Sediment variations in the Kuchi Lake, southern Taiwan: Climate signal or tectonics?

Bachelor thesis in geosciences 30 hp

Oscar Fransner

Abstract

Climate archives are of greatest significance when it comes to paleoclimate studies, since these types of archives in a natural way have registered and preserved the conditions of the past. There are several types of climate archives, one of the most commonly used are lake sediments, because lakes can reveal different types of information, for example weathering, vegetation and precipitation. Another reason why lakes are important in climate research is because they are widely spread over the world, and therefore they can be chosen depending on where the focus of the study will be. In this study, -the Lake Kuchi in the southern part of Taiwan, situated at the boundary between the Asian Mainland and the Western Pacific, was used. What makes this densely populated region of the world particularly interesting for climate research is because it is affected not only by monsoons, but also by typhoons and earthquakes.

In this paleoclimate study, a total 16 core sections from three different coring points in the Kuchi Lake were analyzed. The main goal was to clarify if the lake could be used as a reliable climate archive, and also interpret the depositional environment of the sediment layers in the cores. All core sections were described and analyzed with the ITRAX XRF-scanner, which lead to the conclusion that the cores consist of a sedimentary sequence of alternating gray clay and dark gray gyttja clay layers, capped by peat, gyttja or clayey gyttja at topmost part.

By sieving samples from all different layers, it was observed that some dark gyttja clay layers contained terrestrial organic matter, and hard, angular clay clasts that suggest intense rain falls and flash floods as transportation mechanism. The uppermost part of the cores, from 310 cm to the top layers, consist of homogenous clay and in situ organic matter which indicate calmer depositional environments compared to the alternation between dark gyttja clay and homogenous gray clay. LOI-950 data indicate that the carbonate content of the Kuchi Lake is low, since the weight loss during this temperature is insignificant compared to LOI-550, which stood for the majority of the weight loss.

Thus, the sediment sequence in the Kuchi Lake consist of alternation of clays deposited in a calm and relatively deep lake, mixed with layers apparently flushed in from land, possibly due to typhoons. This alternation is capped by organic rich layers, including peat, which indicating filling up of the basin, and shallower conditions.

Keywords: Taiwan, Kuchi Lake, climate archive, sediment core, XRF

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1. Introduction

The main aim of this study is to investigate if the Kuchi Lake in southern Taiwan can be used as a natural climate archive or not. There are two main reasons why this lake was selected. The first reason is because the Kuchi Lake has been shown in previous studies (Lee et al., 2010a, 2010b) to contain a long, presumably continuous and undisturbed sediment record, which is a great advantage in paleoclimate studies. The second reason is that the Kuchi Lake is situated in a geographical area affected not only by monsoons, but also by typhoons and earthquakes. These factors, together with the fact that Southeast Asia is a densely populated area where people's everyday lives are affected by the climate, makes the Kuchi Lake to an interesting place to study. If the Kuchi Lake can be used as a reliable climate archive, the next step will be to interpret the different sediment layers in the lake, which can hint what kind of climate factors that have shaped them.

2. Study area

2.1 Taiwan

Taiwan (figure 2.1a) is an island situated above an active subduction zone off the eastern coast of China. The location and size of Taiwan gives a varying climate ranging from subtropical climate in the north to tropical in the south. The East Asian monsoon has an important role in the regional climate since it brings wet summers and dry winters to Taiwan. Another climate related phenomenon that is common in this part of the world is typhoons, which usually strike Taiwan between late summer and early fall every year. The typhoons bring locally strongly precipitation, which for instance lead to increased sediment discharge. All these factors together make Taiwan into a relatively active island, both when it comes to seismic activity and climate phenomena.

2.2 Kuchi Lake

Kuchi Lake, also known as Tungyuan Pond, (figure 2.2a) is situated close to the Pacific Ocean, in an area with low mountains in southern Taiwan (22°10' N, 120°50' E; 360 m above sea level).

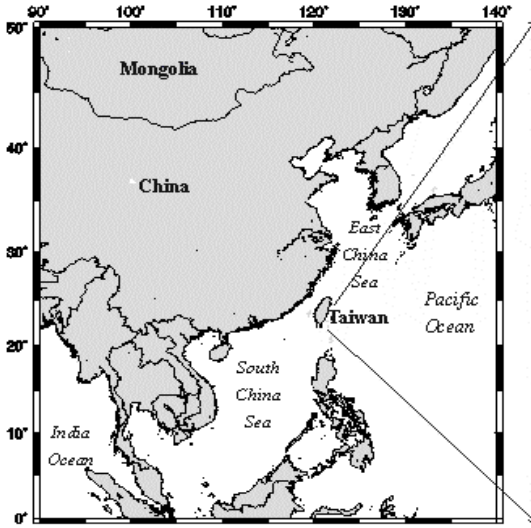

Figure 2.1a. The location of Taiwan (From Yang et al., submitted).

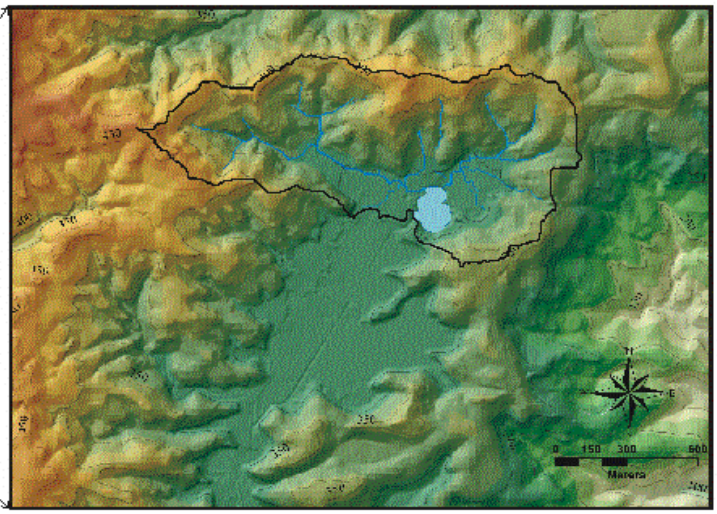

Figure 2.2a. The location of Kuchi Lake, Taiwan (From Yang et al., submitted).

The area of the Kuchi Lake is 0.02 km², and the deepest part of the lake is 2 meters. Evergreen lowland broad-leaved forest is growing around the lake on a bedrock that primary consists of shale, siltstone and argillite (Hsieh et al., 1996; Ho, 1986). The Kuchi Lake has been unaffected by anthropogenic factors until the middle 20th century, when the lake was modified by dredging to act as a water reservoir, which lead to mixing of the uppermost meter of sediment in the lake (Chen, 2000).

In the Kuchi Lake area, the average monthly air temperature has varied between 20.5 and 28.0 degrees Celsius since the measurements started in 1897 (Yang et al., submitted). The annual precipitation in this area of Taiwan is 2144 mm, and of this, 90 % falls during the summer monsoon (Lee et al., 2010b).

Three different coring points were appointed in the Kuchi Lake during the sampling that was made in January, 2010 (figure 2.2b). The first coring point is found in the middle of the lake (the needle in the bottom), the second one at the edge of the reed (the needle in the middle), and the third coring point to the northeast of the lake, in the wetland.

Figure 2.2b. Satellite image of the Kuchi Lake, southern Taiwan. The yellow needles are representing the three coring points in the Kuchi Lake (From Google Earth).

3. Basics of the methods

3.1 XRF

X-ray fluorescence spectrometry (XRF) is an element analysis method that takes advantage of the different energy levels that exist among electrons, depending on which electron shell in the atom they belong to. An X-Ray tube emits X-ray radiation towards the sediment core that is being analyzed. If the emitted energy is higher than the binding energy of the electrons, it will expel electrons inside the atoms from their electron shells. The expelled electrons will

create spaces (initial vacancies) where the electrons had their original positions in the electron shells. In turn, this will cause other electrons to fill the initial vacancies from where the excited electrons came, which happens since the atom prefers to get back to its original, stable electron configuration. When the regrouping of electrons takes place, surplus energy will be emitted (fluorescence). Electrons further out from the atom have higher energy than electrons closer to the atom. This means that the energy difference between the expelled and the incoming electron will be emitted, and it is the emitted energy that will be recorded by a detector in the ITRAX. Different elements can be identified since certain elements emit X-ray fluorescence with characteristic energy levels. The abundance of a specific element can therefore be detected due to the intensity of radiation at a specific wave length (or energy), which is relative to the concentration of the element (Weltje et al., 2008).

The ITRAX is an important multifunctional tool when it comes to sediment core studies since it in an accurate and none-destructive way collects different types of data from the core being analyzed. Except its main function – the XRF-scanning, the ITRAX also makes an optical and a radiographic image of the core that is being scanned (Croudace et al., 2006).

3.2 Sieving

Sieving is a method used to separate larger grains and fragments embedded in the sediment. This is done since the fragments can tell something about the sedimentation history. The sieving method is a cheap and fast analysis that should be done in the end of a project since it also is a destructive method. When preparing for this method, sediment samples are cut from the core and later placed in a strainer with desired mesh size. The next step is to rinse the samples one by one with tap water, until only the particles bigger than the mesh size is left in the strainer. The particles are later examined and described under a microscope.

3.3 Carbon-14

^{14}C is formed naturally by reactions in the atmosphere between neutrons from cosmic rays and nitrogen. The ^{14}C is then oxidized to CO_2, which later enters the biosphere. All living organisms assimilate ^{14}C in an equal proportion to the amount of ^{14}C in the atmosphere at the moment. When an organism dies, the uptake of ^{14}C stops, and the ^{14}C in the dead body will start to decay. This makes it possible to date when the decay started, and in that way find out how old the organic matter is (Aitken, 1974). The production of ^{14}C is not constant. This is due to several factors, but one of them is because the frequency of cosmic rays varies through time, which means that the ^{14}C age of a specific sample must be calibrated to get the calendar year age of the sample (Damon, 1970).

In this study it was decided to pick out seeds, leafs and insect remains since this kind of material need to be deposited relatively fast, or else it will degrade and disappear. Wood pieces are for example relatively resistant, and may be transported far before they are buried in the sediment, which in turn will lead to an inaccurate age of the sediment sequence were the wood was found. Another example that can cause dating problems are roots, since they can reach far down into the sediment even though the plant is living on the surface. This will make the age of that depth appear younger than it is (Grant-Taylor, 1972). Also some pieces

of wood were sampled from the same depth as the other organic fragments for ^{14}C. This was done to determine the age difference between the wood and the more "secure" samples.

3.4 Loss on ignition

Loss on ignition (LOI) is an analysis method for sediment samples which takes advantage of specific ignition temperatures where different matters disappear. By weighting the sediment samples before and after they have been exposed to a specific temperature in the oven, and then calculate the difference between the two weights, a relatively accurate estimate of the weight percent of water, organic matter and carbonates can be achieved for each sediment sample (Heiri et al., 2001).

The sediment samples are being exposed to three different temperatures when doing the LOI. In the first step, the samples are dried by placing them in an oven at 105 degrees Celsius for 12 to 24 hours. This will indicate the sediment water content of the samples. The next temperature for the samples in the oven is 550 degrees Celsius during 4 hours. At this temperature, any organic matter will be oxidized to carbon dioxide. When reaching the last temperature of 950 degrees Celsius, carbonates will lose their carbon dioxide. After the reaction, only calcium oxides remain. The temperature of 950 degrees Celsius should be kept for 2 hours, before the oven can be turned off. After each heating process, the samples have to be taken out and weighed to calculate the weight loss (Heiri et al., 2001).

The following formulas were used to calculate the weight percent after the different temperatures in the oven (After Heiri et al., 2001):

Water loss (g) = (WW) – (DW105)

LOI550 = ((DW105 – DW550) / DW105) * 100

LOI950 = ((DW105 – DW950) / DW105) * 100

WW = wet weight, before the sample has been dried in the oven. DW = Dried weight, after respective temperature exposure in the oven.

4. Material and methods

4.1 The sediment cores

The sediment cores were obtained in January, 2010, through collaboration between the geoscience departments of Stockholm University, National Taiwan University, and Academia Sinica. The coring was made using a Russian corer. In total, 16 core sections from three different coring points were recovered. The cores from coring point 1 and 3 were sampled with a thicker diameter of the Russian corer compared to coring point 2. During the coring, the resistance when pushing the Russian corer down in the sediment depends on two factors – increased coring depth together and width of the Russian corer. By choosing a thinner diameter of the Russian corer, the resistance will decrease, which was done in the case with CP2 in order to reach larger depths. The drawback of the smaller coring device is that a considerably smaller amount of sediment is retrieved. Coring point 1 (CP1) consists of two

continuous core sections from the same hole. CP2 consists of ten sections from three different holes. These sections overlap each other. Overlap is a technique used to obtain a continuous sequence of a core, without any gaps in between different sections. Overlapping sections are also found in CP3, which consists of four different sections from three different holes.

4.2 Core descriptions

The first step was to unpack and describe one core section at a time. By analyzing one section at a time, the others were prevented from drying out. Before the description started, the core surfaces were scraped to get a new and fresh surface. The sediment surfaces had been oxidized during the time that has passed since the sampling. This led to a change in consistence and color of the surfaces of the clay layers, which made scraping necessary before the core description.

The first step of the description was to visually divide the specific core section in different layers. After the division a more detailed description was performed, where the following attributes were examined in each layer: Type of transition, type of sediment and color. Occurrence of organic particles and other fragments were also noted.

4.3 Correlation of the core sections

After the core descriptions and lithology logs were finished, the core sections were correlated in two different ways. First, a correlation between overlapping sections within each coring point was made, which lead to a composite core for each coring point. The composite cores were basically made by selecting the longest continuous core sections (master core) from each coring point, supplemented by intervals of other core sections that not were covered by the master core.

When the three composite cores had been finalized, the next step was to correlate the composite cores from each coring point to each other in order to obtain a lithological profile representing the layering of the lake. The connection in this case was first of all made visually, by matching the core properties that were examined in the description part. The variations in chemistry (ITRAX data), were also important, since it like a finger print can support the visual correlation.

4.4 XRF

All the core sections from CP1, CP2, and CP3 were run in the ITRAX at the Department of Geosciences, Stockholms University, while the core sections from CP1 were also analyzed in the corresponding lab at National Taiwan University. The goal with this analysis was to obtain an optical image, radiographic image and element variations for respective core section. In a first step, the core sections were taken from their plastic liners and placed on a plastic board with the flat side down. This was done since the sizes of the plastic liners that the cores are conserved in are not suitable for the ITRAX. The next step was to do a surface scan and an optical image of the core section. Before the final XRF-scan, the core section was covered in plastic foil to prevent drying during the analysis. The ITRAX analysis will run for different time depending on the exposure time and desired resolution of the core section. The data from the ITRAX were later post-processed using the program Q-spec. After post-

processing, the element curves, optical and radiographic images for each core section was plotted using the ITRAX-plot program.

4.5 ITRAX data

The ITRAX data from the different lithological units were compared to each other by creating scatter plots with a specific element ratio on the X axis and another one on the Y axis. By analyzing how different elements vary between different sediment layers it can support the visual correlation between the different layers.

The ratio between Zirconium and Rubidium can be used as a grain size proxy. The coarser the sediment, the higher the value of the ratio will be. This is because Zirconium is mainly found in medium to coarse silts, while Rubidium is common in clay minerals (Dypvik and Harris, 2001). It is also possible to find Rubidium in K-feldspar, because of the possibility for Rubidium to replace Potassium in crystal lattices. K-feldspar in turn, is common in silt and sand, which means that the Zr/Rb grain size proxy will not work if K-feldspar is the source for the Rubidium in the sediment core (Kylander et al., 2011). The ratio between zirconium and rubidium (Zr/Rb) was plotted on the X axis, versus the composite core depths on the Y axis.

4.6 Sieving

At least one sample was obtained from each layer in all the master cores for sieving analysis. Each sample had a volume of approximately 6 cm^3, which after cutting were wet-sieved in a strainer with a mesh size of 0,5 millimeters. The particles that did not pass through the mesh were placed in boxes for later microscopy analysis.

4.7 Carbon-14

Organic fragments were sampled for C-14 dating. This was done by cutting sediment samples from CP2 in a regular interval of 40 centimeters, with exception for gradual transitions, since they are a mix of two different layers and therefore cannot give us any information about the age of either the layer above or the one under. Only CP2 was chosen for radiocarbon dating since it covers the depth of CP1 and CP3 and reaches deeper down in the sediment

The sediment samples of approximately 6 cubic centimeters were taken with a spatula. Each sample was put in an individual box, which was filled with sodium hexametaphosphate (5 grams/10 liters of H_2O) until the top of the sediment samples were covered. By letting the samples stay in the solution for three days, they partly dissolved, which made it easier to sieve them. The sieving of the dissolved sample was done in a strainer with a mesh size of 0,5 mm, by using regular tap water. After the sieving, all the organic particles and fragments were put back in their respective boxes for later analysis under microscope. Here it was decided to primarily pick seeds, leaf fragments and insect remains for the later ^{14}C analysis, but also some wood pieces were isolated for the same reason. As soon as the picking was finished, the fragments were put in individual glass cans and dried in an oven during two days, (the first day in 50 degrees Celsius, and the second day in 115 degrees Celsius). This was done to prevent the samples from becoming moldy, which would have biased the result. After the drying process the samples were packed and sent to the NSF-Arizona AMS Facility at the University of Arizona, USA.

4.8 Loss on ignition

Loss on ignition (LOI) was made on the master cores from all the coring points, (CP1, CP2 and CP3). Sampling for this method was done every 10 centimeters, by cutting approximately one cubic centimeter of sediment for each sample. Exceptions were made for gradual transitions where sampling was avoided, since this kind of transitions is a mix of two different sediment types. The next step was to select a crucible for each sample and with a pencil write the sample number under it. To get the weight of all the individual samples, the crucibles were first weighted empty. After that they were weighted again, but this time with the samples inside. The ignition was done in an oven in three steps, each step with a special temperature. During the first step, the samples were heated in 105 degrees Celsius during 12 hours, the second time the samples were heated in 550 degrees Celsius during 4 hours, and the last time the samples were heated in 950 degrees Celsius during 2 hours. After each ignition, the crucibles with the samples inside were weighted and compared with the previous weight, which made it possible to calculate how much weight that was lost after each ignition.

5. Results

5.1 Core descriptions

As described in *Study area*, the core sections have been sampled from three different coring points in Kuchi Lake. In this chapter, the three coring points will be described one at a time. In the beginning of each description, a short overview will be given containing all the different types of sediment layers that are found in each coring point. After the overview, the composite cores will be described from the bottom to the top based on the different layers and the kind of contacts there are between the layers. In the end of each description, points worth highlighting from the individual sections that cannot be represented in the composite core will be described.

CP1

CP1 was taken in the centre of the Kuchi lake and consists of two consecutive sections (figure 5.1a), reaching from 150 to 350 centimeters below the surface of the lake. No overlapping core was obtained at this coring point.

These two core sections can be divided into three distinct parts depending on their respective sediment characteristics. The bottom layer consists of homogenous beige clay with an orange patchy pattern, which indicates a high grade of oxidation. In this layer organic particles are rare. The second distinct sediment layer is made of dark brown peat with organic fragments in both millimeter and centimeter size, and the uppermost layer is dark gray homogenous clay where organic particles are rare, similar to the clay layer in the bottom.

The beige clay with orange patchy pattern in the bottom of the core stands for the longest part, reaching from 350 to 217.5 centimeters in depth, and shows a gradual transition to the peat layer, which exists between 217.5 and 195 cm (with exception from 206 to 212 cm, where a part has been lost). The peat consists of a wide variation of different types of organic fragments, from millimeters to centimeters in size. After a sharp contact (which probably was

caused by the dredging of the lake as mentioned in *Study area*) the uppermost layer, consisting of dark gray clay is found, and reaches from 195 to 150 centimeters.

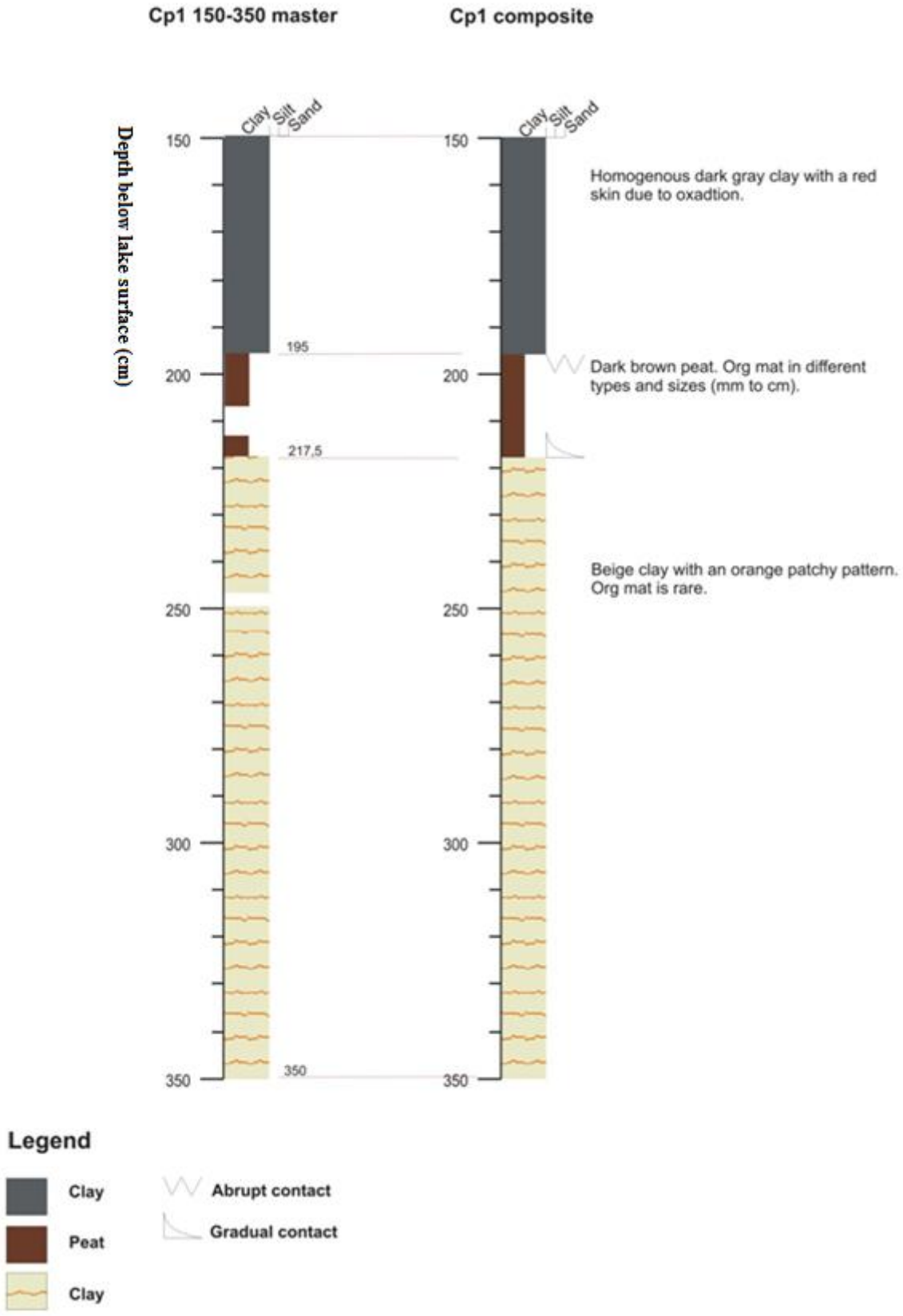

Figure 5.1a. Lithology log for CP1.

CP2

CP2 was taken at the boundary of the reed area of the Kuchi Lake. This coring point consists of three sets of different continuous cores (figure 5.1b). The first core is from 140 to 540 cm, the second one from 200 to 700 cm, and the last one reaches from 530 to 630 cm. In a simplified way it is possible to say that the three different cores contain four different types of sediment, from the bottom to the top they are: dark gray gyttja clay, light gray clay, beige clay layer with an orange patchy pattern (which resembles of the corresponding beige clay in CP1) and an interval rich in organic matter of different types.

The majority of CP2, from 700 to 310 centimeters, consists of an alternation of two different types of sediments, which in most of the cases are separated from each other by gradual contacts. The first of the two types of sediment in this sequence is the dark gray gyttja clay with abundant organic matter, which is overlain by a layer of the homogenous grayish clay, with low content in organic matter. This layer alternation ends in a gradual contact to homogenous beige clay, which shows an orange patchy pattern due to oxidation. This layer occurs between 310 and 230 centimeters, and is very similar to the corresponding beige clay that was described in CP1. The light gray clay from the alternation between 700 and 310 centimeters show in all the cases a gradual transition in color. In the bottom of each layer, the clay is light gray, but the further up in the clay, the color changes to beige –similar to the clay layer between 310 and 230 centimeters, except that the orange patchy pattern is missing.

The last interval of CP2 takes over from the beige clay with orange patchy pattern in a gradual contact, and continues all the way to the top of the core (from 230 to 145.5 centimeters). This interval consists of 4 different organic rich layers. At the bottom grayish brown clay with abundant coarse organic fragments is found. This layer has a gradual contact to the overlying layer of brown clayey gyttja that is rich in thread shaped organic matter. Followed by a new gradual contact, an interval of dark brown gyttja appears. This layer also has a gradual contact to the top layer of CP2, which is brown clayey gyttja, rich in thread shaped organic matter, very similar to the previous clayey gyttja layer.

In the dark gray gyttja clay layer between 585 and 487 centimeters, light gray clay laminations (1-2 centimeters thick) were found through the whole layer, which suggest sudden sediment depositions from another source compared to the gyttja clay.

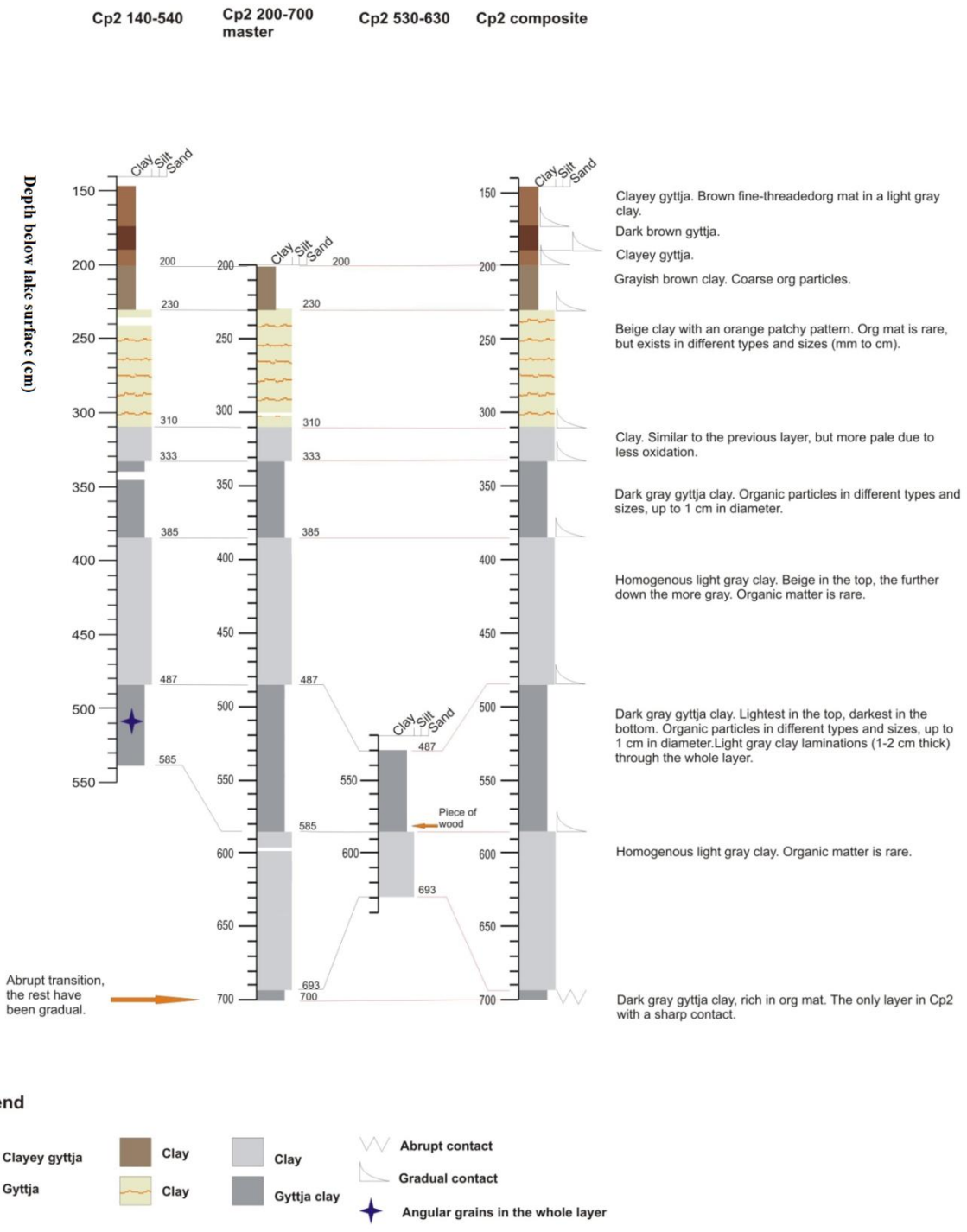

Figure 5.1b. Lithology log for CP2.

CP3

CP3 was taken in the marsh northeast of the Kuchi Lake, and consists of three different cores (figure 5.1c). The first core consists of two sections and reaches from 0 to 200 cm, the second one from 50 to 150 cm and the last core is from 120 to 220 cm. These cores also cover four different types of sediment. From the bottom to the top they are: beige clay with orange patchy pattern, dark brown to gray gyttja clay, beige clay with brown spots and a dark brown gyttja layer.

In the bottom of CP3 (220-130 cm), a layer consisting of beige clay with orange patchy pattern is found, that looks similar to the corresponding layers in the other two cores. After a gradual transition, the next layer (130-80 cm) from the bottom in CP3 is grayish dark brown gyttja clay, which also has a gradual transition to the next distinct layer, which is beige clay (80-43 cm), containing brown spots in the top that increases upward in the layer. The transition to the upcoming layer is abrupt. The abrupt contact is probably due to the dredging as seen in the top layers of the previous cores described above. The brown spots in the layer are also believed to have been formed at the time when the Kuchi Lake was dredged, since the dredging lead to a mixing of the topmost sediment. The X-ray images from the brown spotted layers of CP3 support this idea, since they show a messy pattern and very abrupt transitions compared to the sections further down which are unaffected by the dredging. The layer above the abrupt contact is in this case dominated by a recent grass root horizon (43-4 cm).

Worth to note is that the beige clay with orange patchy pattern shows an abrupt change in the amount of fragments after 195 cm in CP3 120-220. Here the color of the clay changes to a more olive green shade with very coarse material which continues to the end of the core section. Also, the core section CP3 100-200 shows a change in grain size from clay to sand between 173 and 182 cm.

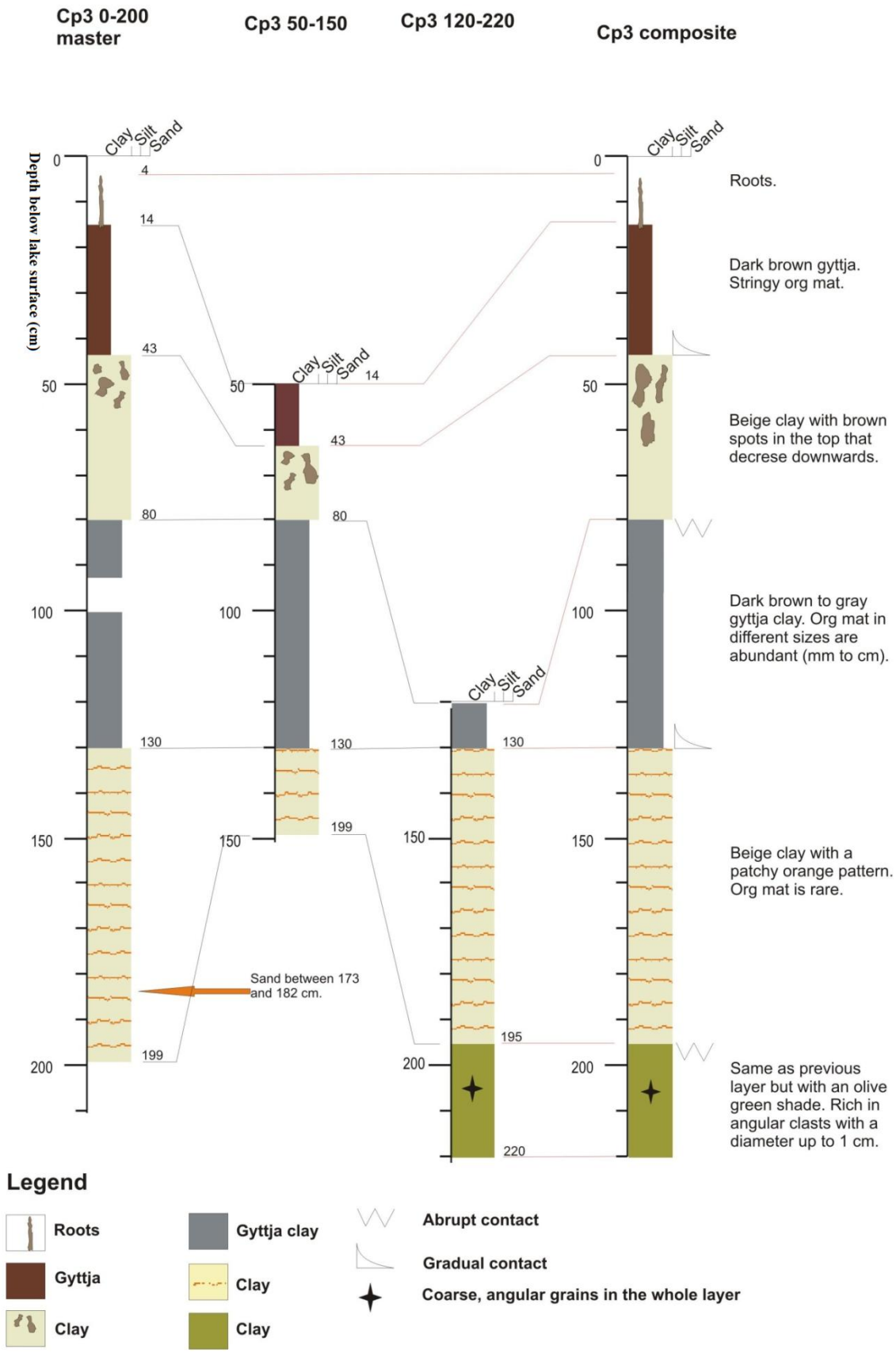

Figure 5.1c. Lithology log for CP3.

5.2 Correlation of the composite cores

The only obvious layer that can be found in all the three different coring points is the beige clay with orange patchy pattern (figure 5.2a). The layers above the beige clay are hard to correlate, since those layers (in CP1 and CP3) are disturbed due to the dredging, but they all show strongly increased organic content.

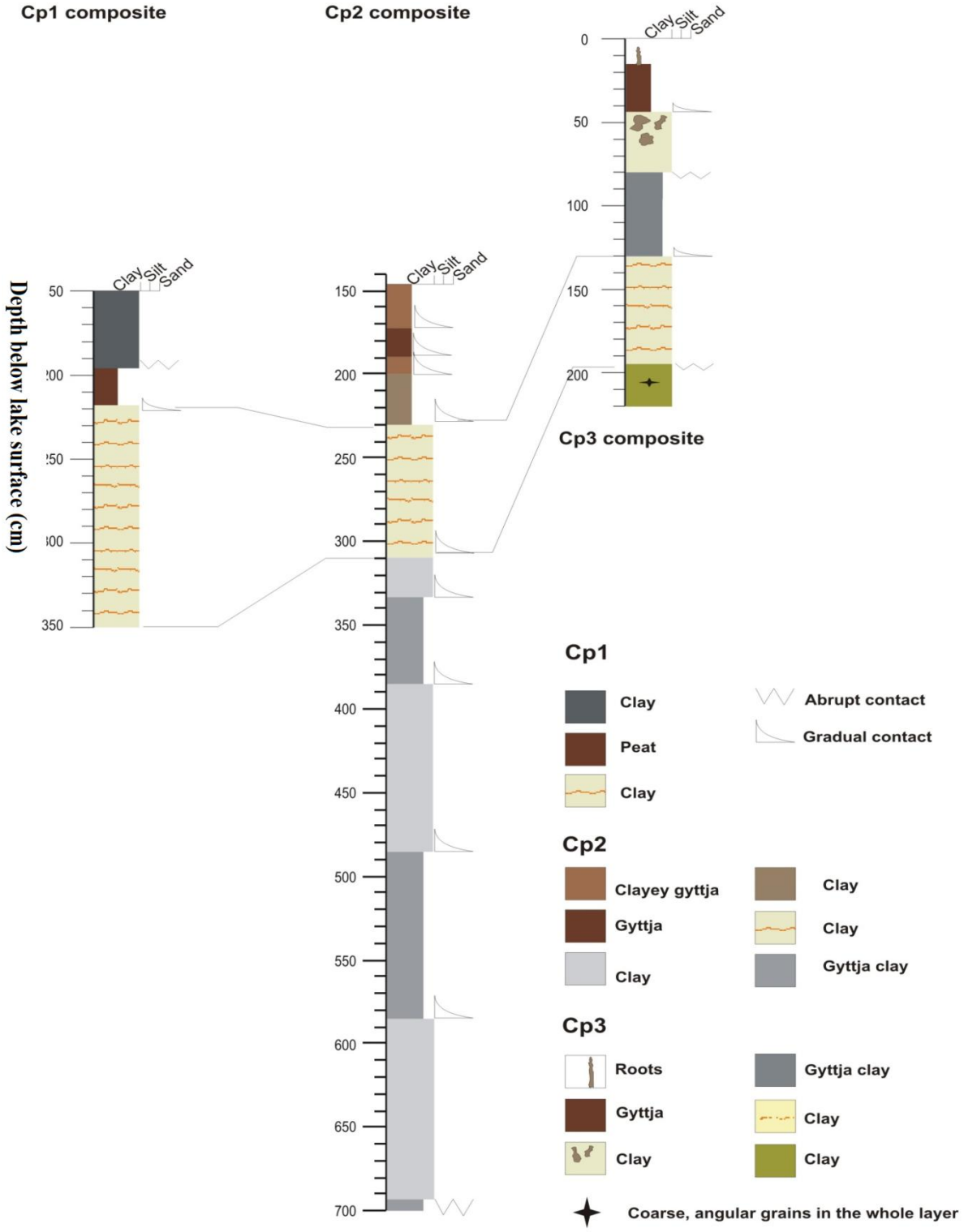

Figure 5.2a. Correlation of the composite cores.

5.3 ITRAX data

A further evidence of the correlation between all the sequences that contain the beige clay with orange patchy pattern can be seen in figure 5.3a. Here the ratio between zirconium and rubidium (Y-axis) has been plotted against the ratio between iron and calcium (X-axis) for all the layers that consist of the beige clay with the orange patchy pattern. The scatter plot (figure 5.3a) shows a relatively good connection between the different layers, especially for the Fe/Ca ratio, while the Zr/Rb ratio shows a bigger variation between the different cores. CP2 shows the highest Zr/Rb values, middle values for CP1 and lowest values for CP3. According to the Zr/Rb grain size proxy, this result may suggest a change in the grain size between the different cores, where the coarsest grained sediment is found in CP2, and the finest grained sediment in CP3. Since the element ratios have approximately the same values, the chemical correlation supports the visual correlation that was mentioned in *Correlation of the composite cores.*

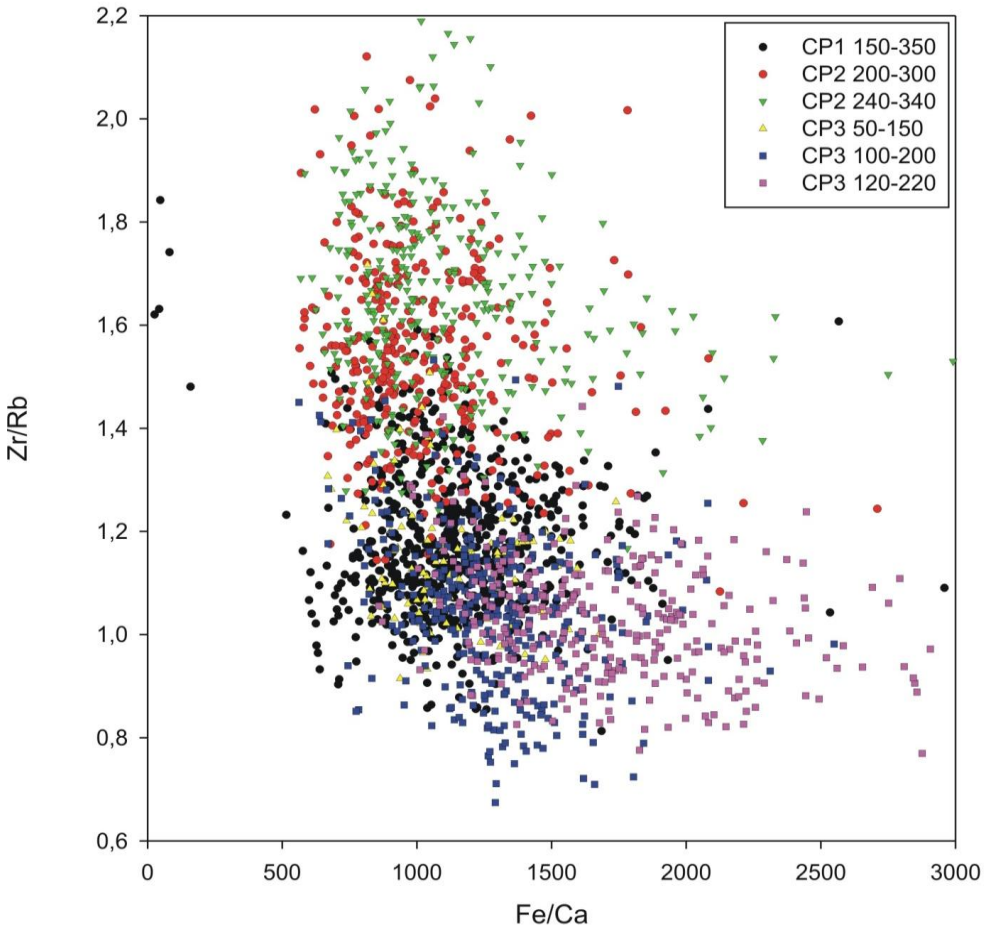

Figure 5.3a. A scatter plot with containing element ratios from all the sediment sequences that consist of the beige clay with orange patchy pattern. The legend shows which core sections the data have been collected from.

When it comes to the Zr/Rb ratios for the three different composite cores a few conclusions can be made. The Zr/Rb values for all the clay layers (black plots) in the three cores are relatively stable, while peaks can be seen in all the cores respective organic rich layers (5.3b, 5.3c, 5.3d). However, the great peaks in the Zr/Rb ratio in the organic rich layers do not in this case mean that the organic rich layers contain more zirconium and rubidium than the clay layers. This can be seen in the abundance of rubidium and zirconium (blue and red, respectively) (figure 5.3b). In this case the interpretation is that the great peaks in the Zr/Rb ratio always correspond to minima peaks in the rubidium and zirconium content, which makes the Zr/Rb proxy for grain size unreliable – at least when comparing clay layers and organic rich layers to each other. The reason why the Zr/Rb proxy is unreliable in the organic rich layers can be dilution, since too low concentrations of the both elements will lead to a misleading result.

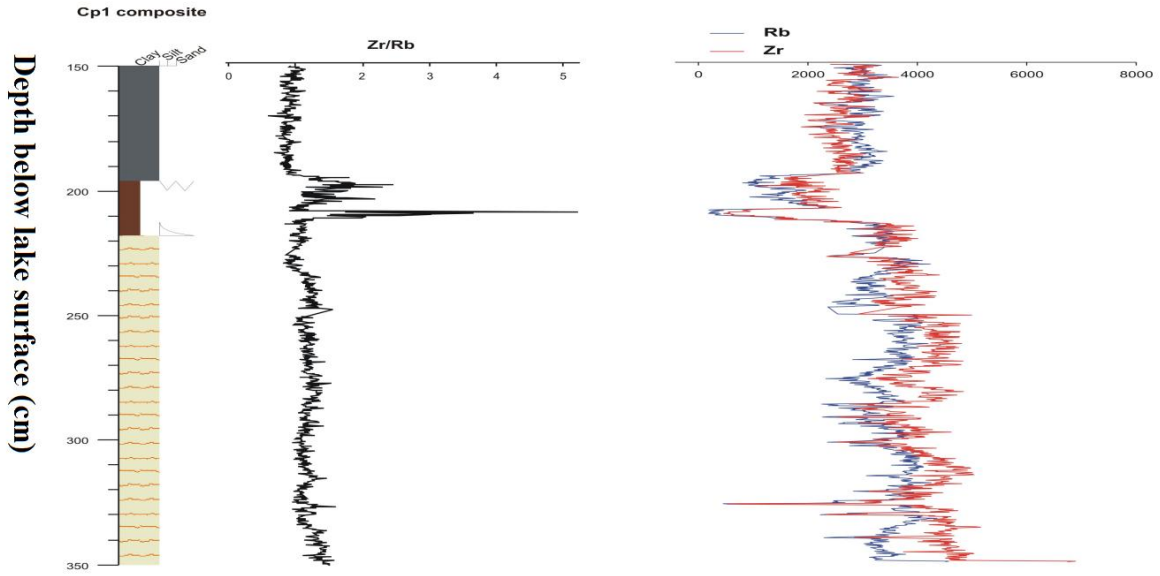

Figure 5.3b. CP1 with its Zr/Rb ratio (black plot), and single element variations, where Rb is represented by the red plot, and Zr is represented by the blue plot.

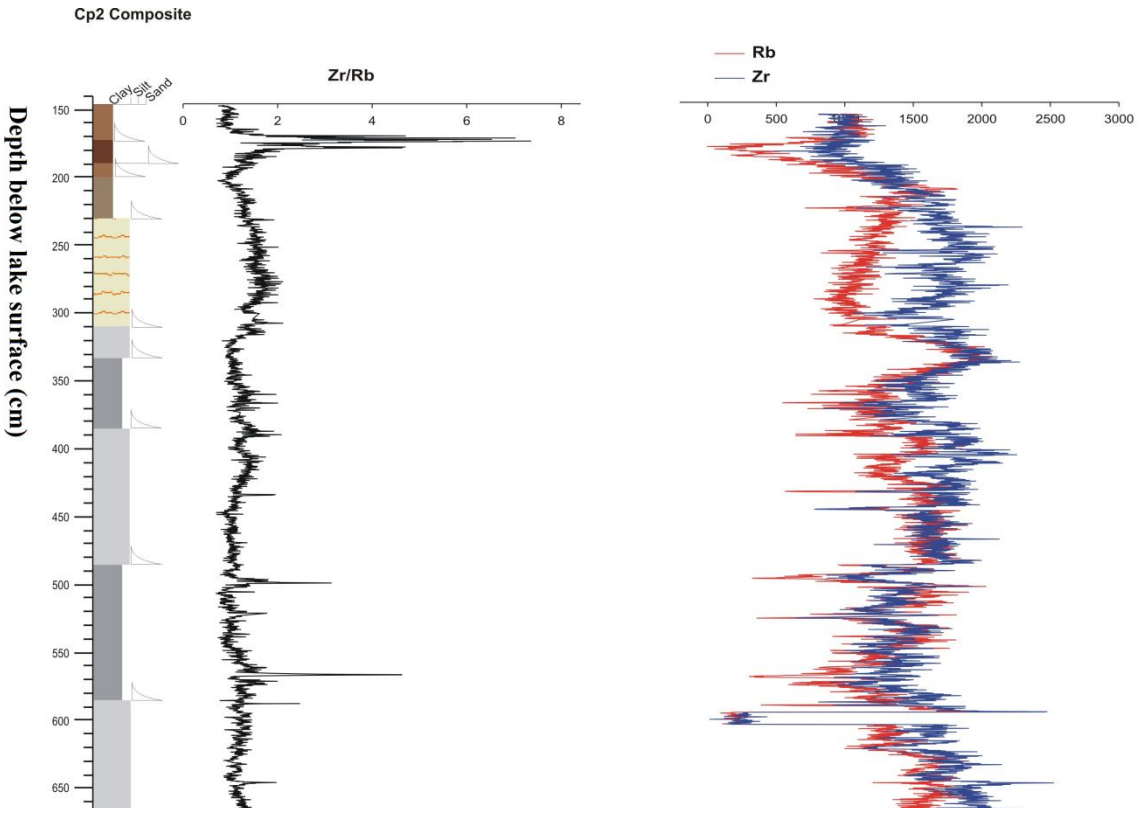

Figure 5.3c. CP2 with its Zr/Rb ratio (black plot), and single element variations, where Rb is represented by the red plot, and Zr is represented by the blue plot.

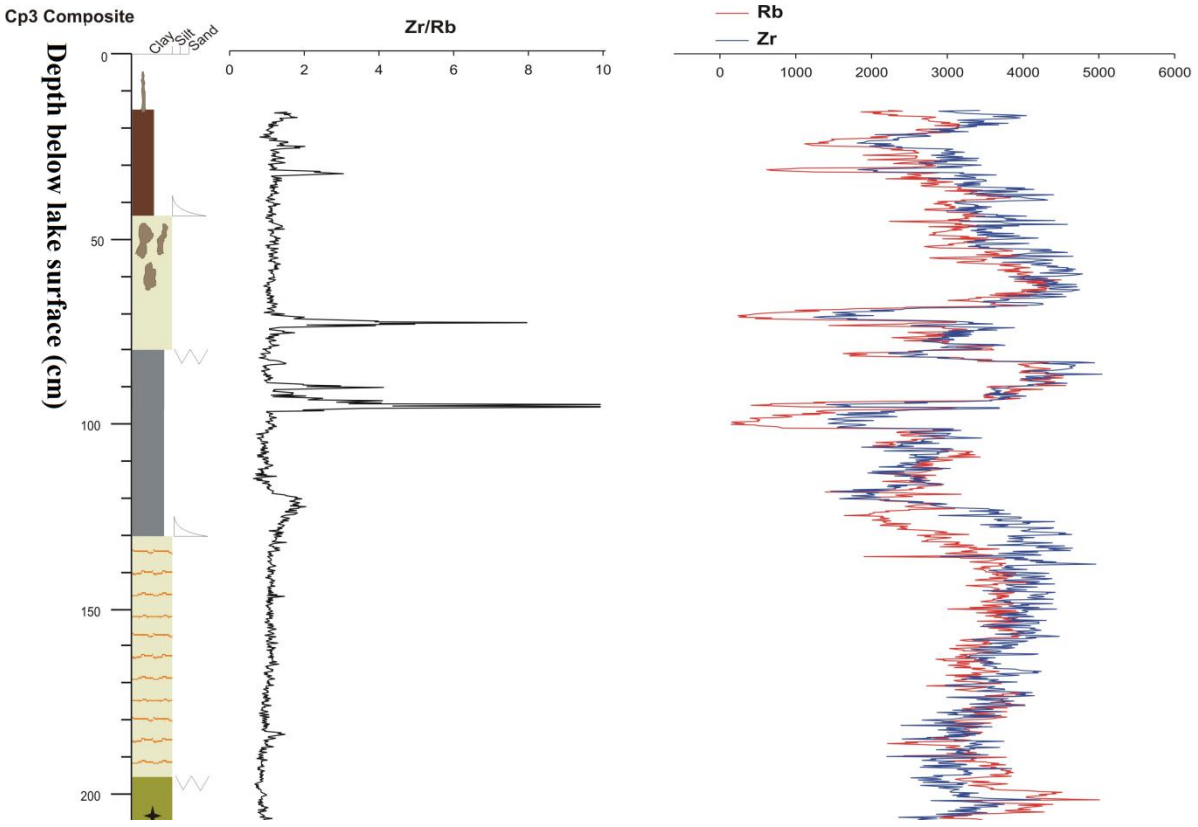

Figure 5.3d. CP3 with its Zr/Rb ratio (black plot), and single element variations, where Rb is represented by the red plot, and Zr is represented by the blue plot.

5.4 Sieving

The sieving reveled that there in total are four different types of particle content found in the three coring points (figure 5.4a).

The peat layer from CP1, clayey gyttja and gyttja from CP2, together with the gyttja from CP3, share the same type of particle content. These layers are all rich organic matter, mostly thread shaped particles with a beige to yellow color. Reed remains are also common here. The next group of particles is found in both the beige clay with the orange patchy pattern and in the light gray clay. In these types of sediments the particle content is very low –in most of the cases nothing was left after the sieving. The gyttja clay found in CP2 and in CP3 show similar types of particles in the sediment. This group is the most dramatic one, containing angular clay clasts with a diameter up to 0.5 centimeters. These layers are also rich in terrestrial organic matter, especially twigs and bark, but lacks the thread shaped fragments found in the peat and gyttja layers described above. The last unique particle content is found in the bottom of CP3, which both contains angular clay clasts (with a diameter up to 0.5 centimeters) and rock fragments (figure 5.4b). These kind of grains are found in a chaotic pattern in the whole layer, which otherwise has a matrix made of clay. Similar grains were found in CP1 250-350 cm, where angular grains in different sizes up to a diameter of 1 centimeter were found inside the homogenous beige clay with the orange patchy pattern, at a depth of 325 centimeters.

The beige clay with brown spots (43-80 cm) in CP3 together with the grayish brown clay (200-230 cm) in CP2 show a mix in the particle content of the uppermost organic rich layers together with flushed in terrestrial organic matter. This is probably due to the dredging of the lake as mentioned in *Study area* and *Core descriptions.* (Table data for the sieving results can be found in *Appendix 9.1*).

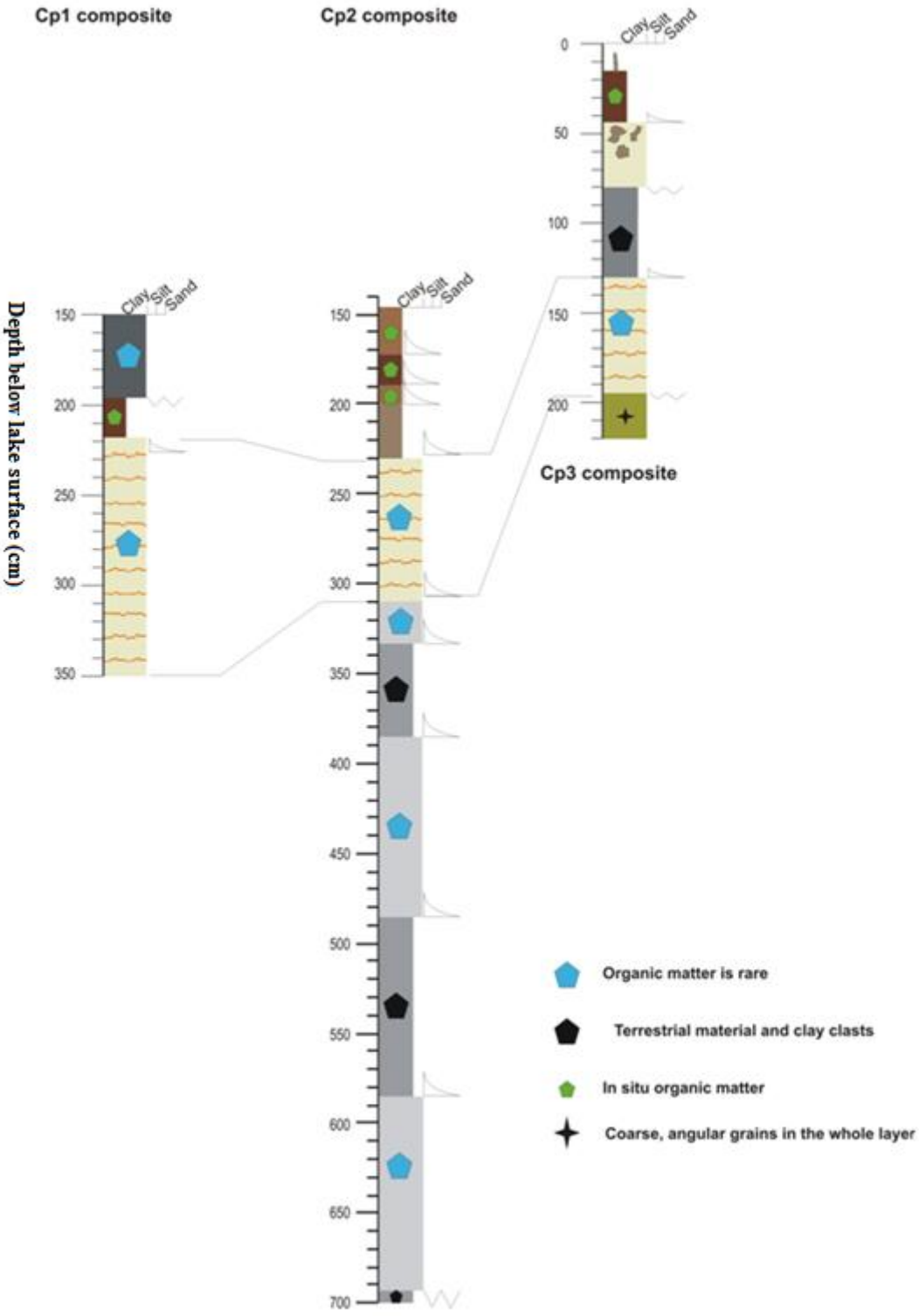

Figure 5.4a. The composite cores and a description of the different types of material that were observed in the coarse fraction.

Figure 5.4b. Result after sieving the sample taken between 208,5-211,5 cm, from the core section CP3 120-220 cm. Note the pen in the background for scale.

5.5 Carbon-14

The results from the 14C-dating of the selected samples unfortunately did not return from the radiocarbon laboratory before the printing of this thesis.

5.6 Loss on ignition

Loss on ignition was measured on all three cores with XY-resolution. Here the loss on ignition data will be compared to the lithological changes of the three composite cores. Furthest to the left in each figure the composite core is found, while the LOI data is placed to the right.

CP1

As mentioned in the chapter *Core description*, CP1 consists of three different layers, -two different types of clay and a peat layer in between them. The clay layers show a low weight loss of organic matter after the ignition at 550 degrees Celsius, (not more than 10 %), while the peat layer shows a weight loss of maximum 42 % after ignition at the same temperature. The weight loss due to the burning of carbonates after 950 degrees Celsius, led to a further weight loss of approximately 2 percent units compared to the loss during 550 degrees Celsius, which indicates low carbonate content (figure 5.6a).

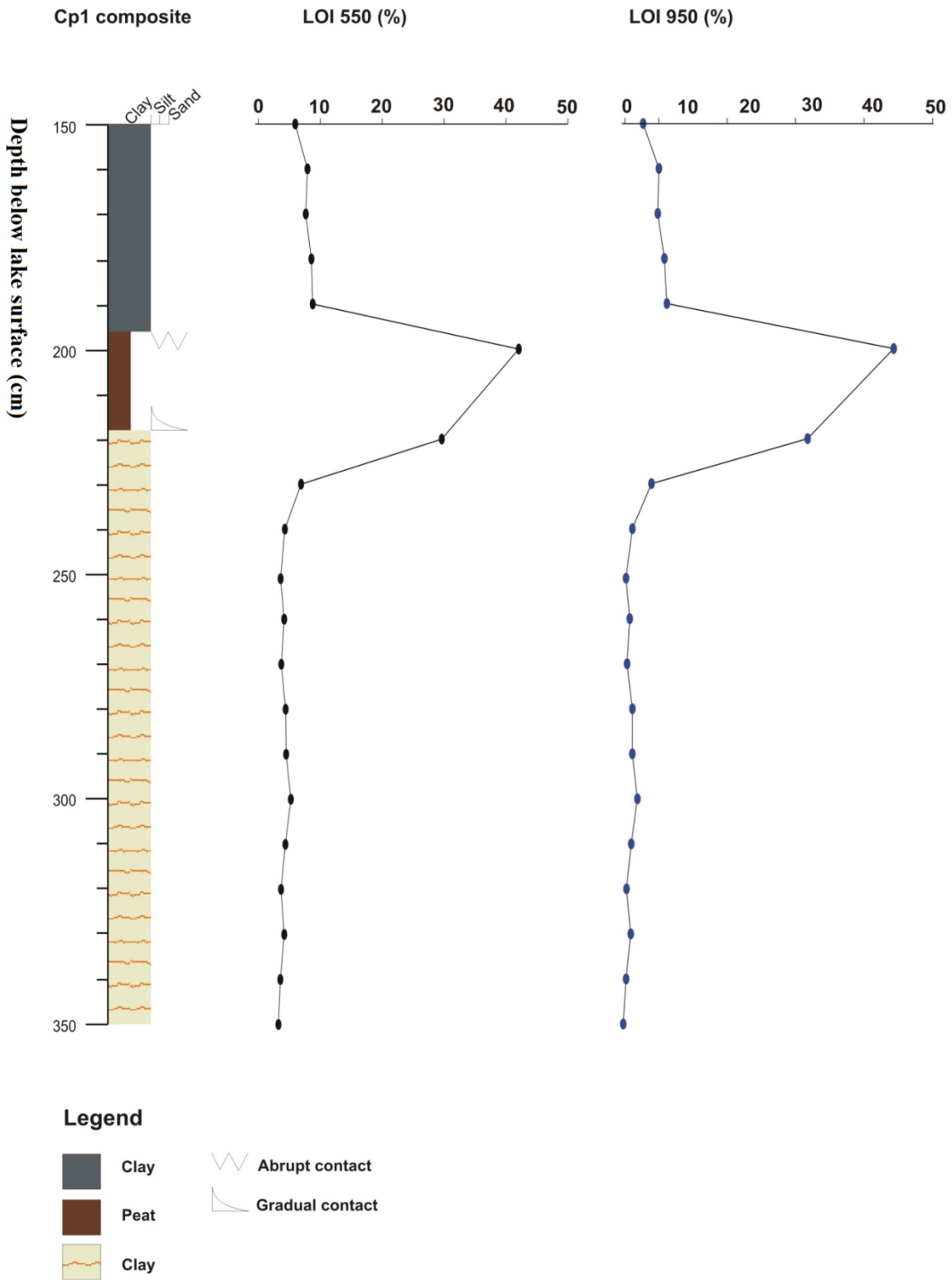

Figure 5.6a. CP1 (composite) and LOI data in weight percentage from 550 and 950 degrees Celsius.

CP2

The alternation between the light gray clay and the gyttja clay from 700 cm to 310 cm, shows a good correlation to the LOI plots (figure 5.6b). Here it can be seen that a low loss in both organic matter and carbonates is a fact in the clay layers, while the gyttja clay layers show a relatively high loss in organic matter. The beige clay with orange patchy pattern also shows a low loss in both organic matter and carbonates -a similar LOI pattern as the light gray clay further down in CP2. The top of CP2 (220 to 145,5 cm) is relatively rich in organic matter, which can be seen in the weight percentage lost after the ignition at 550 degrees Celsius, where a peak is situated in the gyttja layer. Just like CP1, the LOI plots also show that most of the total weight lost happened during the temperature of 550 degrees Celsius, and that the additional loss during 950 degrees Celsius stands for approximately 2 percent units for each sample, which also here indicates that the carbonate content is low.

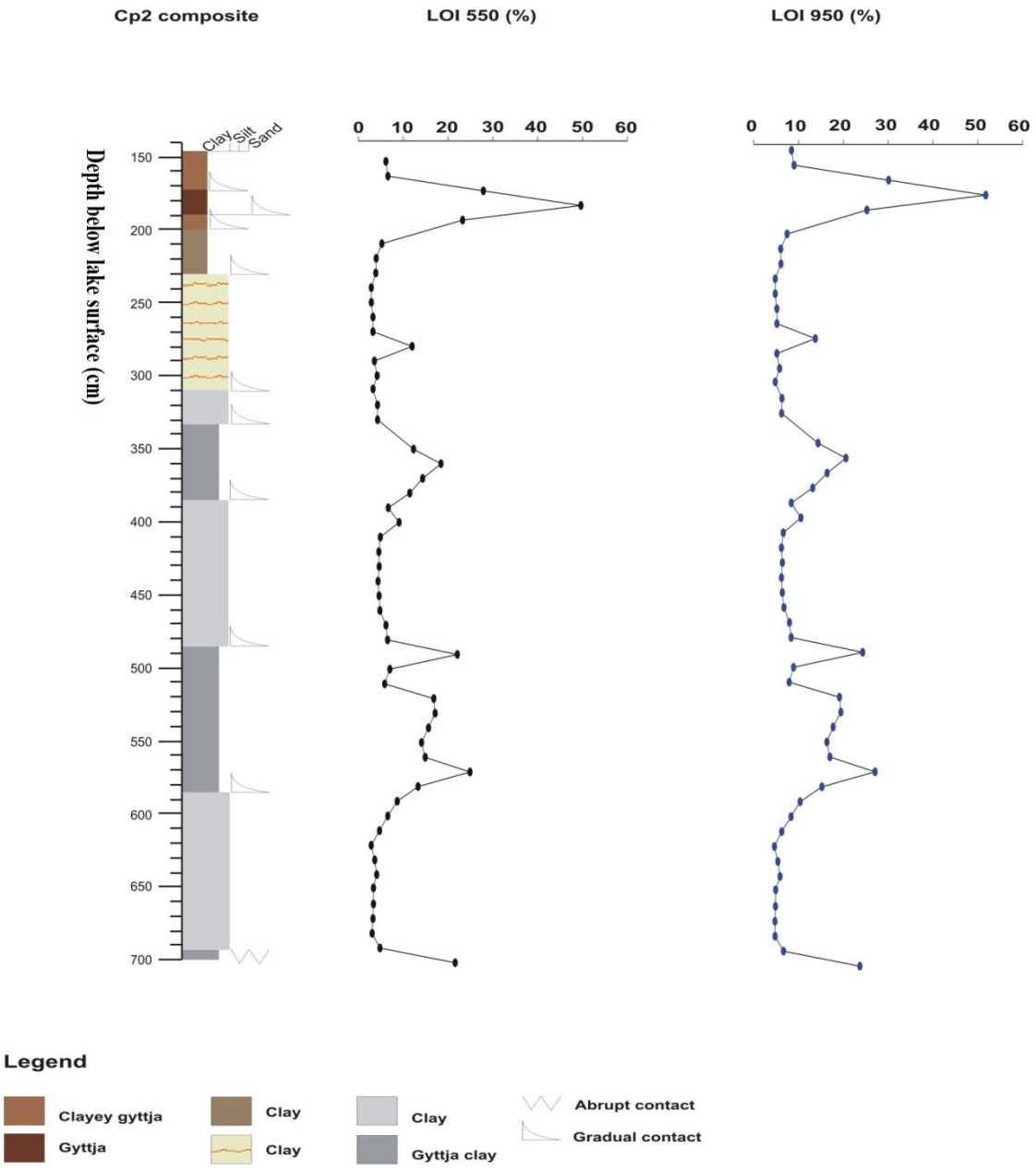

Figure 5.6b. CP2 (composite) and LOI data in weight percentage from 550 and 950 degrees Celsius.

CP3

The bottom half of CP3 shows a low loss in both organic matter and carbonates, which is expected since this part consists of homogenous clay. The uppermost half of this core shows a great variation in the LOI data (figure 5.6c). The gyttja layer in the top shows a relatively high weight lost in organic matter after 550 degrees. The two different clay layers that follow the gyttja have one great LOI peak each. The peaks are due to the relatively big organic fragments that are common in both clay layers. Just like the cores for CP1 and CP2, also CP3 shows that the majority of the weight loss happened during the ignition of 550 degrees Celsius, and that the additional loss at 950 degrees is low, which means that the cores have low carbonate content.

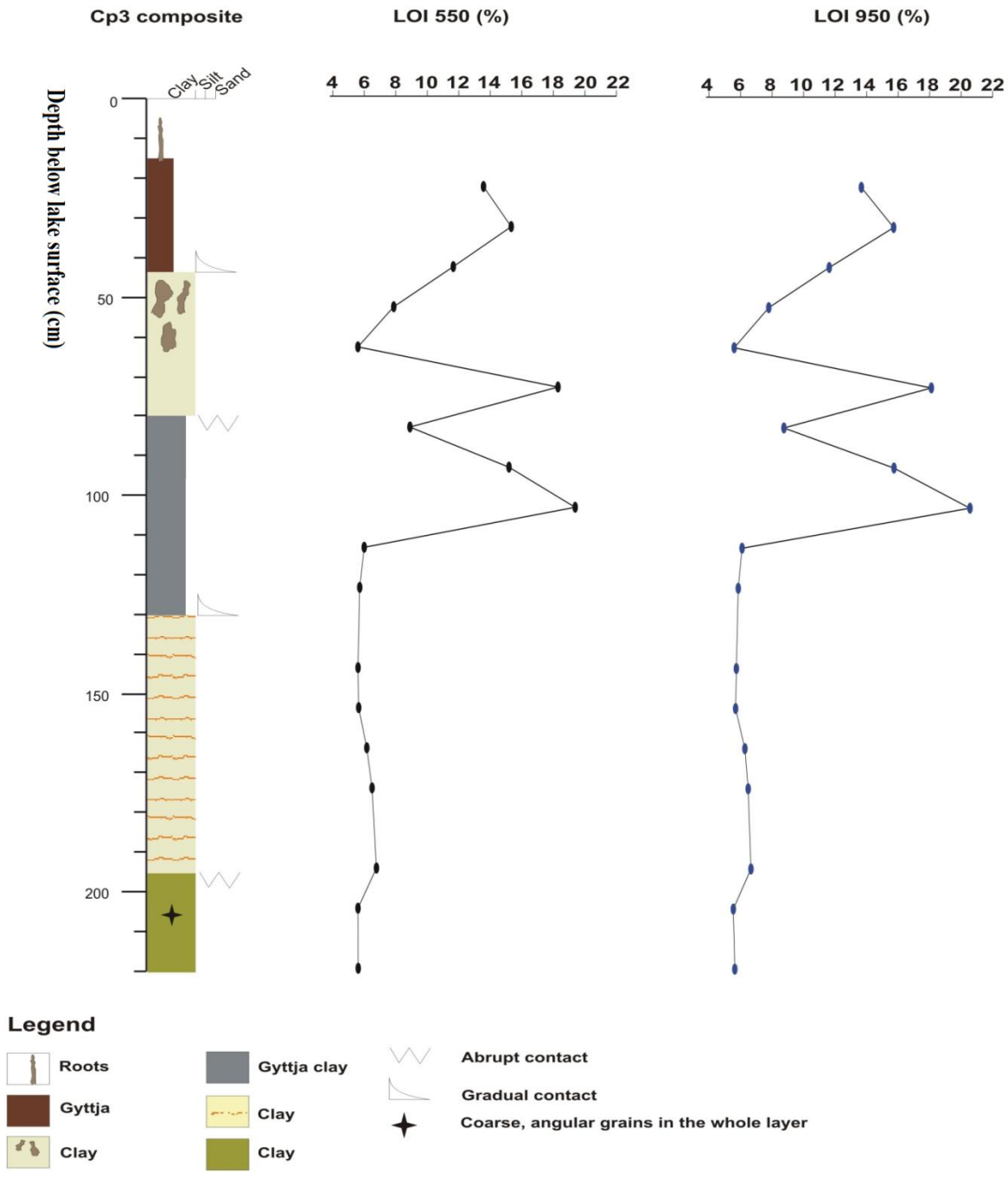

Figure 5.6c. CP3 (composite) and LOI data in weight percentage from 550 and 950 degrees Celsius.

6. Discussion

Figure 6.a indicates how many different types of sediment there are in the Kuchi Lake, and how they have been changing through time. Today a marsh is found where CP3 is situated. However, the fourth layer from the top of CP3 shows the beige clay with an orange patchy pattern, which is of the same type of clay as the one found in the bottom of CP1, and under the organic rich top of CP2. Because clay particles only settle in calm, and relatively deep water, under similar conditions that is found in CP1 today, this indicates a bigger and deeper lake at the time when the clay in CP3 was deposited. In CP1 it can be seen that the second layer from the top in this core is made of peat, while the layer under it is made of clay. Since peat formation requires marsh environments with a low water level, it is likely that the water volume of the Kuchi Lake has changed during the time covered by the sediment cores, which could have lead to peat formation during a low water level, and clay formation during a high water level. Another possible alternative instead of a decreased water level is an increased sediment deposition, with a shrinking lake as a consequence.

The alternation between light gray clay and the darker layers with more organic matter in CP2 cannot be explained in the same way as the previously mentioned peat layer in CP1. Instead I propose three different main hypotheses regarding the evolution of this sediment alternation, which will be presented and discussed here.

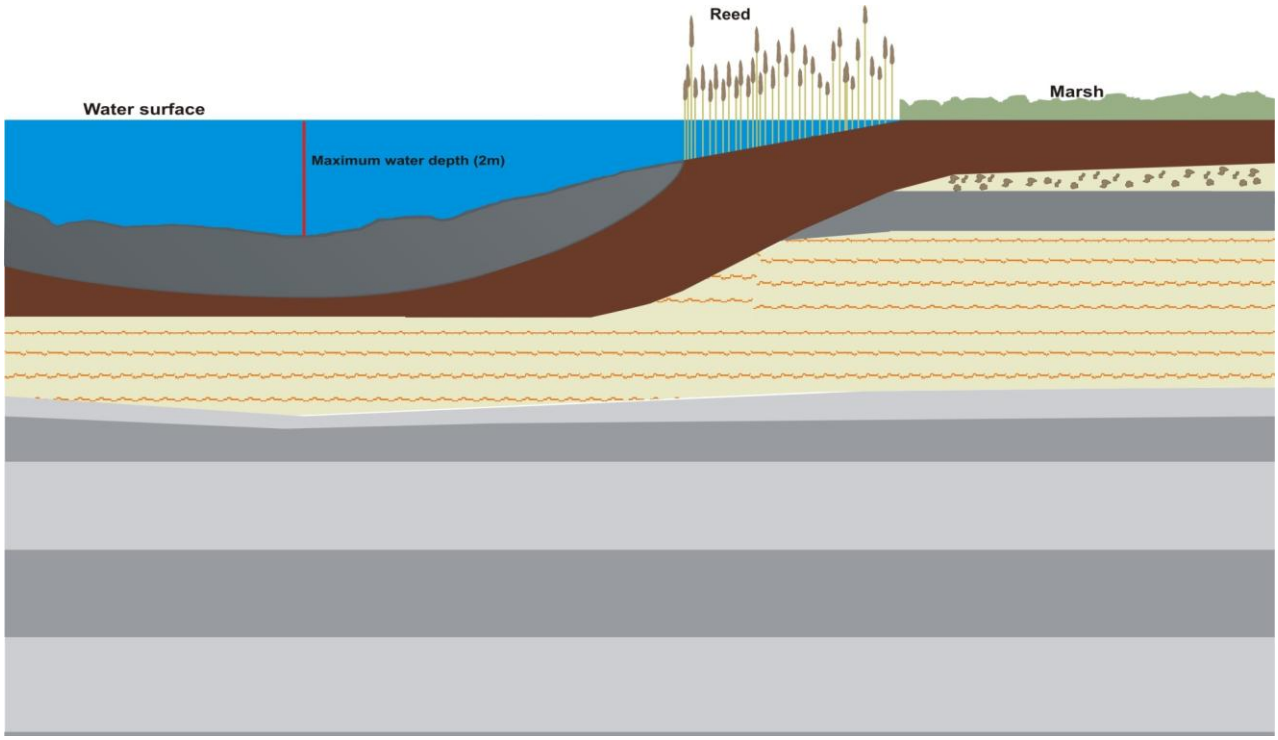

Figure 6.a. Profile of the Kuchi Lake, with sediment layers constructed after the three composite cores.

Hypothesis 1

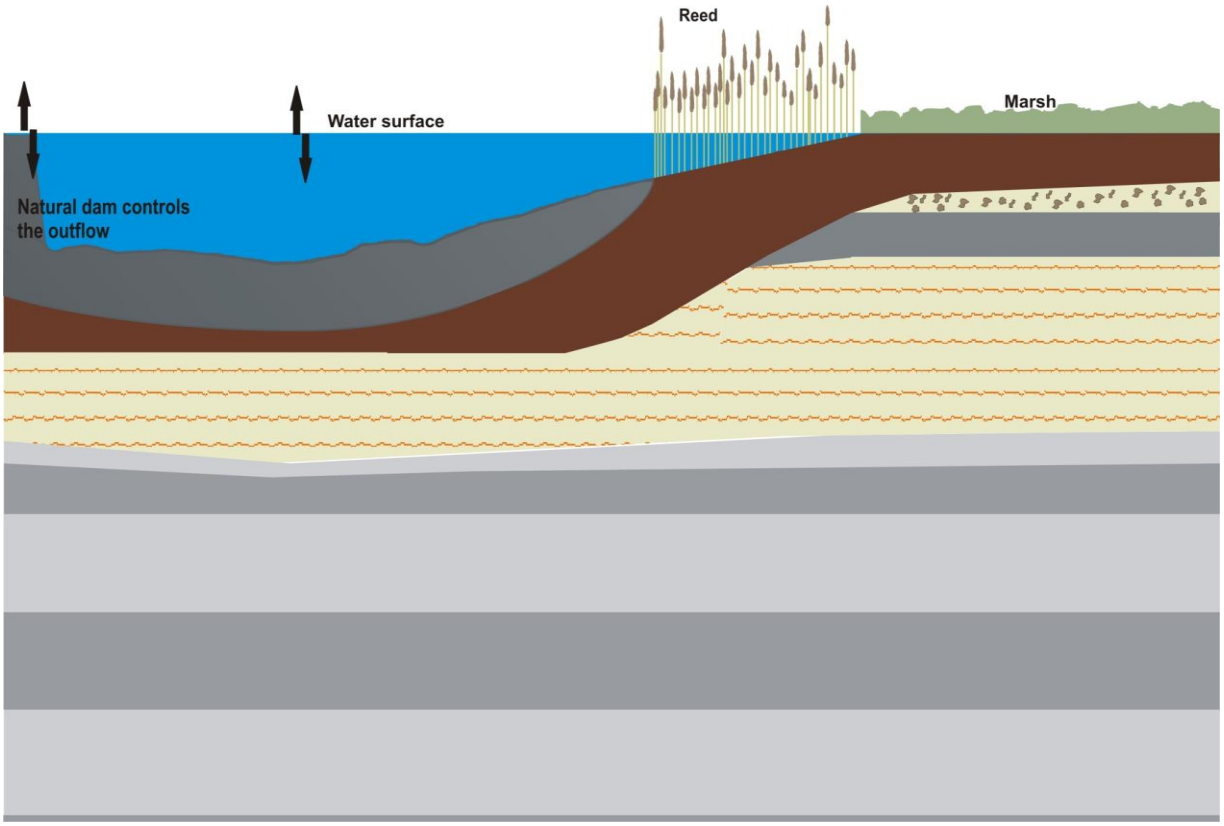

Figure 6.b. Hypothesis 1: A natural dam controls the water level of the Kuchi Lake.

Since the Kuchi Lake is situated in a tectonically active area, an early hypothesis was that a fault is acting as a dam, which controls the water level by changing the height of the threshold in the outlet area of the Kuchi Lake (figure 6.b). This phenomenon could have been the answer to the variation between the organic rich and clay rich layers found in CP2. Since clay is deposited in relatively deep and calm water where the particles can settle, it should mean that when the water level was high enough for clay to be created, the threshold was high enough to prevent the water from leaving the lake. When the dam on the other hand was lower, more water would have been able to escape, and thereby change the lake into a marsh. The marsh would in turn favor the formation of peat.

Hypothesis 2

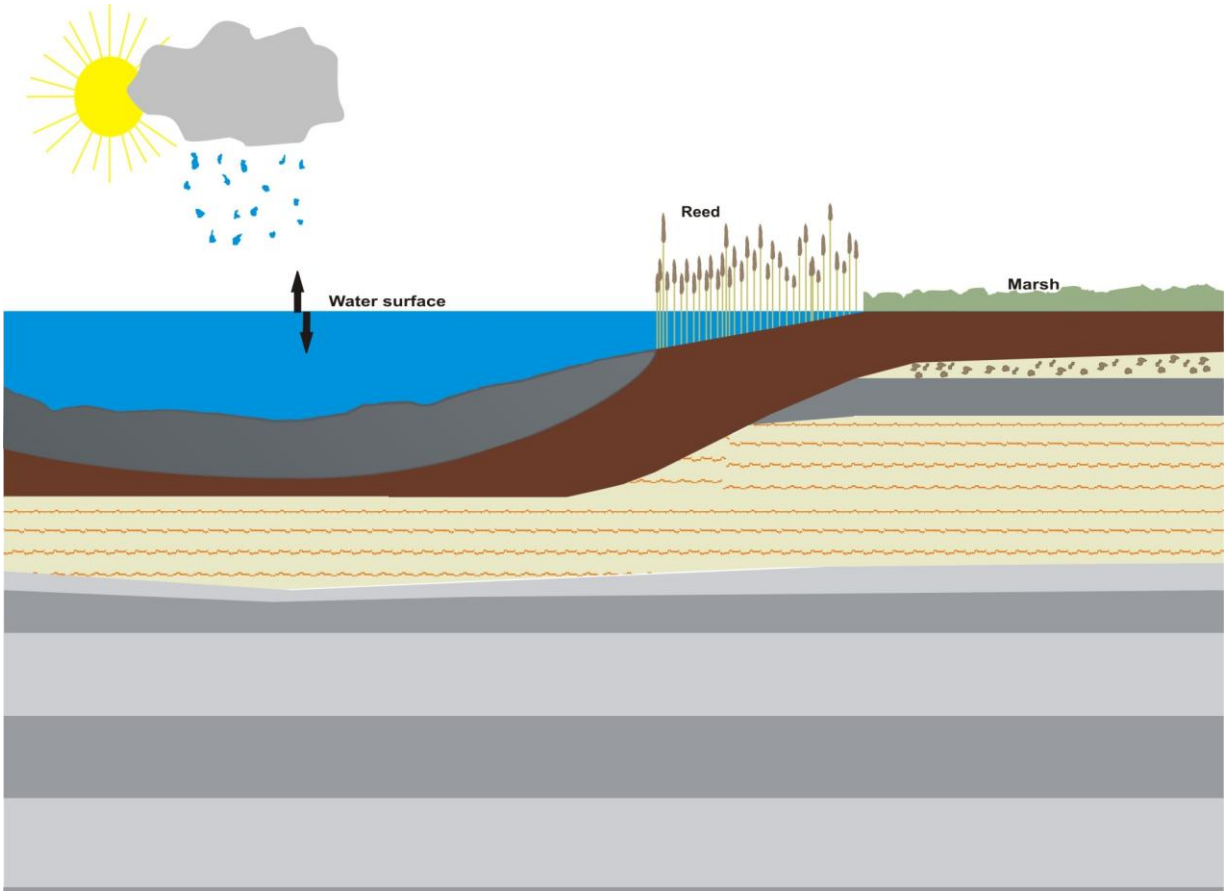

Figure 6.c. Hypothesis 2: Dry, respective wet periods control the water level of the Kuchi Lake.

An alternative hypothesis is that drier and wetter periods have changed the water level of the lake, and in that way changed the conditions for sedimentation and favored the formation of the clay, respective the organic rich layers (figure 6.c).

Hypothesis 3

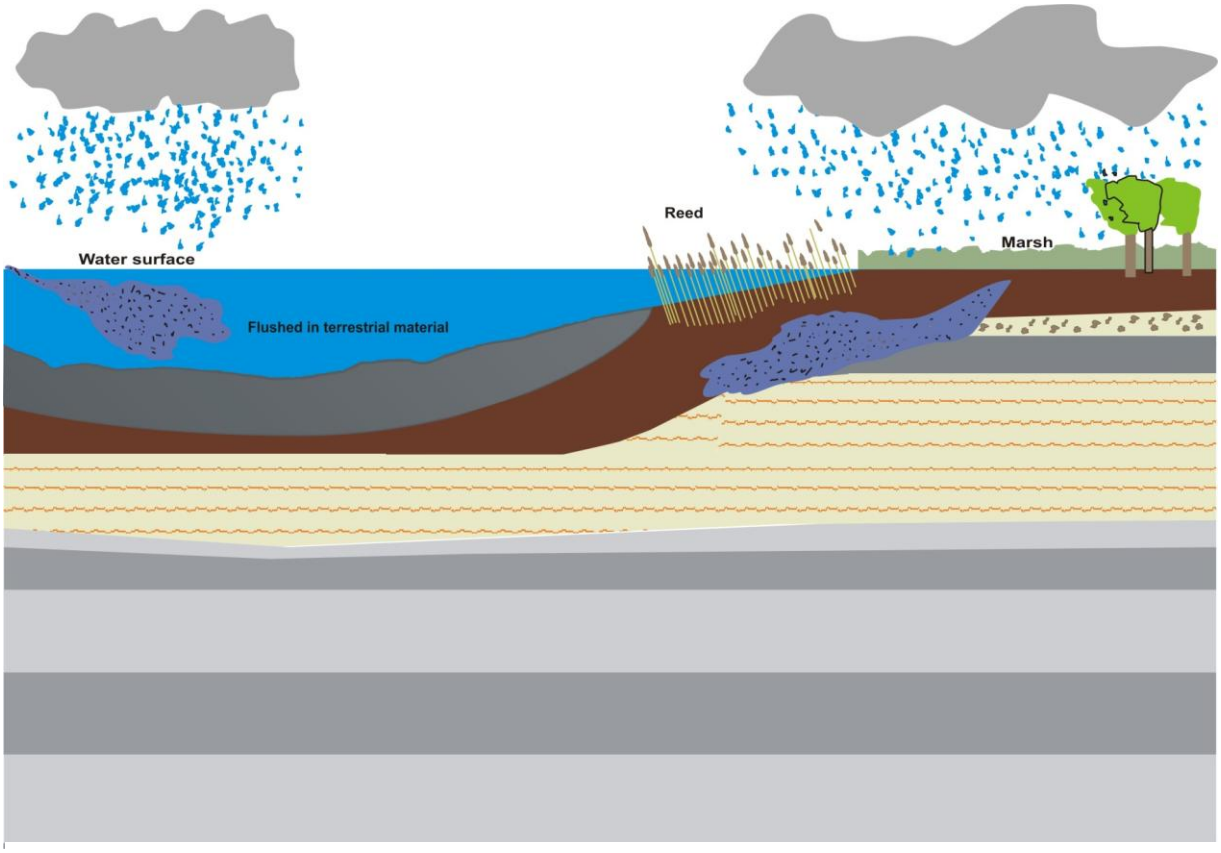

Figure 6.d. Hypothesis 3: Flushed in terrestrial material is the answer to the returning gyttja clay layers in the sediment of the Kuchi Lake.

The third hypothesis postulates that the water level of the lake stayed relatively high and stable during the whole time interval that covers the alternation of light gray clay and the darker layers with more organic matter in CP2. In this case the hypothesis for the organic rich gyttja clay layers in the alternation of CP2, is that they were formed during several intense rain falls (probably caused by typhoons) that flushed in all the organic matter and clay clasts from surrounding land (figure 6.d). Further evidence that points in this direction is the angular rock fragments that were found in CP3 120-220 (figure 5.4b). Because of the size and angularity of the fragments, a possible way of transportation is a relatively powerful flush from the nearby area. Also the light gray clay laminations in the gyttja clay layer between 585 and 487 centimeters in CP2, points in this direction, since they suggest intense sedimentation from another source due to the sharp contacts and different composition compared to the gyttja clay. A possible phenomenon that can cause this kind of powerful flushes is typhoons, which, as mentioned in *Study area*, usually strike Taiwan every year and bring locally strongly precipitation.

Discussion of the hypotheses

Both hypothesis 1 and 2 in the CP2 case can be refuted, since it was shown that the organic rich layers in CP2 consists of gyttja clay that have been flushed in together with terrestrial matter and clay clasts. This means that the organic rich layers (the gyttja clay) have little to do

with a changing water level in the lake. This makes the third hypothesis most likely (figure 6.d). One argument against the third hypothesis is that the transitions from the clay to the organic layers in CP2 are gradual in all the cases except one (the last transition in CP2 200-700). More abrupt transitions would be expected during the intense rain falls that flushed in terrestrial material to the lake. However, there is no doubt that the organic material and the clay clasts in the gyttja clay are terrestrial from the beginning.

7. Conclusion

From the results presented above, two main conclusions regarding the formation of the lake sediments and the lake's suitability as a climate archive can be made:

Since it was possible to correlate the lake cores to each other, it means that the deposition of the sediment in the lake have been controlled by the same factors, which is an important criteria for climate research. Except the disturbed parts that can be found in the uppermost layers in all the cores, the Kuchi Lake can therefore be used as a reliable climate archive.

At least three different natural factors have shaped the lithology of the Kuchi Lake sediments– Intense rain falls, calm conditions and drying or slowly refilling by incoming sediment to the lake. The alternation between the dark gyttja clay and the homogenous grayish clay that is found between 700 and 310 cm in CP2, suggest pulses of intense precipitation that brought the terrestrial material and the clay clasts to the gyttja clay layers. Between the pulses of flushed-in material, the grayish clay layers testify to calmer conditions, with a relatively high water level, where clay particles have been able to settle. Also the beige clay with orange patchy pattern points at the same calm conditions. This means that it is the climate that has shaped the sediment, and that the tectonics has an insignificant impact on the evolution of the Kuchi Lake.

When it comes to the volume change of the Kuchi Lake, the beige clay with orange patchy pattern also tells that the Kuchi Lake earlier has been bigger, since an open lake must have existed in CP3, which today is a marsh. The peat layer in CP1 may indicate that the lake also has been smaller, which can be explained in two different ways. The first one is a decreased water level, which favored formation of peat. The second possible case is that the lake is getting shallower due to incoming sediment, which later leads to peat formation when the lake is shallow enough.

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8.2 Illustrations

The cover page photo was taken by Jyh-jaan Huang, National Taiwan University, Taipei, Taiwan, during the coring of the Kuchi Lake.

Figure 2.1a and 2.2a were provided by Tien-Nan Yang, Academia Sinica, Taipei, Taiwan.

Figure 2.2b is a print screen from Google Earth, which together with the coordinates for the coring points were provided by Jyh-jaan Huang, National Taiwan University, Taipei, Taiwan.

9. Appendix

9.1 Sieving result tables

The following three tables show data from the sieving result from the respective master cores.

CP1

Depth (cm)	Description
175	Stone (0,5 cm in diameter)
206	Thread shaped organic matter and twigs
235	Empty
325	Clay clasts
336	Empty

Table 9.2a. Sieving result from CP1.

CP2

Depth (cm)	Description
175	Thread shaped organic matter
183	Thread shaped organic matter
200	Thread shaped organic matter
219	Thread shaped organic matter, but poorer than the previous
240	Empty
245	Empty
253	Empty
266	Empty
280	Empty
311	Empty
330	Empty
345	Rich in wood pieces
365	Clay clasts, rich in wood pieces and roots
380	Wood pieces with bark on some of them
395	Empty
417	Thread shaped organic matter, but poorer than the ones in the top, a few wood pieces
430	Two wood pieces (1*0,5 cm)
460	Empty
465	Empty
480	Empty
495	Clay clast (1*0,5 cm)
509	Clay clasts, twigs (1 cm long)
511	Clay clasts, wood pices
522	Empty
546	Clay clasts, rich in wood pieces and roots
566	Rich in roots and wood pieces
580	Clay clasts, wood pieces, roots
596	Wood pieces (0,5*1 cm)
610	Empty
632	Empty
650	Empty
669	Empty
685	Empty
695	Rich in roots and wood pieces

Table 9.2b. Sieving result from CP2

CP3

Depth (cm)	Description
36	Thread shaped organic matter and bark
56	Thread shaped organic matter and bark
88	Clay clasts, wood pieces
210	Clay clasts

Table 9.2c. Sieving result from CP3