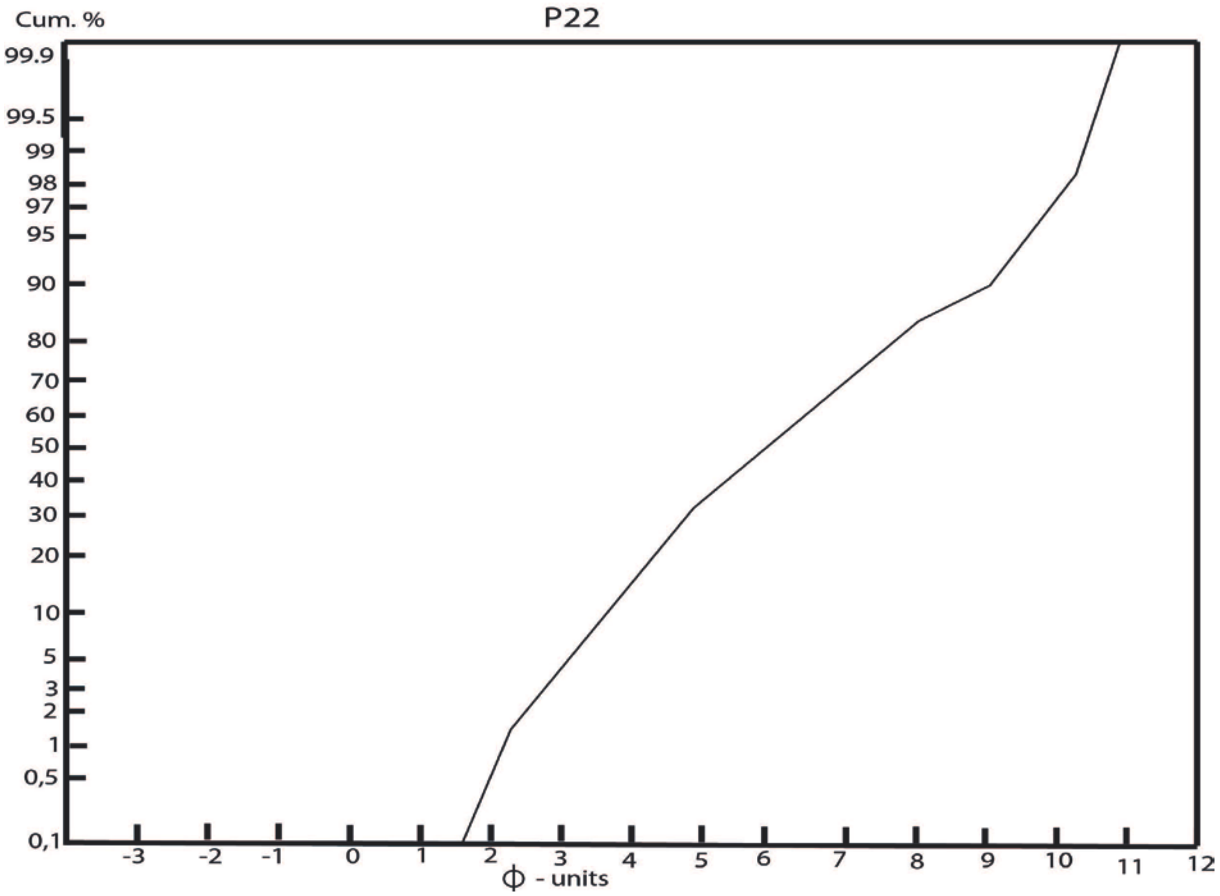
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units


Cum. %
P22
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99.5
99
98
97
95
90
80
70
60
50
40
30
20
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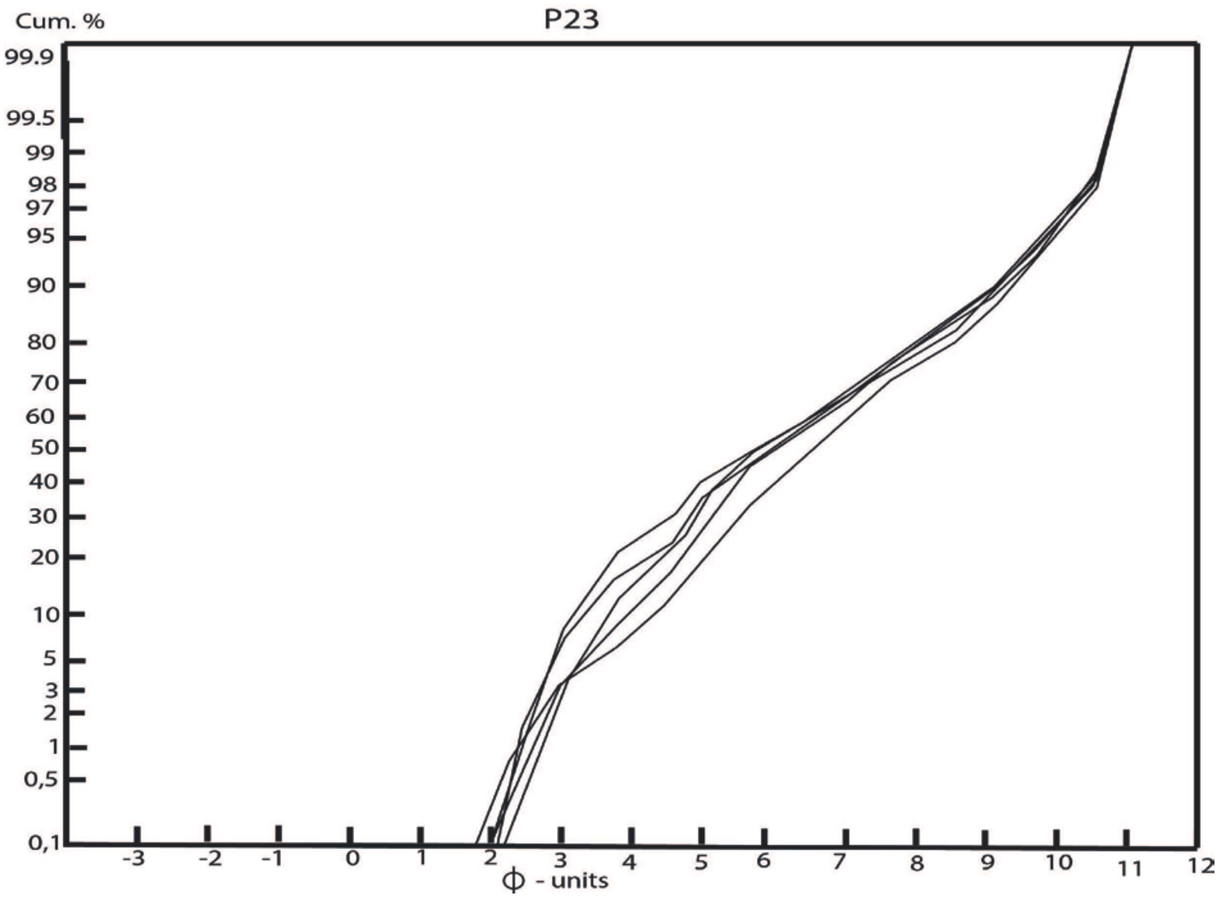
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units



Cum. %
P23
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
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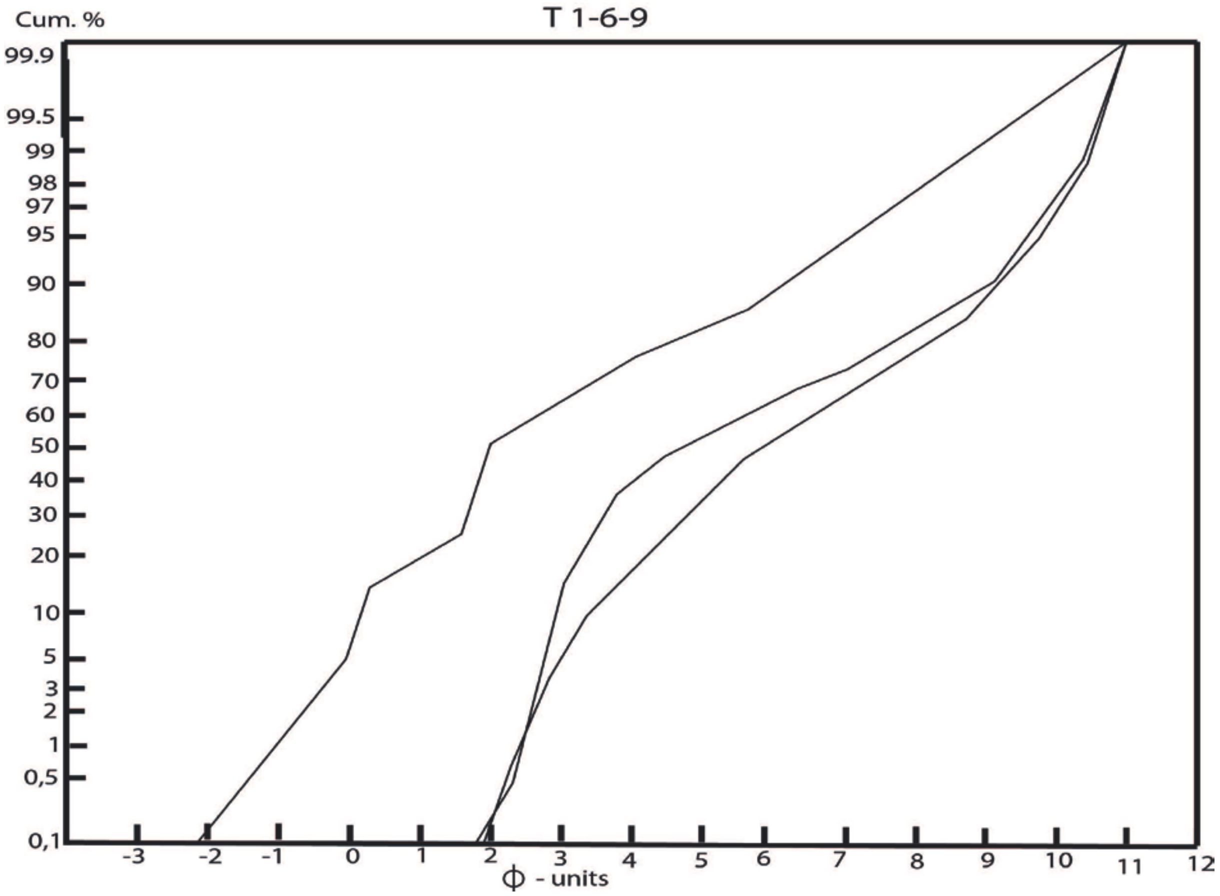
11
12
Φ - units



Cum. %
T 1-6-9
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
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7
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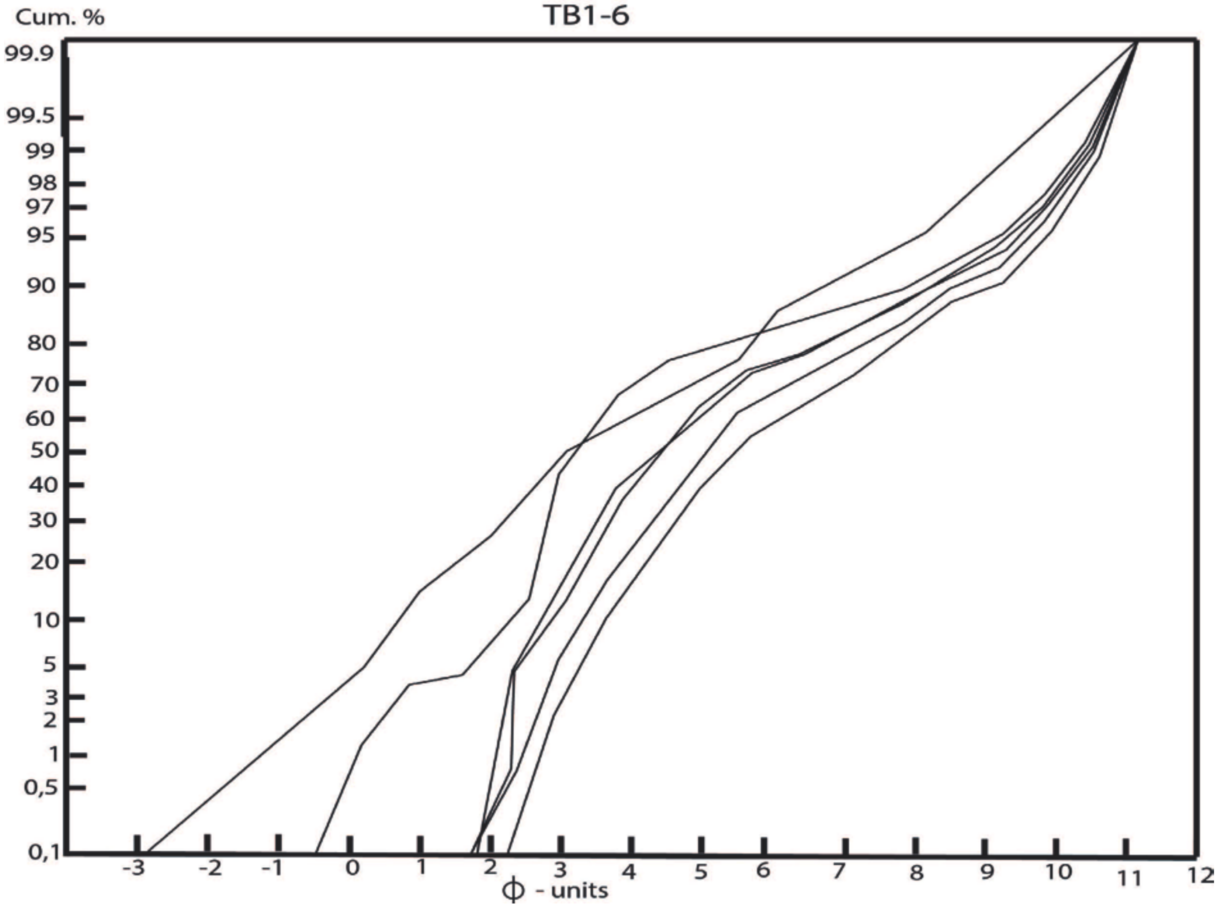
10
11
12
Φ - units


Cum. %
TB1-6
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99.5
99
98
97
95
90
80
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60
50
40
30
20
10
5
3
2
1
0,5
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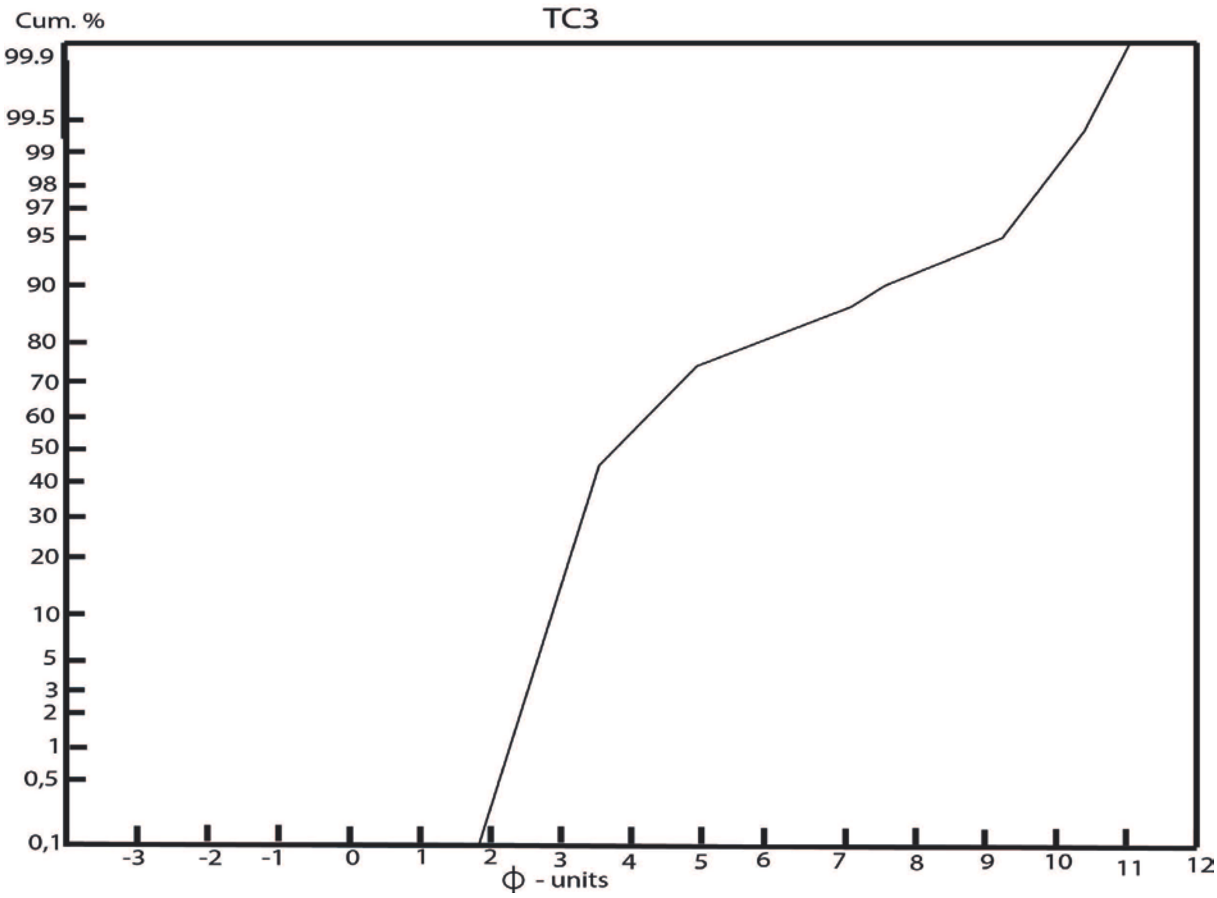
6
7
8
9
10
11
12
ϕ - units


Cum. %
TC3
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
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0
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6
7
8
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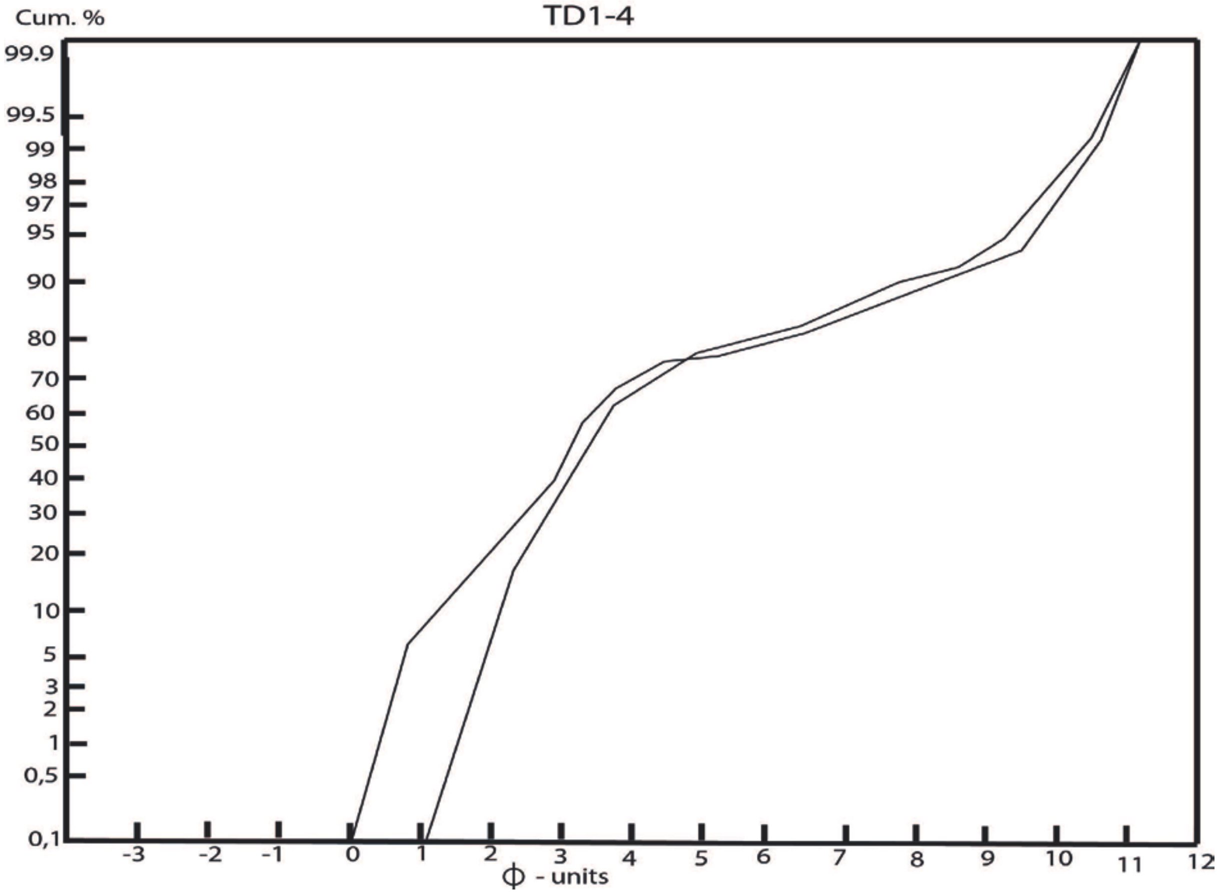
10
11
12
ϕ - units


Cum. %
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3
2
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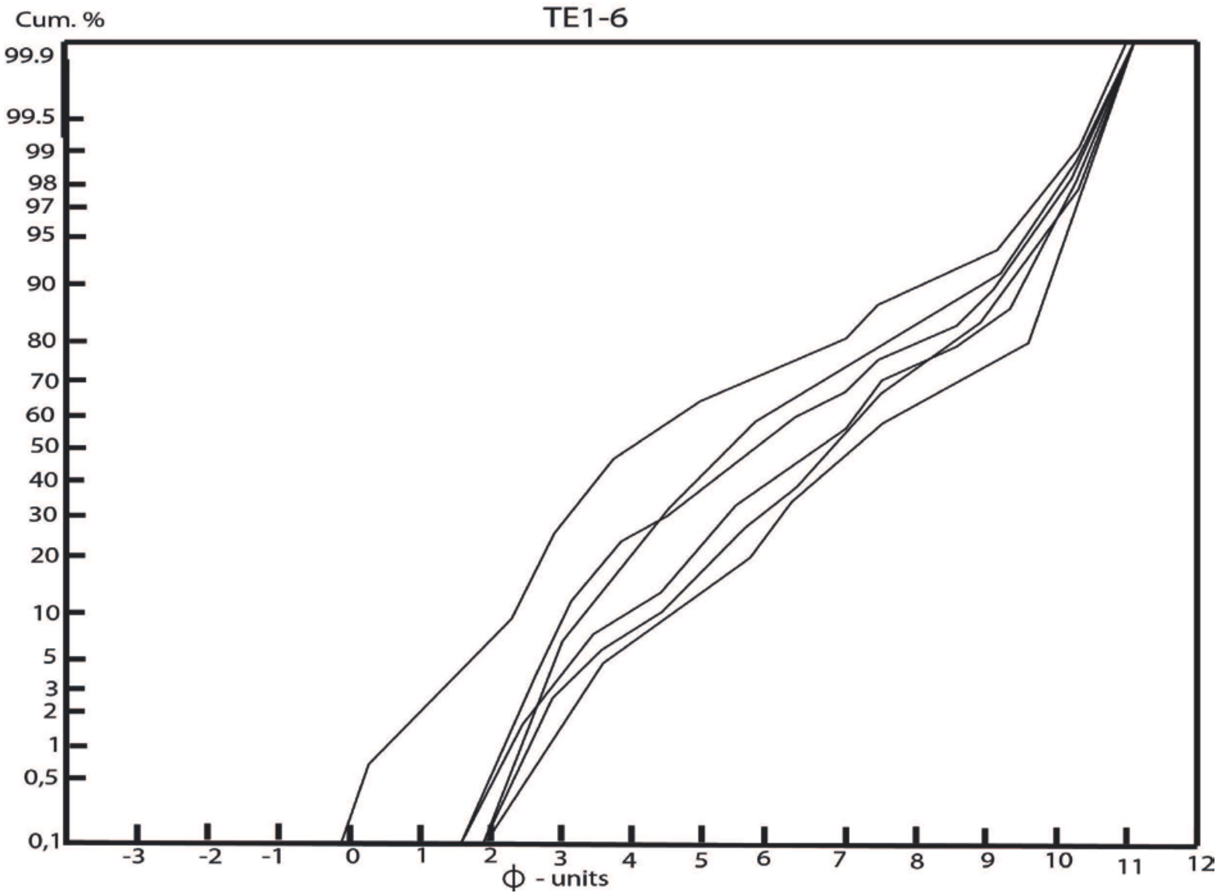
11
12
ϕ - units


Cum. %
TE1-6
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98
97
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90
80
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50
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3
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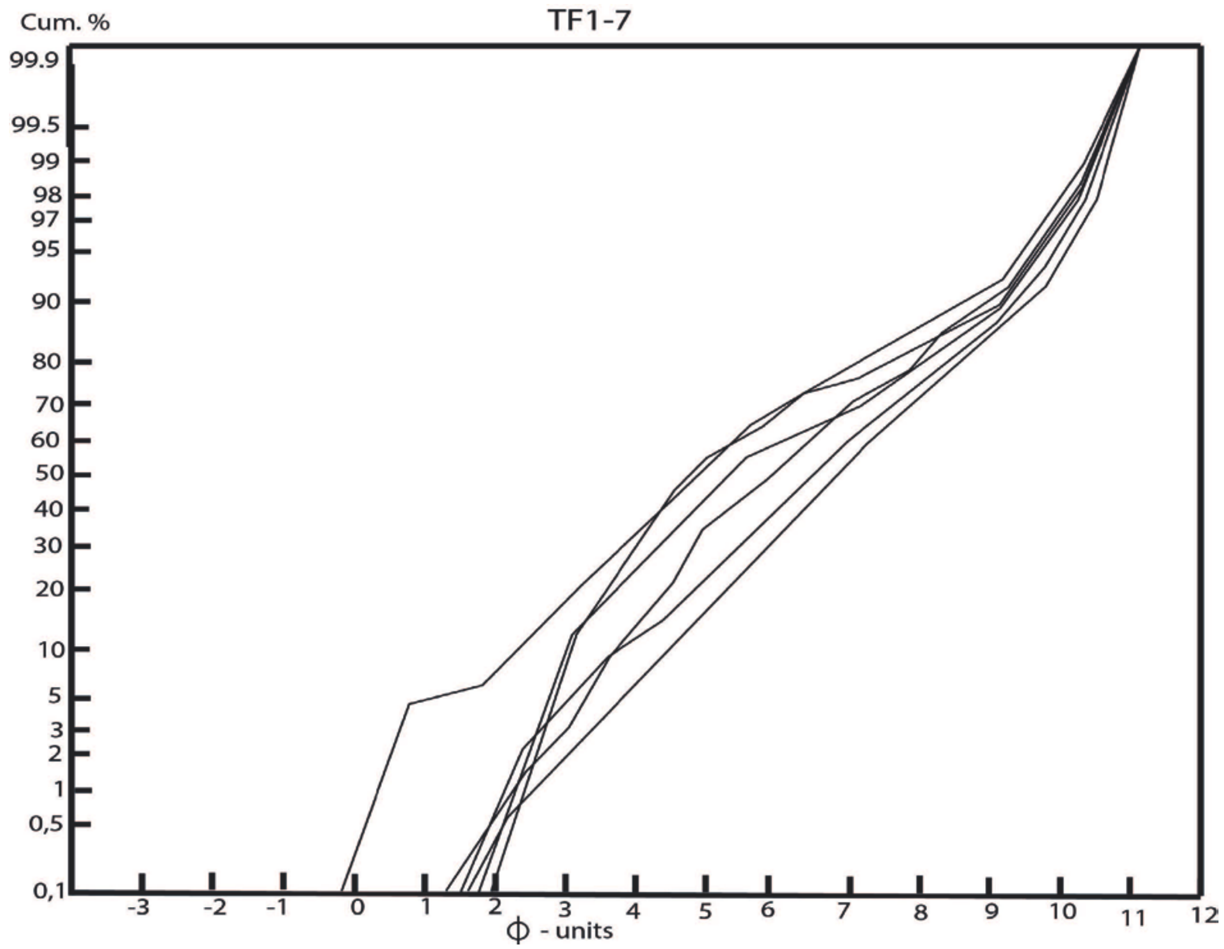
ϕ - units



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-3
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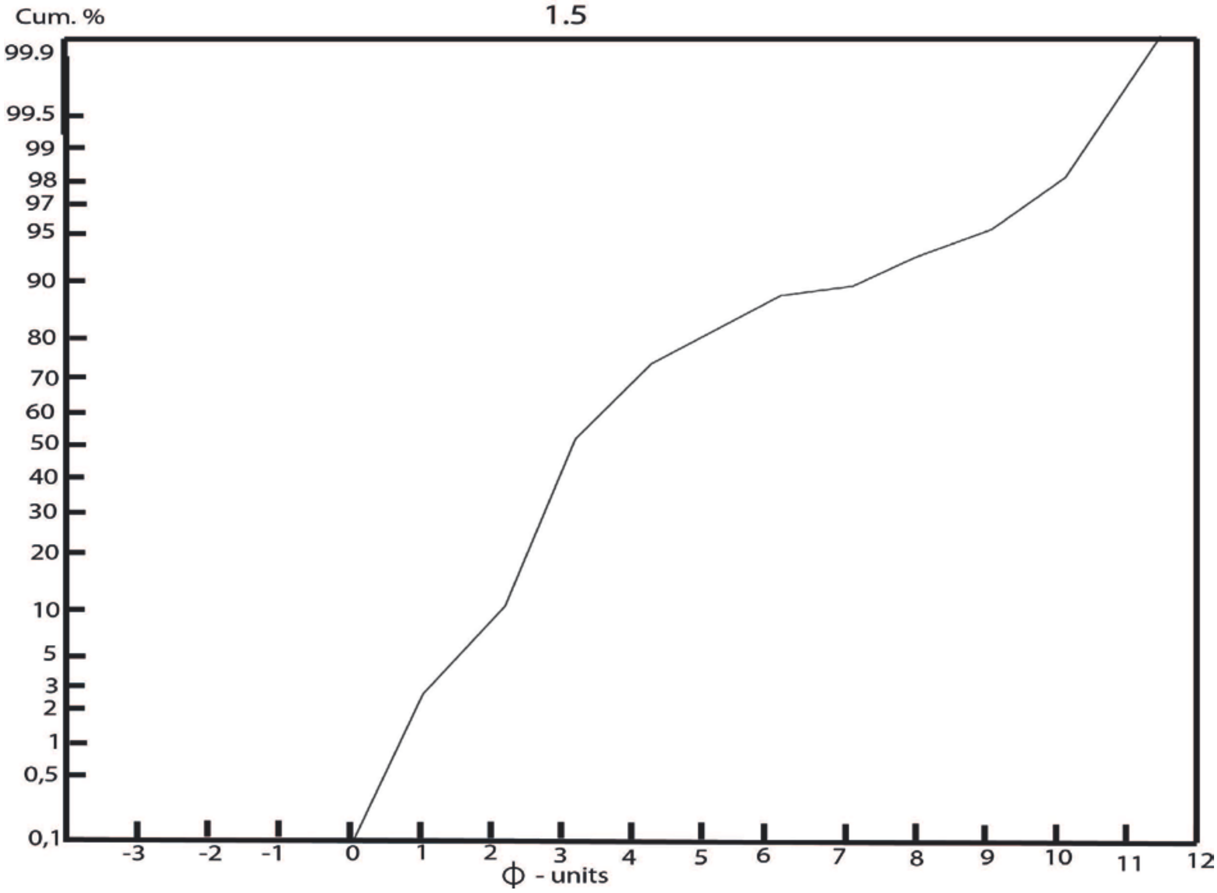
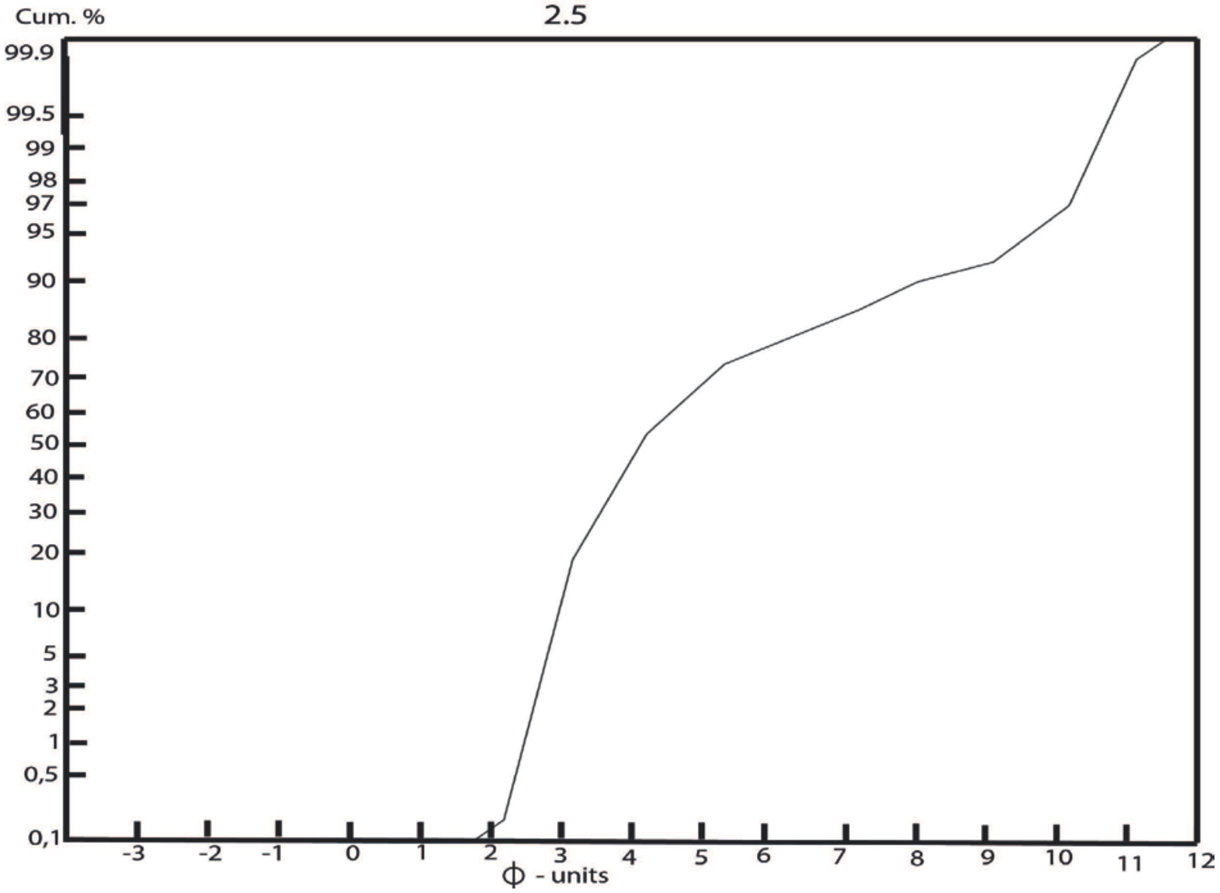
Φ - units

Appendix G:

Below are cumulative grain size plots based on grain size analysis done in lab; for each profile and surface sample from field season 2011.




Cum. %
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99.9
99.5
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97
95
90
80
70
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50
40
30
20
10
5
3
2
1
0,5
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-3
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-1
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4
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7
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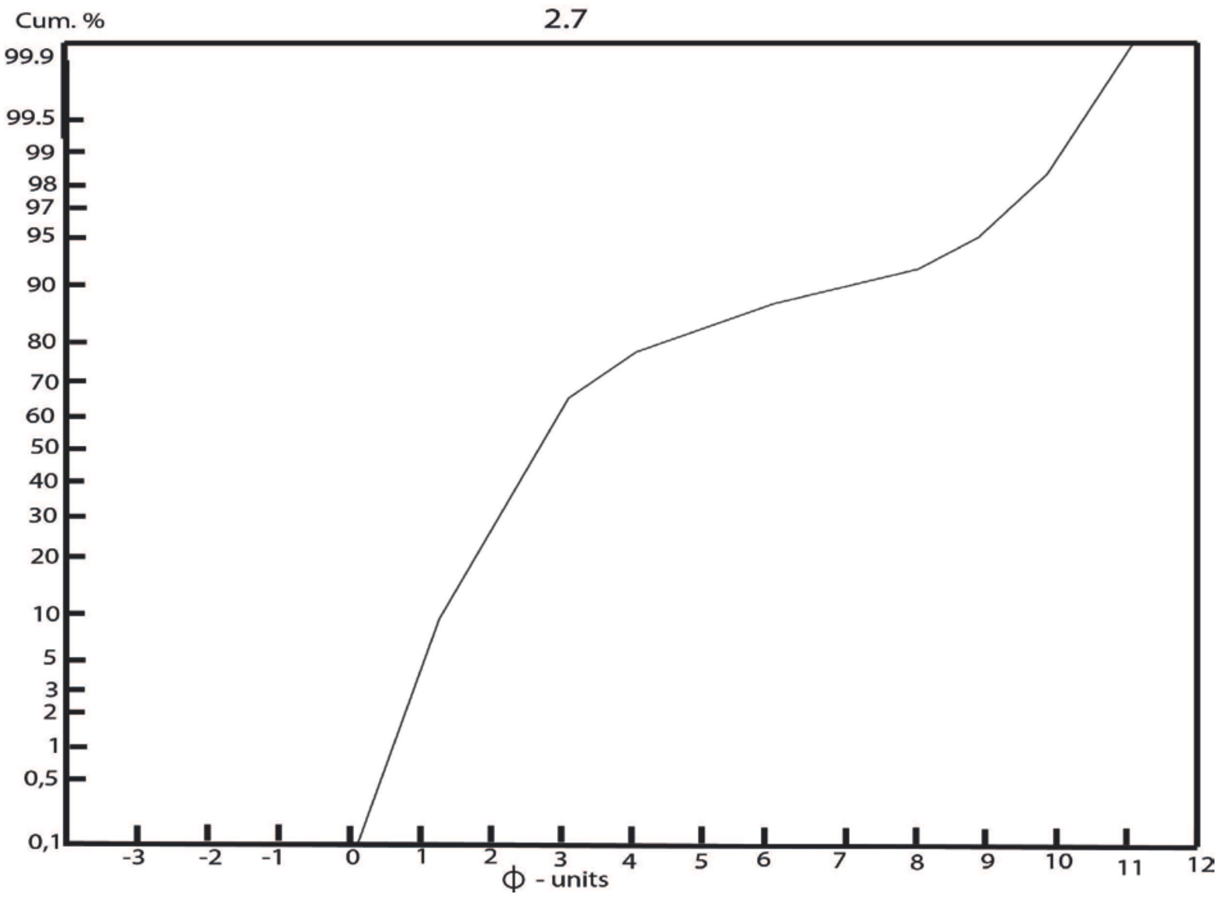
11
12
Φ - units


Cum. %
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99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
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5
3
2
1
0,5
0,1
-3
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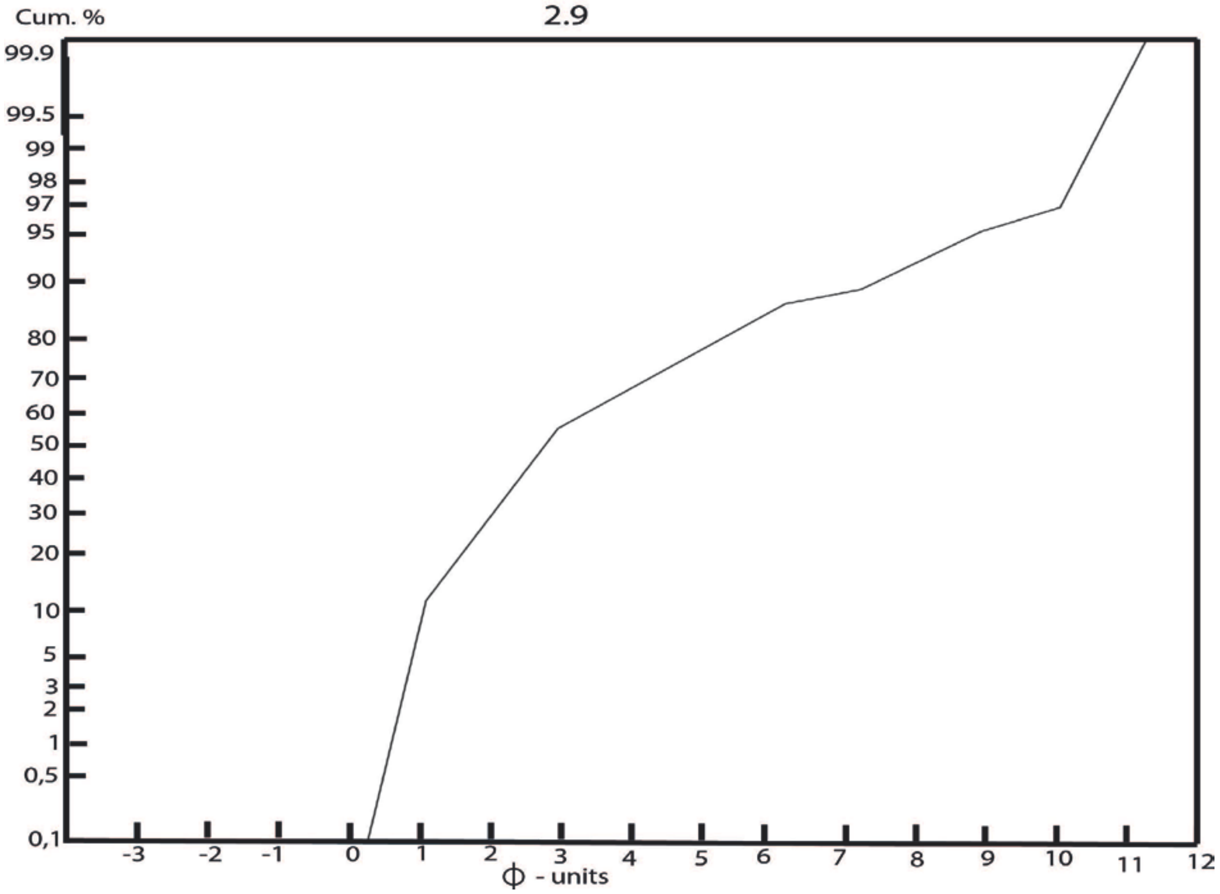
11
12
Φ - units

2.9


Cum. %
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99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
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2
1
0,5
0,1
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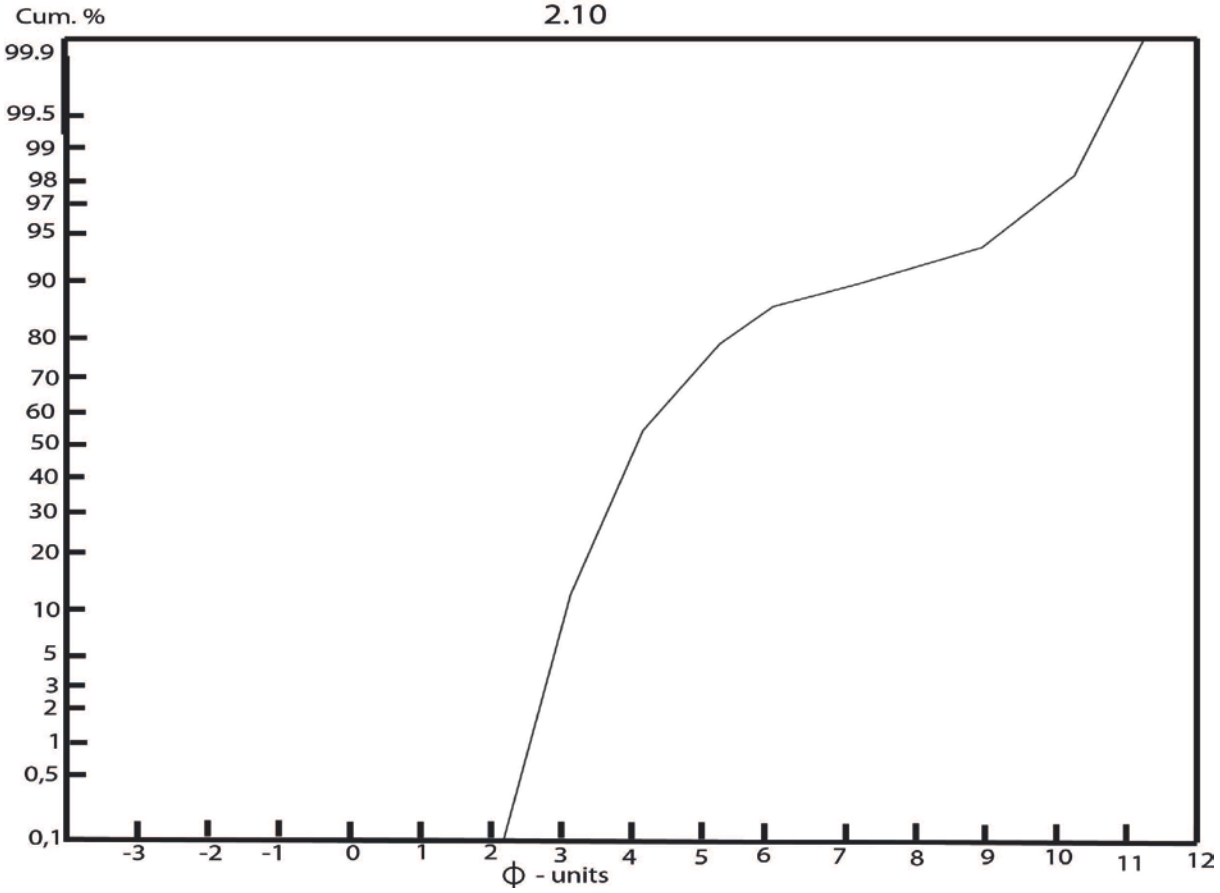
12
Φ - units

2.10


Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
-2
-1
0
1
2
3
4
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7
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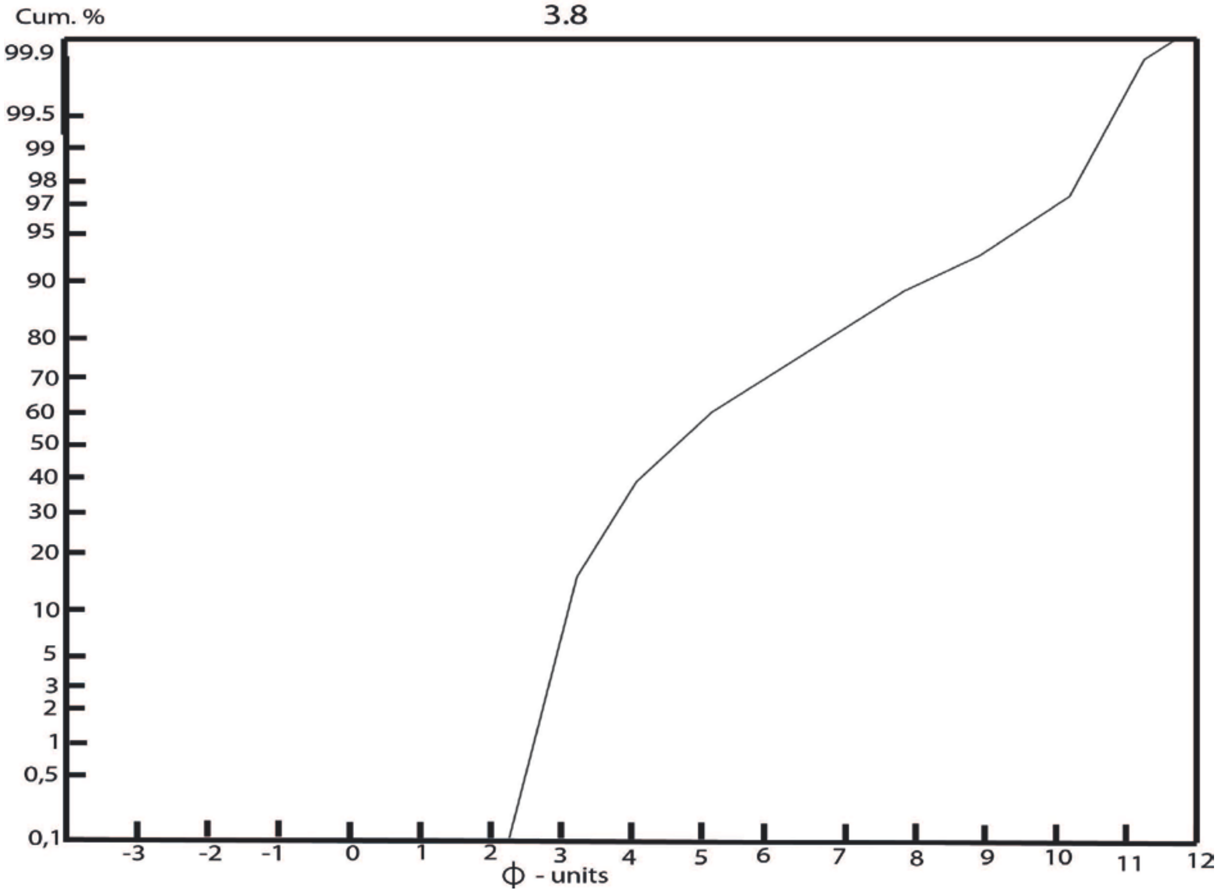
11
12
Φ - units


Cum. %
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99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
-3
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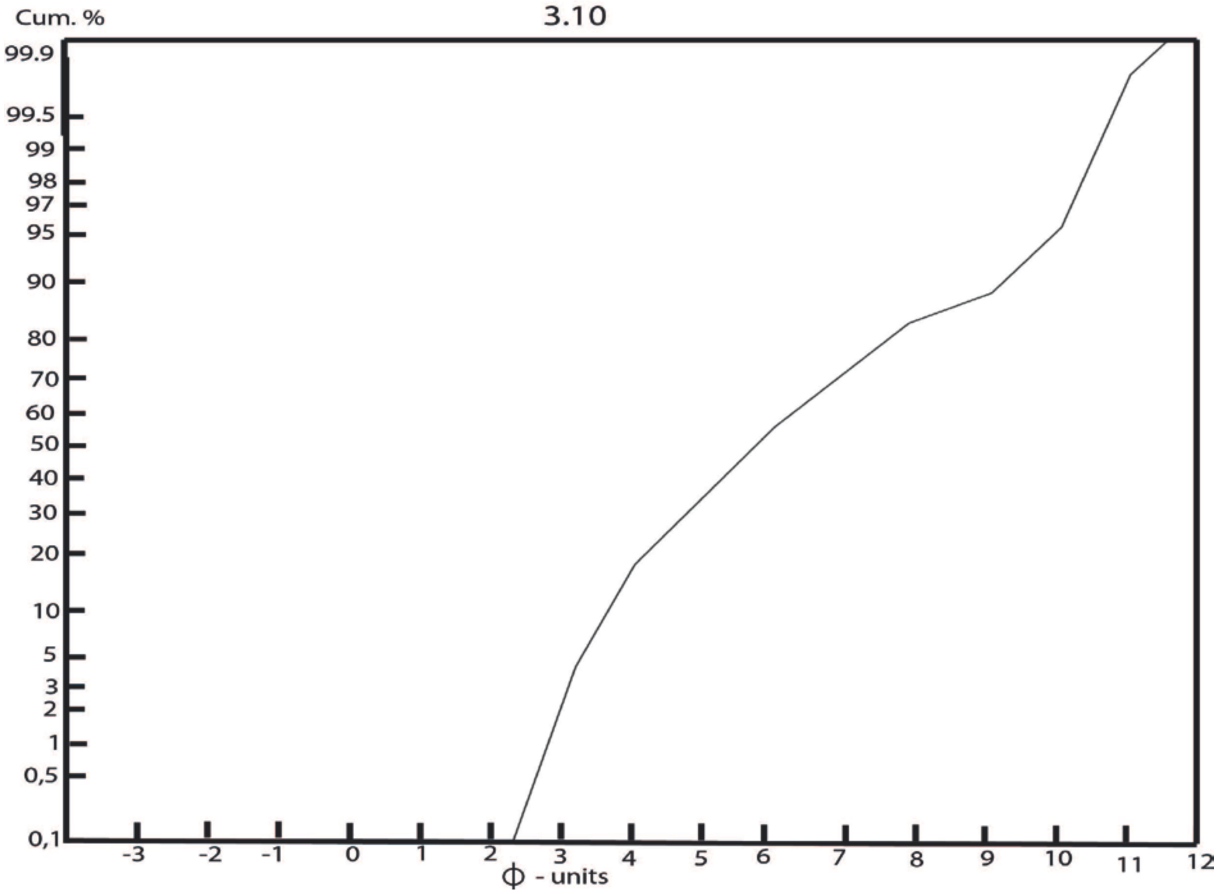
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
ϕ - units


Cum. %
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99.5
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80
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40
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20
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5
3
2
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0,5
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-3
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-1
0
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2
3
4
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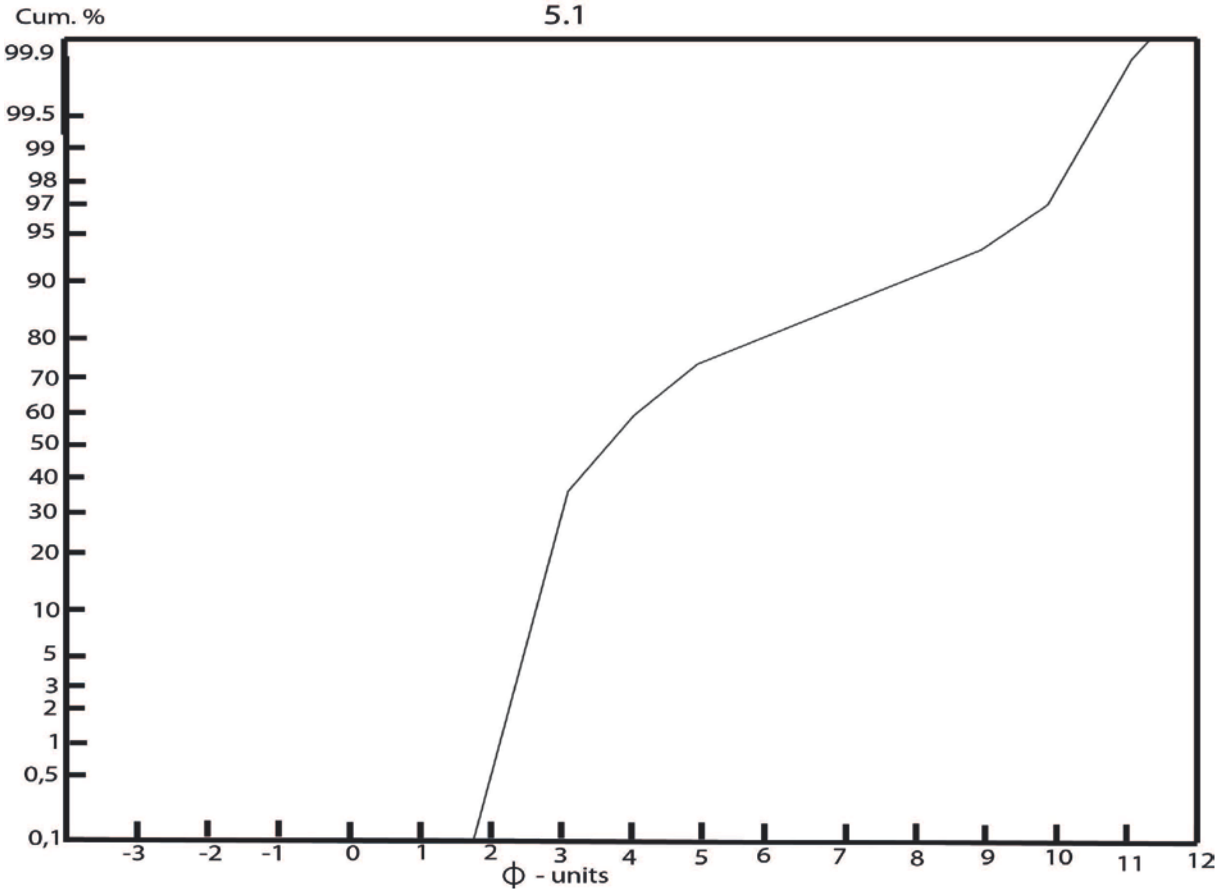
6
7
8
9
10
11
12
ϕ - units



5.1
Cum. %
99.9
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0,5
0,1
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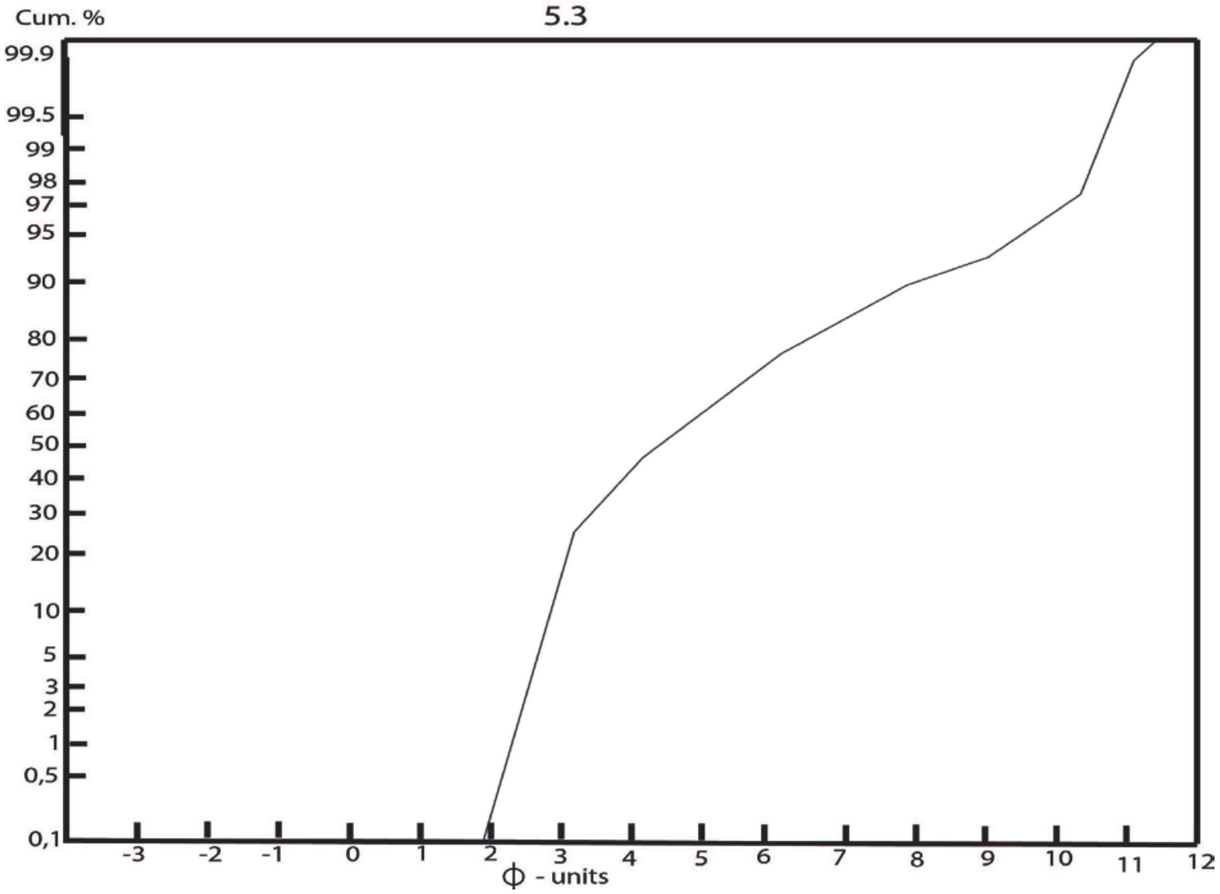
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Φ - units



5.3
Cum. %
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99.5
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80
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40
30
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10
5
3
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1
0,5
0,1
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-1
0
1
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3
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7
8
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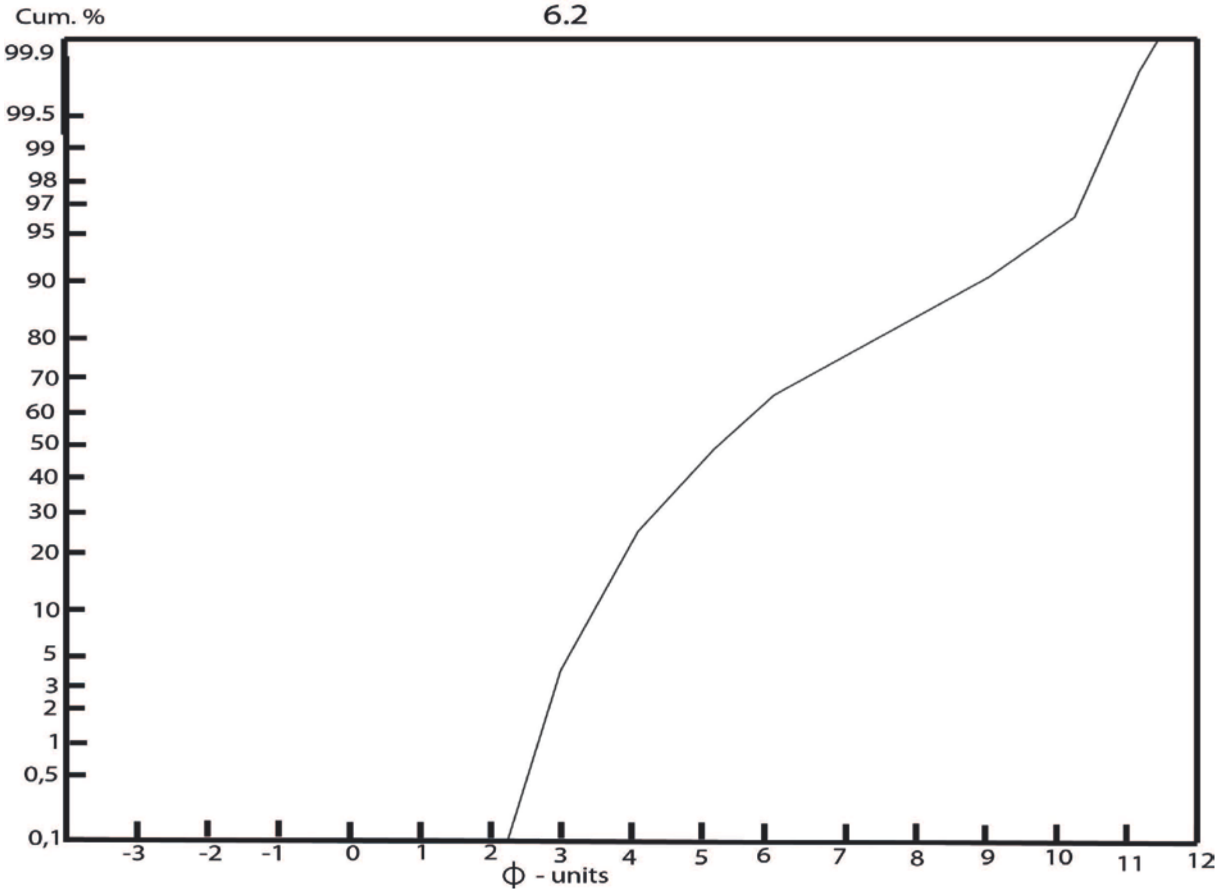
11
12
Φ - units


Cum. %
6.2
99.9
99.5
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97
95
90
80
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50
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0,5
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-1
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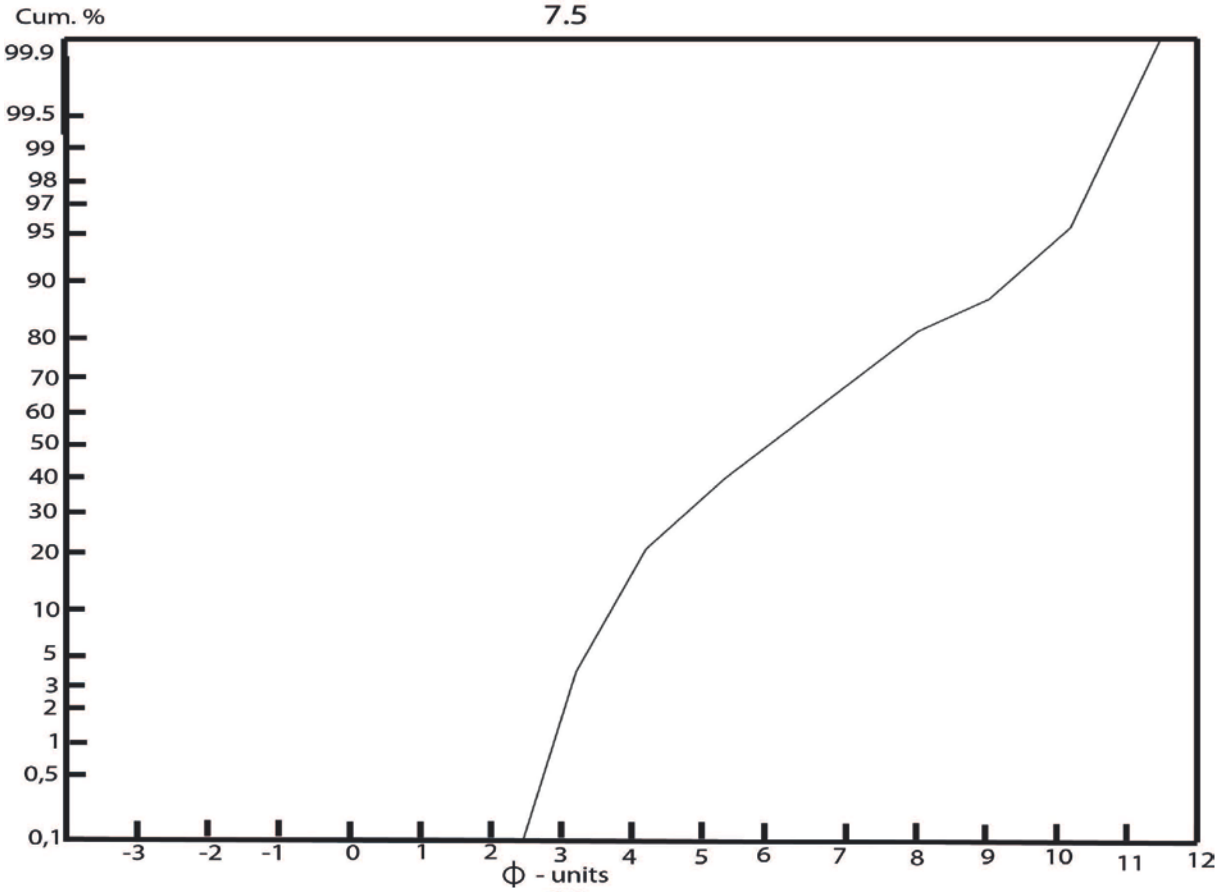
11
12
Φ - units


Cum. %
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80
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40
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3
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0
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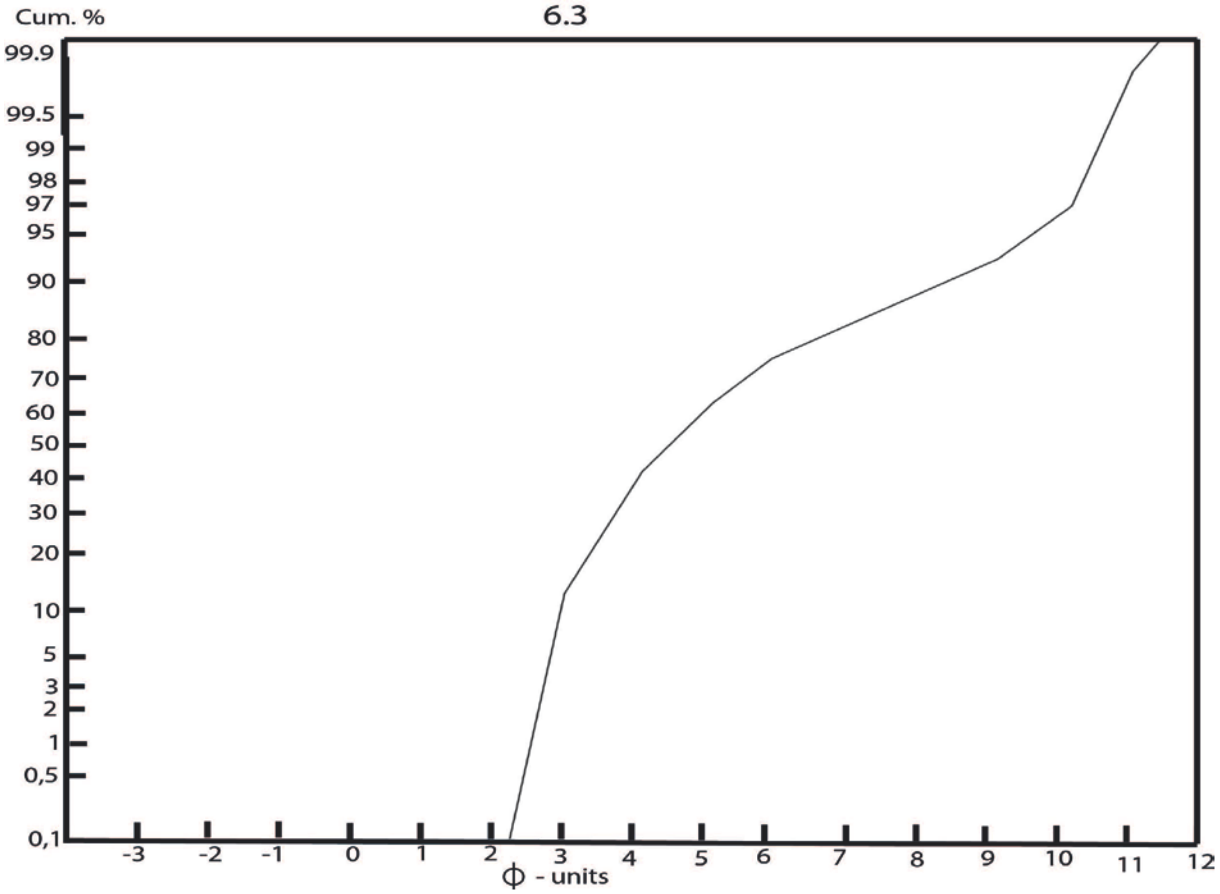
6
7
8
9
10
11
12
ϕ - units


Cum. %
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20
10
5
3
2
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0,5
0,1
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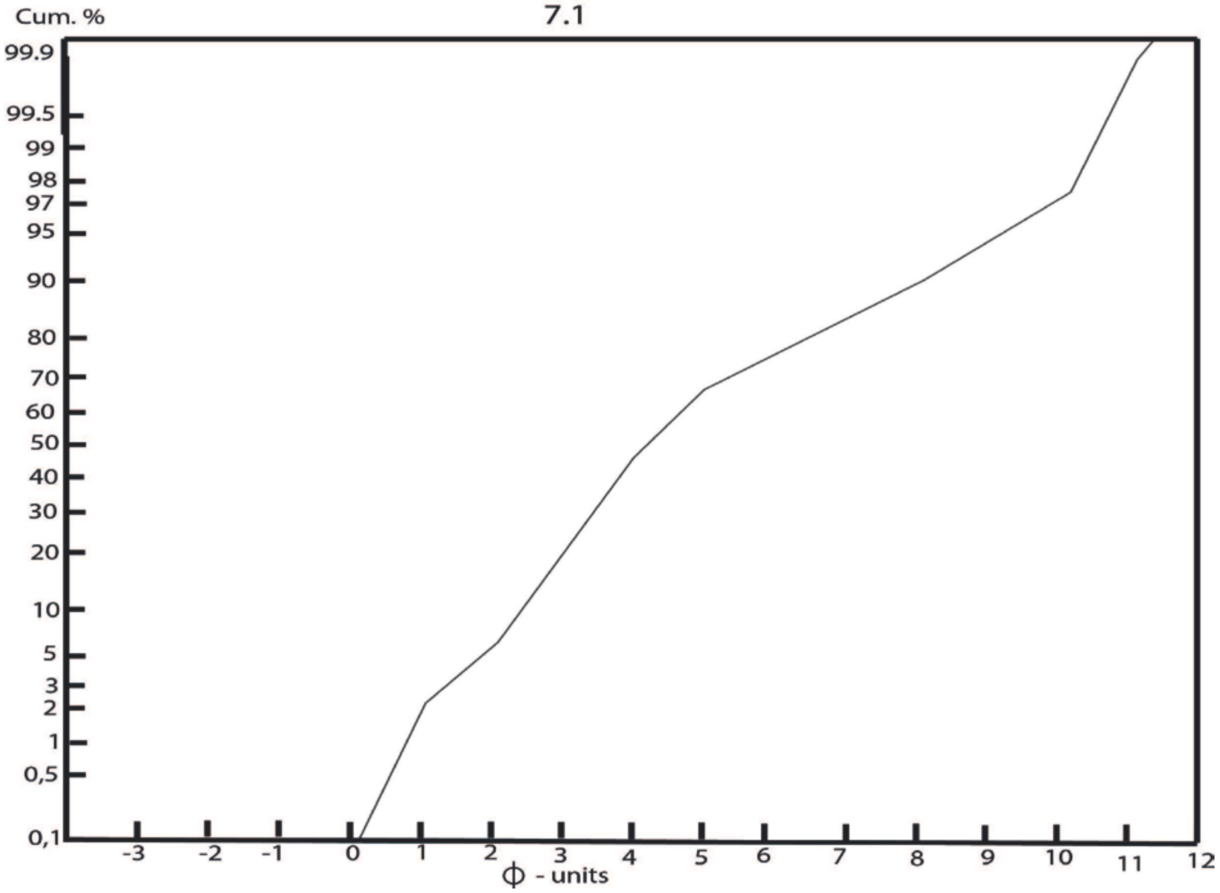
9
10
11
12
ϕ - units

7.1


Cum. %
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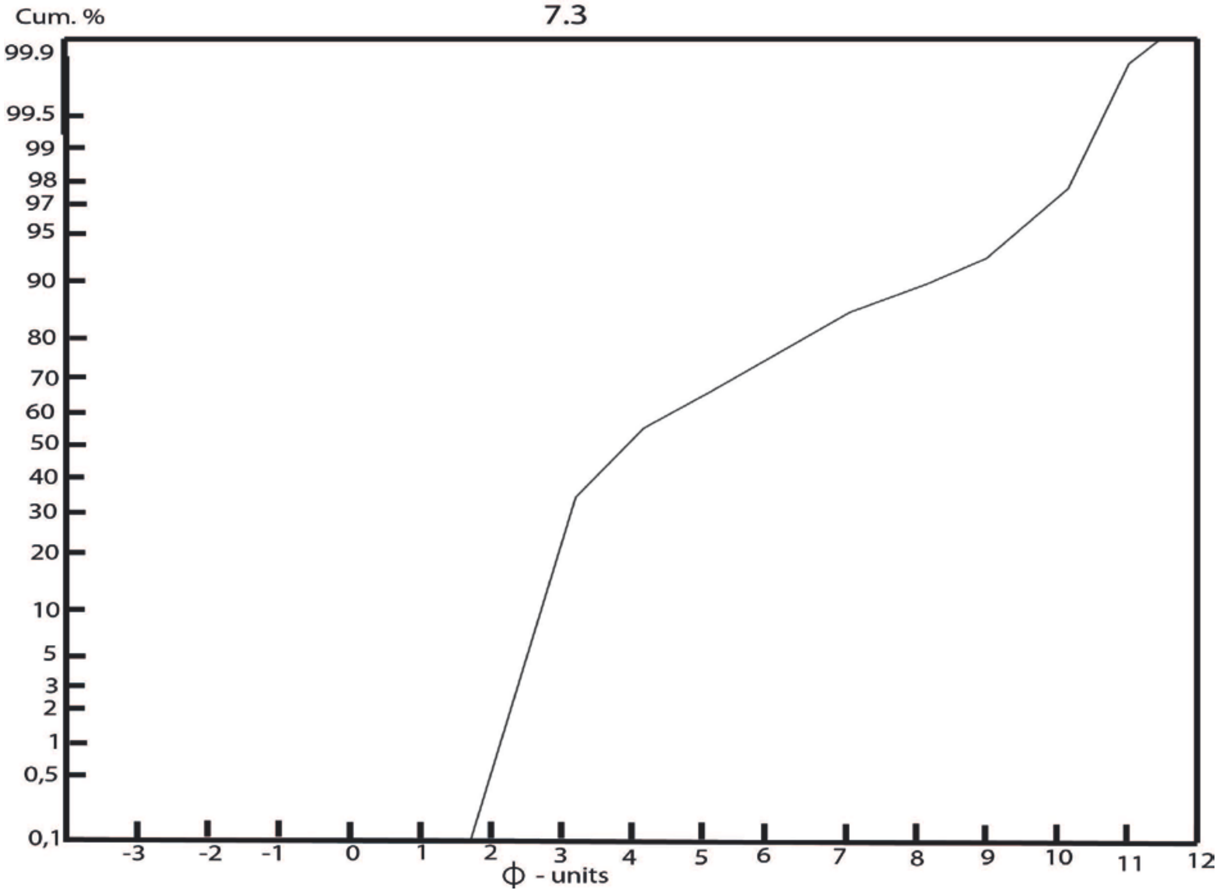
Φ - units

7.3


Cum. %
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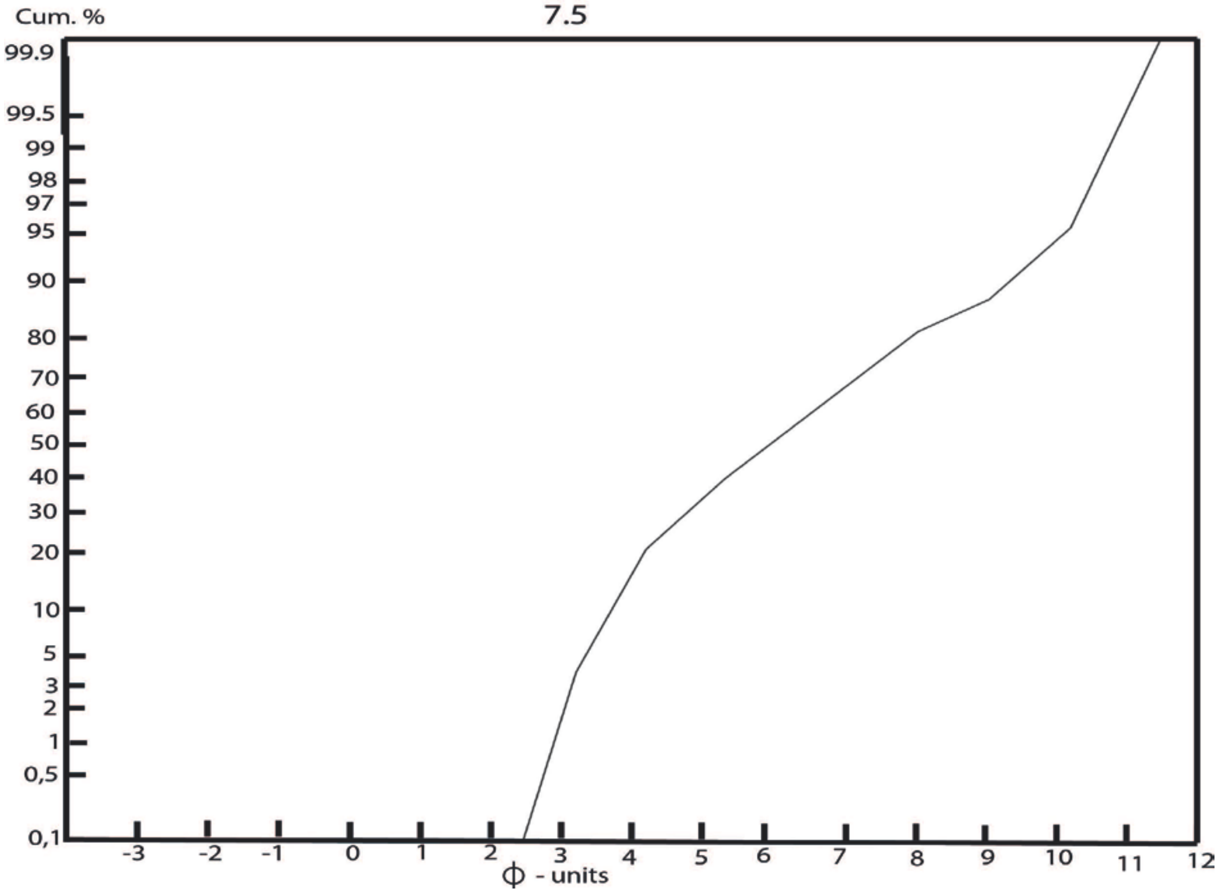
Φ - units



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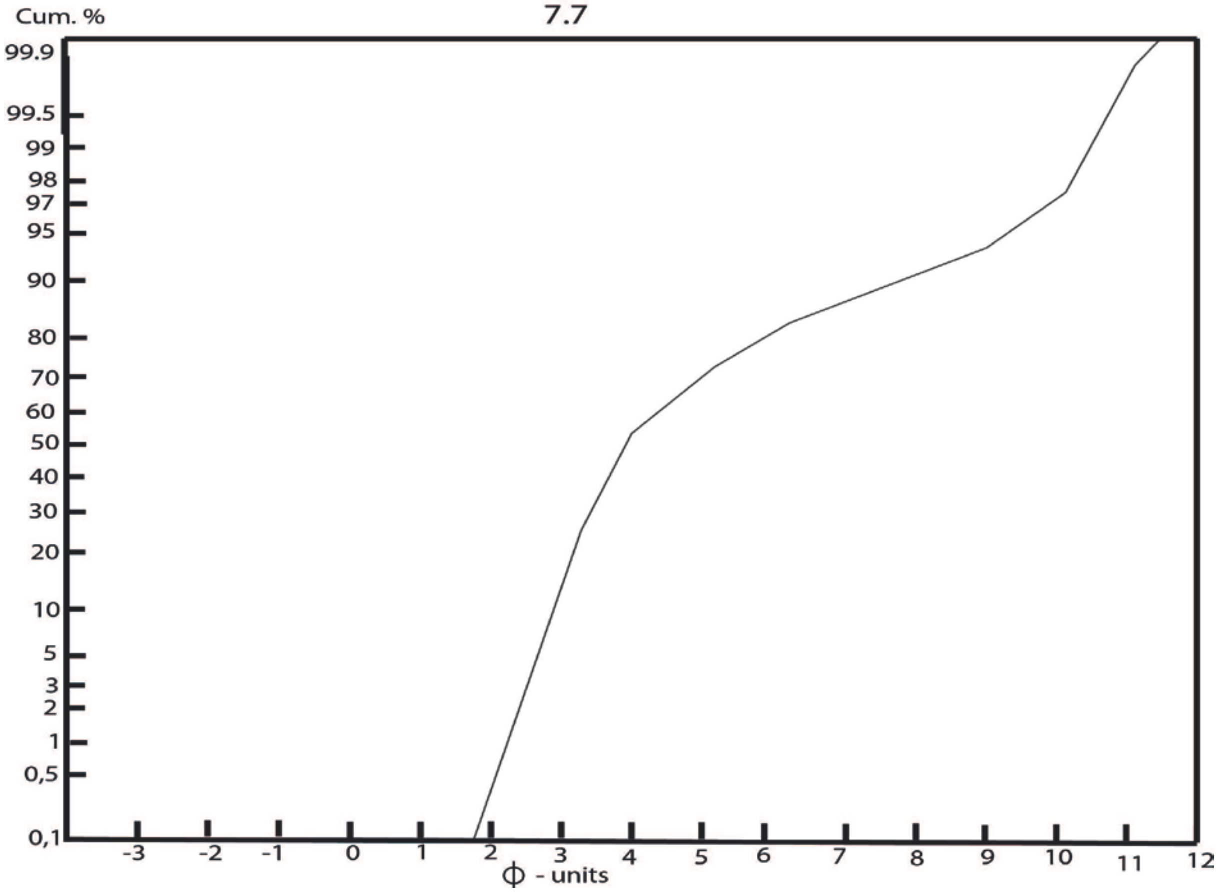
Φ - units



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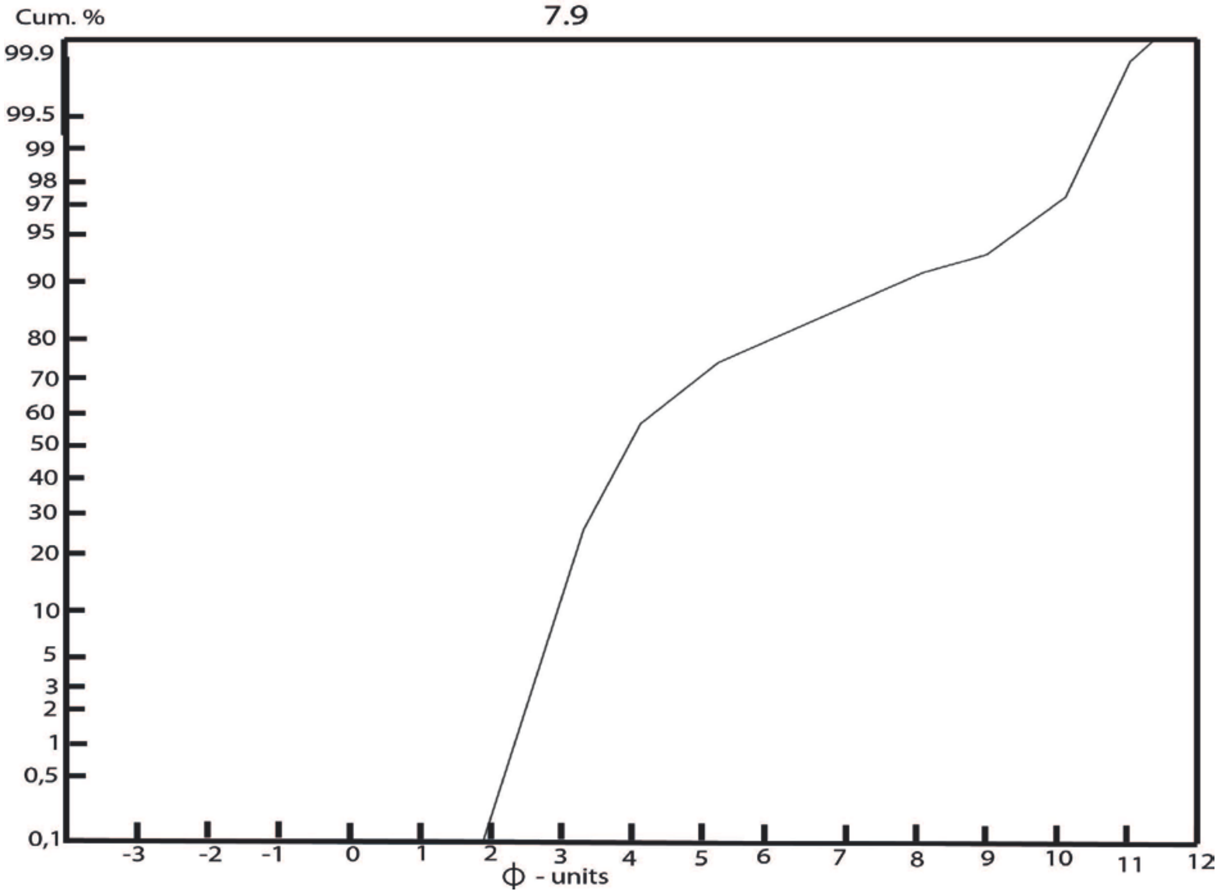
Φ - units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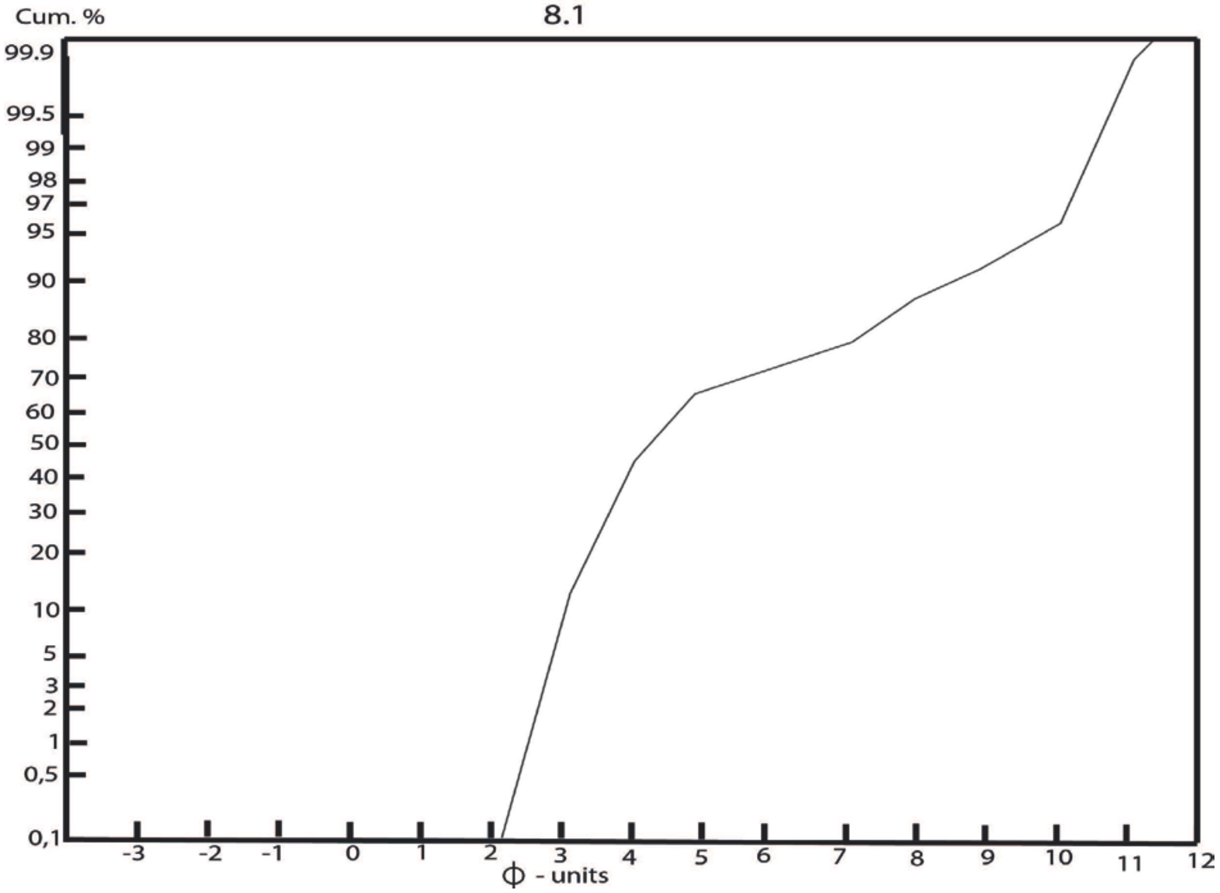
ϕ - units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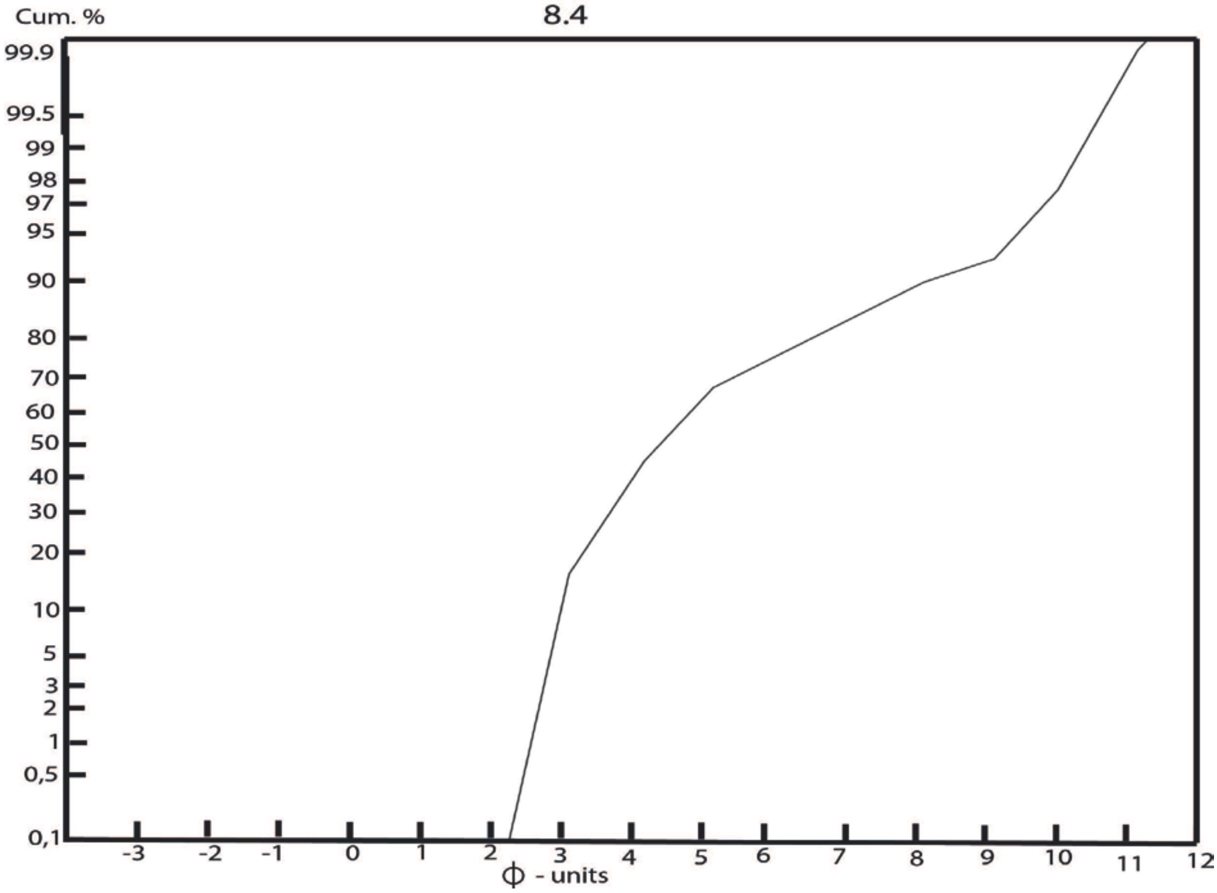
12
ϕ - units

8.4


Cum. %
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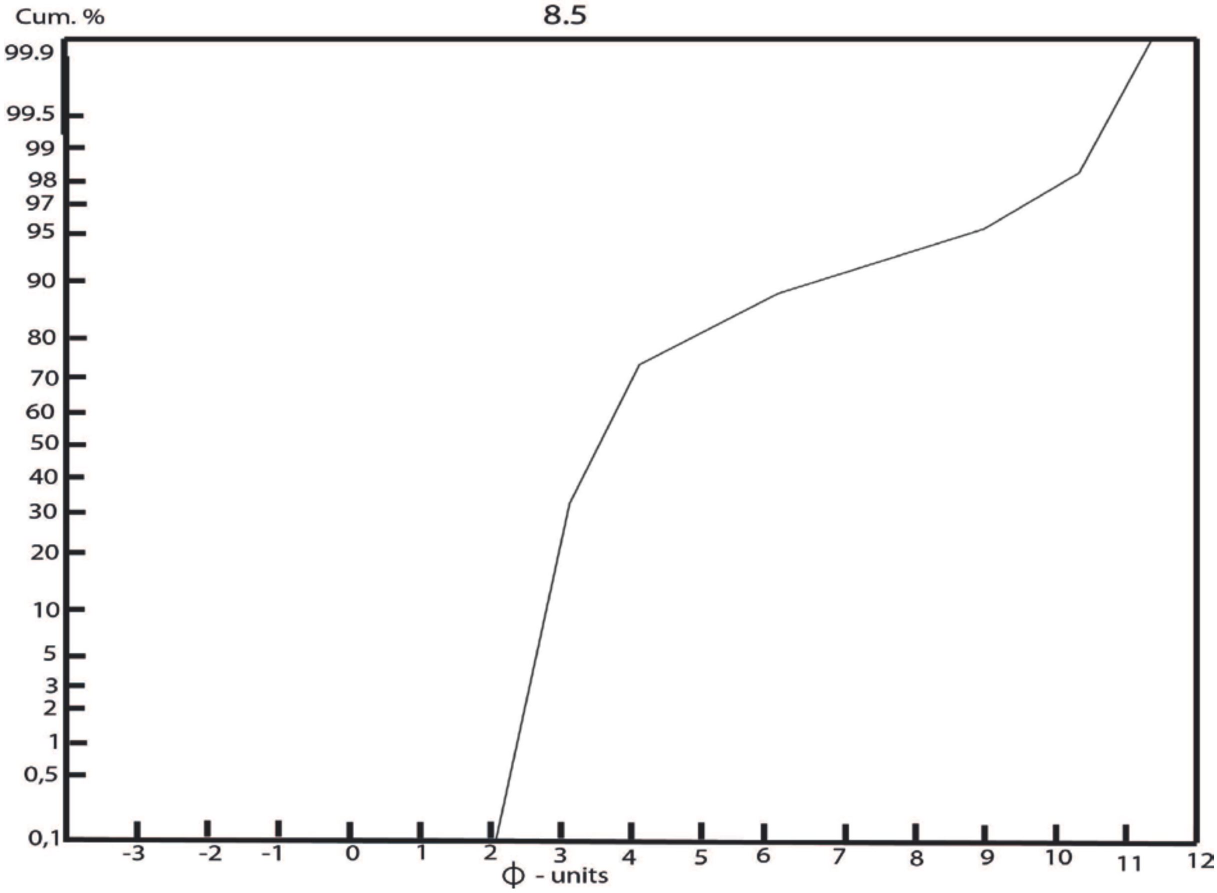
12
Φ - units

8.5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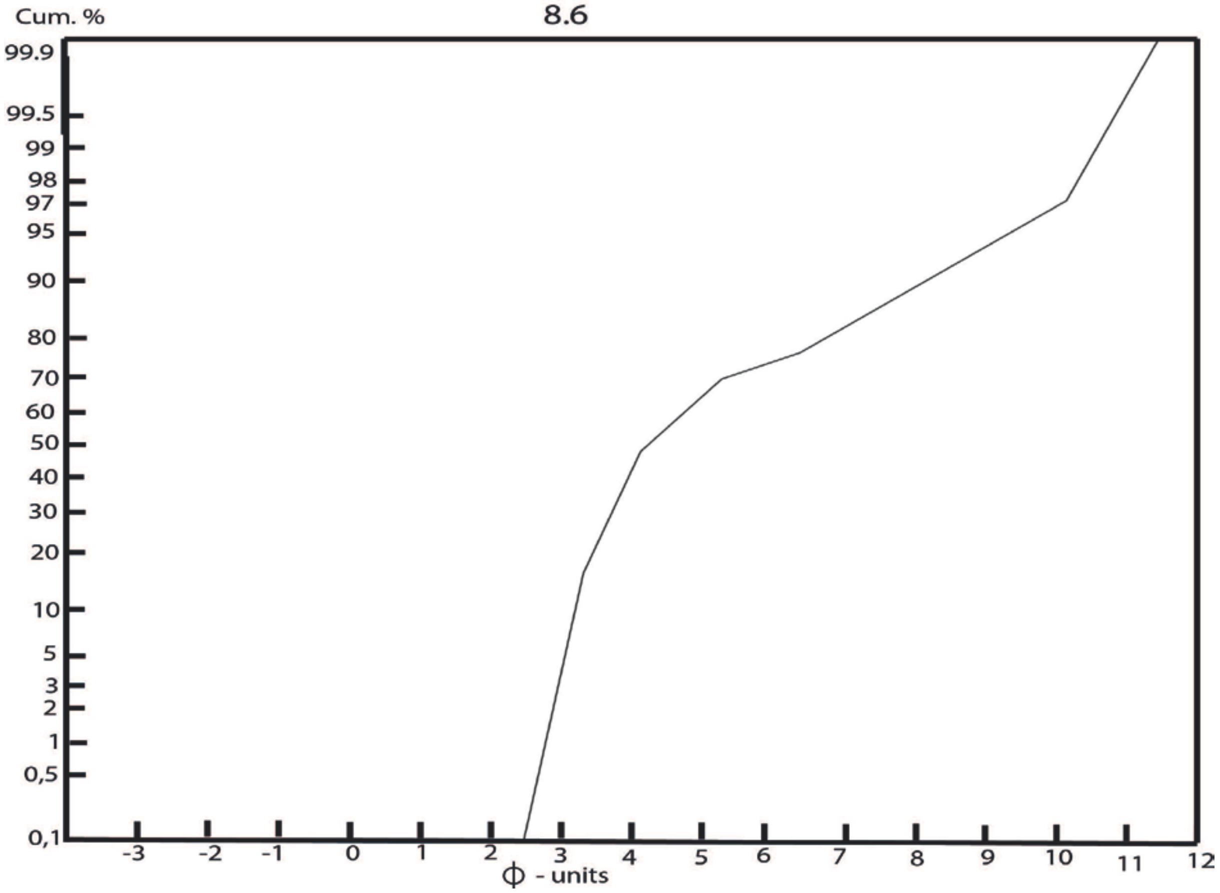
Φ - units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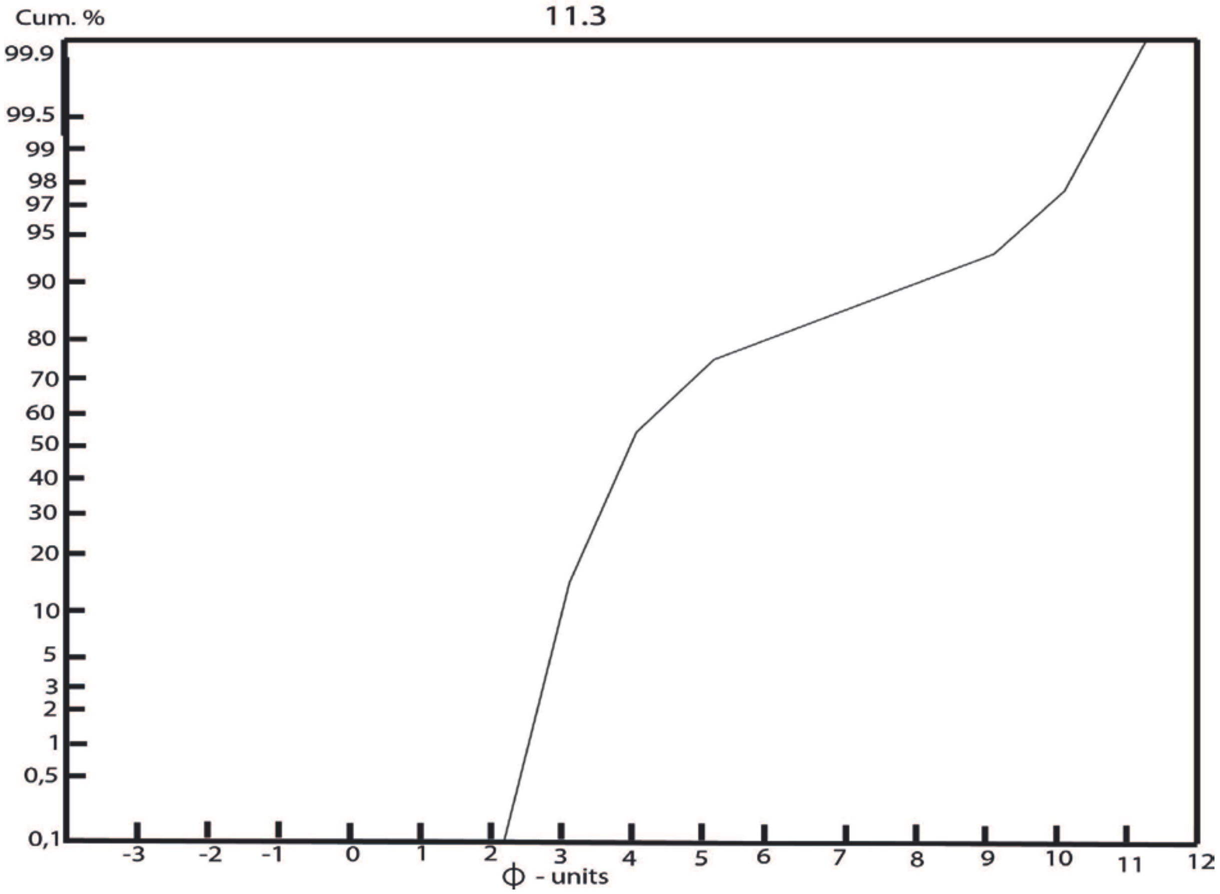
Φ - units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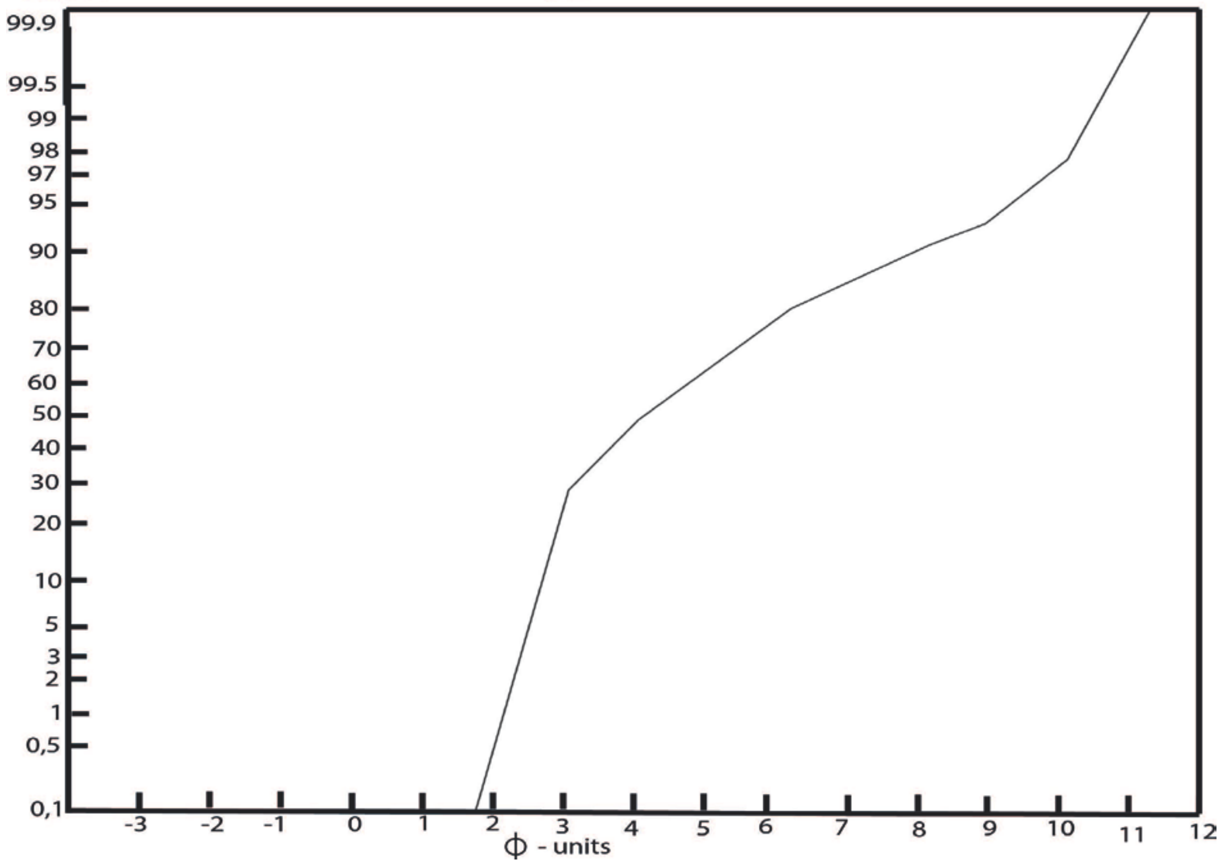
12
Φ - units

9.2


Cum. %
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0,1
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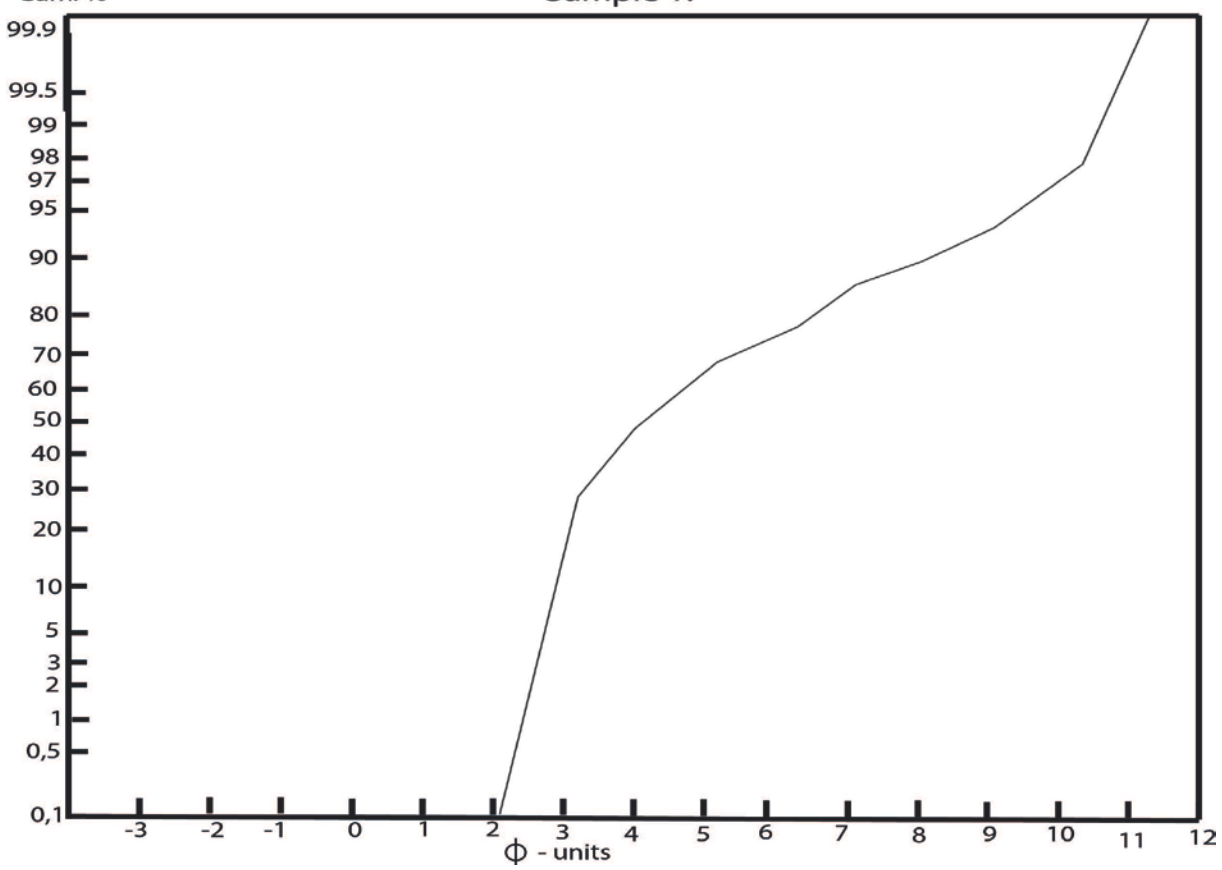
11
12
ϕ - units

Sample 1.


Cum. %
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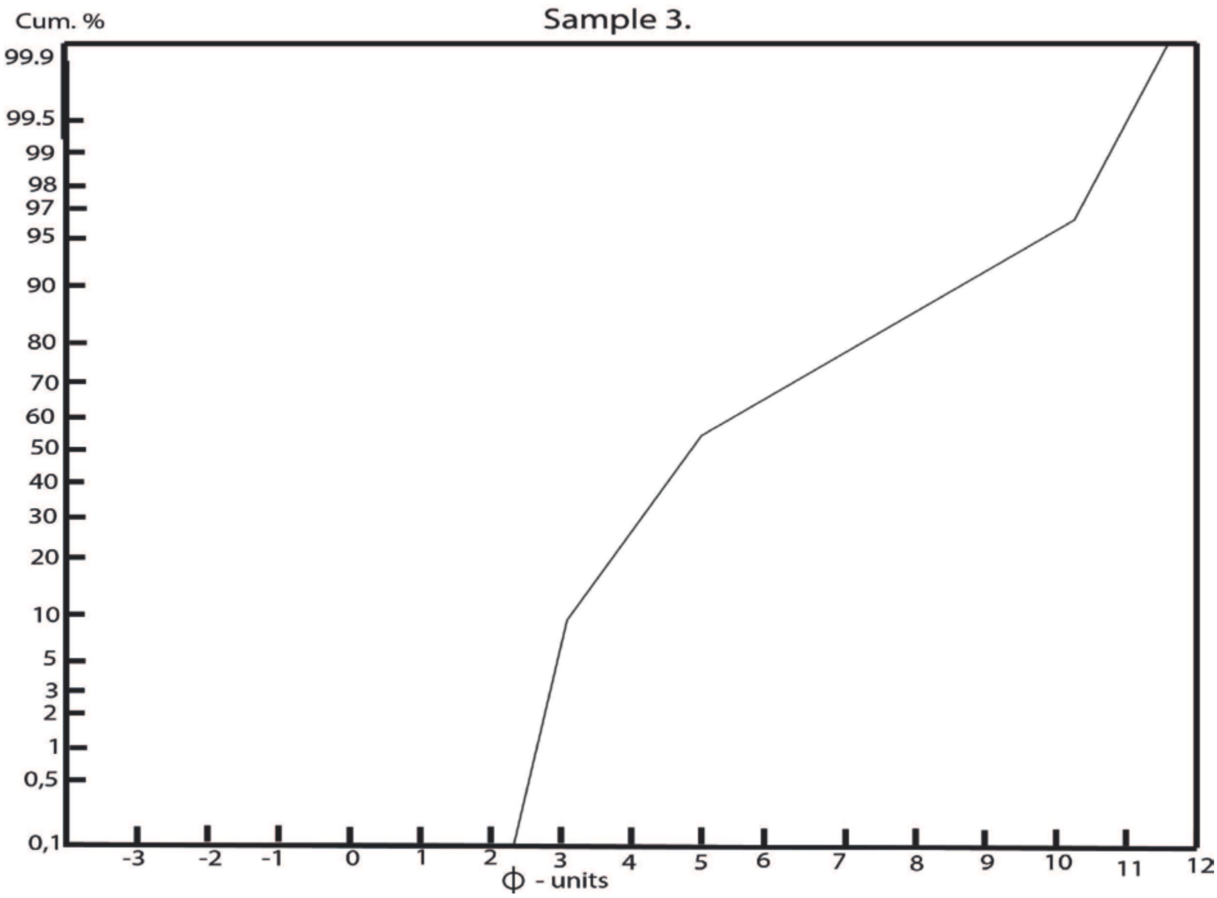
ϕ - units


Cum. %
Sample 3.
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9
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11
12
ϕ - units

Appendix H:

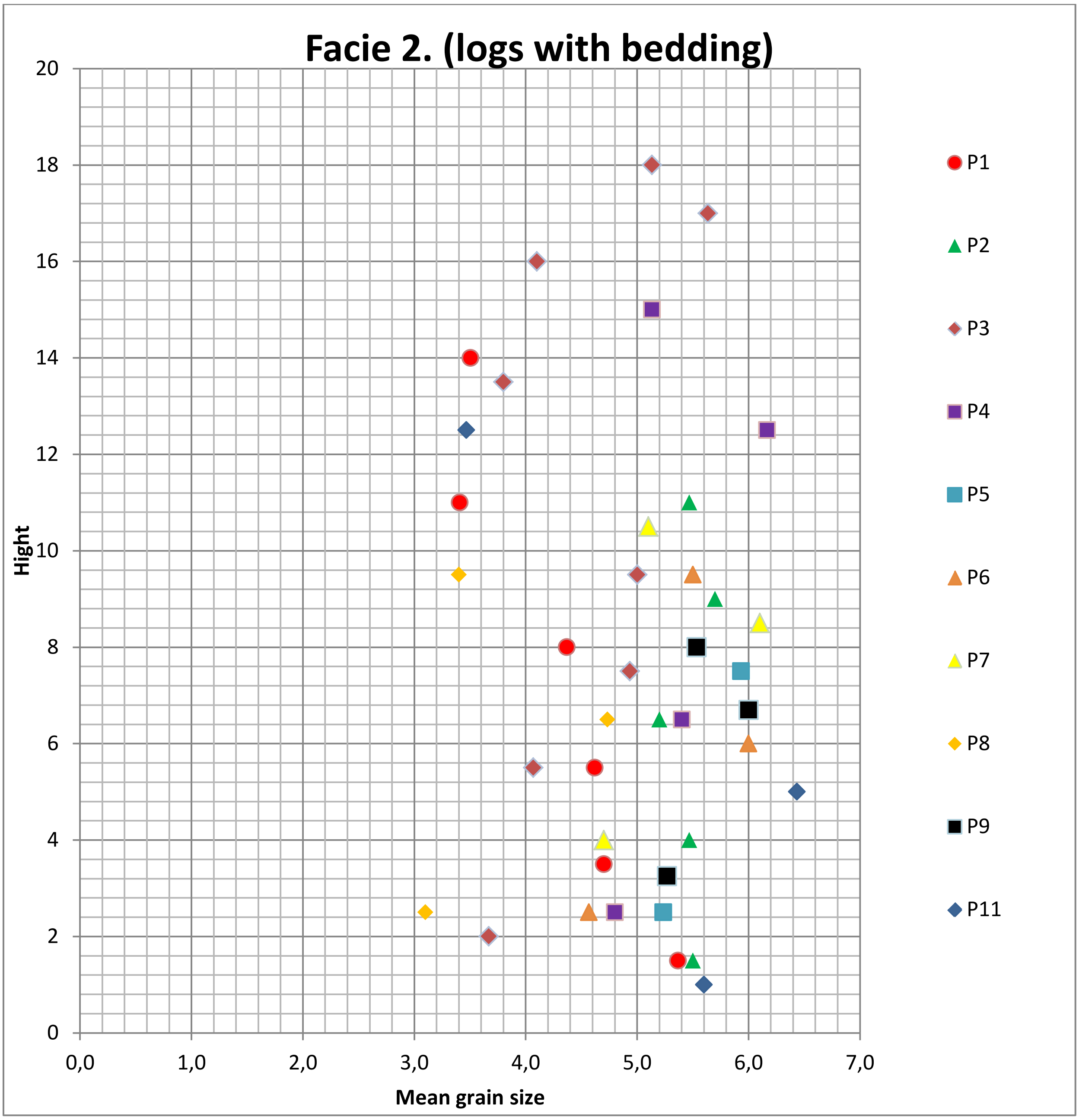

Figure 1: Mean grain size with depth for facie 2.

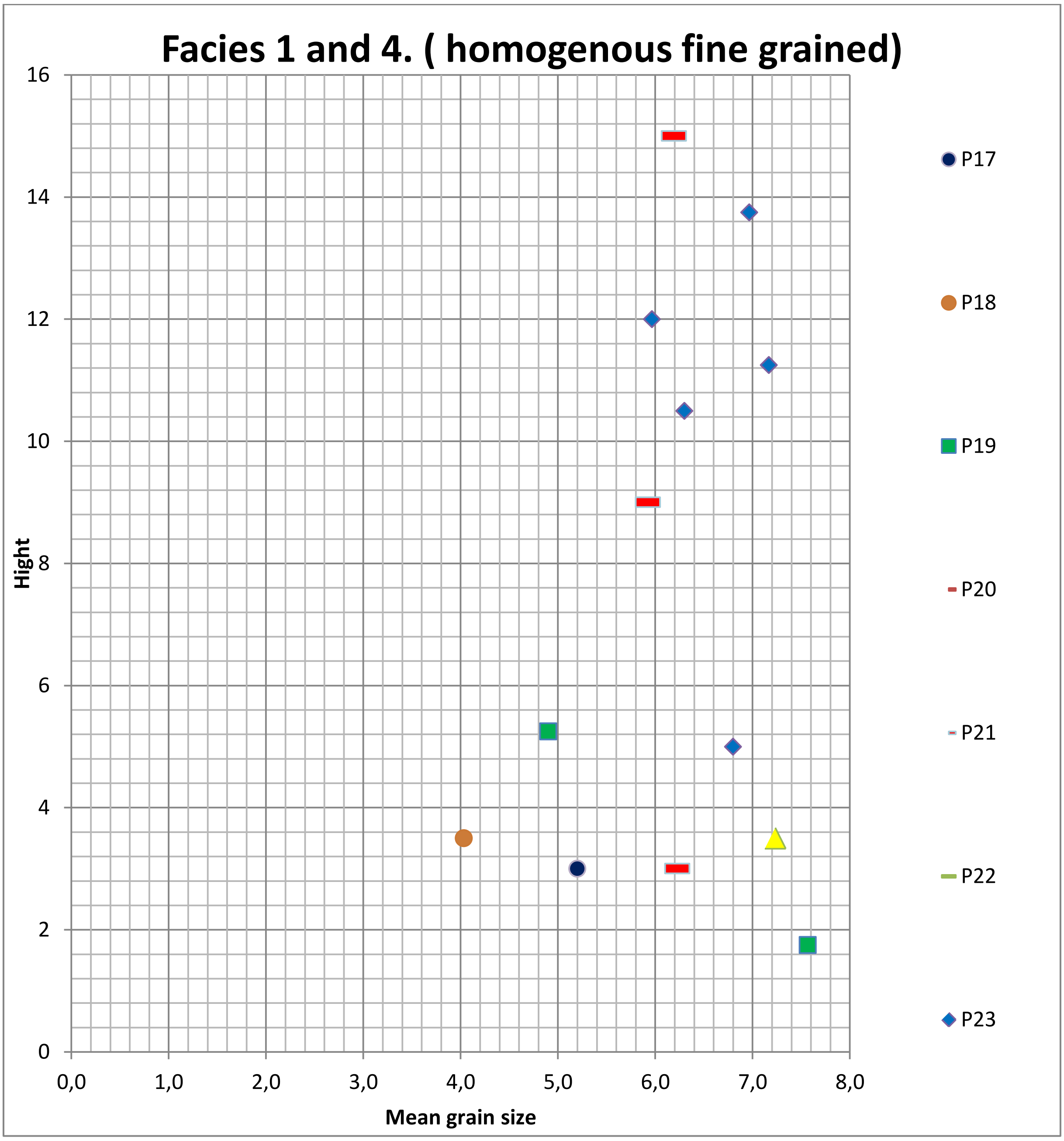

Figure 2: Mean grain size with depth for facies 1 and 4.

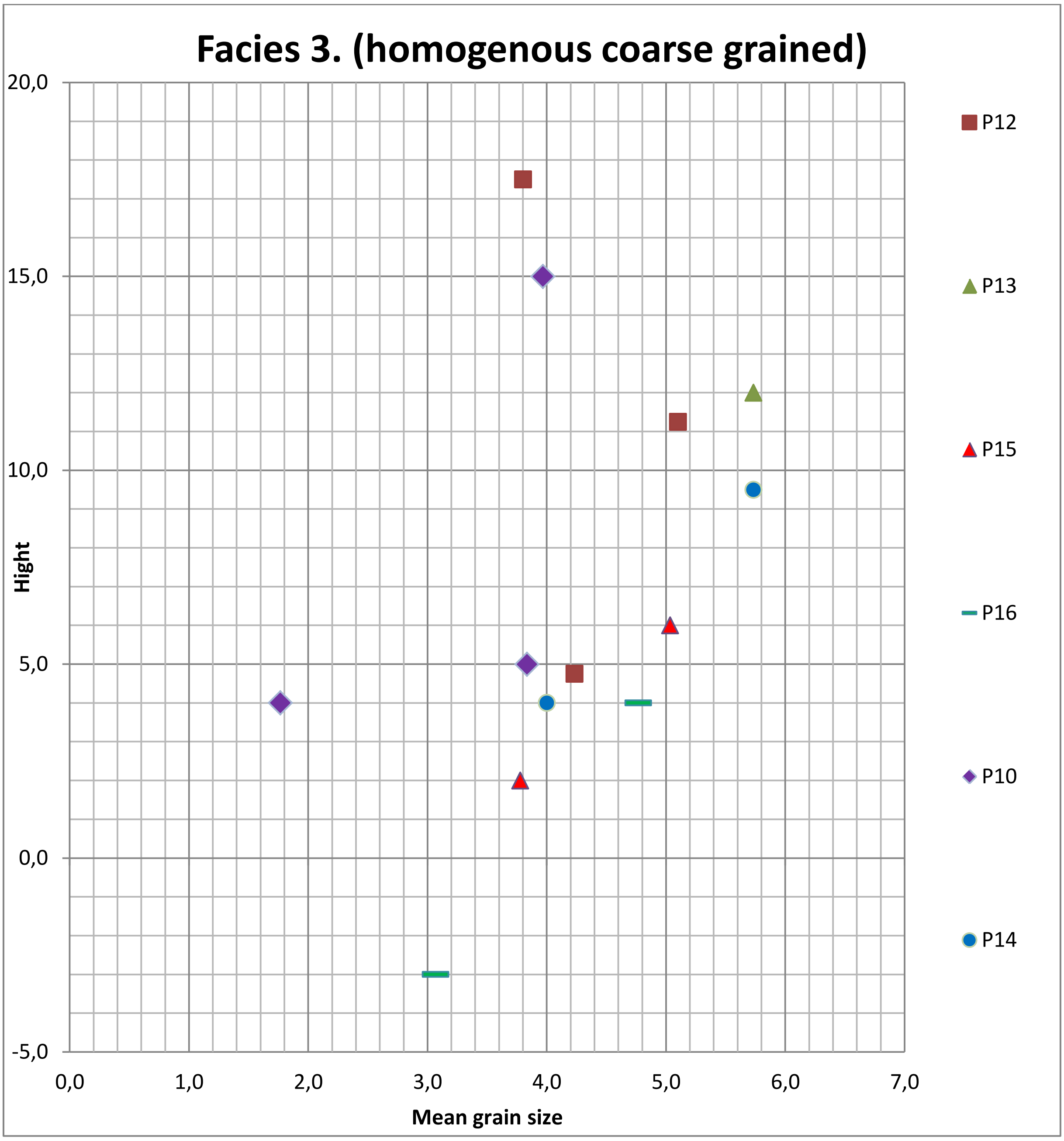

Figure 3: Mean grain size with depth for facie 3.

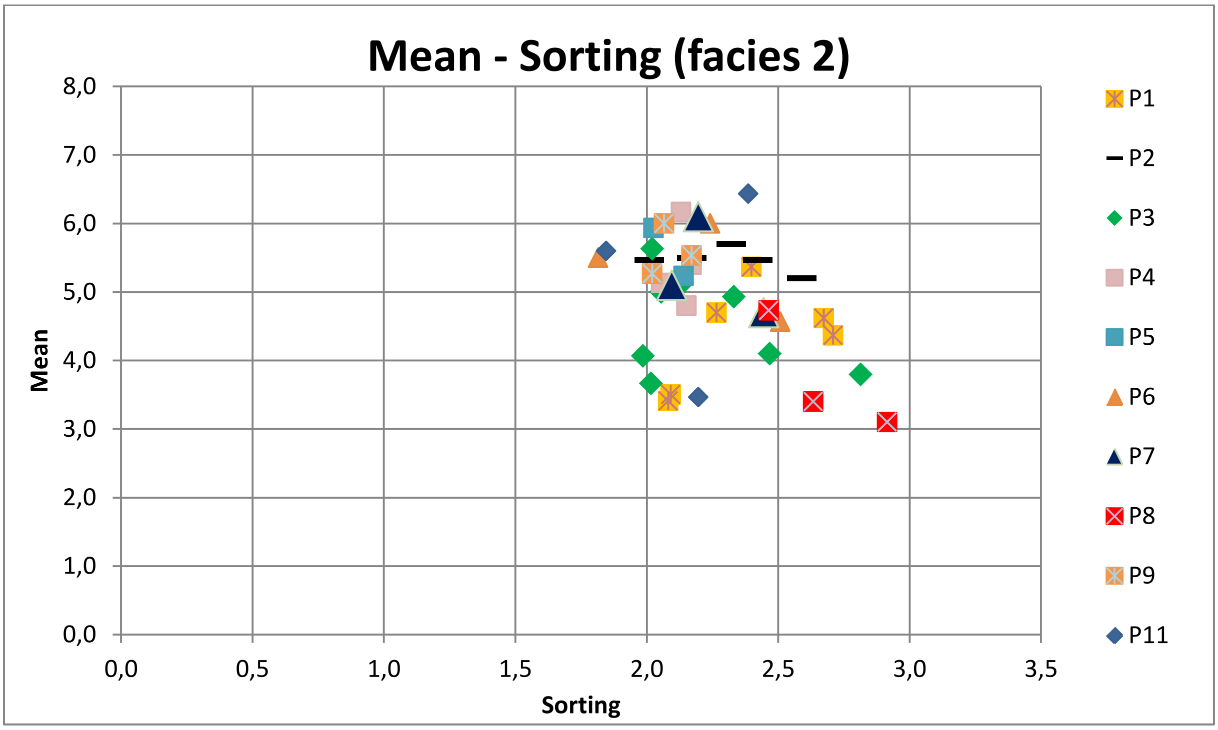

Figure 4: Relationship between mean and sorting for facies 2.

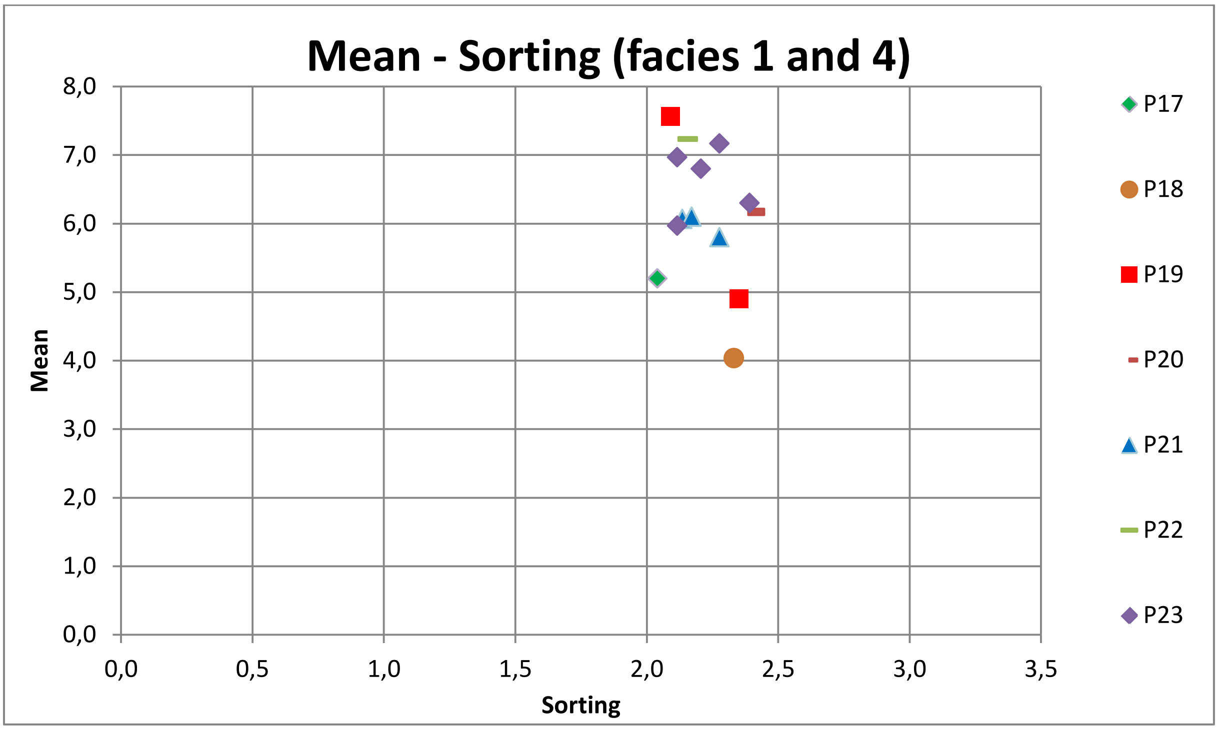

Figure 5: Relationship between mean and sorting for facies 1 and 4.

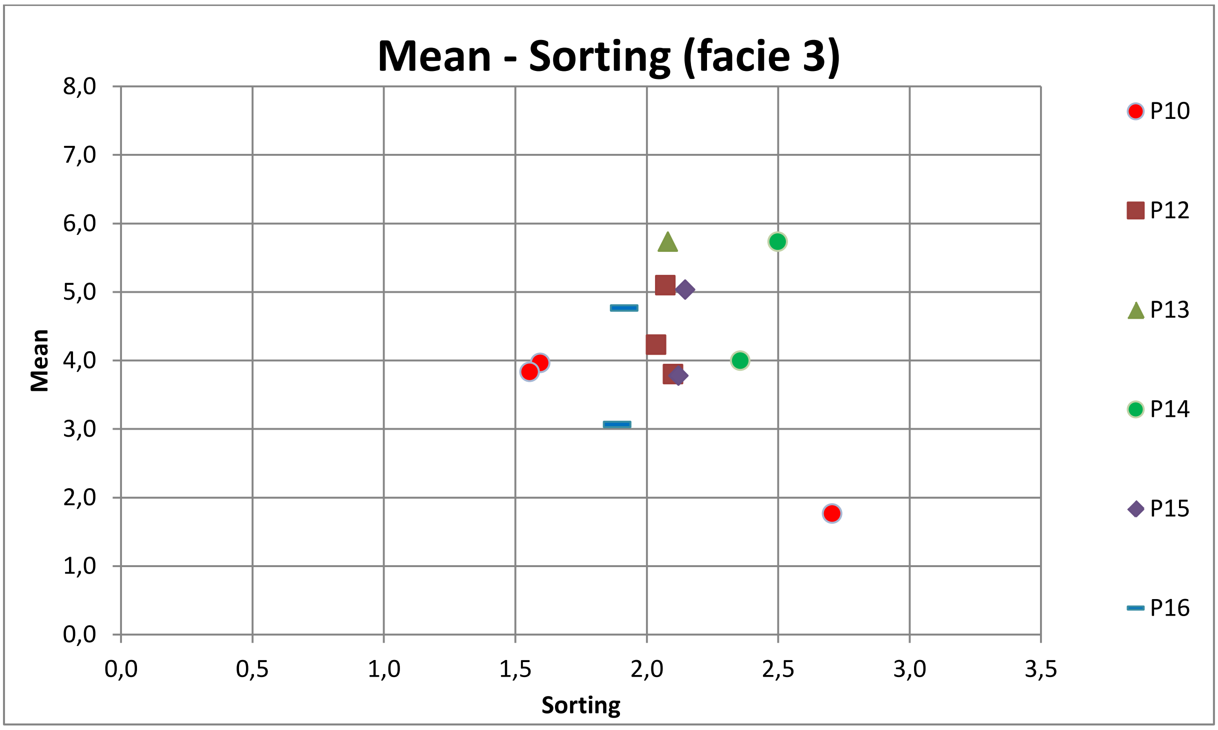

Figure 6: Relationship between mean and sorting for facie 3.

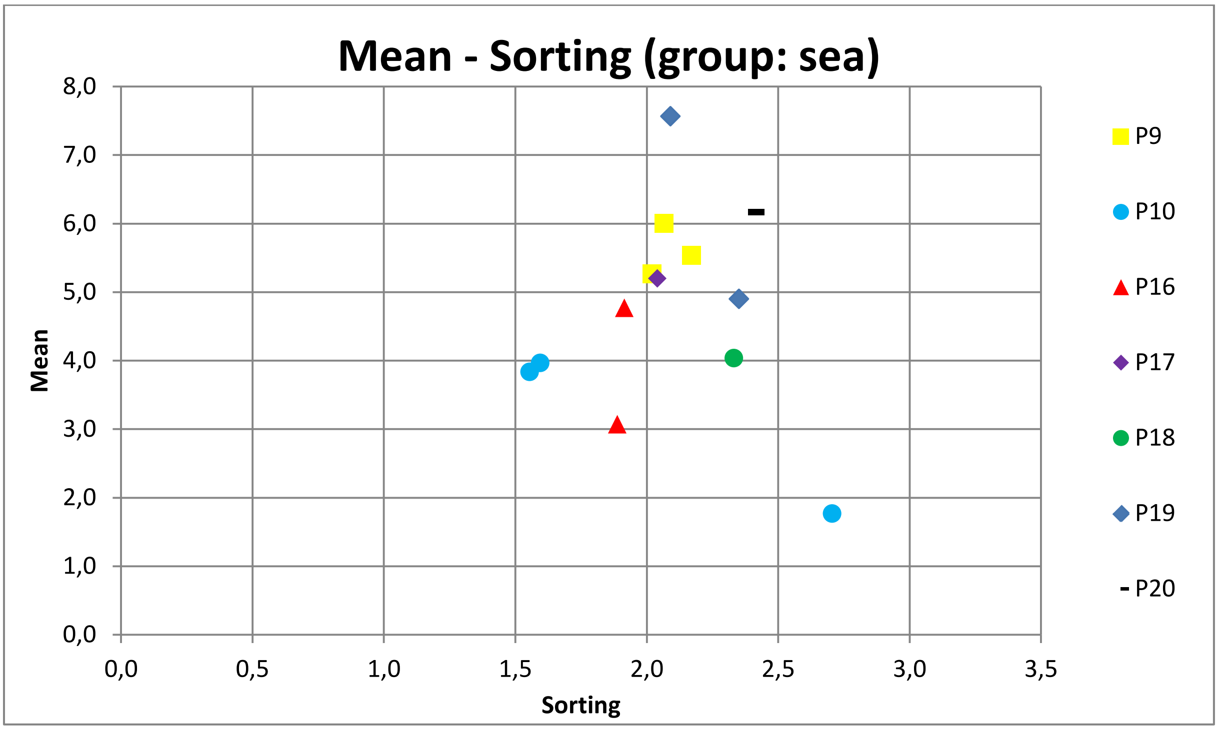

Figure 7: Relationship between mean and sorting for group sea.

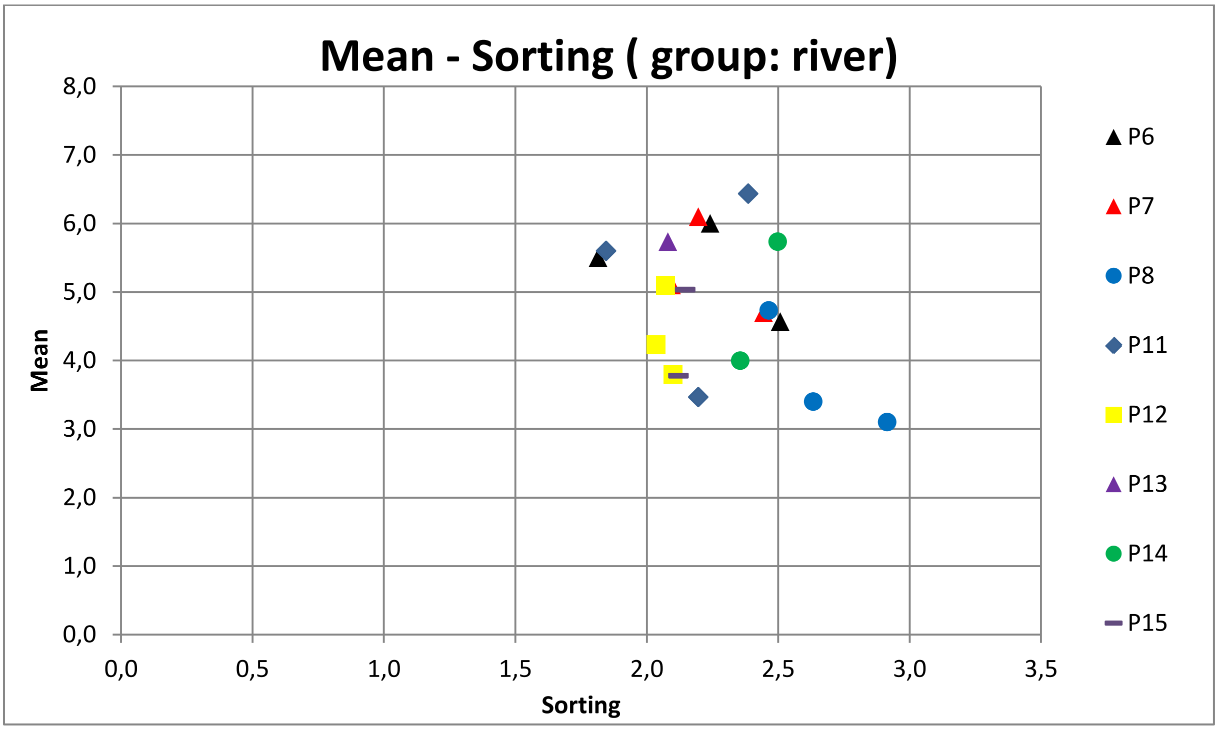

Figure 8: Relationship between mean and sorting for group river.

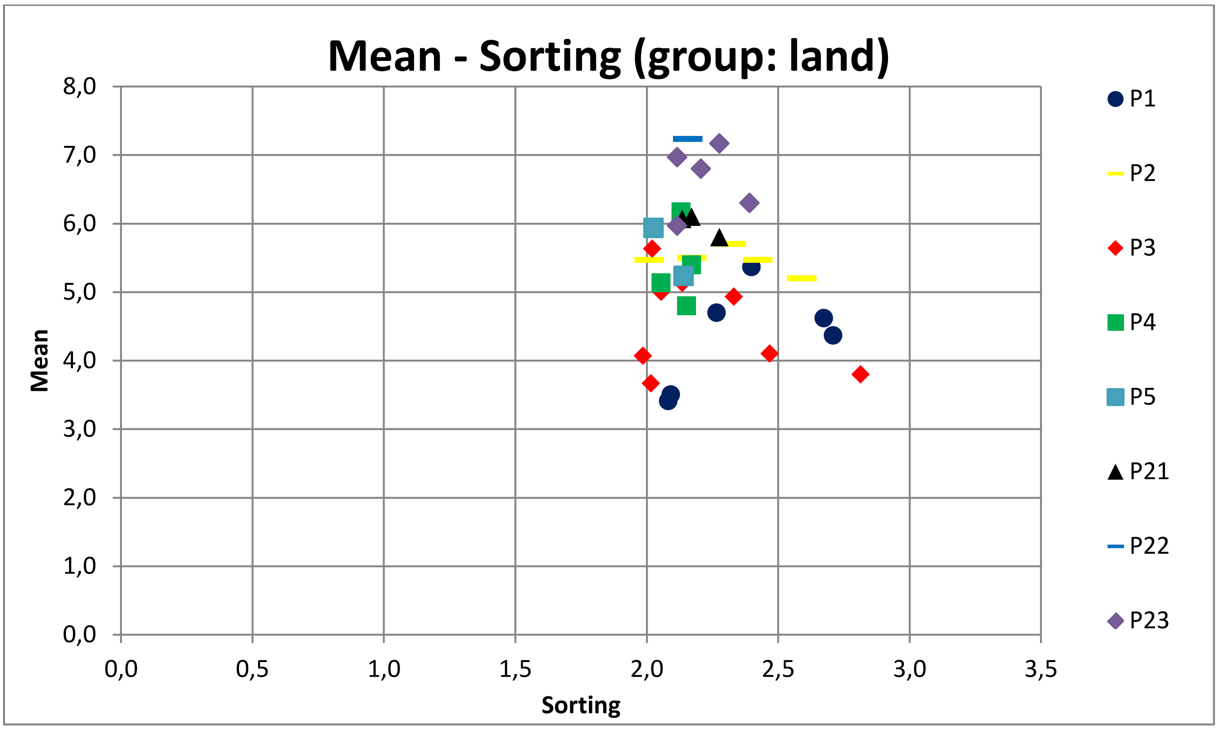

Figure 9: Relationship between mean and sorting for group land.

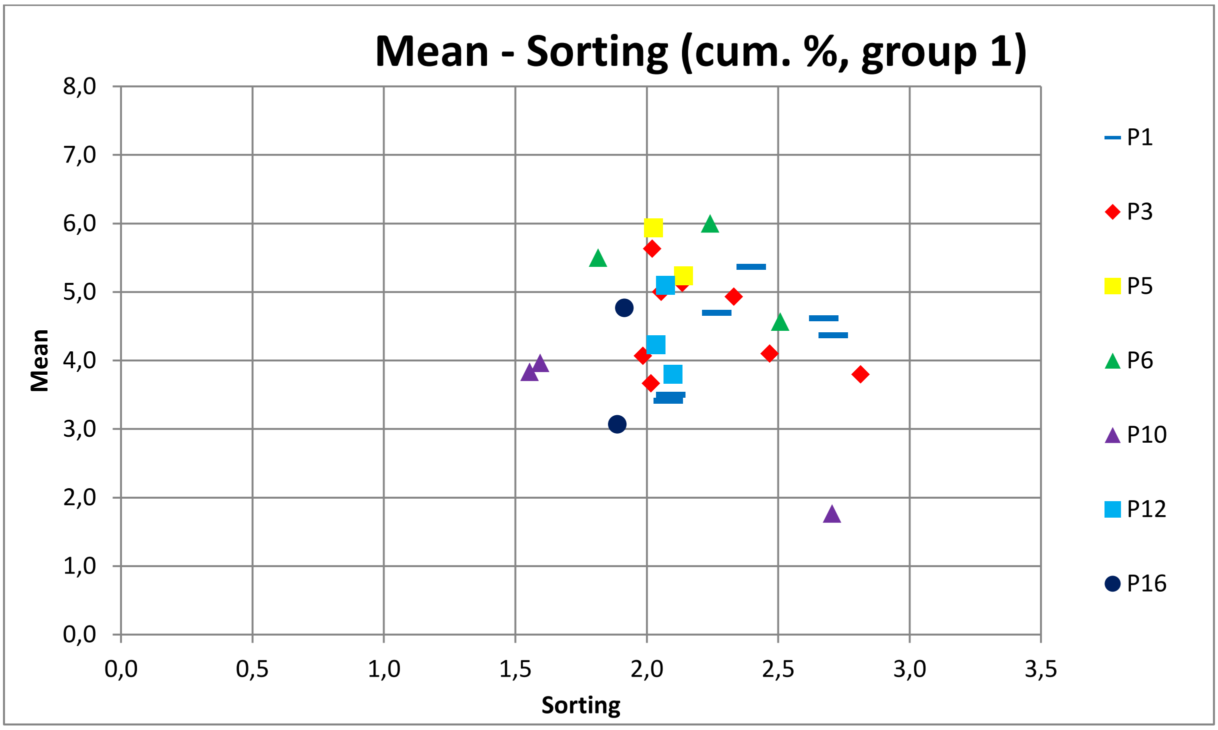

Figure 10: Relationship between mean and sorting for cum. % group 1.

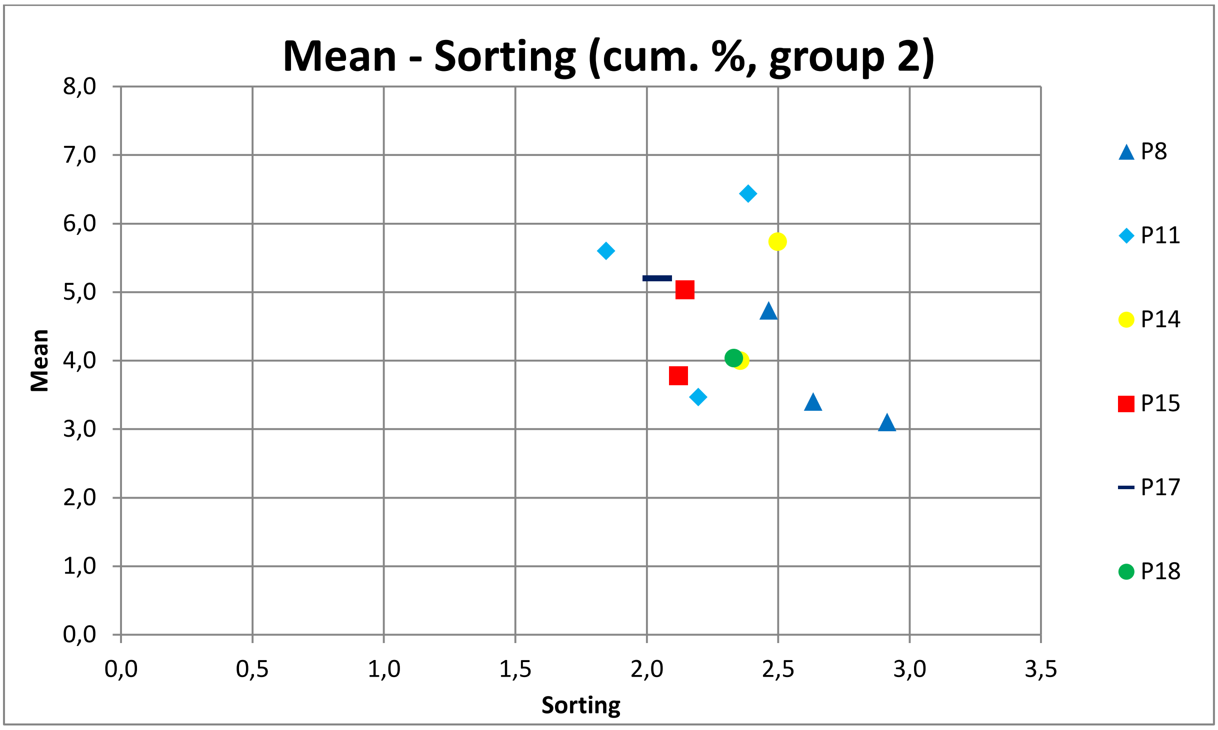

Figure 11: Relationship between mean and sorting for cum. % group 2.

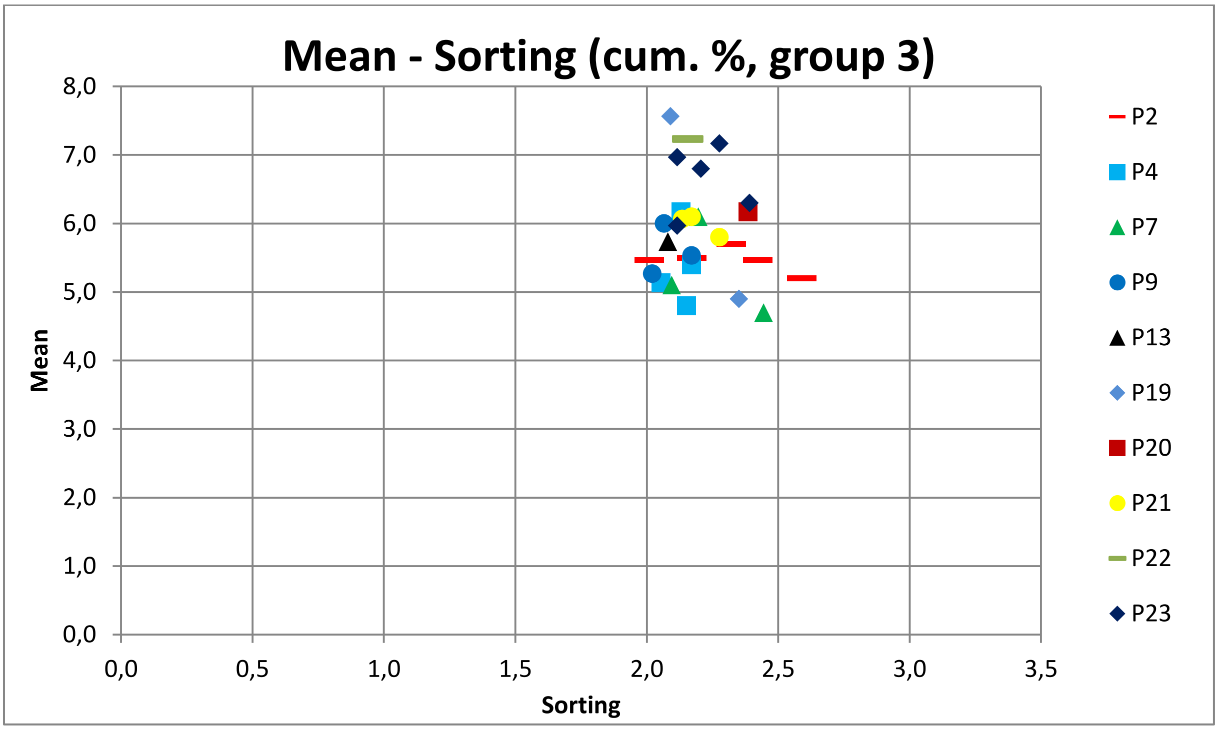

Figure 12: Relationship between mean and sorting for cum. % group 3.

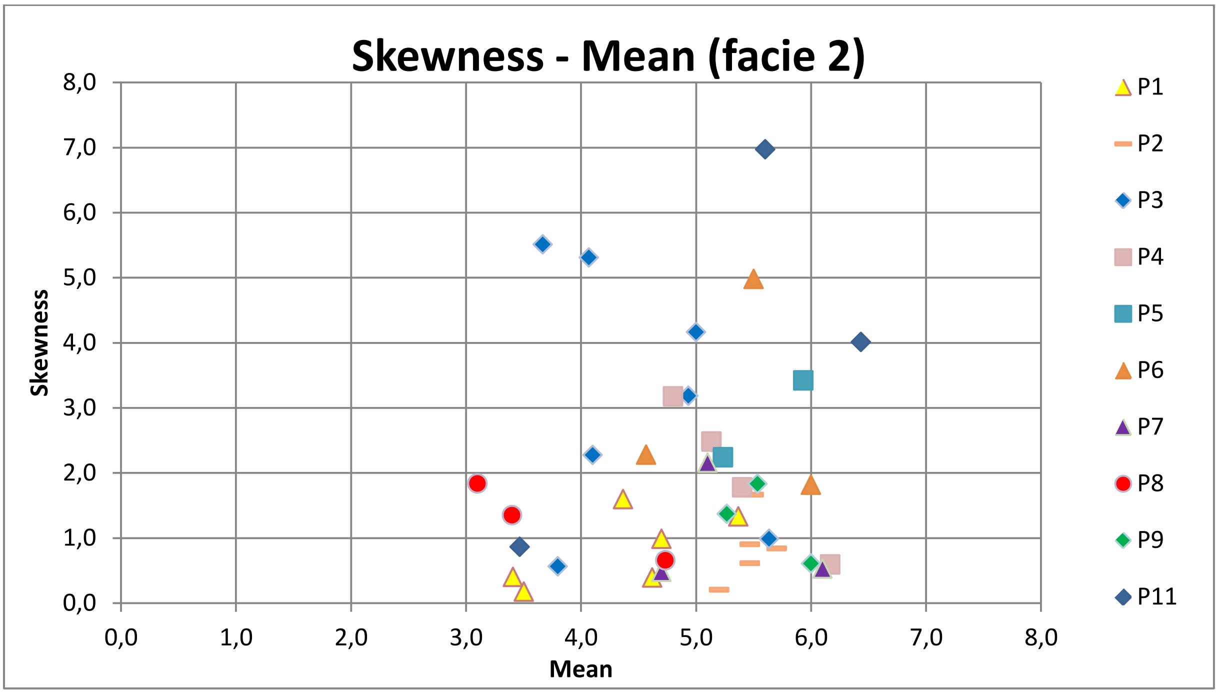

Figure 13: Relationship between skewness and mean for facie 2.

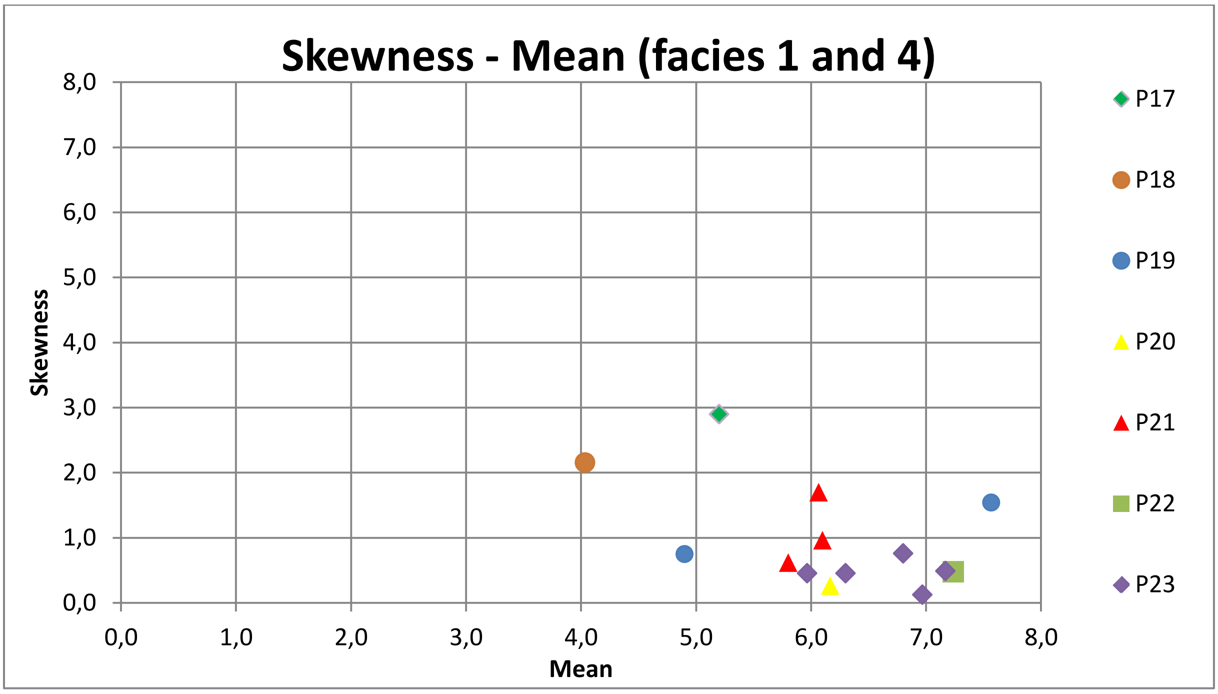

Figure 14: Relationship between skewness and mean for facies 1 and 4.

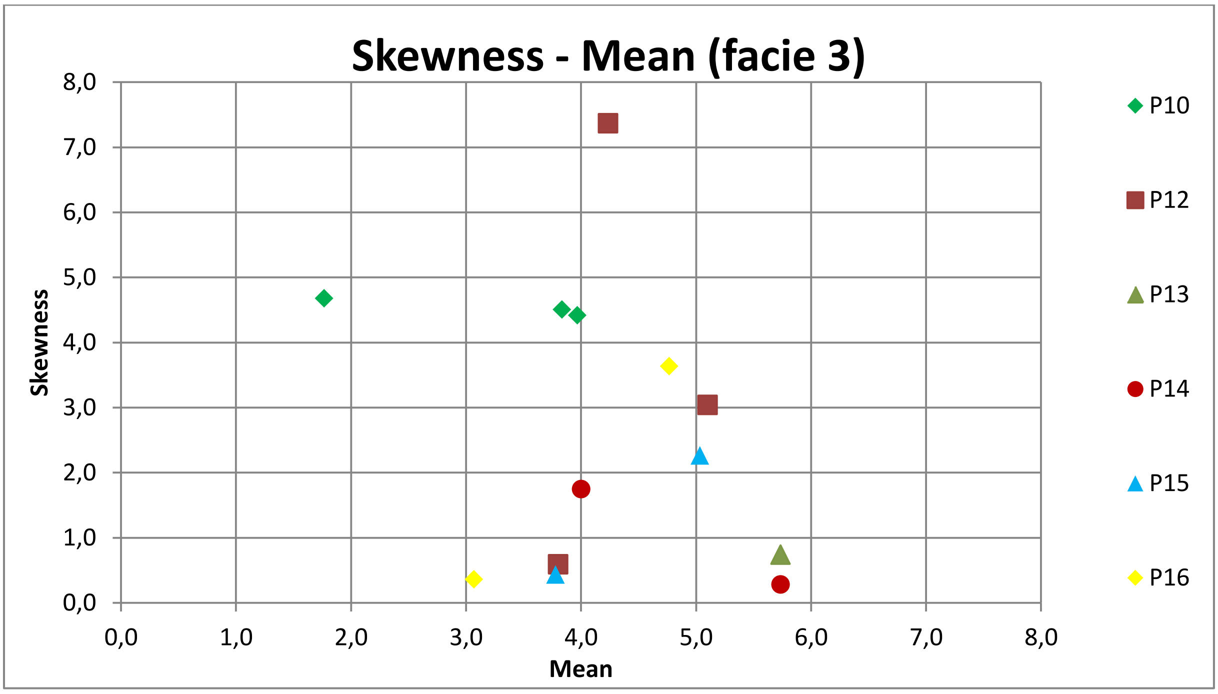

Figure 15: Relationship between skewness and mean for facie 3.

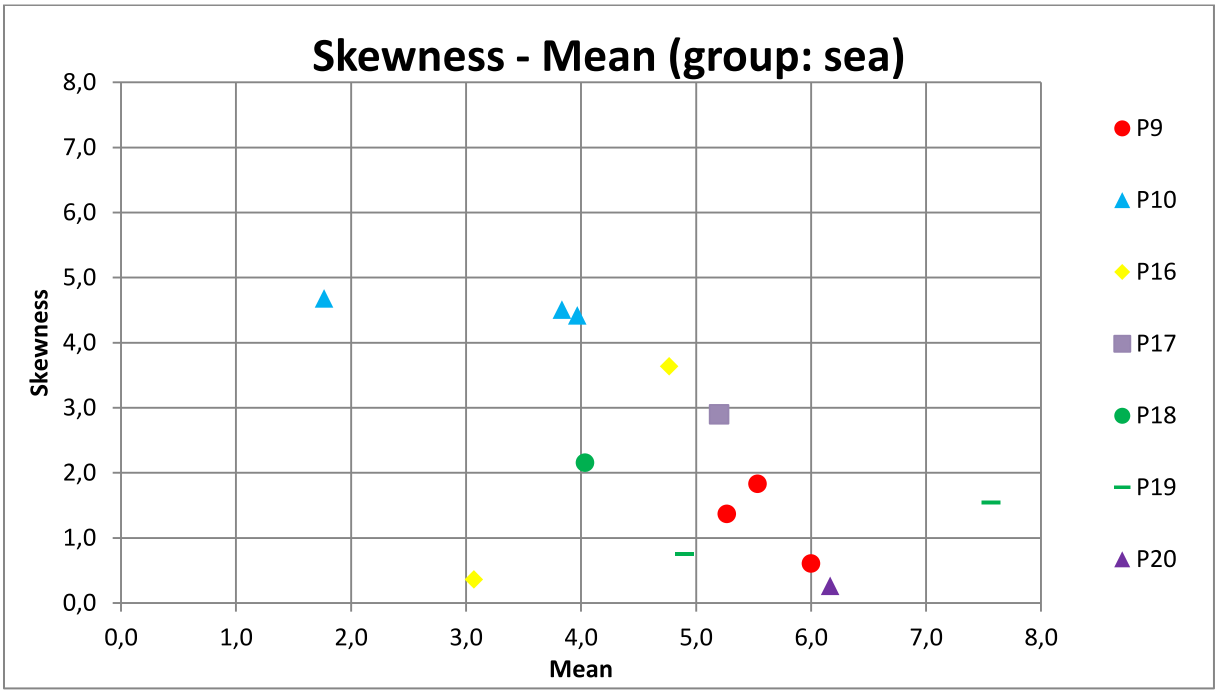

Figure 16: Relationship between skewness and mean for group sea.

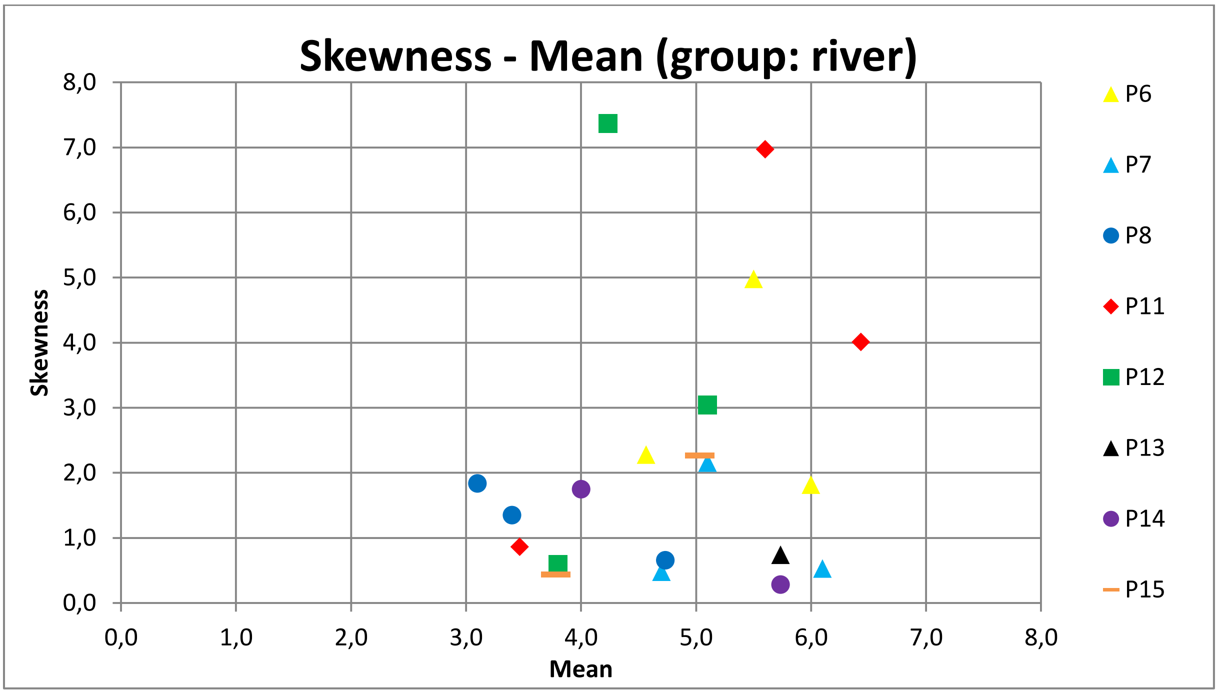

Figure 17: Relationship between skewness and mean for group river.

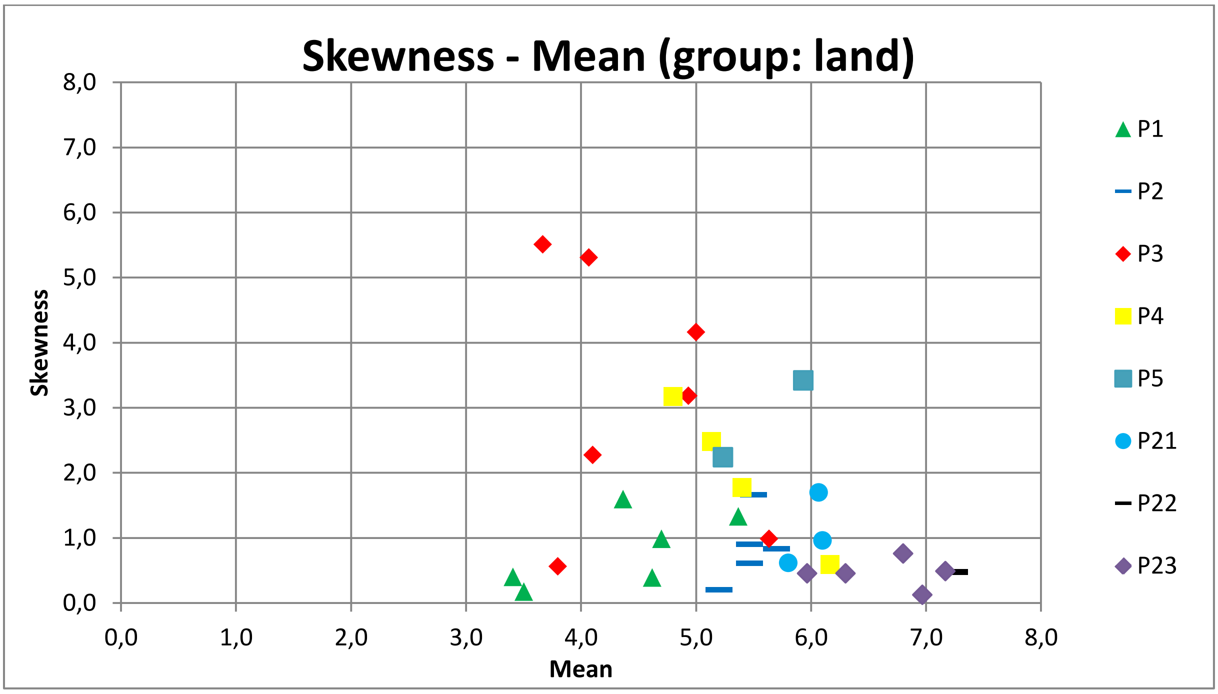

Figure 18: Relationship between skewness and mean for group land.

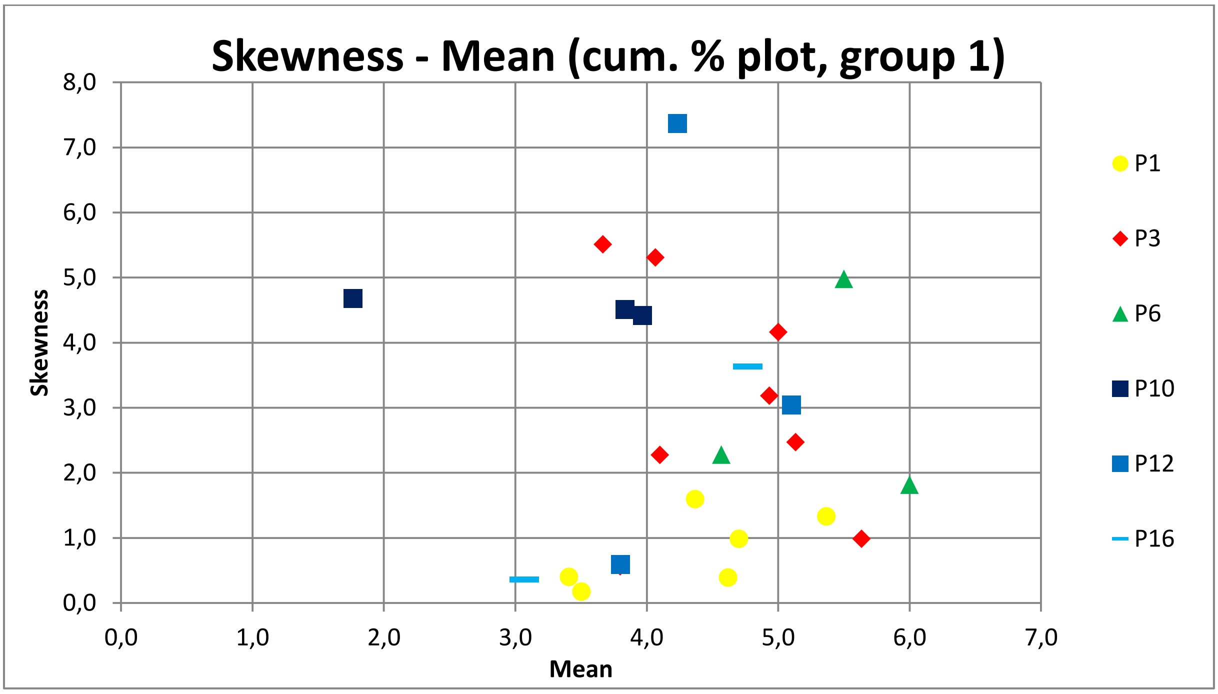

Figure 19: Relationship between skewness and mean for cum. % plot, group 1.

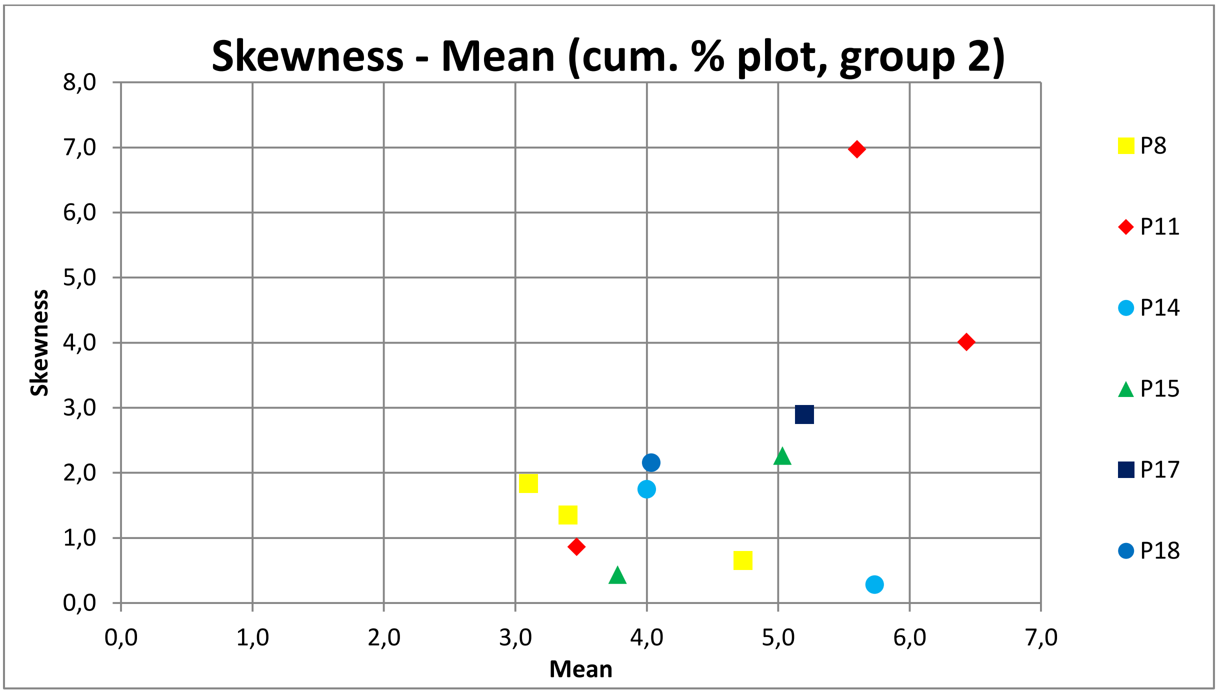

Figure 20: Relationship between skewness and mean for cum. % plot, group 2.

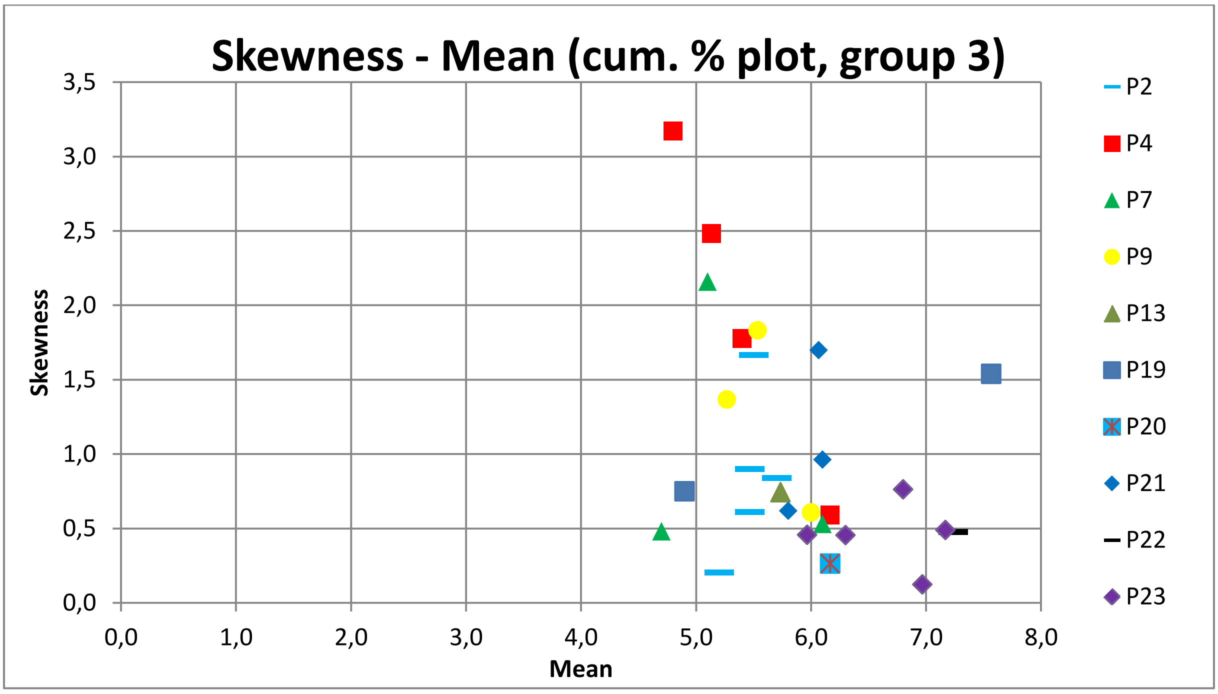

Figure 21: Relationship between skewness and mean for cum. % plot, group 3.

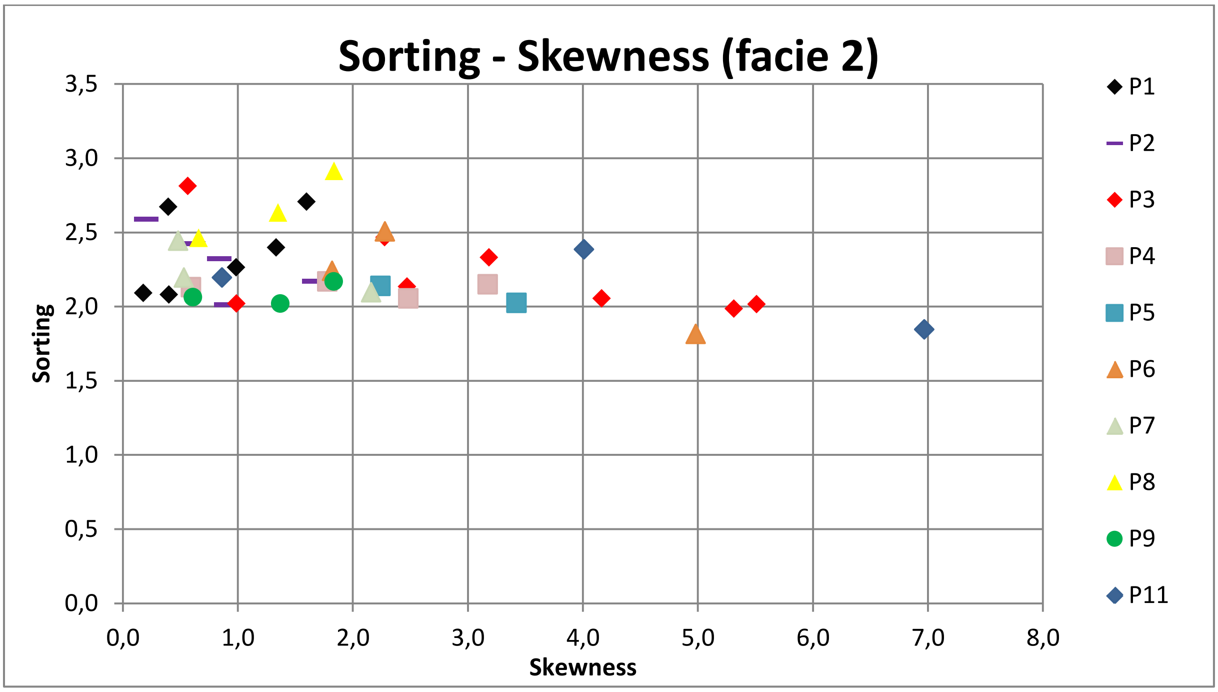

Figure 22: Relationship between sorting and skewness for facie 2.

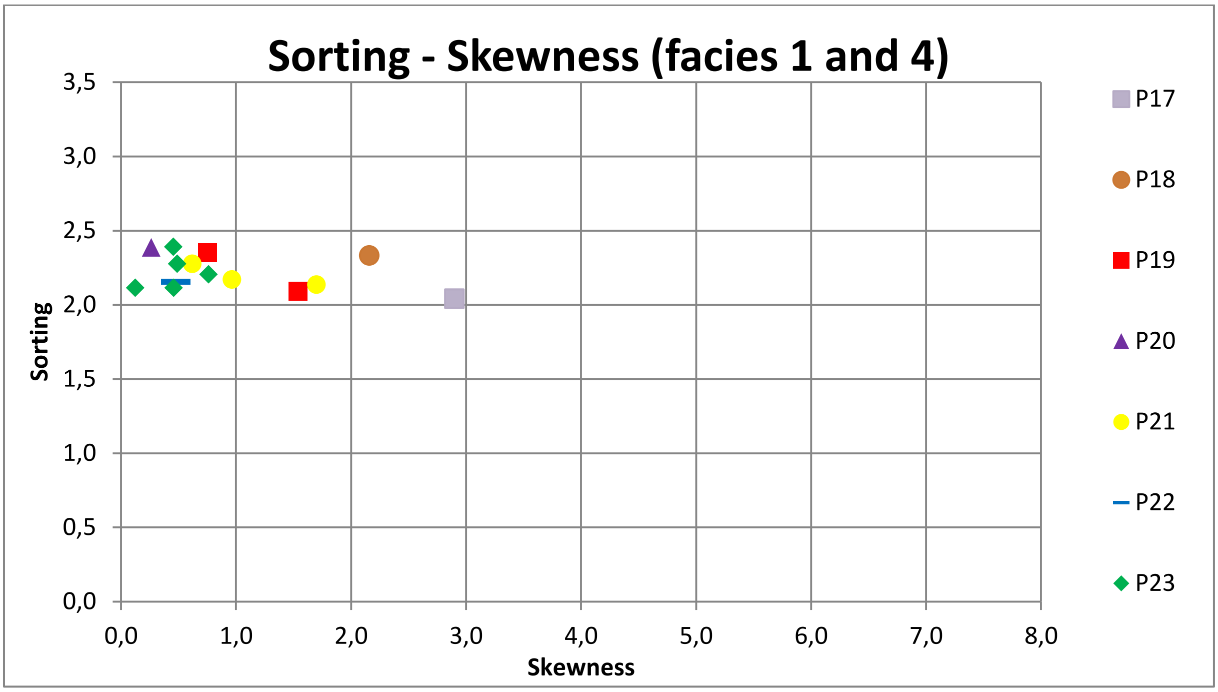

Figure 23: Relationship between sorting and skewness for facies 1 and 4.

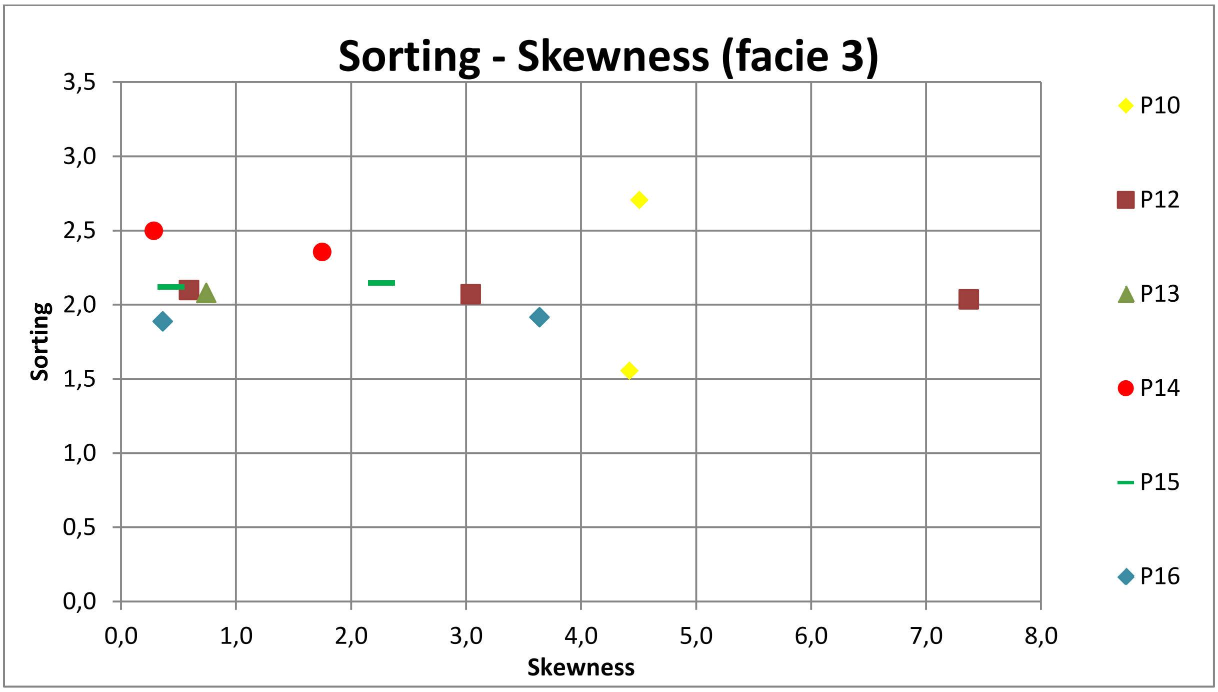

Figure 24: Relationship between sorting and skewness for facie 3.

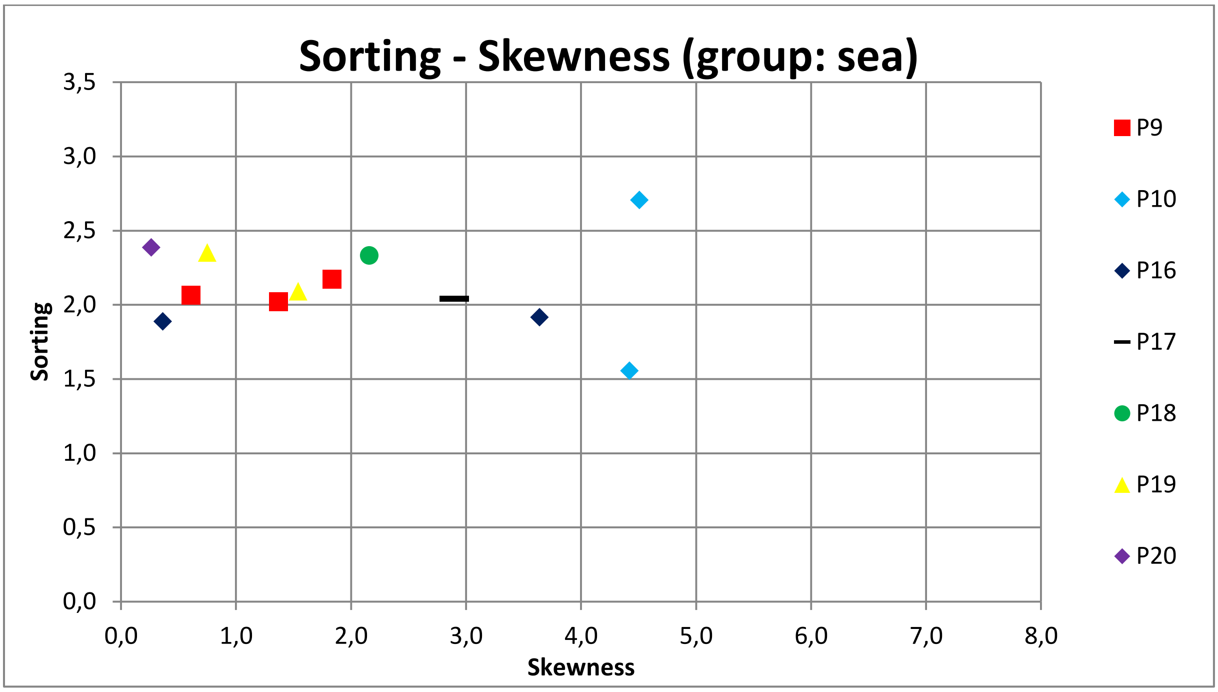

Figure 25: Relationship between sorting and skewness for group sea.

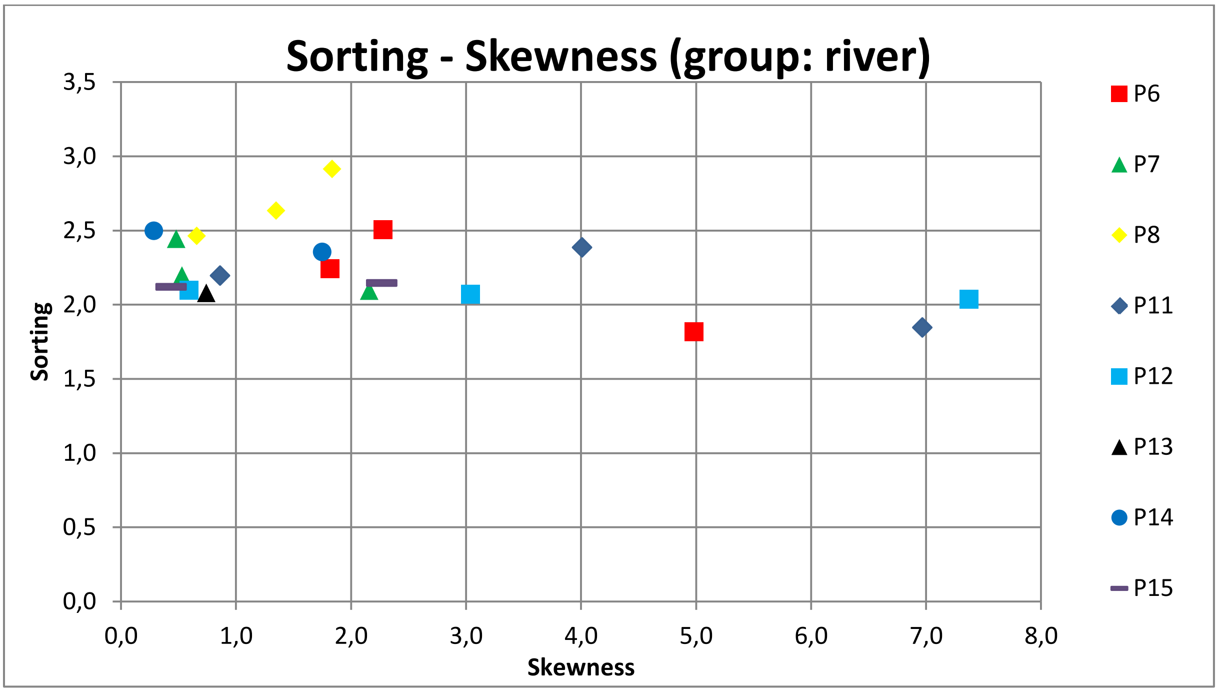

Figure 26: Relationship between sorting and skewness for group river.

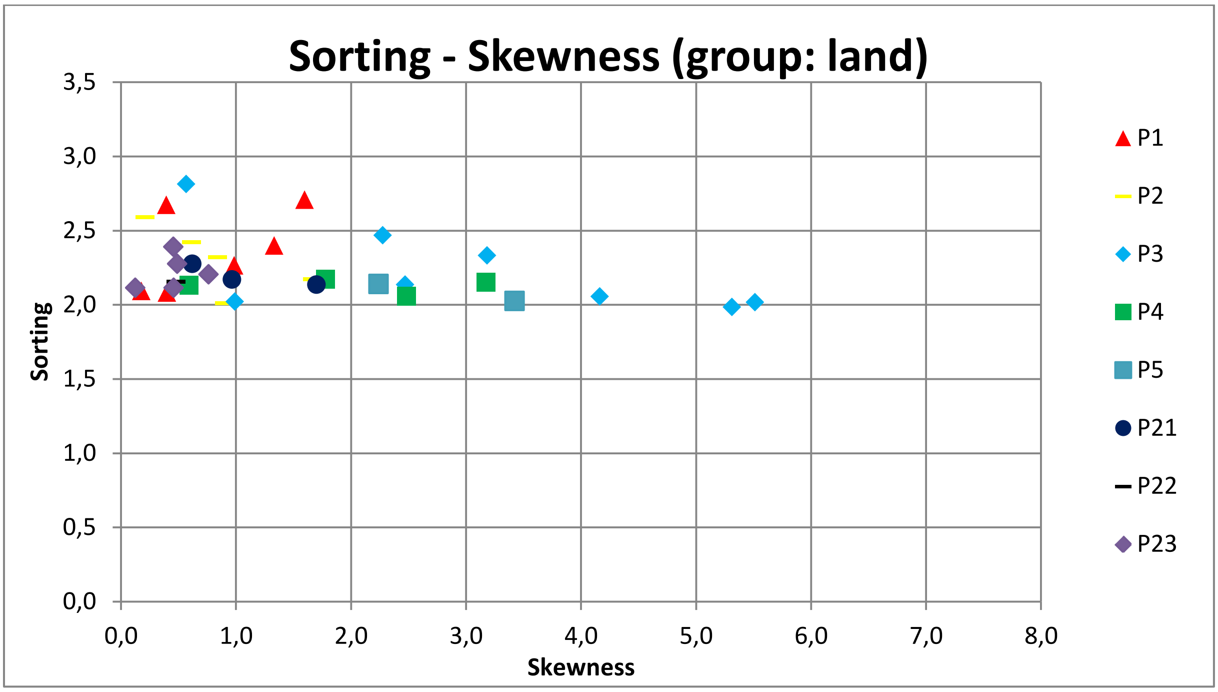

Figure 27: Relationship between sorting and skewness for group land.

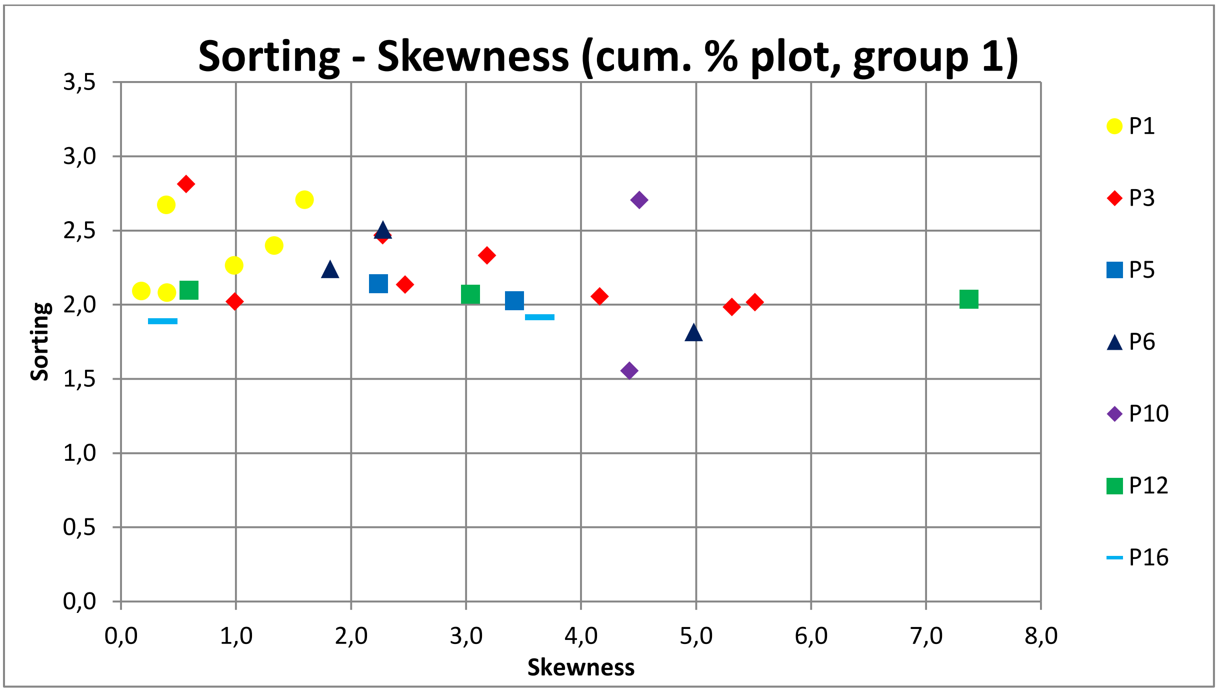

Figure 28: Relationship between sorting and skewness for group cum. % group 1.

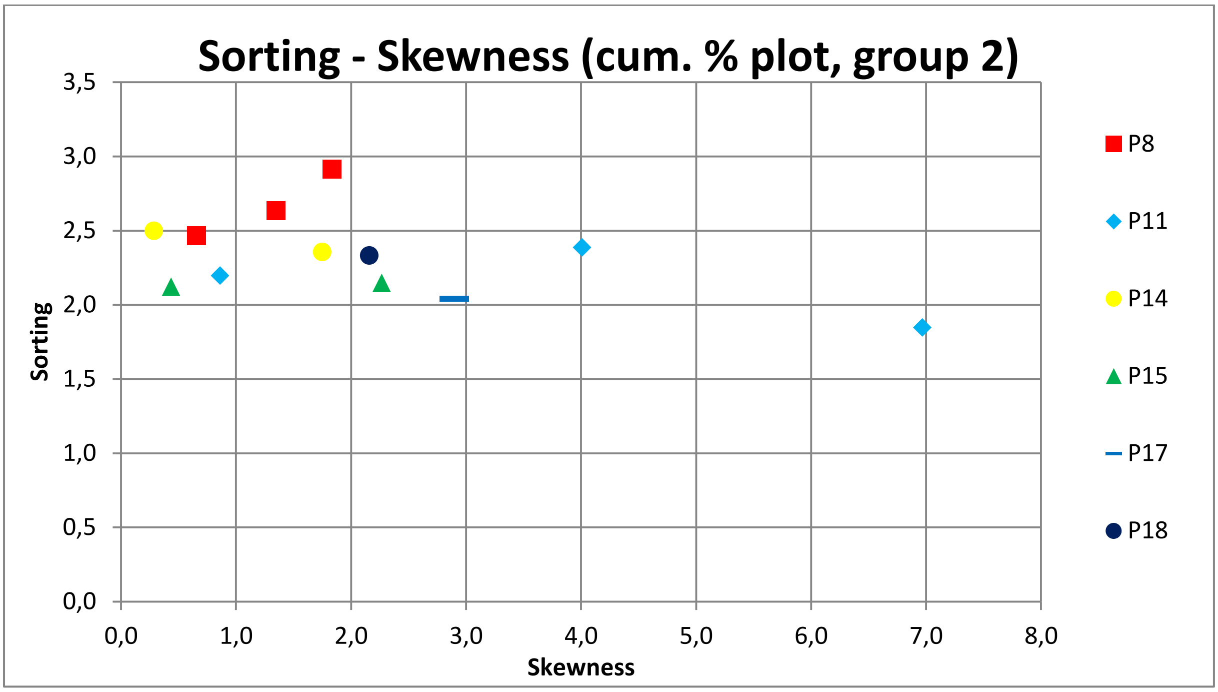

Figure 29: Relationship between sorting and skewness for group cum. % group 2.

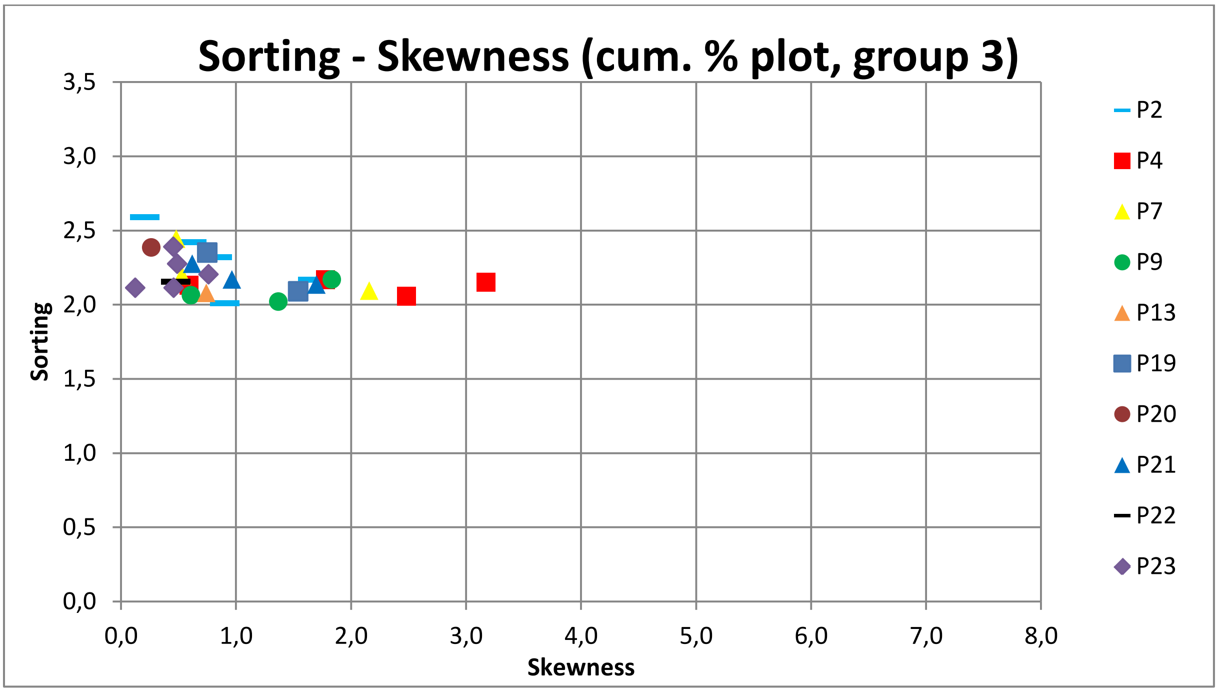

Figure 30: Relationship between sorting and skewness for group cum. % group 3.

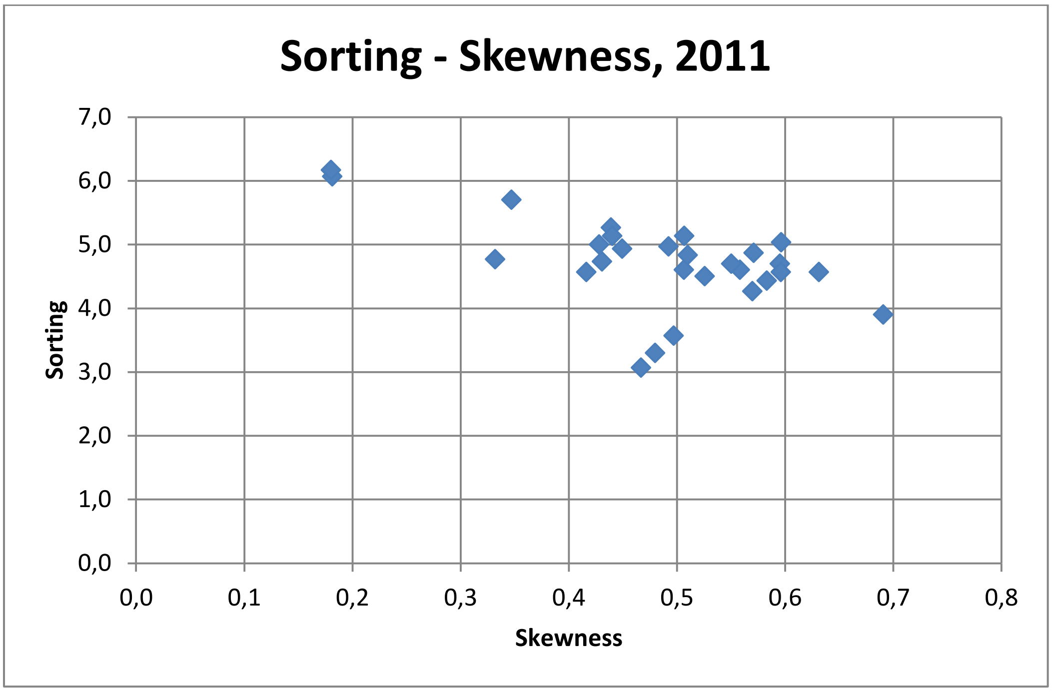

Figure 31: Relationship between sorting and skewness.

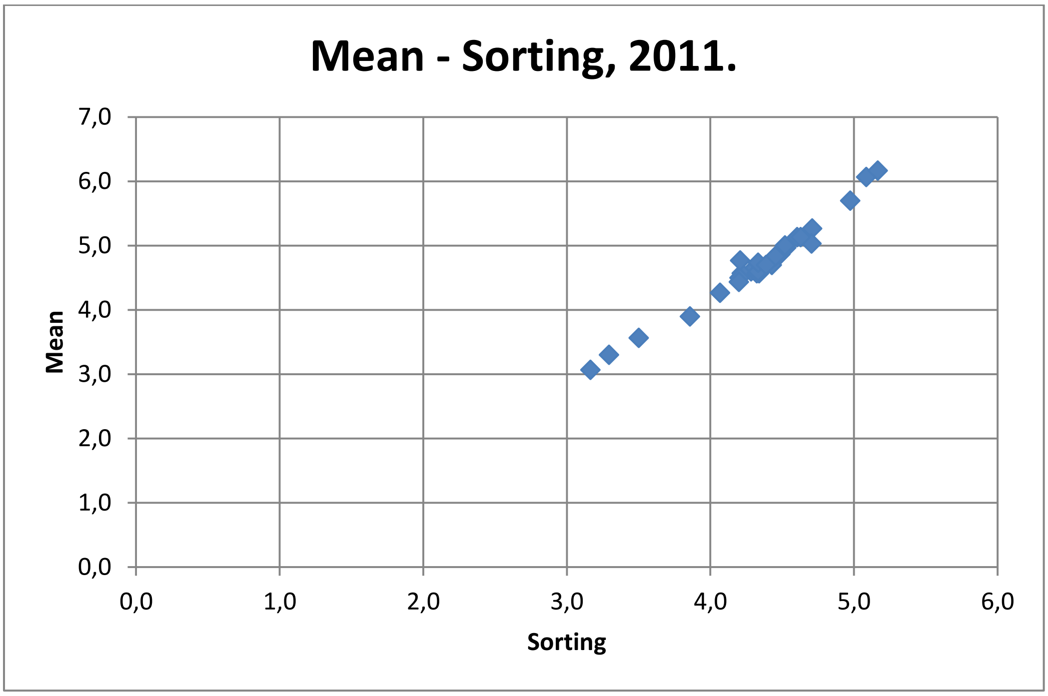

Figure 32: Relationship between mean and sorting.

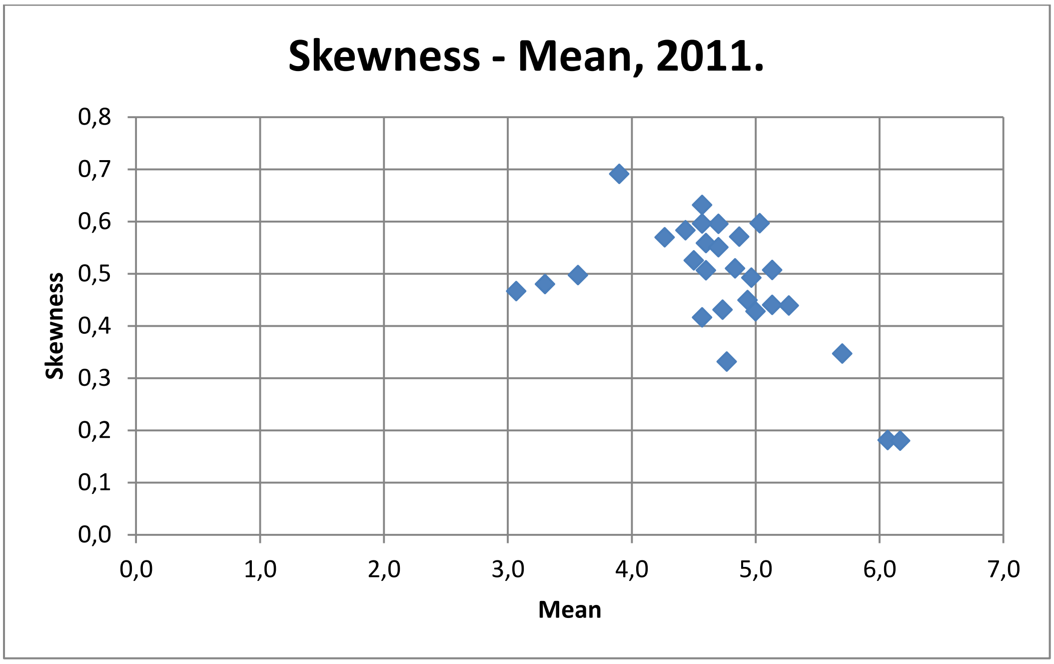

Figure 33: Relationship between skewness and mean.