Stratigraphic studies of a Holocene sequence from Taniente Palet bog, Isla de los Estados, South America

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Cover Picture: Taniente Palet bog in a valley that streches down to Bahia Crossley. (Photograph: Svante Björck)

Stratigraphic studies of the Taniente Palet bog at the north-western corner of Isla de los Estados, Tierra del Fuego, South America

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Abstract: Fourteen somewhat overlapping 1-m cores, forming a total sequence of about 10.90 metres, were retrieved from Taniente Palet bog on Isla de los Estados, Argentina. The cores were described and correlated both visually and by measuring magnetic susceptibility and loss on ignition. Twelve samples were also taken for radiocarbon dating. The results were then interpreted and compared with those from other localities in the region. Comparisons were also made on a more global scale.

The sequence from Taniente Palet bog mainly consists of peat of different humification degrees with some units of minerogenic material. However, the bottom of the sequence is dominated by minerogenic material. Available radiocarbon dates show that there is an age-reversal at the bottom of the sequence, indicating re-deposition in this part. The re-deposition was interpreted as reflecting a period of increased precipitation between around 7600 and 7500 cal. B.P. The inferred precipitation increase may have caused the stream connected to the bog to flood and transport minerogenic material eroded from bedrock and/or till, as well as older peat eroded from upstream, down to Taniente Palet bog. It is possible that the precipitation increase at this time reflects a more southerly position of the southern westerlies. After around 7500 cal. B.P. the heavy precipitation is believed to have ceased. However, results indicate that changes in climatic conditions may also have occurred at around 6500, 5200, 1400 and 600 cal. B.P. Data indicate that the medieval warm period (MWP) and the little ice age (LIA) also may be registered in the sequence. The suggested climatic changes at Taniente Palet bog appear to correlate relatively well with inferred climatic changes at other localities in southern Tierra del Fuego and in the South Atlantic region. In addition, the results from Taniente Palet bog may also support the idea of a Holocene bipolar seesaw climate effect.

Keywords: Holocene, South America, Tierra del Fuego, peat, paleoclimate.
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Stratigrafiska studier av torvmarken Taniente Palet bog i det nordvästra hörnet av Isla de los Estados, Tierra del Fuego, Sydamerika

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Trondman, A., 2007: Stratigrafiska studier av torvmarken Taniente Palet bog i det nordvästra hörnet av Isla de los Estados, Tierra del Fuego, Sydamerika. *Examensarbeten i geologi vid Lunds universitet*, Nr. 216, 27 sid.+ Bilagor, 20 poäng.

Sammanfattning: Fjorton, något överlappande, en meter långa borrkärnor har tagits från mossen Taniente Palet bog på ön Isla de los Estados, belägen i Tierra del Fuego i Argentina. De fjorton borrkärnorna bildar tillsammans en hel sekvens på ungefär 10.90 meter. Borrkärnorna har beskrivits och korrelerats, både visuellt och med hjälp av magnetisk susceptibilitet och glödförlust. Tolv prover har också tagits för åldersbestämning av sekvensen. Dateringen har skett med hjälp av kol-14-metoden. Kol-14-åldrarna har sedan kalibrerats till kalenderår. Slutligen har resultaten tolkats och jämförts med resultat från andra lokaler i regionen, men även mer globala jämförelser har gjorts.

Sekvensen från Taniente Palet bog består främst av torv av olika humifieringsgrad med minerogent material på några nivåer. Botten av sekvensen domineras dock av minerogent material. Åldrarna i botten av sekvensen är omväxlande unga och gamla, vilket indikerar att materialet på den här nivån har omlagrats. Omlagringen har tolkats som att spegla en period med ökad nederbörd mellan ungefär 7600 och 7500 cal. B.P. Den antagna nederbördsökningen kan ha orsakat en översvämning av bäcken, som är kopplad till mossen, och medfört att material eroderades från berggrunden, moränen och andra torvmarker uppströms och sedan fördes med ner till Taniente Palet bog. Det är möjligt att nederbördsökningen vid den här tiden berodde på en mer sydlig position av det sydliga västvindsbältet. Nederbörden minskade troligen efter ungefär 7500 cal. B.P. Resultaten indikerar dock att det var förändringar i klimatförhållandena även runt 6500, 5200, 1400 och 600 cal. B.P. Resultaten indikerar också att den medeltida värmeperioden och lilla istiden kan vara registrerad i sekvensen. De föreslagna klimatförändringarna vid Taniente Palet bog verkar korrelera relativt bra med antagna klimatförändringarna vid andra lokaler i södra Tierra del Fuego och i den Sydatlantiska regionen. Dessutom antyder resultaten att en så kallad ”gungbrädeseffekt” av klimatet kan finnas även under holocen.

Nyckelord: holocen, Sydamerika, Tierra del Fuego, torv, paleoklimat.
Handledare: Mats Rundgren, Svante Björck, Ingmar Unkel

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1 Introduction

Isla de los Estados is an island that is situated at the south-eastern tip of Tierra del Fuego, Argentina, South America. The island is located in a climatically sensitive area, which makes it very interesting for the study of climate changes. In December 2005 fieldwork was conducted on the island by a group of scientist from Sweden and Argentina. The fieldwork was carried out at several sites. One site, a bog called Taniente Palet bog, is situated at Bahia Crossley in the north-western part of the island. Here 14 somewhat overlapping 1-m cores were taken from two different bore holes, with one metre in between, forming a total sequence of about 10.90 metres. In this study, these cores are described, correlated with each other and dated in order to interpret and discuss the possible environmental changes experienced by the area during the Holocene. Only one paleoenvironmental study has been carried out in this area before, which was a pollen analysis by Johns (1981) based on cores taken from the island during an expedition in 1971. However, the core sequence from 1971 is not as long as the one taken in 2005. Since pollen analysis has not yet been made on the sequence from 2005 and no dating has been made on the sequence from1971, it is difficult to correlate and compare these two sequences. In addition, there is no detailed stratigraphic description of the sequence from 1971 that can be used for comparisons with the one from 2005. However, comparisons with other localities in the region are also made. In addition, possible changes at Taniente Palet bog are briefly discussed in a more global perspective.

1.1. Aims

The main purpose of this study is to describe, date and correlate the 14 overlapping cores from Taniente Palet bog on Isla de los Estados to attain a complete stratigraphic sequence. The second purpose of this study is to interpret the stratigraphical changes in the sequence and try to find out whether these changes reflect local climatic changes or if they can be related to regional changes, or even to climatic changes in the northern hemisphere.

To be able to interpret the sediments and the changes in the sequence, knowledge about the environment and the climate is important. Therefore, this report will start to give a general background description concerning for example geology, climate and vegetation for Tierra del Fuego and Isla de los Estados, as well as a description of the coring site.

2 Background

Tierra del Fuego (Fig. 1) is located in the southernmost part of Argentina between the latitudes 52ºS and 56ºS, and is surrounded by oceans – the Atlantic Ocean to the east, the Pacific Ocean to the west and the Southern Ocean to the south. It is a large archipelago, which consists of the main island Isla Grande and several smaller islands, and has a total land surface of around 66 000 km^2. Isla Grande comprises 70 % of this area (Tuhkanen, 1992).

Isla de los Estados (Fig. 1, 14), or Staten Island, is located southeast of Tierra del Fuego at around 55°S and 64°W and is the south-eastern extremity of the South American Andes (Johns, 1981; Dudley, 1983). The island is approximately 65 km long, 32 km wide at its broadest point and 0.4 km at its narrowest point, and oriented in an east-west direction (Dudley, 1983). The coastline of Isla de los Estados is very irregular with fjords and bays dissecting it (Johns 1981; Dudley, 1983). The island is separated from Isla Grande to the west by a 30 km wide strait, Estrecho de le Maire. To the south it is separated from the Antarctic Peninsula and South Shetland Islands by the Drake Passage (Johns, 1981), which is an approximately 1000 km wide, stormy open sea area (Tuhkanen, 1992).

Figure 1. Map of Tierra del Fuego and Isla de los Estados, Argentina, South America (http://encarta.msn.com)

2.1 Environmental description and geology

2.1.1 Tierra del Fuego

The relief of Tierra del Fuego is relatively variable, and this can especially be seen in a west-east direction (Fig. 2). According to Tuhkanen (1992) the topography of Tierra del Fuego can roughly be divided into two different parts – one more mountainous part and the other dominated by flat lowland. The western part, in particular the part adjacent to the Pacific Ocean, consists of steep mountains and narrow valleys, broken up in several landmasses with water in-between them. The landscape has been influenced by the repeated glaciations during the Pleistocene. Today, mountain glaciers are abundant, and some of them are fed by ice caps and stretches through the valleys down to sea level. The highest parts of Tierra del Fuego are situated in the western parts of Isla Grande with peaks ascending 2400-2500 m a.s.l. In the north-eastern part, the mountainous land changes into flat lowland, the Patagonian plain, although there are smaller hills and mountains here as well. The eastern area is more an intermediate region where the plain merges together with the mountains (Tuhkanen, 1992).

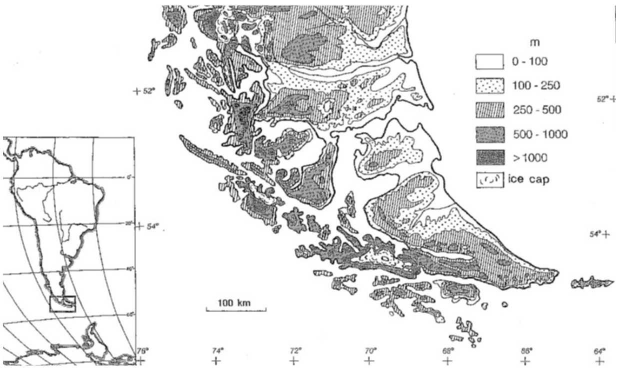

Figure 2. Topography of Tierra del Fuego (Tuhkanen, 1992)

The two main relief areas for Tierra del Fuego that have been described above can, according to Tuhkanen (1992), be explained by the geological history of the region. There are two major geological units that can be distinguished: the Andean Cordillera on the Antarctic and Pacific side of Tierra del Fuego, and the Magallanes sedimentary basin (pampas) on the Atlantic side. The Andean orogenic area can be divided into three mountain ranges: the Costal, Central and Marginal Cordilleras. The Coastal Cordillera mainly consists of andesites, diorites, granodiorites and granite. The Central Cordillera is mainly made up of metamorphic rocks, penetrated by granites and granodiorites, and the Marginal Cordillera consists of Cretaceous sedimentary bedrock. The Magallanes sedimentary basin is made out of Tertiary sedimentary rocks, which are covered by Quaternary glacial and fluvioglacial deposits like sands, gravels, clays and till (Tuhkanen, 1992).

2.1.2 Isla de los Estados

Isla de los Estados is a part of the Andes, which makes the island very rough and mountainous, with the highest mountain, Mtes. Bove, having an altitude of 823 m a.s.l. According to Dudley (1983), the flattest areas on the island are located around Bahia Crossley where the elevation stretches to 30 m a.s.l. at the most. Most parts of the coastline constitute of steep cliffs rising out of the sea, but there are also parts with sandy or cobbled and pebbly beaches. The substrate in the lower situated areas on the island is often peaty and waterlogged. There are also abundant streams and streamlets on Isla de los Estados, but these are not often more than a few meters wide (Dudley, 1983).

According to Johns (1981), the bedrock on Isla de los Estados is mainly made out of silicic volcanic rocks, which were formed by volcanic islands in a shallow marine environment. In the northern and western parts of the island outcrops show that the volcanic rocks are overlain by black mudstones and shales. The contact between the two sequences is conformable. The volcanic and sedimentary sequences are thought to be of Upper Jurassic and Lower Cretaceous age. Structurally, Isla de los Estados is an asymmetric syncline with the axis extending in an east-west direction. Studies have also shown that the fold probably is overturned, since there are places were the sedimentary rocks are overlain by the volcanic rocks. The latest orogenic activity in the area occurred in the late Pliocene when the final uplift of the Andes took place, which formed the Cordillera along the south-western rim of Tierra del Fuego and which Isla de los Estados is the extremity of (Johns, 1981).

In contrast to other parts of Tierra del Fuego, Isla de los Estados has no glaciers today. There are, however, evidences of earlier mountain glaciers throughout the island, like abundant steep fjords and cirque lakes (Dudley, 1983).

2.2 Present-day climate

2.2.1 Tierra del Fuego

The climate of Tierra del Fuego is influenced by the strong westerly winds that prevail at this latitude (40-60ºS), caused by cyclones moving along a path to the east or southeast across the tip of the continent, and its relatively near location to Antarctica (Fig. 3) (Tuhkanen, 1992). Tierra del Fuego is considered to be one of the stormiest parts of the world (Johns, 1981). Because Antarctica holds > 90 % of the ice on earth, it creates a large temperature gradient between the South Pole and the equator (Heusser, 1989a). This gradient is nearly 40 % greater than the temperature gradient in the Northern Hemisphere. The gradient in the Southern Hemisphere is responsible for the strong westerly winds that prevail here. Studies show that intensification of the westerlies is related to the Antarctic ice cover and the extent of sea ice. The latitudinal position of the west wind belt also depends on the extent of the Antarctic ice. During periods of large ice masses around Antarctica the west wind belt has been intensified and displaced northwards. This happened, for example, during the LGM (Heusser, 1989a).

According to Tuhkanen (1992), the geomorphology of the region, especially the Andes, is also of great importance for the climate, for example causing orographic precipitation and rain shadows in some parts. The mountain chains can also affect the strength and direction of the winds more locally (Tuhkanen, 1992).

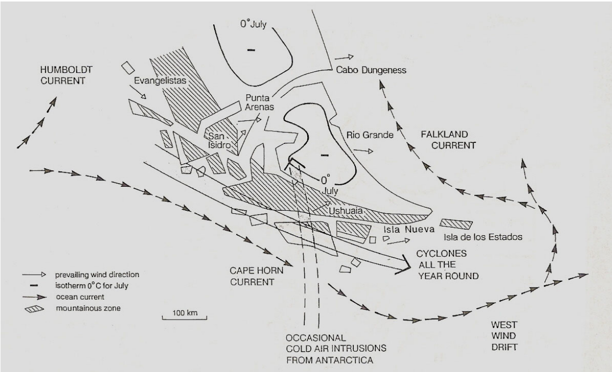

Figure 3. Prevailing wind directions and ocean currents around Tierra del Fuego
(Tuhkanen, 1992)

Tierra del Fuego is situated between the semi-permanent subtropical high-pressure cells, which stretch from c. 20 to 40°S, and the subpolar low-pressure trough, which occurs approximately on the Antarctic Circle. These systems are fairly stable throughout the year, causing the west winds to prevail during the entire year (Tuhkanen, 1992). However, to some extent, the two systems fluctuate seasonally, which also cause seasonal fluctuations of the westerly wind belt. The wind belt advances towards the equator in the winter and retreats poleward in the summer. However, this large seasonal shift of the stormtrack, comparable to modern conditions, developed first after 4500 yr B.P. (c. 5300 cal. B.P.) (Markgraf, 1993).

Sometimes during the winter cold stable Antarctic air masses reach north over Tierra del Fuego causing brief sunny, dry, cold and windy periods (Fig. 3) (Tuhkanen, 1992). The northward moving Antarctic air may also be warmed and moistened by the seawater, reaching Tierra del Fuego as a cool, moist and unstable current, which then joins the west winds. The winds during the summer and spring are often more persistent and stronger than during the winter, which can explain the cool growing season in the region. Due to the cyclonic west wind drift, there are no long warm periods, only a couple of days of warmth, during the summer. The mean annual wind speed is 12 m/s in the west and southwest and 4-6 m/s in the lee of the Cordillera due to the sheltering effect. On the Patagonian coast, the wind speed has an average of 8 m/s (Tuhkanen, 1992).

The proximity to the sea affects the temperature and creates a more oceanic climate (Tuhkanen, 1992). The large influence from the sea reduces the seasonality in the region and keeps the average temperatures in the coastal areas above freezing point even during the coldest months. Since the seasonal differences are small, the temperature range is not great either. The largest difference between mean temperatures for the warmest and coldest month of the year is found in the inland (c. 13°C), where the ocean does not have as great influence on the climate as in the coastal areas. Some other characteristics of the climate in Tierra del Fuego are that there are rarely any extreme temperature conditions and the average daily temperature ranges are small. Thunderstorms and hail are also very unusual in Tierra del Fuego. Due to the relatively even temperature regime in the region, the growing season (period with daily mean temperatures of +5°C or higher) is relatively long, although quite cool. There can also be frosts during the growing season in the inland areas, even during the summer. In the inner parts of Isla Grande the ground is permanently frozen, down to about one metre (Tuhkanen, 1992).

The special climatic conditions, concerning pressure and winds, together with the presence of the Andean mountain chain, create a strong rainfall gradient across the region (Tuhkanen, 1992). The distribution of soil and vegetation, as well as land use is strongly reflected by this pattern. The moist air from the South Pacific is precipitated as rain in the lowlands and snow in the mountains on the western coast. At the Central Cordillera the precipitation increases, which is due to the orographic influence of the mountains. When the wind has lost its moisture it flows eastwards and becomes dry, which causes the aridity of the eastern and north-eastern parts of the region. Maximum precipitation in Tierra del Fuego is about 4000-5000 mm per year. The amount of precipitation decreases towards the southeast. Tierra del Fuego receives rainfall in all seasons, so there is no distinct dry season during the year. Most of the rain falls during the autumn or summer, which can be explained by the greater intensities of the rainstorms during these periods. It is the higher water vapour content in the air during this time of year that is generating the more powerful storms. At altitudes above 1000 metres, the precipitation usually falls as snow. The permanent snowline lies at around 700-900 m a.s.l., but it varies locally (Tuhkanen, 1992).

Tierra del Fuego is generally very cloudy, with cloudiness of an average of 80-90 %. The cloudiness also influences the amount of sunshine reaching the area (Tuhkanen, 1992). In winter, mean daily sunshine is low, with a minimum daily average of about one hour. The maximum average is about 6.2 hours per day and occurs during the spring and summer (Tuhkanen, 1992).

2.2.2 Isla de los Estados

Since Isla de los Estados is a part of Tierra del Fuego, climate on the island is similar to the rest of the region, with only some small differences. Isla de los Estados is also subjected to the westerly winds, which contain much moisture causing precipitation throughout the year. In contrast to many other parts of Tierra del Fuego, the climate of Isla de los Estados shows a more pronounced seasonal differentiation (Dudley, 1983). On Isla de los Estados, the mean temperature for January is 9.2°C and 2.6°C for July. The mean annual temperature is 5.7°C and the mean annual precipitation is 1701 mm (Johns, 1981). Annual precipitation is less in southern Tierra del Fuego relative to its western parts, which is partly due to the fact that the mountain chain is not oriented transversely to the westerly winds in these parts (Tuhkanen, 1992). Although snowfall is not as common on Isla de los Estados as in the western parts of Tierra del Fuego, it does occur, especially during winter (Dudley, 1983). Weather is highly variable on the island, and it can shift rapidly and unpredictably several times during a day. The annual cloud cover is estimated to be around 74 % for Isla de los Estados, which is somewhat lower than for other parts of Tierra del Fuego (Dudley, 1983).

The very special climate of Isla de los Estados, and the rest of Tierra del Fuego, makes it quite unique, and only a few other places on Earth have similar climate. Such areas are for example found on the coast of Iceland, on The Faeroe and Shetland islands, in the Scottish mountains, on the north-western coast of Norway and on the southern coast of Alaska (Tuhkanen, 1992). There are, however, some differences in the vegetation between these areas.

2.3 Present-day vegetation

Plants growing in Tierra del Fuego need certain characteristics to thrive under the special climatic conditions that prevail in the region. They need to be able to utilize the long and cool growing season, as well as coping with the strong winds, which can damage the plants physically (Tuhkanen, 1992). While plants in inland areas, where frosts may occur even during summer, have to be adapted to intense cold, plants growing in the west and southwest do not need to withstand cold due to the direct oceanic influence there (Tuhkanen, 1992).

2.3.1 Tierra del Fuego

Tuhkanen (1992) presents seven different vegetation formations (Fig. 4) that traditionally have been distinguished in Tierra del Fuego. These are moorland, rainforest, mixed forest, deciduous forest, woodland, steppe and andi-alpine vegetation. Here follows a short presentation of these formations. The vegetation formations in Tierra del Fuego are roughly oriented parallel to each other and the coast. Therefore, they are presented in the order they occur, from the west to the east coast.

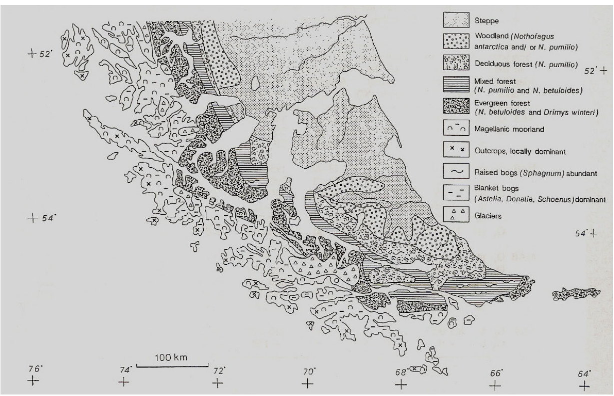

Figure 4. Vegetation formations in Tierra del Fuego (Tuhkanen, 1992)

Moorland is found in the most western and southern parts of Tierra del Fuego, and consists of several bog communities. The most common vegetation types on the bogs are dwarf shrubs, cushion plants, sedges and bryophytes. Even patches of evergreen forest can develop in more sheltered places.

Evergreen (rain-) forest is a very dense forest dominated by *Nothofagus betuloides* (Fig. 5), a type of southern beech belonging to the Fagaceae family, and *Drimys winteri* (Fig. 6), a small tree belonging to the plant family Winteraceae . The floor of the forest is often covered by *Hymenophyllum* spp. (Hymenophyllaceae), a type of fern. There is also a large quantity of epiphytes in the forest. The flora is quite species poor and consists almost entirely of evergreen plants. The decomposition rate is very slow in this type of forest, which causes a large amount of dead organic material to accumulate on the forest floor. The forest is very dense and therefore one of the worlds most impenetrable. In depressions in the terrain, mires and bogs are widespread and characterized by cushion plants like for example *Astelia pumila* (Fig. 7).

Figure 5. Nothofagus betuloides (www.florachilena.cl)

Figure 6. Drimys winteri (www.florachilena.cl)

Figure 7. Astelia pumila
(http://web.ujf-grenoble.fr)

Mixed forest occurs in a narrow area between the zone of evergreen forest and the zone of summergreen forest, stretching from north to southeast of Tierra del Fuego. This type of forest consists mainly of *Nothofagus pumilio* (Fig. 8) and *N. betuloides*, and is one of the most productive forests in the region. The forest has double canopies, with the upper reaching at least 25-30 metres above ground. On the eastern border of the mixed forest, there are hardly any evergreen forest species left, or they are confined to bogs.

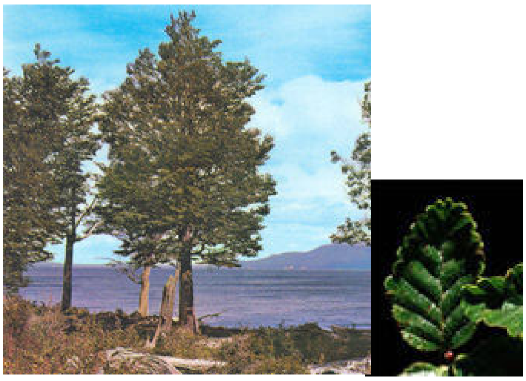

Figure 8. Nothofagus pumilio
(http://en.wikipedia.org/wiki/Lenga_Beech; www.florachilena.cl)

Deciduous forest mostly consists of the southern beech *N. pumilio*. In these forests, the flora is species poor and the field layer is poorly developed because of the shadowing from the tree crowns. *Sphagnum* bogs, often raised, are widespread in this vegetation formation, and the peat-forming species are commonly *Sphagnum* and *Carex* (Cyperaceae). *Empetrum* is also a common species on these bogs.

Woodland formation forms communities that are a mix of forest and steppe, which have rich field and shrub layers. The dominating trees in this formation are *Nothofagus antarctica* (Fig. 9) and *N. pumilio*. *N. antarctica* has trunks that are bent and twisted, and are creeping or ascending. These trees have a maximum height of about 8 metres. In the woodlands, *Marsippospermum* (Juncaceae) (Fig. 10) commonly dominates the mires, but *Sphagnum* may also be important, as well as *Carex*.

Figure 9. Nothofagus antarctica
(www.florachilena.cl)

Figure 10. Marsippospermum grandiflorum
(http://web.ujf-grenoble.fr)

Steppe, often uniform and treeless, covers large areas of Isla Grande, and is dominated by different grasses. Most of the steppe area is intensively grazed, largely by sheep. Mires are rare in this vegetation formation. The mires that exist are mainly concentrated to rivers and springs, and are dominated by *Carex*, *Juncus* (Juncaceae) and grasses. The peat layers that are formed are often very thin.

Andi-alpine vegetation is varied. The upper timberline forms a boundary between the forest and the alpine zone. The timberline on Isla Grande lies at about 450-650 m a.s.l., but it can vary due to variations of local conditions. Between the forest and the alpine zone there is often a zone of *N. pumilio* and/or *N. antarctica*, which is very dense and difficult to penetrate. There are mainly four factors that determine the type of vegetation in the alpine zone; the altitude, availability of water, exposure to winds and the type of substrate. Heaths, feldmark and meadows are some of the vegetation types that usually can be found in the alpine zone. Cushion heaths are very common in the highlands of Tierra del Fuego. Feldmark is gently sloping areas with rock screes and talus deposits, characterized by dense lichen communities.

2.3.2 Isla de los Estados

Isla de los Estados belongs to the easternmost part of the evergreen rainforest formation, which extends south to 56ºS, only around 800 km from the Antarctic Peninsula, and is the southernmost forest existing today (Johns, 1981). The forest on Isla de los Estados is dense and impenetrable and is dominated by the southern beech *Nothofagus betuloides* (Johns, 1981). It is mainly the more sheltered areas on lower mountain slopes and valleys that are dominated by *Nothofagus* and *Drimys*, which are characteristic species in the evergreen rainforest (Dudley, 1983). At sites that are more exposed to the strong winds, vegetation is more similar to that of the moorland. The vegetation on Isla de los Estados is not only influenced by strong winds but also by other factors like, for example, the availability of water, altitude and the type of substrate. The most common substrate on the island is peat, especially in low and intermediate areas. The cold and wet climate is favourable for the formation of peat. The topography influences the drainage patterns, which is reflected in the distribution and composition of the vegetation. The mountain tops mostly consist of bedrock and mineral soil with peat accumulations in a few places. The larger peat accumulations are found in lower lying areas, where water accumulates (Dudley, 1983).

Dudley (1983) presents seven different vegetation formations or associations that are distinguished on Isla de los Estados. These are the littoral association, the maritime tussock formation, the evergreen forest formation, the scrub formation, the meadow formation, the Magellanic moorland formation and the alpine formation. These resemble the formations described above for the entire Tierra del Fuego, except for the littoral association and the maritime tussock formation. The littoral association consists of, as the name implies, different plants growing along the shoreline, and the maritime tussock formation is dominated by the tussock grass *Poa flabellata*. Tussocks can grow to be 2-3 metres high and are so densely distributed that it is difficult for other plants to compete with them. The evergreen forest formation is, as described above, dominated by *N. betuloides* and *Drimys winteri*. The scrub formation is characterized by two vegetation associations: the *Nothofagus antarctica* association, which is the deciduous, summer green forest, and the *Nothofagus betuloides – Marsippospermum grandiflorum* association, where *N. betuloides* forms the evergreen forests in which *M. grandiflorum* is the dominant ground cover. The meadow formation consists of a *Marsippospermum grandiflorum* association, which often occurs in lowlands and valleys. The largest meadow formations on the island occur in the valleys around Bahia Crossley. The Magellanic moorland formation is a quite complex vegetation formation since it consists of several subunits that may overlap each other. Three associations may be distinguished: the *Empetrum rubrum* association, the *Caltha* association and the *Astelia pumila* association. The *Empetrum rubrum* association is the dominating subunit of the Magellanic moorland formation and consists mainly of *E. rubrum* (Ericaceae) and *M. grandiflorum*, but *N. betuloides* and *D. winteri* also occur in this association. *Sphagnum* is often present in the moorland formation as well, although *Sphagnum* bogs are not seen anywhere on Isla de los Estados. The *Caltha* association is localized where *Empetrum* and *Marsippospermum* are less dense, and is dominated by *Caltha dionaeifolia* (Ranunculaceae) (Fig. 11) and *C. appendiculata*. *A. pumila* also occurs in this association, and together with the two *Caltha* species it often forms large areas of dense, low and flat mats. The *Astelia pumila* association mostly consists of dense mats of *A. pumila*, which occurs on upper slopes as well as on steep slopes at high altitudes. Examples of other genera that occur in this association are *Caltha*, *Gunnera* (Gunneraceae) (Fig. 11, 12) and *Drosera* (Droseraceae) (Fig.13). The alpine formation is characterized by creeping plants. *N. antarctica* and *E. rubrum* are often present, but are dwarfed and grow very near the substrate surface. Generally, weedy species are nearly absent on Isla de los Estados.

Figure 11. Gunnera (1) (the green leaf) and *Caltha* (2) (http://web.ujf-grenoble.fr)

Figure 12. Gunnera (www.florachilena.cl)

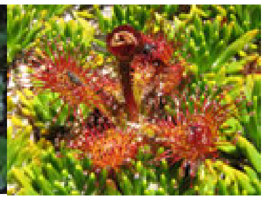

Figure 13. Drosera (www.florachilena.cl)

2.4 Vegetation and climate history

2.4.1 Tierra del Fuego

The vegetation and climate history of Tierra del Fuego is somewhat complicated due to the varying topographic and climatic conditions over short distances, but also due to a complex glacial history (Rabassa et al., 2000). As a result, pollen records are difficult to compare from different parts of the region. The vegetation and climate history of Tierra del Fuego presented in this part will therefore be focused on the southern parts of Tierra del Fuego. The original ^{14}C ages have been converted to calibrated years by visually reading off the INTCAL04-calibration curve (Bronk Ramsey, 1995, 2001), shown in brackets.

The first palynological studies in Tierra del Fuego was made in the early 20th century, and during the latter part of the century the southern South America became an area of intense palynological research (Heusser, 1995). For example, studies of *Sphagnum* peat bogs on Isla Grande have improved the understanding of the palaeoclimate in the region during the Late Glacial and Holocene (Rabassa & Roig, 1996). Following the Last Glacial Maximum (LGM), the climate became warmer and rapidly favoured the development of the *Nothofagus* forests (Heusser, 1989b; Rabassa & Roig, 1996). The warming occurred during the late-glacial, after around 15 000 ^{14}C years B.P. (c. 18 500 cal. B.P.). However, this warming episode was interrupted by a cold and dry episode, which is estimated to have occurred between c. 13 000 and 10 500 ^{14}C years B.P. (c. 15 300 and 12 600 cal. B.P.) (Heusser 1989a, 1989b, 1989c, 1990, 1995; Rabassa & Roig, 1996). The cooler climate resulted in a recession of the forest and expansion of the tundra (Heusser 1989b; Rabassa & Roig, 1996). Maximum warmth occurred at around 9000 ^{14}C years B.P. (c. 10 200 cal. B.P.) (Heusser, 1989b). During the late Holocene, after around 5000 ^{14}C years B.P. (c. 5700 cal. B.P.), the climate became cooler and wetter (Heusser, 1990; Rabassa & Roig, 1996). This led to the development of closed forests, ponds and lakes. In the small ponds and lakes, as well as in shallow depressions, *Sphagnum* peat has been able to accumulate. Cooler and wetter conditions are also more favourable for peat growth (Rabassa & Roig, 1996).

In the early Holocene, there was a greater productivity of open woodland, probably representing the forest-steppe ecotone, indicating drier and warmer climate (Heusser, 1989b, 1990). Thereafter, expanded closed forests and mires with *Empetrum* reached maximum production, probably due to cooler and wetter climate. According to Heusser (1990), pollen data from the Harberton bog, southern Isla Grande, show that the southern beech *Nothofagus* was relatively extensive among *Empetrum* and grass communities prior to 13 000 ^{14}C years B.P. (c. 15 300 cal. B.P.). However, by 13 000 ^{14} C years B.P. (c. 15 300 cal. B.P.) the southern beech was significantly reduced in its distribution, and until 10 500 ^{14}C years B.P. (c. 12 600 cal. B.P.) the vegetation was dominated by an impoverished tundra. Around the time of this cold episode, the glacier in the Beagle Channel (south of Isla Grande) is thought to have slowed down its retreat or even to have re-advanced. After around 10 500 ^{14}C years B.P. (c. 12 600 cal. B.P.) glaciers wasted extensively due to a warmer climate, and *Nothofagus* could re-expand. At the onset of the Holocene, around 10 000 ^{14}C years B.P. (c. 11 600 cal. B.P.), vegetation consisted of open beech woodland and grass steppe. The woodlands then successively changed into closed forest, and after 5000 ^{14}C years B.P. (c. 5700 cal. B.P.) closed forests dominated the landscape. The grass steppe was replaced by mires, which were expanding. This is indicated by an increase of *Empetrum* shown in the pollen record; *Empetrum* is a typical mire species (Heusser, 1990). After 5000 ^{14}C years B.P. (c. 5700 cal. B.P.), peat bogs increased their accumulation rate (Rabassa et al., 2000). From around 5000 ^{14}C years B.P. (c. 5700 cal. B.P.) until present, there was probably also increased storminess and cloud cover in the region (Heusser, 1989c). Palaeoclimatological data from southern Chile show that both temperature and precipitation have fluctuated during the entire Holocene (Heusser, 1989a). In addition, also Pendall et al. (2001) have carried out a palynological study on a 16 000 year old peat core from the Harberton bog. The results show a similar climatic and vegetational development as described above. Pendall et al. (2001) conclude that the paleoenvironment inferred from the pollen data is characteristic for all records from southern South America, with only some local differences.

Studies also show that the westerly stormtracks have shifted in latitude, not only seasonally, as today, but also over longer periods. This has caused the precipitation to fluctuate as well (Heusser, 1989a; Markgraf, 1993; Mayr et al., 2007). According to Markgraf (1993), there was a precipitation increase at around 12 500 ^{14}C years B.P. (c. 14 700 cal. B.P.) that extended down to 50°S, indicating a polewards shift of the stormtracks. However, it did not reach Tierra del Fuego until around 9000 ^{14}C years B.P. (c. 10 200 cal. B.P.). As mentioned earlier, the large seasonal latitudinal shift of the stormtracks, comparable to modern conditions, developed first after 4500 ^{14}C years B.P. (c. 5300 cal. B.P.).

2.4.2 Isla de los Estados

Although Tierra del Fuego has become an area of great climatological and vegetational interest, until now, only one paleoclimatological and paleobotanical investigation has been carried out on Isla de los Estados. The investigation was made by Johns (1981), who carried out a palynological study on a peat sequence at Bahia Crossley, and identified four major cycles of pollen composition, which were interpreted to reflecting four major climatic cycles. The pollen cycles include three different taxa: *Nothofagus*, Compositae (Asteraceae) and Ericaceae. Each cycle or zone starts with a gradual increase from minimum to maximum values of *Nothofagus*. At the upper boundary, to the next cycle, *Nothofagus* rapidly decreases to minimum values again. The Compositae and Ericaceae cycles are out of phase with one another as well as with the *Nothofagus* cycles, but the length of these cycles are the same. In each cycle, Compositae reaches its peak just below the peak for the *Nothofagus* cycle (e.g. at the end of each cycle), and Ericaceae reaches its peak just above the peak for the *Nothofagus* cycle (e.g. at the beginning of each cycle). The four cycles represent the postglacial period. At the top of the three lowest zones, *Nothofagus* reaches its maximum development, which probably reflects the presence of Magellanic evergreen forest. The Compositae component of the cycles is difficult to assign to a specific vegetation formation since it comprises so many different types of plants, which thrive in different types of environments. One possible vegetation formation that can fit the pollen profile is the meadow formation, which consists mainly of *Marsippospermum*. The Ericaceae component of the cycles correlates best with the Magellanic moorland formation, probably the *Empetrum rubrum* association. Compositae and Ericaceae have an inverse relationship to one another, which might be explained by competition between these two taxonomic groups. The percentage of arboreal pollen, in this case mainly *Nothofagus*, in the cores is believed to have a direct correlation with temperature changes. Johns (1981) compared a temperature curve from Chile for the postglacial period (Heusser & Streeter, 1980) with the arboreal pollen curve at Bahia Crossley and found that the two curves showed the same general pattern, which implies that periods with higher temperature appear to coincide with periods with high percentages of arboreal pollen. Therefore, the cyclicity of *Nothofagus* in the cores should reflect fluctuations in temperature. Moreover, the percentage changes of Ericaceae may be caused by changes in precipitation (Johns, 1981). According to Heusser (1989c), periods rich in *Empetrum* imply somewhat drier surface conditions. Another factor that influences the vegetation, and has been mentioned before, is the wind. Changes in wind activity cannot be detected in the study of pollen, but marine dinoflagellates are found almost continuously throughout the cores from Isla de los Estados, and these are good indicators of changes in wind intensity (Johns, 1981). The marine dinoflagellates may have been transported to the bog by seawater droplets picked up from the sea surface by the wind, or by scattered water droplets from the wave action along the shore. Therefore, an increase in the percentage of dinoflagellates indicates an increase in wind activity. The highest percentages in the sequence at Bahia Crossley are found in the upper parts of it (Johns, 1981). Unfortunately, there are no available dates for the sequence to use for comparisons with other palaeoclimatic studies. The marine dinoflagellates might as well have been transported to the bog through flooding by the ocean, but since there are no other evidences of marine transgressions in the sequence it is more likely that they have been transported here by the wind.

2.5 Volcanic activity and fires in Tierra del Fuego

At several sites in Tierra del Fuego late-glacial and postglacial tephra layers have been found in mires and stream cuts, indicating volcanic activity (Heusser, 1995). Using geochemical methods, the tephras have been traced to their source vents, and dated. For example, at around 6625-6930 ^{14}C years B.P. (c. 7500-7800 cal. B.P.) the Hudson volcano (c. 46°S) in Patagonia erupted and ash was transported all the way down to Tierra del Fuego. Sources of ash in Tierra del Fuego are for example Volcán Fueguino (c. 55°S) and a volcanic field northeast of Isla Grande (Heusser, 1995).

Charcoal has also been found at several sites in Tierra del Fuego, indicating past fires. The occurrence of charcoal in the records suggests recurrent fires, variable in intensity. The common occurrence of charcoal also suggests that the fires were widespread. Palaeoindians are believed to be the main cause of fires during the Holocene (Heusser, 1995). Also the peat core from the Harberton bog, studied by Pendall et al. (2001), contains high charcoal concentrations after 10 500 ^{14}C years B.P. (c. 12 600 cal. B.P.), suggesting high fire frequency. In addition, the core shows a c. 3000 years long hiatus in moss growth during the early Holocene, which also is related to frequent fires (Pendall et al., 2001).

2.6 Holocene changes in relative sea level in Tierra del Fuego

There is evidence of marine transgressions at several sites in Tierra del Fuego. Data from southern Tierra del Fuego record that relative sea level at around 5000-6000 ^{14}C years B.P. (c. 5700-6800 cal. B.P.) was 8-10 metres higher than today. These changes are related to glacioisostatic and hydroisostatic loading-unloading of land (Heusser, 1995). Björck et al. (2007) and Unkel et al. (2007, unpublished) have studied other localities on Isla de los Estados. A sediment sequence from the Lago Galvarne bog shows that there might have been a marine transgression at around 4000 years ago. The theory is supported by diatom analyses and high Br concentrations in the deposits.

3 Site description

Taniente Palet bog is located at Bahia Crossley, Isla de los Estados (Fig. 14).

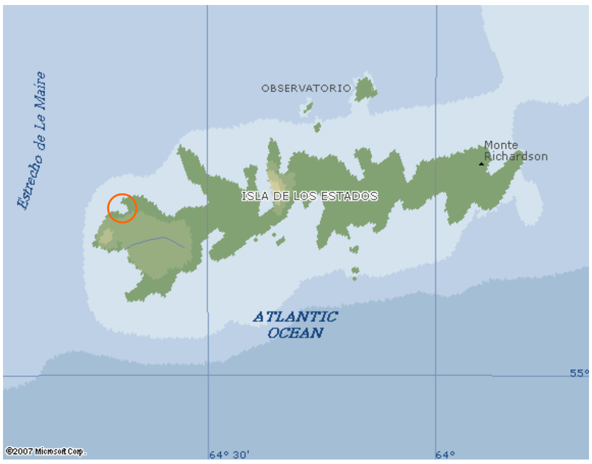

Figure 14. Isla de los Estados and Bahia Crossley (red circle) (http://encarta.msn.com)

The bog (Fig. 15) mainly consists of *Marsippospermum*, and is located in a valley that stretches down to Bahia Crossley. The exact (GPS) position of the coring is S54°48´00,3´´ and W64°40´01,1´´, which is 430 metres from the shore at an elevation of 8 m a.s.l. (at high tide). The local bedrock in the uplands around the valley consists of sedimentary Jurassic deposits, mainly mudstones and shales, which are covered by Pleistocene glacial and glaciofluvial deposits in the valley. Younger fluvial and aeolian sands are also found, as well as marine sediments along the coast. A small river runs through the bog and the distance between the coring point and the stream is approximately 60 metres. Vegetation can be characterized as a savannah-like *Marsippospermum grandiflorum* (Fig. 10) grass meadow with shrubs, such as *Chiliotrichum diffusum* (Compositae) (Fig. 16) and *Pernettya mucronata* (Ericaceae) (Fig. 17), as well as occurrences of shrubby *Nothofagus betuloides* (Fig. 5).

Figure 15. Coring at Taniente Palet bog (Photograph: Svante Björck)

Figure 16. Chiliotrichum diffusum (http://upload.wikimedia.org)

Figure 17. Pernettya mucronata (www.paghat.com)

4 Methods

4.1 Fieldwork

4.1.1 Coring

Coring was carried out in December 2005 with a Russian sampler (ø 5 cm). In total, 14 cores were retrieved. Two bore holes, with one metre in between, were used when retrieving the cores. Each core is 1 m long and their overlap was in the field estimated to be around 20 cm, which gave an estimated total sequence length of around 10.90 m. Because of erroneous measurements in the field, there is, however, no overlap between core 10 and 9. In addition, also due to difficulties to measure exact depths in deep coring, the overlap between core 12 and 13 as well as core 13 and 14 is much larger than 20 cm. The cores were transported in PVC tubes to Lund University where they were kept in a cold room.

4.2 Laboratory work

To be able to correlate the 14 cores, a visual description and estimation of correlation depths was made. However, since it was difficult to distinguish the different units in the peat further methods were used to get a more valid correlation. These methods were magnetic susceptibility and loss on ignition (LOI). The cores were also sampled for radiocarbon dating and photographed.

4.2.1 Description of cores

All the cores were described in the laboratory, and the depths for all unit boundaries were measured. Since the sequence mostly consists of peat of different humification degree, a five-grade scale was constructed to describe these variations, where P stands for peat and the number represents the degree of humification:

P1. Very low humified
P2. Low humified
P3. Medium humified
P4. High humified
P5. Very high humified

Humification degree is used because during wetter periods the organic material cannot decompose due to the lack of oxygen, which leads to lower humified peat than during drier periods. The varying humification degrees of the peat therefore reflect periods of drier or wetter climate.

Some of the peat units contain high amounts of minerogenic material, although the units are still considered to be peat due to the dominance of organic material in them. These peat units are also labelled with S and/or G, depending on whether it is sand or gravel or both in the peat. A four-grade scale was constructed to describe the amount of sand and/or gravel in the peat units:

1. Occasional/Some
2. Relatively rich in
3. Rich in
4. Very rich in

There are also units in the sequence that are not peat but instead minerogenic. A two-grade scale was used to describe these units:

SG. Sandy gravel
GS. Gravely sand

However, these units have a varying degree of organic material as well. Therefore, a four-grade scale was constructed to describe the amount of organic material in the more minerogenic units, where O stands for organic material and the number represents the amount of organic material:

O1. Occasional/Some
O2. Relatively rich in
O3. Rich in
O4. Very rich in

The labels presented above were used in the descriptions of the cores.

In some parts, the peat contains pieces of wood, sticks, roots as well as sand- and gravel grains. The amount of these elements in the peat is described by a four-grade scale:

Occasional/Some
Relatively rich in
Rich in
Very rich in

Because the presence of these elements is relatively scattered and may cross layer boundaries, the occurrence is presented as subunits in the description of the cores.

In the description of the cores, the colour of the peat was also taken into account. A three-grade scale was used in this case:

Light brown (L)
Medium brown
Dark brown (D)

In the descriptions, light brown units have been marked with an L, and dark brown units have been marked with a D. Most units in the sequence are medium brown. Therefore, if there is no colour label in the description of the unit, it is medium brown.

Some units consist entirely of wood, and these units have been labelled W in the descriptions.

The layer boundaries (upper and lower boundaries) have also been studied, and all have been considered to be gradual.

4.2.2 Dating

In total, twelve samples of about 1 cm^3 were taken for radiocarbon dating. The sampling was made at critical levels, such as lithologic boundaries, to create a consistent age-depth model. The twelve ^{14}C dates were then calibrated with the program OxCal 4.0 (Bronk Ramsey, 1995, 2001) and the SHCal04 calibration data set (McCormac et al., 2004). The calibrated ages used in this paper are the midpoints of the age ranges (Table 1).

4.2.3 Photographing

The cores were also photographed to better display the sequence. Four pictures, slightly overlapping each other, were taken for each core. Since each core is 1 m long, each picture represents c. 25-30 cm of a core. The four pictures were then merged together in Photoshop 8.0 to get a whole picture of each core.

4.2.4 Magnetic susceptibility

Magnetic susceptibility is a measure of the magnetizability of a sediment, which depend on the amount of ferro-magnetic minerals (minerals containing iron) in the sediment (Roberts, 2002). This is generally a good correlation tool, and is particularly useful in correlation of lake sediments (Roberts, 2002). Since minerogenic material is abundant in the sequence from Taniente Palet bog, this method has been used as a correlation tool.

All cores were measured at a 10 mm resolution, resulting in a high-resolution magnetic susceptibility profile for each of them. The data for individual cores were plotted in Grapher 2.0 and were then visually compared and matched with each other to get the actual overlap between the cores. Some of the magnetic susceptibility curves were, however, not easy to match, which partly depends on local occurrences of wood and stones that can cause extreme values. In such cases the overall trends of the curves were used for the correlations. In some cases it was too difficult to determine the overlap, and therefore, another correlation tool had to be used – loss on ignition (LOI).

4.2.5 Loss on ignition

Loss on ignition is a measure of the organic content in the sediments (Bengtsson & Ennell, 1986) and is in this case used as complementary correlation tool to the magnetic susceptibility.

Sampling was made according to the following description. In general, samples of c. 1 cm^3 were taken every 5 cm. Some samples had to be adjusted so that no unit got missed in the sampling, which is important for the correlation as well as the interpretation of the stratigraphic changes. Additional samples were taken at layer boundaries, which also could be important for the correlation and the understanding of stratigraphical changes. In such cases one sample was taken at each side of the boundary. It is important that the sample is representative for its unit, which means that if there was a single piece of wood or a stone in the sediment, samples had to be adjusted to avoid this. The LOI samples were taken close to the magnetic susceptibility measure points, although the LOI samples were taken at the side of the cores and the magnetic susceptibility were measured at the centre and top of the cores.

Samples were measured in the following manner. Wet samples were weighed, placed in weighed crucibles. Then they were dried in an oven at 105°C overnight (c. 12 hours). After the samples had cooled they were weighed again, and then burned in an oven at

550°C for two hours. This procedure causes the organic material to burn, leaving only minerogenic material left. The samples then had to cool off in a desiccator to prevent them from attracting moisture again. After cooled they were weighed again. To calculate the organic content in the samples the following equation was used:

$$LOI = \frac{B-C}{B-A} * 100 \quad (\%)$$

A = Crucible weight
B = Dried sediment + crucible weight
C = Burnt sediment + crucible weight

The calculated values of LOI were then plotted against depth in Grapher 2.0. The resulting curves were then compared and matched with each other to find the depth of overlap between the cores.

5 Results

5.1 Correlations

The cores are presented from the bottom of the sequence to the top, from core 14 to core 1. Core 13 is excluded from the total sequence because it covers the same depth as the upper part of core 14 and the lower part of core 12. Since core 14 and 12 can be correlated, core 13 is excessive and therefore excluded. All depths presented in this part are field depths, that is, depths as they were estimated in the field. The descriptions and overlaps of the cores are presented in Appendix 1-14 together with photographs of the cores as well as with graphs showing magnetic susceptibility and LOI. The photographs of each core are divided into two parts to facilitate the presentation of them. Each core is therefore presented in two different pictures. One picture shows the lower part and the other is showing the upper part of the core. The lowermost part of the sequence, which is the lower part of core 14, and the uppermost part of the sequence, which is the upper part of core 1, are presented first and last, respectively. These two different parts will be briefly commented regarding the stratigraphy as well as the magnetic susceptibility and LOI results. The comments on the other parts of the sequence are more focused on the correlations, i.e. the methods used as basis for correlation and the extent of overlaps etc.

In general, some of the extreme magnetic susceptibility values are difficult to explain just by looking at the surface of the cores. Stones or pieces of wood hidden under the surface of the cores might cause these extreme values. Therefore, further examinations are needed. Another problem is that the magnetic susceptibility and LOI values in some cases diverge from each other. For example, a peak in magnetic susceptibility should correspond to a dip in the LOI and vice versa, but this is not always the case. The explanation for this might be that the sampling points of magnetic susceptibility and LOI differs somewhat. As described under *Methods*, the magnetic susceptibility is measured at the centre and top of the cores and the LOI sample are taken at the side of the cores. This difference in position between the sampling points may be enough to cause the divergent values.

The lowermost part of the sequence (lower part of core 14) (App. 1) mostly consists of low humified fen peat rich in sand and gravel. At two different levels, there are large pieces of wood, which have been divided into separate units. The magnetic susceptibility values are relatively uniform, although there are slightly higher values where there is more minerogenic material. The LOI values fluctuate between around 40 and 90%, and tend to be somewhat higher where there is wood, but only marginally.

The correlation between core 14 and 12 (App. 2) is based on the visual stratigraphy of the cores. The two cores have relatively distinct layers, which can be used to correlate the cores. The overlap between core 14 and 12 is determined to be 51 cm. The correlation point is set to a layer boundary at 10.16 m in core 14 and 9.95 m in core 12. The correlation point is the point or level where the sequence is set to continue from one core to the next. The magnetic susceptibility curves also support this correlation. Although the absolute values differ somewhat, the general trend is the same for the two cores. Sampling for LOI was not needed for the correlation between core 14 and 12.

The correlation between core 12 and 11 (App. 3) is based on both the visual stratigraphy of the cores and the magnetic susceptibility results. The overlap between core 12 and 11 is 8 cm. Because the cores show relatively clear stratigraphy that can be used for correlation and the magnetic susceptibility graphs show a good match, LOI was not needed as a third correlation tool. However, LOI samples have been taken for both cores, but not for the overlap. The LOI sampling was made on core 12 up to the level where the overlap starts, and then the sampling continued on core 11 (App. 3). The higher magnetic susceptibility values and the lower LOI values are found at the levels with more minerogenic material. The correlation point was set to a layer boundary at 9.21 m in core 12 and 9.13 m in core 11.

The correlation between core 11 and 10 (App. 4) is mainly based on the visual stratigraphy of the cores and the magnetic susceptibility results. The overlap between the two cores is determined to be 20 cm. The chosen overlap is supported by the fact that both cores at this level consist of low humified fen peat (P2) with a thin unit rich in silt-sand. The two magnetic susceptibility curves also follow the same trend, although the absolute values differ somewhat. LOI samples were also taken for this overlap, and those results support the correlation as well. The correlation point is set to the upper boundary of the silty-sandy unit in the peat, which is at 8.28 m in both cores.

Cores 10 and 9 do not overlap (App. 5), due to mistakes in field. The top of core 10 represents the same depth as the bottom of core 9. The two magnetic susceptibility graphs show similar values at the top of core 10 and at the bottom of core 9, which could be expected since they at this point represent the same level. On the other hand, the two LOI graphs show a large difference between the values at the top of core 10 and at the bottom of core 9. Core 10 has much lower LOI values than core 9, but this might be explained by the generally higher content of silt and sand in core 10. The reason for this could be that the cores were not taken at the exactly same point, which can cause differences between the cores. The higher content of silt and sand at the top of core 10 does, however, not show up in the magnetic susceptibility graph, but this can be explained by the difference in sample points between the magnetic susceptibility and the LOI sampling.

The correlation between core 9 and 8 (App. 6) is mainly based on the visual stratigraphy of the cores and on the magnetic susceptibility results. The overlap determined between the two cores is 16 cm. The chosen overlap is supported by the fact that both cores at this level consist of low humified fen peat (P2), and a thin layer of medium humified fen peat (P3). The two magnetic susceptibility curves also follow the same trend, although the absolute values differ somewhat. LOI samples were also taken for this overlap, but those results do not match as well as the magnetic susceptibility results. The LOI values are lower for core 8 than for core 9, which might be explained by the generally high content of silt and sand at the bottom of core 8. The reason for this could be a difference in presence of minerogenic material between the coring points. The correlation point was set to the upper boundary of the medium humified fen peat (P3) layer, which is at 6.42 m in core 9 and 6.46 m in core 8.

The correlation between core 8 and 7 (App. 7) is based on all three correlation methods: visual stratigraphy, magnetic susceptibility and LOI. The overlap between cores 8 and 7 was very difficult to determine due to differences in the stratigraphy between the two cores as well in the magnetic susceptibility and LOI results. Taking the results from all methods into account, the overlap between the two cores was set to be 22 cm. An overlap of 22 cm is a reasonable estimate considering that the assumed overlap in the field was 20 cm. The higher magnetic susceptibility and lower LOI values at the bottom of core 7 can be explained by the high content of silt in this interval. Core 8 does not show any units rich in minerogenic material similar to core 7, which might explain the relatively uniform values of magnetic susceptibility and LOI for core 8. The difference in minerogenic material between core 7 and 8 could be caused by a difference in minerogenic material between the coring points. The correlation point was set to the upper boundary of the low humified fen peat (P2) layer, which is at 5.78 m in core 8 and 5.76 m in core 7.

The correlation between core 7 and 6 (App. 8) is mainly based on the magnetic susceptibility results. The overlap between these two cores was also somewhat difficult to determine due to the absence of a clear stratigraphy and the differences in LOI results between the two cores. The magnetic susceptibility results, on the other hand, show a relatively good match for the chosen overlap, which is 16 cm. The magnetic susceptibility data show the same trend, although the absolute values differ somewhat between the two cores. Core 6 shows higher magnetic susceptibility values than core 7, which might be explained by the occurrence of sand grains in core 6. The reason for this difference in sand between the two cores may be the difference in coring points. This is, however, not seen in the LOI results, which might be explained by the difference in sample points between the magnetic susceptibility and the LOI sampling. Because there are no layer boundaries to use as a correlation point in this case, the magnetic susceptibility data had to be used instead. The correlation point was set to a level where both records show peak values, which is at 4.84 m in core 7 and 4.88 m in core 6.

The correlation between core 6 and 5 (App. 9) is mainly based on the magnetic susceptibility and LOI results. The determined overlap between the two cores is 19 cm. Both the magnetic susceptibility and LOI results show a good match between the two cores, although the absolute values differ somewhat. The generally higher magnetic susceptibility and lower LOI values for core 6 are probably caused by a larger amount of sand grains in core 6 than core 5, which may be explained by the difference in coring points. At around 4.10 m, both cores show a large dip in LOI. This might be caused by a higher content of minerogenic material at that level, although there are no corresponding peaks in magnetic susceptibility. The reason for this might be the difference in sample points between the magnetic susceptibility and the LOI sampling. The reason why the two LOI dips are not exactly at the same depth might be explained by the sampling. If the samples would have been taken more closely at this level, the dips might have matched better. Because there are no layer boundaries to use as a correlation point in this case, the magnetic susceptibility data had to be used instead. The correlation point was set to a level where both records show low values, which is at 4.13 m in core 6 and 4.14 m in core 5.

The correlation between core 5 and 4 (App. 10) is mainly based on the magnetic susceptibility and LOI results. The overlap between the two cores is determined to be 21 cm. This overlap is the most likely one taking both the magnetic susceptibility and LOI results into account. 21 cm also appears reasonable, considering the field estimation of 20 cm. Both cores have occasional sand grains in the peat, and the fluctuating magnetic susceptibility and LOI values are probably caused by the varying amount of sand at different levels in the cores. The stratigraphy could not be used for correlation in this case due to the absence of layer boundaries. Since there are no layer boundaries to use as a correlation point, the magnetic susceptibility graphs had to be used instead. The correlation point was set to a level where both records show low values, which is at 3.27 m in core 5 and 3.26 m in core 4.

The correlation between core 4 and 3 (App. 11) is mainly based on the LOI results, although the magnetic susceptibility results have been used for the correlation as well. The overlap between the two cores was determined to be 15 cm. This choice of overlap is supported by the two LOI curves, which show a very good match for the overlap. The magnetic susceptibility curves for the two cores follow the same trend for the overlap, although the absolute values differ somewhat. Both cores have occasional sand grains in the peat, and the higher magnetic susceptibility values for core 3 might be caused by a generally higher content of sand in core 3 than in core 4. The higher sand content in core 3 could be explained by the difference in coring point between the cores. This is, however, not seen in the LOI results, which may be explained by the different sampling points for magnetic susceptibility and LOI. The stratigraphy cannot be used for the correlation in this case due to the lack of layer boundaries. Since there are no layer boundaries to use as a correlation point, and the magnetic susceptibility curves do not show a very good match, the LOI graphs had to be used instead to find a correlation point. The correlation point was set to a level where both records show a small peak, which is at 2.495 m in core 4 and 2.545 m in core 3.

The correlation between core 3 and 2 (App. 12) is mainly based on the visual stratigraphy of the cores, although magnetic susceptibility and LOI results also were important correlation tools. The overlap between the two cores is determined to be 26 cm. The chosen overlap is supported by the fact that both cores consist of peat at this level, with a transition from low humified fen peat (P2) to very low humified fen peat (P1) at 1.82 m in core 3 and 1.76 m in core 2. Both cores do also have occasional sand grains in the peat. The two magnetic susceptibility curves follow the same trend for the overlap, although absolute values differ somewhat. This is also true for the LOI curves. At around 1.81 m in core 3, magnetic susceptibility shows a large peak. This is likely to be caused by a small stone lying under the surface of the sampling point. The generally higher magnetic susceptibility values for core 2 are probably caused by a generally larger amount of sand grains in core 2 than in core 3, which might be explained by the difference in coring point between the cores. The correlation point was set to the upper boundary of the low humified fen peat (P2) layer, which is at 1.82 m in core 3 and 1.76 m in core 2.

The correlation between core 2 and 1 (App. 13) is mainly based on the stratigraphy of the cores and on the magnetic susceptibility results. LOI was, however, also an important correlation tool. The overlap between the two cores is determined to be 20 cm, which is identical to the overlap estimated in field. The chosen overlap is also supported by the fact that both cores consist of very low humified fen peat (P1) at this level, and the magnetic susceptibility curves follow the same trend for the overlap, although the absolute values differ somewhat. The top of core 2 corresponds to a stratigraphic boundary in core 1. In addition, the two LOI curves show a good match for the overlap. Since there are no layer boundaries to use as a correlation point, the magnetic susceptibility graphs had to be used instead. The correlation point was set to a level where both records show a peak, which is at 0.94 m in both cores.

The uppermost part of the sequence (upper part of core 1) (App. 14) consists almost entirely of very low humified fen peat (P1), which is rich to very rich in coarse roots. The top of the sequence represents very recent peat, which is why there are still coarse roots in it. At the top, there might also be living roots that belong to plants that are growing on the bog today, which explains why they are not decomposed. LOI values vary between 95 and 99 %.

5.2 Chronology

The calibrated ages are plotted against depth, together with the results from magnetic susceptibility and LOI for the total sequence (App. 15). The ages are presented with error bars. An age model was also developed (Table 1, Fig. 18) for the last 7500 years based on a five-degree polynomial fitted to eight calibrated dates. The four calibrated dates at the bottom of the sequence were excluded from the age model due to the age-

Table 1. Radiocarbon data for the Taniente Palet bog sequence

Field depth (cm)	Corrected depth (cm)	^{14}C-age ± 1σ	Age range (± 1σ) (cal. B.P.)	Age (mid point) (cal. B.P.)	^{14}C-lab nr
50	50	145 ± 50	290-0	145	LuS 6799
150	150	870 ± 50	910-720	815	LuS 6800
250	244	1855 ± 50	1870-1720	1795	LuS 6801
350	348	2800 ± 50	2970-2810	2890	LuS 6802
452	451	3740 ± 50	4220-3980	4100	LuS 6803
558	561	4250 ± 50	4870-4660	4765	LuS 6804
657	662	5595 ± 50	6420-6300	6360	LuS 6805
767	772	6600 ± 50	7560-7430	7495	LuS 6806

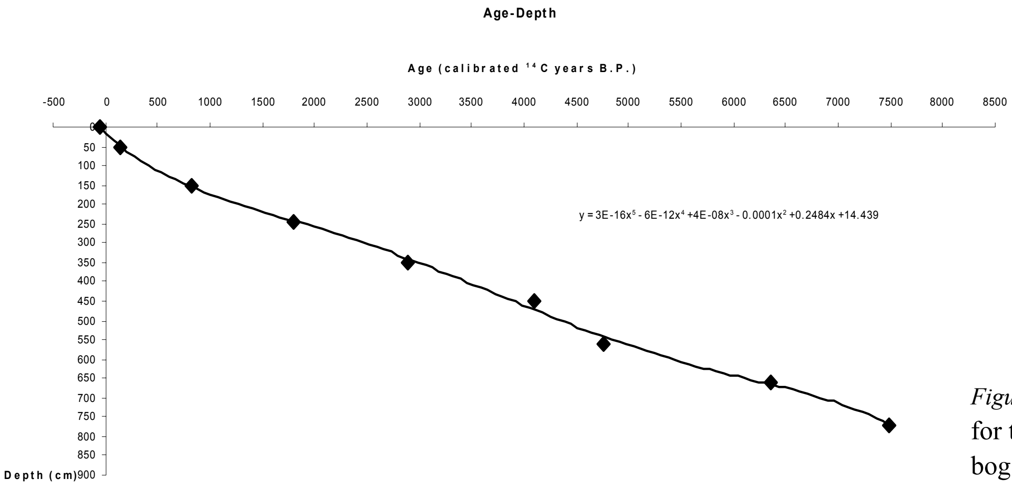

Figure 18. Age model for the Taniente Palet bog sequence

reversal shown by these dates. The lowermost date of the sequence is c. 7600 cal. B.P., and thereafter ages of c. 8950 cal. B.P., c. 8600 cal. B.P., c. 9200 cal. B.P. and c. 7500 cal. B.P. are attained. This age-reversal indicates that the deposits are not in situ. After around 7500 cal. B.P. the dates become gradually younger, indicating that the deposits is in situ at this level and upward in the sequence. The age model spans the interval from c. 7500 cal. B.P. (radiocarbon date at 772 cm) to the present, i.e. the top of the sequence. A hypothesis for the age-reversal at the bottom will be presented in the following chapter. The calculated ages from the age model were also plotted against the results from magnetic susceptibility and LOI (App. 16). A running average for magnetic susceptibility and LOI is also shown in the graphs.

5.3 The complete sequence

The main purpose of this study is to describe, date and correlate the 14 overlapping cores from Taniente Palet bog on Isla de los Estados to create a complete stratigraphic sequence. The descriptions of the individual cores and the results of the radiocarbon dating and the correlations have been presented above. The cores were then put together to form a complete sequence (App. 15), which will be presented in this section. When all cores had been put together to a complete sequence, the depths were adjusted in relation to the ground surface. Therefore, all depths presented in this part are new and corrected depths. The sequence is presented together with descriptions as well as with graphs showing magnetic susceptibility and LOI for the complete sequence. These graphs also show the depths and ages of the available radiocarbon dates. In addition, Appendix 16 shows an overview of the interpretations together with the magnetic susceptibility and LOI records.

Both stratigraphy and magnetic susceptibility as well as LOI results show that the bottom of the sequence is very different from its upper part (App. 15). The sequence mainly consists of peat of different humification grades, but the bottom of the sequence generally consists of more minerogenic material as well as some large pieces of wood. The deposits at the bottom indicate that the conditions must have been different from those when the peat in the rest of the sequence was formed. There are, however, also some smaller units of peat in the lower part of the sequence. The magnetic susceptibility curve is also very different at the bottom. The values are generally higher and fluctuate much more in the bottom than in the upper part of the sequence. However, the values in the lowermost part (the lowermost 50-70 cm) are relatively low, although fluctuating, but this is probably due to the large pieces of wood that are present there. The LOI curve looks different in the bottom as well, although the LOI values continue to fluctuate further up in the sequence than the magnetic susceptibility values do. The LOI values are generally lower in the bottom than in the rest of the sequence. However, the LOI values in the lowermost part of the sequence (the lowermost 50-70 cm) are relatively high, probably because of the large pieces of wood present there. Also the dates show that the conditions at the bottom must have been different from those at the upper part of the sequence. As described earlier, the dates in the bottom show an age-reversal, which suggests that the deposits are not in situ. The dates fluctuate between older and younger, and this should not be the case if the deposits are in situ.

After around 7500 cal. B.P. the dates become gradually younger. This indicates that the peat is in situ from this point in the sequence and upward. In addition, from around this point in time the magnetic susceptibility values are lower and more uniform and do not fluctuate as much as before, with some exceptions. At around the same time the LOI values get generally higher, although they continue to fluctuate somewhat further up in the sequence. The lower magnetic susceptibility and higher LOI values are probably caused by the dominance of organic material in the upper part of the sequence, compared to its lower part. Although the values of magnetic susceptibility and LOI are more uniform after around 7500 cal. B.P., there are some exceptions. At around 670 cm and at 575 cm, which corresponds to around 6500 and 5200 cal. B.P., respectively, there are large peaks in the magnetic susceptibility record. The LOI record shows corresponding dips at these levels. The peak at 670 cm is a result of an upward trend in the magnetic susceptibility values. After the peak the values gradually decrease again. The trend of increasing magnetic susceptibility values suggests that it represents a period of changed environmental conditions. The magnetic susceptibility peak at 575 cm, on the other hand, appears to represent only a shorter event. However, both peaks/dips correspond well to units of very low humified fen peat with high amounts of minerogenic material in the sequence.

The LOI record also shows large dips at around 210 cm and 125 cm, which corresponds to around 1400 and 600 cal. B.P., respectively. These dips correspond to two smaller peaks in the magnetic susceptibility. The dip/peak at 210 cm fits well with a small unit rich in sand. The peat is low humified at this level. The dip in LOI at 125 cm is more difficult to explain since the corresponding peak in the magnetic susceptibility is relatively small, and there is no distinct minerogenic unit that could explain the dip of the LOI values. There are, however, occasional sand grains in the peat at this level. It is possible that the LOI sample contained more minerogenic material than were detected in the magnetic susceptibility measurements. The peat is very low humified at this depth. Between the two dips at 210 cm and 125 cm, the LOI values fluctuate somewhat. After the dip at 125 cm, the LOI values increase and then stay relatively uniform in the rest of the sequence. At around 180 cm (c. 1000 cal. B.P.), the magnetic susceptibility values increase somewhat, and at around 90 cm (c. 400 cal. B.P.) they decrease again. The magnetic susceptibility values are also somewhat higher in the uppermost 20 cm (c. 50 cal. B.P. until present).

At around 550 cm, which corresponds to around 4800 cal. B.P., the LOI curve shows a relatively large dip. However, the magnetic susceptibility curve shows no peak at this level. The LOI dip is at a level where the peat is relatively rich in silt-coarse sand. Therefore, it is possible that minerogenic material has been present in the LOI samples, but has not been detected in the magnetic susceptibility measurements. As have been mentioned before, the positions of the LOI and magnetic susceptibility samples are differing somewhat, and can thereby cause divergent values. In addition, at around 410 cm (c. 3600 cal. B.P.), it appears as if the magnetic susceptibility rapidly decreases somewhat, but this is not the case. This is an effect of the difference in absolute values between core 6 and 5 caused by the correlation of the two cores. Generally, however, the magnetic susceptibility and LOI results correspond well with one another throughout the sequence. In addition, no tephras have been found in the sequence, as indicators of volcanic eruptions.

6 Interpretations and discussion

A second purpose of this study is to interpret the stratigraphical changes in the sequence and try to find out whether these changes reflect local climatic changes or if they can be related to regional changes or even to climatic changes in the northern hemisphere. First, a discussion and a suggested interpretation of the stratigraphical changes in the sequence will be presented. That is, what was the environmental development at the bog at Bahia Crossley? The sequence will be discussed and interpreted from the bottom to the top. Secondly, there will be a discussion about whether these possible changes might be caused by local climate changes or if they can be related to more regional or global climate changes. All interpretations are highly speculative due to a limited set of data. Therefore, further research, locally, regionally and globally, is necessary to enable more valid conclusions. A palynological study of the complete sequence, for example, would enable a firmer interpretation of the environmental development at Bahia Crossley. It would also enable comparisons with other localities. Therefore, the results of the study are open for both further examination and new interpretations of the data available as well as new research on Isla de los Estados and elsewhere.

6.1 Interpretation of the environmental development at Taniente Palet bog

In general, in between large dips and peaks in the magnetic susceptibility and LOI records, the values fluctuate only to some degree, which probably reflect only minor fluctuations in precipitation, storminess and temperature. According to Heusser (1989a), both temperature and precipitation has been fluctuating during the entire Holocene.

As shown by the stratigraphy as well as the magnetic susceptibility and LOI records, the bottom of the sequence is very different from its upper part (App. 15). The dates attained for the sequence also confirm that something has happened at this time in history. As presented above, the five lowermost dates show an age reversal, which indicates that the sediments are not in situ. However, it is reasonable to assume that the lowermost date (c. 7600 cal. B.P.) and the fifth date (c. 7500 cal. B.P.) from the bottom are correct and that the material at these levels is in situ. On the other hand, the three intermediate dates (c. 8950, 8600 and 9200 cal. B.P.) indicate that those deposits are not in situ. This material must have been re-deposited. But the question is then, what has caused this re-deposition?

One likely theory for the re-deposition is that an increase in precipitation shortly after c. 7600 cal. B.P. (App. 16) caused the stream connected to the bog to flood. The stream then may have eroded the bedrock and/or till and brought minerogenic material, as well as older peat eroded from upstream areas down to Taniente Palet bog. At around 7500 cal. B.P. the heavy precipitation is believed to have ceased, and peat started to form in situ. Considering that Isla de los Estados is mainly subjected to westerly winds, which contain much moisture causing precipitation throughout the year, this hypothesis seems to be likely. In addition, there is a hypothesis about the westerly stormtracks shifting in latitude, which causes latitudinal changes in precipitation. Markgraf (1993) made a comparison of palaeoclimatic changes in Tierra del Fuego with those at lower latitudes showing latitudinal changes in precipitation. Markgraf (1993) suggests that these changes primarily reflect latitudinal shifts in the westerly stormtracks. As have been mentioned earlier, there was a precipitation increase in southern South America at around 12 500 C^{14} years B.P. (c. 14 700 cal. B.P.), which extended down to 50°S. This indicates a shift of the stormtracks poleward. However, it did not reach Tierra del Fuego until around 9000 C^{14} years B.P. (c. 10 200 cal. B.P.) (Markgraf, 1993). Also Heusser (1995) has studied changes in the westerlies. Heusser (1995) gives an example where Torres del Paine (c. 51ºS) (Patagonia), Estrecho de Magallanes (c. 53ºS) and Tierra del Fuego (c. 53-56ºS) were compared. According to Heusser (1995), the west winds appear to have had a large influence at the latitude of Torres del Paine in the early Holocene, which resulted in higher lake levels and humidity. This also allowed expansion of *Nothofagus*. Along Estrecho de Magallanes and in Tierra del Fuego, on the other hand, precipitation was reduced during this period, causing a slow expansion of the steppe. In the late Holocene conditions were reversed; Torres del Paine experienced drier climate due to the reduced influence of the west winds, and the higher latitudes became wetter with increased precipitation because of the more southern position of the west wind belt (Heusser, 1995).

There is also a new study by Ljung (2007), who studied the Holocene climatological and environmental development on the Tristan da Cunha island group in the central South Atlantic (c. 37°S, 12°W). Ljung's results show that the Holocene is climatically a very dynamic period with large fluctuations in precipitation and temperature. For example, at around 8600 cal. B.P. there is evidence of a significant water table rise on Nightingale Island, which probably is the result of increased precipitation at this time. Ljung (2007) suggests that the cause of this precipitation increase may be a more northerly position of the Southern Hemisphere Westerlies. According to Ljung (2007) there is abundant evidence in the Southern Hemisphere of a change in the westerlies during early Holocene. There are also several periods of higher precipitation after 8600 cal. B.P. on Nightingale Island, which are about 100 to 1000 years long. However, the results suggest that there was no increased storminess on the island during these periods, which means that it is probably not the westerlies that have caused the increased precipitation during these periods. This is indicated by, for example, a climate record from Chile (c. 41°S) that suggests that the westerlies were positioned further south also at around 7300 and 6600 cal. B.P., as well as at around 4600 cal. B.P. The precipitation on the Tristan da Cunha islands is also dependent on the sea surface temperature (SST) since higher temperatures result in higher air humidity and thereby causes increased precipitation. It is therefore very likely that the periods of increased precipitation after around 8600 cal. B.P. are caused by higher SSTs in the central Southern Atlantic, and not by the westerlies. Indeed, according to Ljung (2007), data from South America indicate that the westerlies were positioned further south during these periods.

As these studies show, the westerlies have shifted in latitude during the Holocene, and therefore, it is possible that the westerlies were positioned at high southern latitudes at the time of the event shown at the bottom of the sequence from the Taniente Palet bog. Hence, it is possible that shifts in the position of westerly stormtracks caused a period of intensified precipitation on Isla de los Estados, causing the stream to flood and transport material eroded further upstream and redeposit it in the Taniente Palet bog. Further research is, however, needed to be able to test this hypothesis.

After c. 7500 cal. B.P. the sequence mainly consists of peat of different degrees of humification, with some units containing silt, sand and gravel as well (App. 15). Generally, the humification degree of the peat depends on how wet it is in the bog. Lower humified peat indicates wetter conditions and higher humified peat indicates drier conditions. Minerogenic material in the peat also indicates wetter climate, because the stream has most likely transported it to the bog during periods of more heavy precipitation. As expected, the units of peat that contain minerogenic material are often very low or low humified peat (P1or P2). However, silt and sand may also have been transported to the bog by winds, and could therefore also indicate more windy or stormy periods.

Generally, from c. 7500 cal. B.P. the magnetic susceptibility values are lower and more uniform and do not fluctuate as much as before (App. 15). At about the same time the LOI values get generally higher, but they continue to fluctuate somewhat further up in the sequence. However, as been mentioned before, there are some exceptions where both magnetic susceptibility and LOI show large peaks or dips in the records. For example, at around 6500 cal. B.P. the magnetic susceptibility values are raised and the LOI values are lowered (App. 15). This peak and dip corresponds to units of generally low humified peat, which is relatively rich in silt to fine gravel (App. 15), and probably represents a period of changed climate. The minerogenic material and the low humified peat indicate a period of wetter conditions. There is also probably a shorter period of changed climatic conditions at around 5200 cal. B.P., which is represented by the peak and dip in magnetic susceptibility and LOI, respectively (App. 15). The peak and dip corresponds well to a unit of very low humified fen peat rich in silt (App. 15), which indicates an event of increased precipitation. It is also possible that winds were stronger at this time since the silt fraction dominates in the peat. Silt can be transported by both water and wind.

There is also a large dip in LOI at around 1400 cal. B.P., which corresponds to a smaller peak in magnetic susceptibility (App. 15). The low humified peat at this level is rich in sand (App. 15). Since there is mainly sand (and some silt) and no coarser particles in the peat, it is possible that the sand has been transported by winds, indicating a period of stronger winds. There may have been wetter conditions at this time as well, since the peat is low humified. The LOI record also shows a dip at around 600 cal. B.P., though the corresponding magnetic susceptibility peak is rather small (App. 15). As explained earlier there is no distinct minerogenic unit at this level. However, there are occasional sand grains in the very low humified peat at this level. The unit with occasional sand grains stretches from c. 490 cm to 120 cm (c. 4200-500 cal. B.P.) (App. 15), but the LOI results suggests that there is a higher amount of sand grains at around 600 cal. B.P., although this is not shown as clearly in the magnetic susceptibility results. The presence of occasional sand grains in the peat indicates stronger wind activity and/or wetter climate, and the very low humified peat also indicates wetter conditions.

The somewhat increased, although fluctuating, magnetic susceptibility values between around 1000 and 400 cal. B.P. (App. 15) may represent a period of changed climatic conditions. These increased values correspond relatively well to a period of fluctuating LOI values, which are somewhat lower in this interval. The peat is generally very low humified in this interval (App. 15), indicating wetter conditions. The peat contains occasional sand grains at this level, and a larger amount of sand grains in this part of the sequence may have caused higher and lower magnetic susceptibility and LOI values, respectively. Because the sand is so scattered in the peat, it is very likely to be aeolian sand. However, if there was increased precipitation during this period, it is also possible that the minerogenic material may have come from the small stream connected to the bog. This inferred wet and windy period on Isla de los Estados at around 1000-400 cal. B.P. corresponds relatively well to a period of increased precipitation on Tristan da Cunha (37°S) at around 1050-300 cal. B.P. According to Ljung (2007), this period of increased precipitation on Tristan da Cunha coincides with the climatic changes during the Medieval Warm Period (MWP) in Southern Africa (c. 1070-630 cal. B.P.) (Cohen & Tyson, 1995). The MWP was generally warm, with a mean annual temperature about 3°C higher than today in the region, but variable (Cohen & Tyson, 1995). Also on South Georgia there are indications of a warm period around 1100 cal. B.P. (Rosqvist & Schuber, 2003). According to Ljung (2007), there is a relatively good correlation of the inferred hydrological changes between Tristan da Cunha and other localities around the South Atlantic, which indicates that there may be a climatic coupling between these places. Mauquoy et al. (2004) have studied a peat sequence from Isla Grande (c. 54.5°S), Tierra del Fuego, which shows evidences of drier conditions at around A.D. 960-1020 (c. 990-930 cal. B.P.) indicating warmer climate, which correspond to the MWP in the Northern Hemisphere. According to Mauquoy et al. (2004), the climate reconstruction carried out on Isla Grande matches the tree-ring evidence for the MWP from the Northern Hemisphere.

Between around 400 and 50 cal. B.P., the magnetic susceptibility values are lowered, and the LOI values are raised (App. 15), which is probably due to the dominance of organic material at this level (App. 15). The peat is very low humified and rich in coarse roots in this interval. The period 400-50 cal. B.P. corresponds relatively well with the time of the Little Ice Age (LIA) in the Northern Hemisphere. Mauquoy et al. (2004) have also found a period of cooler and wetter conditions on Isla Grande that corresponds relatively well with the LIA in the Northern Hemisphere. There is also evidence of the LIA found in southern Africa (c. 650-150 cal. B.P.) (Cohen & Tyson, 1995; Holmgren et al., 1999; Ljung, 2007).

From c. 50 cal. B.P. until the present, magnetic susceptibility values are somewhat increased again (App. 15). A corresponding decrease of the LOI values is, however, not seen in the results. In stead, the LOI values continue to stay high for the rest of the sequence. Very low humified fen peat dominates the upper part, and no minerogenic material can be seen in this part of the sequence (App. 15). Once again, the difference in position between the sample points of magnetic susceptibility and LOI may be the reason for these divergent values.

According to Rabassa & Roig (1996), the southern South American climate in early Holocene was warm and dry. However, according to the available radiocarbon dating (App. 15), the earliest part of the Holocene is not present in the sequence from the Taniente Palet bog. In the late Holocene the climate became cooler and wetter, which for example led to an expansion of mires and bogs (Rabassa & Roig, 1996). The increased magnetic susceptibility and decreased LOI values at around 6500 and 5200 cal. B.P. (App. 15), which have been interpreted as representing periods of wetter climate, may therefore reflect the cooler and wetter climate in southern Tierra del Fuego detected by Rabassa & Roig (1996). However, according to Ljung (2007), there was a long period of increased precipitation on Nightingale Island (c. 37°S) between 6500 and 5500 cal. B.P., which was probably caused by higher SSTs in the central South Atlantic. It is therefore possible that the SSTs were higher also at more southern latitudes at this time causing higher precipitation also on Isla de los Estados. However, according to Ljung (2007), a Chilean climate record (Lamy et al., 2001) indicates that there was also a more southward displacement of the westerlies around this time. Therefore, the most likely explanation for the supposed wet climate on Isla de los Estados at around 6500 and 5200 cal. B.P. is that the westerlies caused increased precipitation at these times.

Also the lower LOI and higher magnetic susceptibility values in the upper part of the sequence from Taniente Palet bog, at around 1400 and 600 cal. B.P., may reflect a wetter late Holocene climate. The inferred wetter climate on Isla de los Estados at around 1400 cal. B.P. corresponds relatively well with the time of supposed hydrological change, detected by Ljung (2007), on the island Tristan da Cunha (c. 37° S) at around 1200 cal. B.P. The most likely explanation for the hydrological change at 1200 cal. B.P. is, according to Ljung (2007), less precipitation and lower lake levels. The climate on Isla de los Estados at around 1400 cal. B.P., on the other hand, is interpreted as being more wet. However, Ljung also presents an alternative explanation for the change at 1200 cal. B.P., which is that the increased total pollen concentration and increased amount of minerogenic and organic material seen in the sediments can be interpreted as increased in-wash caused by increased precipitation. The problem is that increased precipitation only can be inferred from one record on Tristan da Cunha. However, according to Ljung (2007), there was an expansion of the aquatic systems and decreased lake salinity on the Antarctic Peninsula at around 1200 cal. B.P., which indicates a more humid and warm climate at this time (Björck et al., 1996). This supports the idea of a wetter climate on Isla de los Estados around this time. In addition, the inferred wetter and more windy conditions on Isla de los Estados at around 600 cal. B.P. corresponds relatively well to a period of increased storminess, and possible also increased precipitation, on Tristan da Cunha at c. 800-300 cal. B.P.

It is, of course, possible that there is no connection between the climatic changes on Isla de los Estados and the Tristan da Cunha islands, but it is nevertheless interesting that the changes coincide relatively well in time and that they are similar in character. However, the westerlies cannot cause increased precipitation on both Isla de los Estados and Tristan da Cunha at the same time since the latitudinal distance is too large between the two islands, but it still seems to be a connection between the periods of increased precipitation on the islands. One hypothesis is that the SSTs not only increases in the central South Atlantic but also in the southern South Atlantic causing a reduction of the Antarctic sea ice and thereby leading to a more southern position of the westerlies. The position of the westerlies is, in fact, according to Heusser (1989a), partly dependent on the size of the Antarctic sea ice. In this way, precipitation may increase both on Tristan da Cunha and Isla de los Estados at around the same time. However, further research is necessary to be able to draw any valid conclusions.

The minerogenic material at 1400 and 600 cal. B.P. in the Taniente Palet bog sequence (App. 15) may not only be caused by increased precipitation, it may as well have been transported to the bog by winds. It is possible that the wind intensity also increased during this period. According to Heusser (1989c), from around 5000 ^{14}C years B.P. (c. 5700 cal. B.P.) until present, there was probably also increased storminess and cloud cover in the region, which supports the hypothesis about the aeolian sand in the upper part of the sequence. The dinoflagellates found by Johns (1981) in the sequence from Bahia Crossley in 1971 are also indicators of stronger wind activity. There is unfortunately no age information for this sequence that can be used for comparisons. However, Johns (1981) did, for example, find high percentages of dinoflagellates at depths of 200 cm and 125 cm, which correspond well to the depths of the two LOI dips and magnetic susceptibility peaks (c. 210 cm/1400 cal. B.P. and 125 cm/600 cal. B.P.) in the upper part of the sequence studied here. It is difficult to compare depths between different sequences although they are retrieved from the same bog. Even small differences between sampling points may cause divergent results. However, it may give a rough estimation of the time of a possible stormy period. As have been mentioned above, according to Ljung (2007), there was also a period of increased storminess around this time (c. 800-300 cal. B.P.) at the Tristan da Cunha island group in the central South Atlantic.

There are no tephras found in the sequence, although some volcanoes in Tierra del Fuego and Patagonia are known to have erupted during the Holocene, and spread ashes long distances. In addition, charcoal has been found at several sites in Tierra del Fuego, indicating fires (Heusser, 1995). To be able to study the occurrences of fires on Isla de los Estados, the sequence must therefore be sampled for charcoal. So far, this has not been done. It is a subject for future studies. However, according to Dudley (1983), Isla de los Estados has never been permanently inhabited for longer periods of time and have therefore not been disturbed by humans very much. For that reason, charcoal that may be present in the peat is very likely to be produced by natural fires.

As described earlier, there are evidences of marine transgressions at several sites in Tierra del Fuego. However, there are no such evidences in the sequence studied here. The minerogenic material that occurs in the sequence must instead have been transported to the bog by the stream or by winds. Because of the prevailing westerly winds in the region, it is very likely that the finer minerogenic material, like silt and sand, has been transported to the bog by winds. Also Johns's (1981) study at Bahia Crossley shows that there are no evidences in that sequence either that indicate a marine transgression. Johns (1981) did, however, as was mentioned above, find marine dinoflagellates almost continuously throughout the sequence, but since there are no other evidences of marine transgressions in the peat sequences it is more likely that they were transported there by wind. There is, however, evidence of a marine transgression at other localities. Data from southern Tierra del Fuego record that sea level at around 5000-6000 ^{14}C years B.P. (c. 5700-6800 cal. B.P.) was 8-10 m higher that today (Heusser, 1995). However, sea level during this transgression could not have reached the Taniente Palet bog since it is situated at an elevation of 8 m a.s.l. at high tide. The possible marine transgression at around 4000 years ago that Björck et al. (2007) and Unkel et al. (2007, unpublished) have identified in the sequence from the Lago Galvarne bog on Isla de los Estados has most likely not affected the Taniente Palet bog either since there are no evidences of a marine transgression anywhere in the sequence and since the Lago Galvarne bog is located closer to the sea than the Taniente Palet bog.

As was mentioned earlier, Johns (1981) carried out a palynological study on a peat sequence at Bahia Crossley, Isla de los Estados, in which he identified four possible vegetation cycles. Johns interpreted the inferred vegetation cycles as reflecting four major climatic cycles in postglacial time. Instead, it is possible that these vegetation cycles reflect changes of the westerlies, but it must be further investigated before drawing any conclusions. Another hypothesis is that the pollen cycles may be a result of re-deposition of pollen during events of flooding of the bog. It is possible that the stream connected to the bog has transported pollen from upstream and down to Taniente Palet bog. In that case, the pollen cycles should be connected to the minerogenic units in the sequence that are believed to be caused by flooding of the stream. If this hypothesis is true, the pollen cycles detected by Johns (1981) do not reflect changes in vegetation, but instead hydrological changes in the area. However, there is no clear cyclic pattern visible in the sequence that is now under study. In addition, there is no detailed stratigraphic description for the sequence studied by Johns that can be used for comparisons.

However, it is difficult to make any comparisons with Johns's (1981) sequence since it is not dated. In addition, no pollen analysis has been carried out on the sequence that is now under study, which also makes the correlation of the two sequences more difficult. It is hard to identify the suggested cycles only by studying the deposits. Instead, a pollen analysis is needed to be able to do this. However, the deposits can give indications about hydrological changes, depending on the degree of humification of the peat and/or the amount of minerogenic material, which indirectly says something about the climate, but it is still difficult to tie the deposit variations to the vegetation changes identified by Johns (1981). Therefore, further research is needed to be able to draw more valid conclusions about climate and vegetation changes in the area. A palynological study could for example make possible a correlation with Johns sequence as well as with other studied peat sequences in the region. It would also make possible a temperature reconstruction and give a better understanding about the precipitation changes.

6.2 Regional comparisons

The understanding of the timing and the nature of climate changes during both Late Pleistocene and Holocene are important issues in the understanding of the whole climate system (Glasser et al., 2004). Because more scientists have been active in the Northern Hemisphere and because there is a much larger proportion of water in the Southern Hemisphere, there are not as many paleoclimate records in the Southern Hemisphere as in the Northern Hemisphere (Ljung, 2007). To be able to draw more valid conclusions about the climatic linkage between the two hemispheres it is therefore important to get a better understanding of the palaeoclimate in the Southern Hemisphere. Southern South America is a suitable place to study climate changes since the changes, for example, reflect latitudinal displacements of the westerlies, and reveal information about the timing of glacier fluctuations in different parts of the region, which may give information about forcing mechanisms of climate changes (Glasser, 2004). Palaeoclimatic studies on islands in the South Atlantic can also be very useful for the understanding of the Southern Hemisphere climate changes. Changes in the ocean circulation can affect the climate and be registered in the climate records on islands. These climate records can then be compared with climate records in the Northern Hemisphere, revealing information about the inter-hemispheric climate linkages (Ljung, 2007). Before studying the relationship between the two hemispheres it is important to get a better understanding about the timing of climate changes within the Southern Hemisphere as well. Here follows a short discussion about the climatic relationship between Isla de los Estados, Tierra del Fuego, and other places in the South Atlantic region.

The limited set of data in this study makes it difficult to interpret the results and correlate them with results at other localities in the region. In addition, in South America it may be difficult to make comparisons between different localities due to regionally varying climatic conditions. However, the inferred climate changes at Bahia Crossley have, for example, been compared with those at the Tristan da Cunha Island group in the central South Atlantic. As have been shown above, these changes appear to correlate rather well with each other. The inferred climate changes do not only seem to occur at around the same time, but they also appear similar in character. Some of the suggested climate changes on Isla de los Estados can also be correlated with changes at other places in the South Atlantic region. For example, the inferred wetter climate at Bahia Crossley at around 1400 cal. B.P. correlates relatively well with a suggested expansion of the aquatic systems and decreased lake salinity on the Antarctic Peninsula at around 1200 cal. B.P., indicating a wetter climate around that time. In addition, the inferred wetter conditions at Bahia Crossley at around 1000-400 cal. B.P., possibly related to the MWP, do not only coincide with a period of increased precipitation on Tristan da Cunha but also with climatic changes in Southern Africa (c.

1070-630 cal. B.P.). Also the suggested changes around 400-50 cal. B.P., which may be related to the LIA, coincide with changes in Southern Africa and on Isla Grande, Tierra del Fuego. Generally, as have been shown above, the inferred climate changes at Bahia Crossley appear to correlate relatively well with changes at other localities in southern South America and the South Atlantic region. In addition, after comparing data from the Tristan da Cunha Island group with data from other places in the South Atlantic region Ljung (2007) concludes that it appears as if the inferred hydrological changes on the islands may be related to large-scale climate dynamics around the South Atlantic during the Holocene. Ljung's (2007) results suggest that there have been major fluctuations in the oceanic and atmospheric circulation during the present interglacial. Heusser (1989a; 1989b;1989c) have compared temperature variations for the last 30 000 years in the southern Andes, Tierra del Fuego, with Antarctica, and concludes that the South American and Antarctic records are generally very similar. This study is thereby also indicating that the climate records in the Southern Hemisphere are in good agreement with each other. However, as have been pointed out before, more data is required to be able to draw more valid conclusions about the linkage between Isla de los Estados and other places in the region as well as in the Northern Hemisphere.

6.3 Comparisons with the northern hemisphere

The timing and the nature of climate changes between the two hemispheres during the transition from the last glacial to the present interglacial and the Holocene are still not fully understood. The understanding of the climate system and the nature of the relationship between the two hemispheres are very important to be able to predict future climate changes, and therefore, this has become an area of extensive research.

According to Glasser et al. (2004), there are different hypotheses about the timing of the climatic changes during last glacial-interglacial transition and during the Holocene. The different hypotheses rely on different types of evidence. Some evidence points towards the Northern Hemisphere leading the Southern Hemisphere and some the other way around, or towards synchrony between the two hemispheres. Some scientists believe that climate changes in Antarctica are out of phase with the Northern Hemisphere, and that it may be explained by an oceanic mechanism like the bipolar seesaw (Glasser et al., 2004). The bipolar seesaw climate effect causes warming of the Southern hemisphere and cooling of the Northern Hemisphere as a result of a weaker or interrupted thermohaline circulation (THC) (Lockwood, 2001). In addition, there are also scientists that argue that comparisons between the two hemispheres are complicated due to the fact that climate changes also varies regionally (Glasser et al., 2004). According to Lamy et al. (2004), studies of the inter-hemispheric climatic relationship are most commonly focused on comparing climatic data from the Northern Hemisphere with ice core data from Antarctica. The results of theses comparisons indicate asynchronic changes between the two hemispheres, which suggest a bipolar seesaw climate effect where the Southern Hemisphere is warmed as a response of a weakened THC.

There are, however, also terrestrial data that indicate both synchrony and asynchrony between the hemispheres, causing a discussion about a possible bipolar seesaw mechanism (Lamy et al., 2004). However, according to Ljung (2007), the temperature pattern in Antarctica and Greenland during the last glacial is partly out of phase with each other and can be explained by changes in the ocean circulation – a bipolar seesaw climate effect. On the other hand, changes in the ocean circulation during the Holocene have not been as obvious as during glacial times, which have caused scientists to question weather there is a bipolar seesaw effect also during the present interglacial. An interglacial bipolar seesaw climate effect is not visible when comparing ice-cores from Antarctica and Greenland, or marine records from the South and North Atlantic. However, this may, according to Ljung (2007), be explained by the fact that changes in the ocean circulation during the Holocene were much weaker than in glacial times. It is therefore possible that this effect in the Southern Hemisphere may have been restricted to the central South Atlantic. Evidences have been found on the Tristan da Cunha Islands in the central South Atlantic, which suggest that there has been a bipolar seesaw climate effect during the Holocene, although it was weaker. Ljung (2007) has compared the inferred precipitation rich periods on Nightingale Island and the IRD record from the North Atlantic, and found that there is a good match between these two records. This means that when it was cold conditions and abundant sea ice in the North Atlantic, it was warmer and wetter in the South Atlantic. In addition, reconstructions of the deep-water formation in the North Atlantic show that when precipitation is high on Nightingale Island and the IRD is high, the North Atlantic Deep Water (NADW) formation was reduced. This supports the idea of a bipolar seesaw during the Holocene (Ljung, 2007).

The reason for a stronger bipolar seesaw climate effect during glacial times is that freshwater releases from the continental ice sheets had a large influence on the ocean circulation (Ljung, 2007). A large quantity of freshwater into the ocean causes a reduction of the TCH leading to a warming of the south and cooling of the north – a bipolar seesaw climate effect. However, during the Holocene there has to be another forcing mechanism behind the changes in the THC since there are no large continental ice sheets like there was during glacial times (Ljung, 2007). According to Ljung (2007), there are studies that show that the NADW formation has varied during the entire Holocene, which has led to large climate changes in the North Atlantic region.

Ljung (2007) concludes that evidences indicate that there is nearly no time lag between the forces and the effects on the ocean circulation. A freshwater release into the ocean in the north may cause higher SSTs in the south after only a few years. It is possible that only a small reduction in ocean salinity in the North Atlantic may be enough to limit the heat transport from the South Atlantic to the north (Ljung, 2007).

The period of increased precipitation in the central South Atlantic and high amounts of IRD in the north at around 6500-5500 cal. B.P. (Ljung, 2007) correlates relatively well with the periods of inferred wetter conditions at Taniente Palet bog at around 6500 and 5200 cal. B.P. Studies also show that the NADW formation rate was at its lowest point around 6000 cal. B.P. (Ljung, 2007). The increased precipitation in the central South Atlantic and high amounts of IRD in the north at around 1500 and 500 cal. B.P. (Ljung, 2007) also correlates relatively well with the suggested wetter conditions at the bog at Bahia Crossley at around 1400 and 600 cal. B.P. Therefore, also the results from Taniente Palet bog may indicate that there is a Holocene bipolar seesaw climate effect.

7 Conclusions

Fourteen somewhat overlapping 1 m cores, forming a total sequence of about 10.90 metres, were retrieved from a bog called Taniente Palet bog on Isla de los Estados, Argentina, in December 2005. The main purpose of this study was to describe, date and correlate the 14 cores from Taniente Palet bog to attain a complete stratigraphic sequence. The descriptions of the individual cores and the results of the correlations and dating have been presented and demonstrated with figures and photographs. Subsequently, the cores were put together to form a complete sequence, which also has been presented and demonstrated with figures and a photograph. The second purpose of this study was to interpret the stratigraphical changes in the sequence and try to find out whether these changes reflect local climatic changes or if they can be related to regional changes, or even to climatic changes in the Northern Hemisphere. The descriptions, results of the correlations and dates were used for interpretations of the sequence.

The dates show that there is an age-reversal at the bottom of the sequence, which means that the deposits are not in situ and therefore must have been redeposited. In this interval, which is around 7600 to 7500 cal. B.P., the magnetic susceptibility and LOI results are higher respectively lower, and fluctuate much more than in the upper part of the sequence. The deposits in the bottom of the sequence are dominated by minerogenic material, whereas the deposits in the rest of the sequence are dominated by peat of different humification degrees. A likely hypothesis for the re-deposition in the bottom of the sequence is that an increase in precipitation shortly after c. 7600 cal. B.P. caused the stream connected to the bog to flood. The stream then eroded the bedrock and/or till and brought minerogenic material, as well as older peat eroded from upstream areas, down to Taniente Palet bog. At around 7500 cal. B.P. the heavy precipitation is believed to have ceased, and peat started to form at the site again.

After around 7500 cal. B.P., the magnetic susceptibility and LOI values generally only fluctuate to some degree, which probably reflects only minor fluctuations in precipitation, storminess and temperature. However, there are some events or periods with extreme magnetic susceptibility and LOI values, suggesting changed climatic conditions at these times. For example, at around 6500 cal. B.P. there is a large peak in the magnetic susceptibility record and a corresponding dip in the LOI record, which have been interpreted as representing a period of changed climatic conditions. The minerogenic material and the low humified peat at this level indicate a period of wetter conditions. There is also a peak in the magnetic susceptibility record, and dip in the LOI record, at around 5200 cal. B.P. The peak and dip correspond well to a unit of very low humified fen peat rich in silt, which indicates wetter conditions. Since silt is the dominating fraction in the peat, it is possible that also winds were stronger at this time. Another peak and dip in the magnetic susceptibility and LOI record, respectively, at around 1400 cal. B.P. also give indications of changed climatic conditions at this time. The low humified peat with sand and silt at this level indicates wetter and windier conditions. At around 600 cal. B.P. there is a dip in the LOI record, and a small peak in the magnetic susceptibility record, which also have been interpreted as reflecting changed climatic conditions. Occasional sand grains in the very low humified peat at this level suggest windier and/or wetter conditions. However, it appears as if it was generally wetter and windier at Taniente Palet bog between around 1000 and 400 cal. B.P. This period corresponds relatively well to the MWP in southern Africa (1070-630 cal. B.P.). There is also a period between around 400 and 50 cal. B.P. with somewhat lowered magnetic susceptibility and raised LOI values. This time period corresponds relatively well to the time of the LIA in the Northern Hemisphere.

Generally, it appears as if the suggested climate changes at Taniente Palet bog corresponds relatively well to the inferred climatic changes at other localities in southern Tierra del Fuego and the South Atlantic region. In addition, the results from Taniente Palet bog may also indicate that there is a Holocene bipolar seesaw climate effect. However, more data is required to be able to draw more valid conclusions about the linkage between Isla de los Estados and other places in the region as well as in the Northern Hemisphere.

7.1 Further research

To be able to get a better understanding about the climate changes on Isla de los Estados, and to be able to draw more valid conclusions about the linkage between the island and other localities in the Southern Hemisphere as well as in the Northern Hemisphere, further research is needed. For example, a palynological study of the sequence from Taniente Palet bog would enhance the understanding of the paleoenvironment and paleoclimate on Isla de los Estados, and enable comparisons with other localities around the world. In addition, possible presence of charcoal in the sequence would reveal information about the paleoenvironment.

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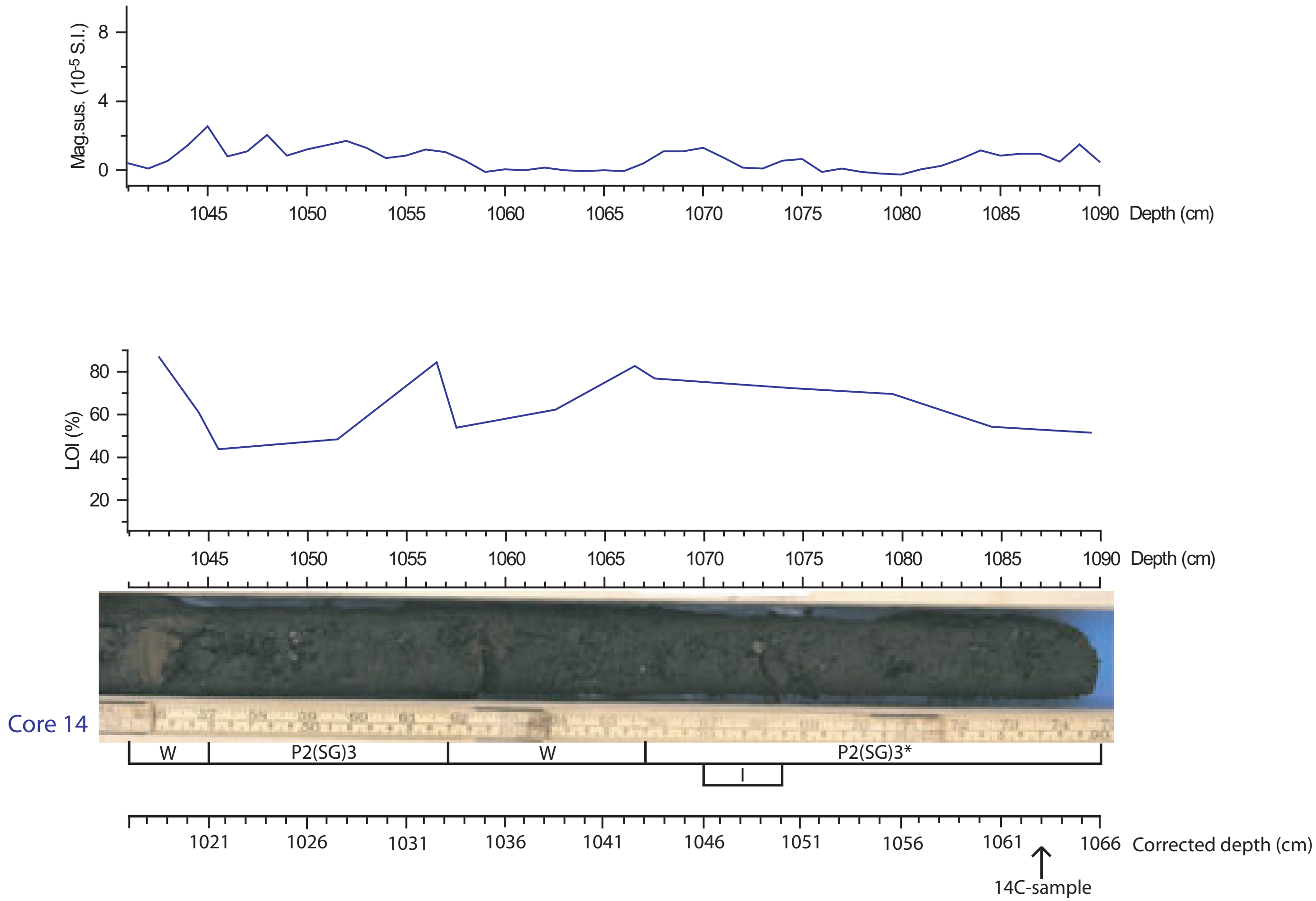
Appendix 1. Core 14

P2(SG)3: Low humified fen peat rich in sand and gravel
Medium brown
W: A large piece of wood

I: Pieces of wood

* Might be drift gyttja

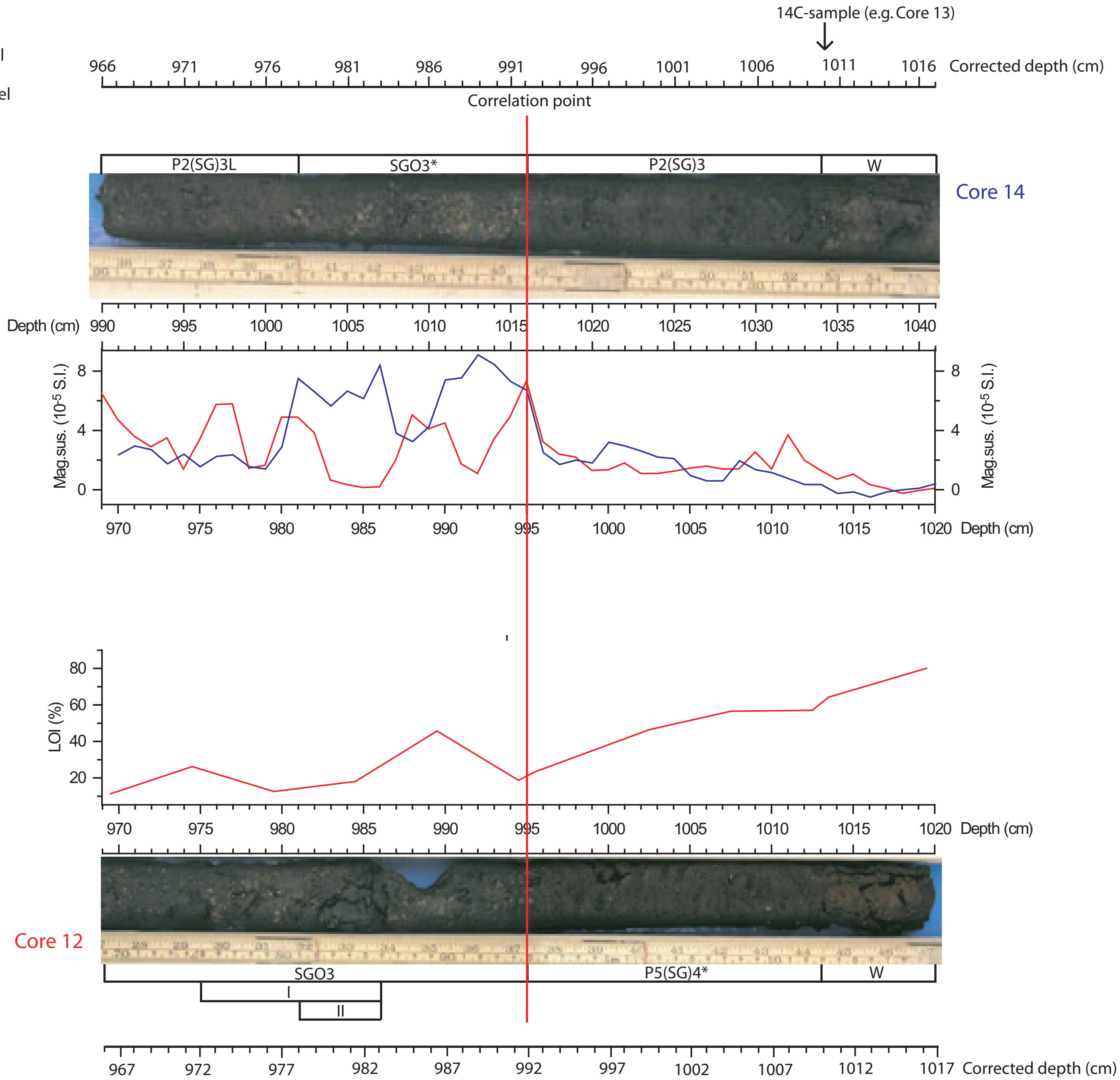


Appendix 2. Core 14 and 12

P2(SG)3: Low humified fen peat rich in sand and gravel
Medium brown
P2(SG)3L: Low humified fen peat rich in sand and gravel
Light-Medium brown.
P5(SG)4: Very high humified fen peat very rich in
sand and gravel
Medium brown.
SGO3: Sandy gravel rich in organic material
(silt-gravel)
W: A large piece of wood

* Might also be drift gyttja

I: Pieces of wood and stones
II: A large piece of wood
(might even be 986-990 cm)

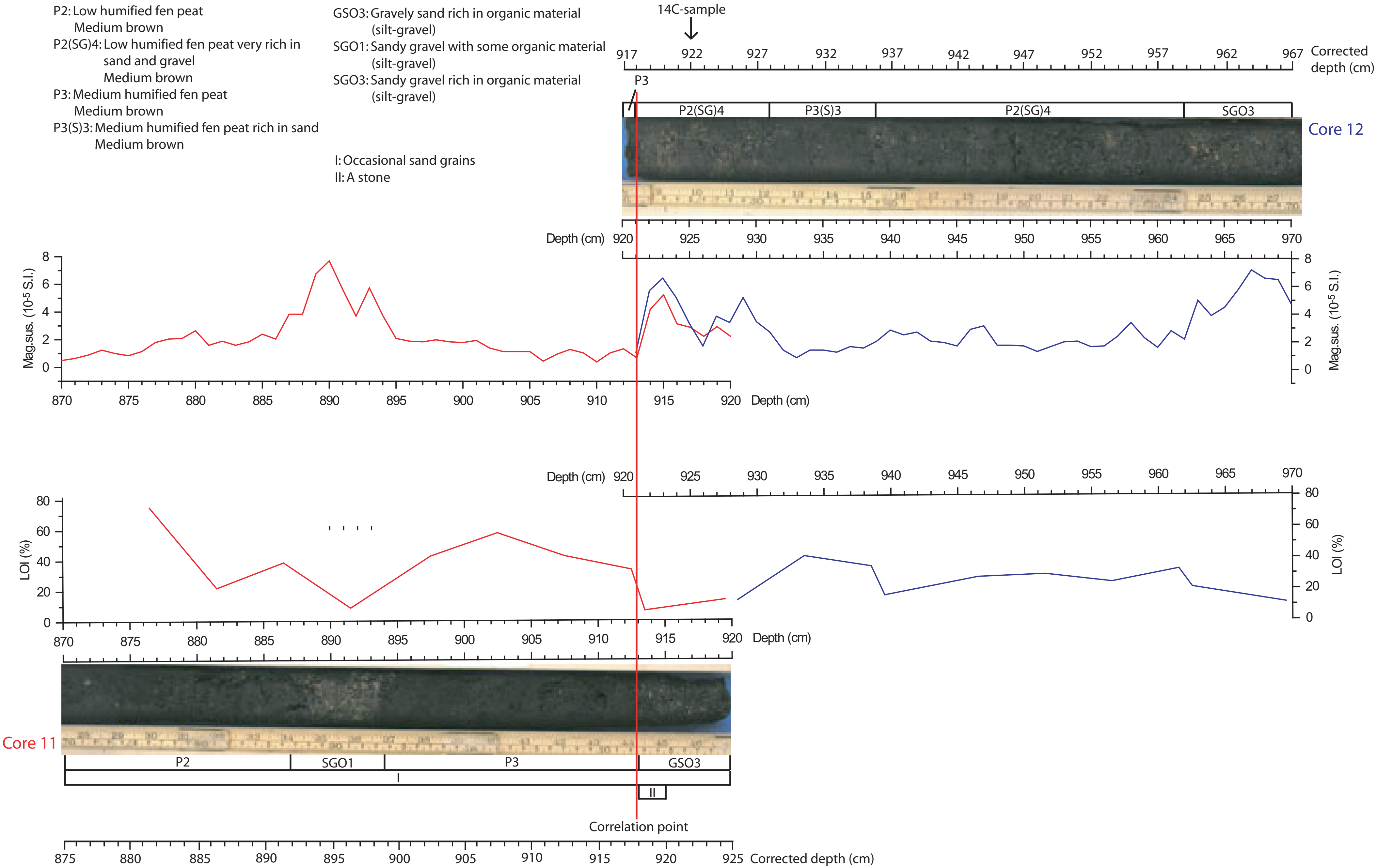


Appendix 3. Core 12 and 11

P2: Low humified fen peat
Medium brown
P2(SG)4: Low humified fen peat very rich in sand and gravel
Medium brown
P3: Medium humified fen peat
Medium brown
P3(S)3: Medium humified fen peat rich in sand
Medium brown

GSO3: Gravely sand rich in organic material (silt-gravel)
SGO1: Sandy gravel with some organic material (silt-gravel)
SGO3: Sandy gravel rich in organic material (silt-gravel)

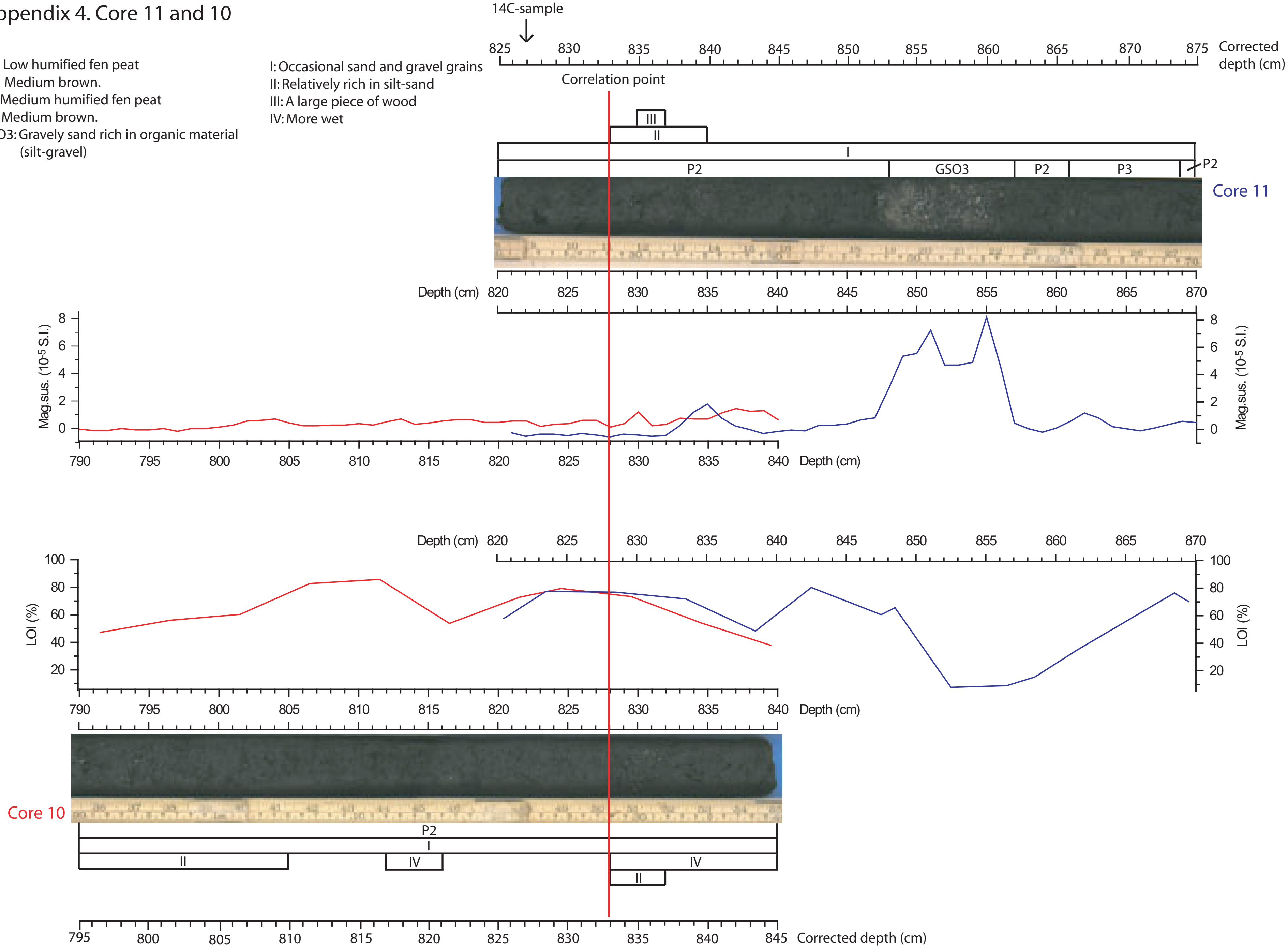
I: Occasional sand grains
II: A stone



Appendix 4. Core 11 and 10

P2: Low humified fen peat
Medium brown.
P3: Medium humified fen peat
Medium brown.
GSO3: Gravely sand rich in organic material
(silt-gravel)

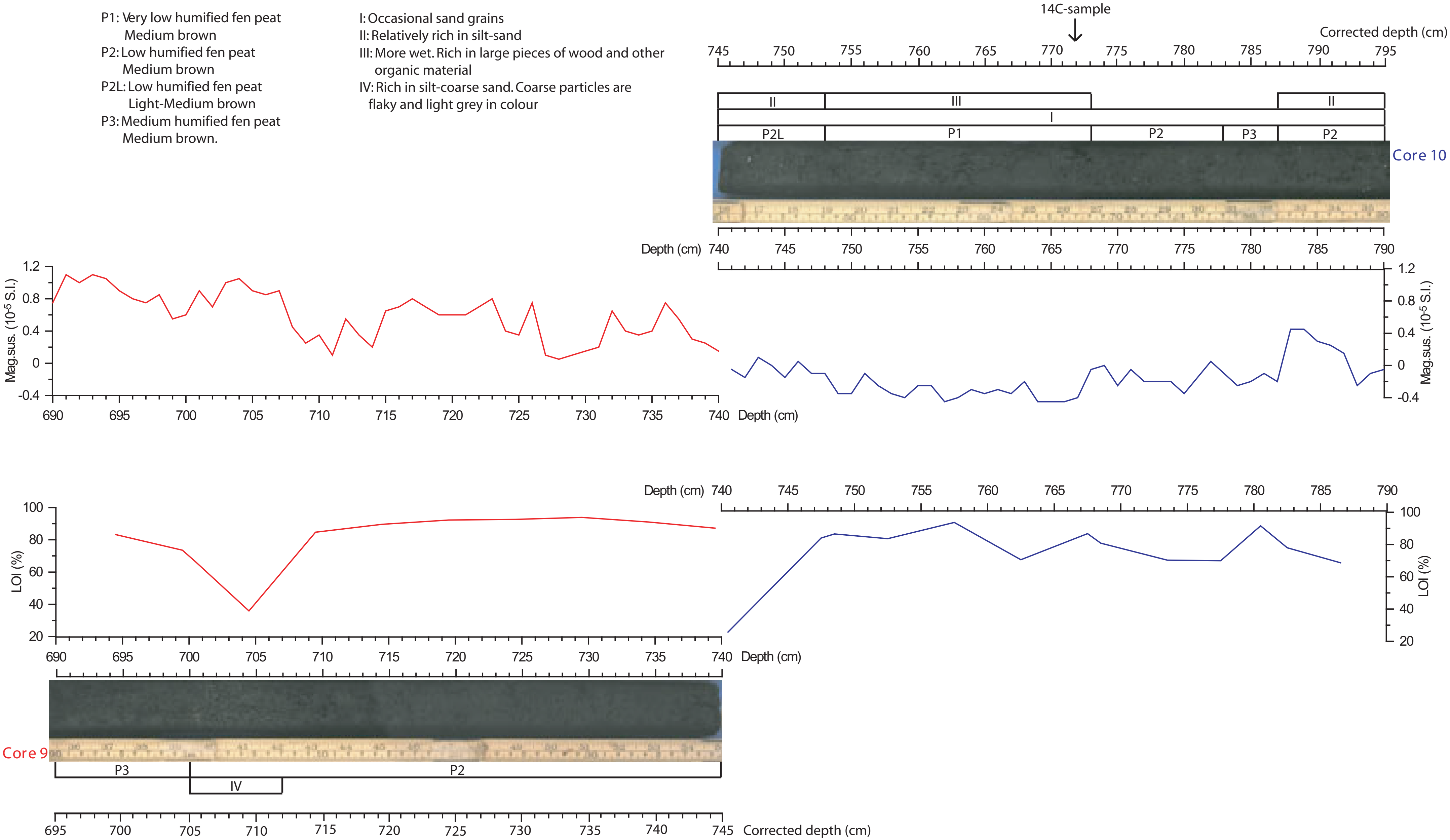
I: Occasional sand and gravel grains
II: Relatively rich in silt-sand
III: A large piece of wood
IV: More wet



Appendix 5. Core 10 and 9

P1: Very low humified fen peat
Medium brown
P2: Low humified fen peat
Medium brown
P2L: Low humified fen peat
Light-Medium brown
P3: Medium humified fen peat
Medium brown.

I: Occasional sand grains
II: Relatively rich in silt-sand
III: More wet. Rich in large pieces of wood and other organic material
IV: Rich in silt-coarse sand. Coarse particles are flaky and light grey in colour

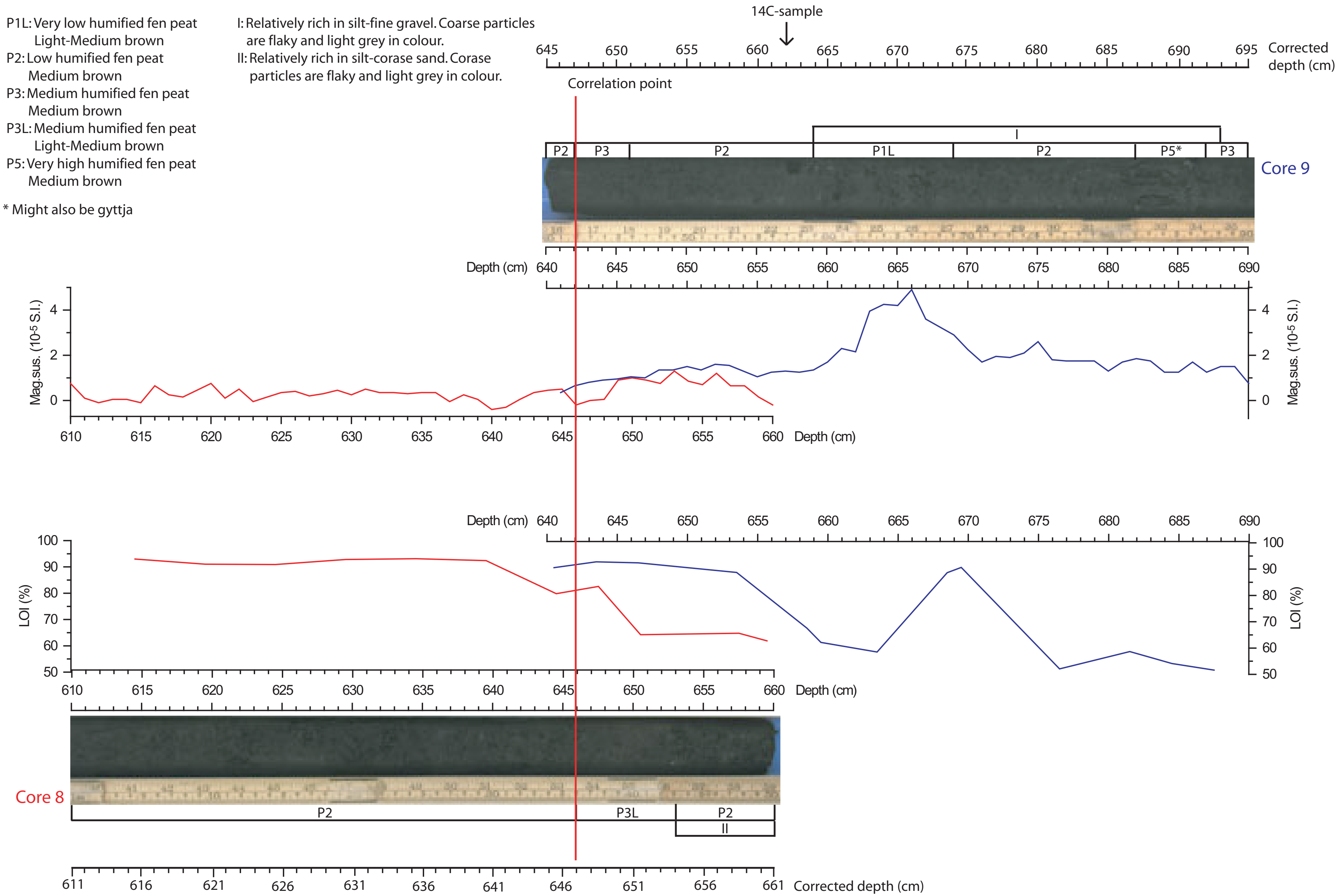


Appendix 6. Core 9 and 8

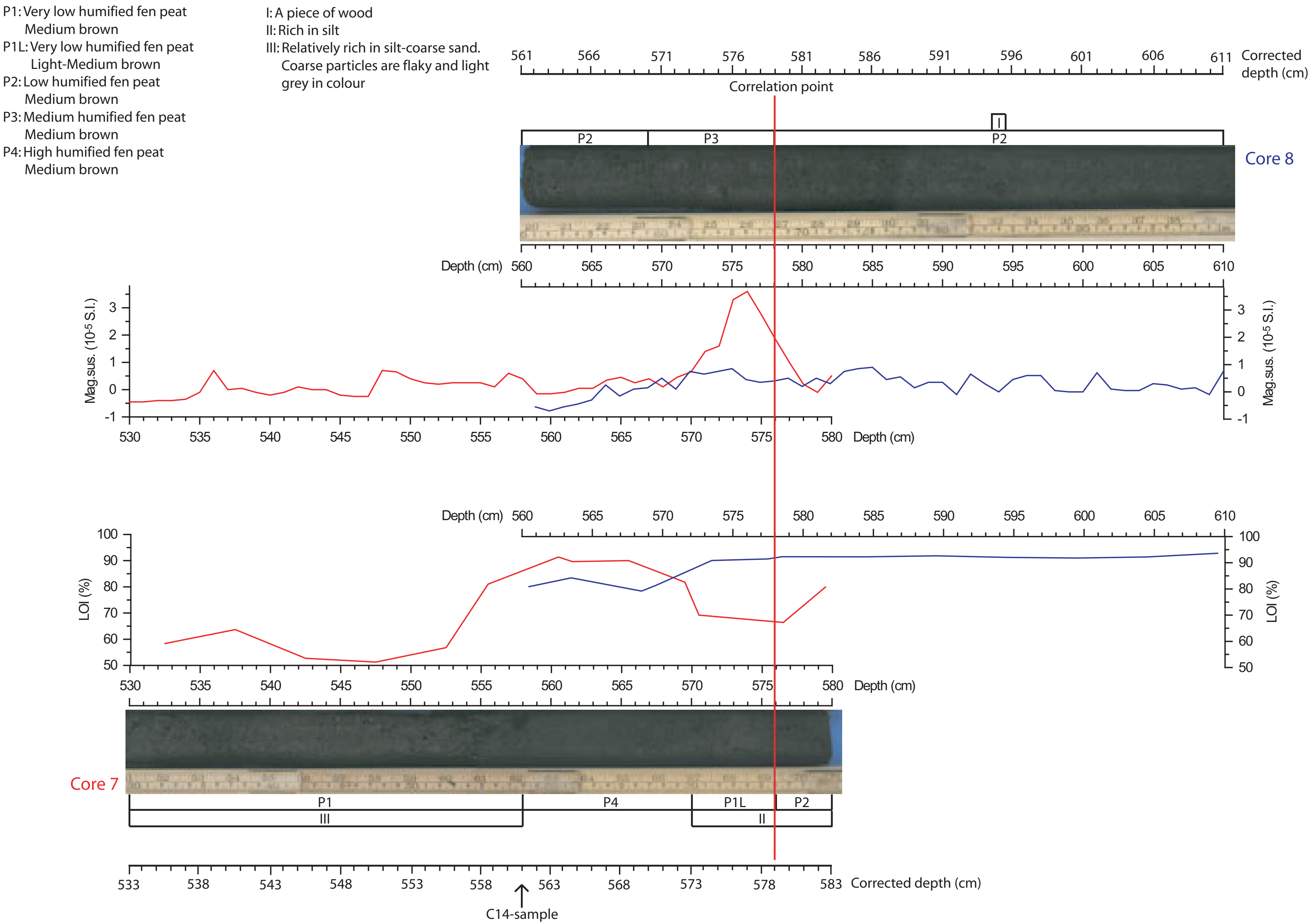
P1L: Very low humified fen peat
Light-Medium brown
P2: Low humified fen peat
Medium brown
P3: Medium humified fen peat
Medium brown
P3L: Medium humified fen peat
Light-Medium brown
P5: Very high humified fen peat
Medium brown

* Might also be gyttja

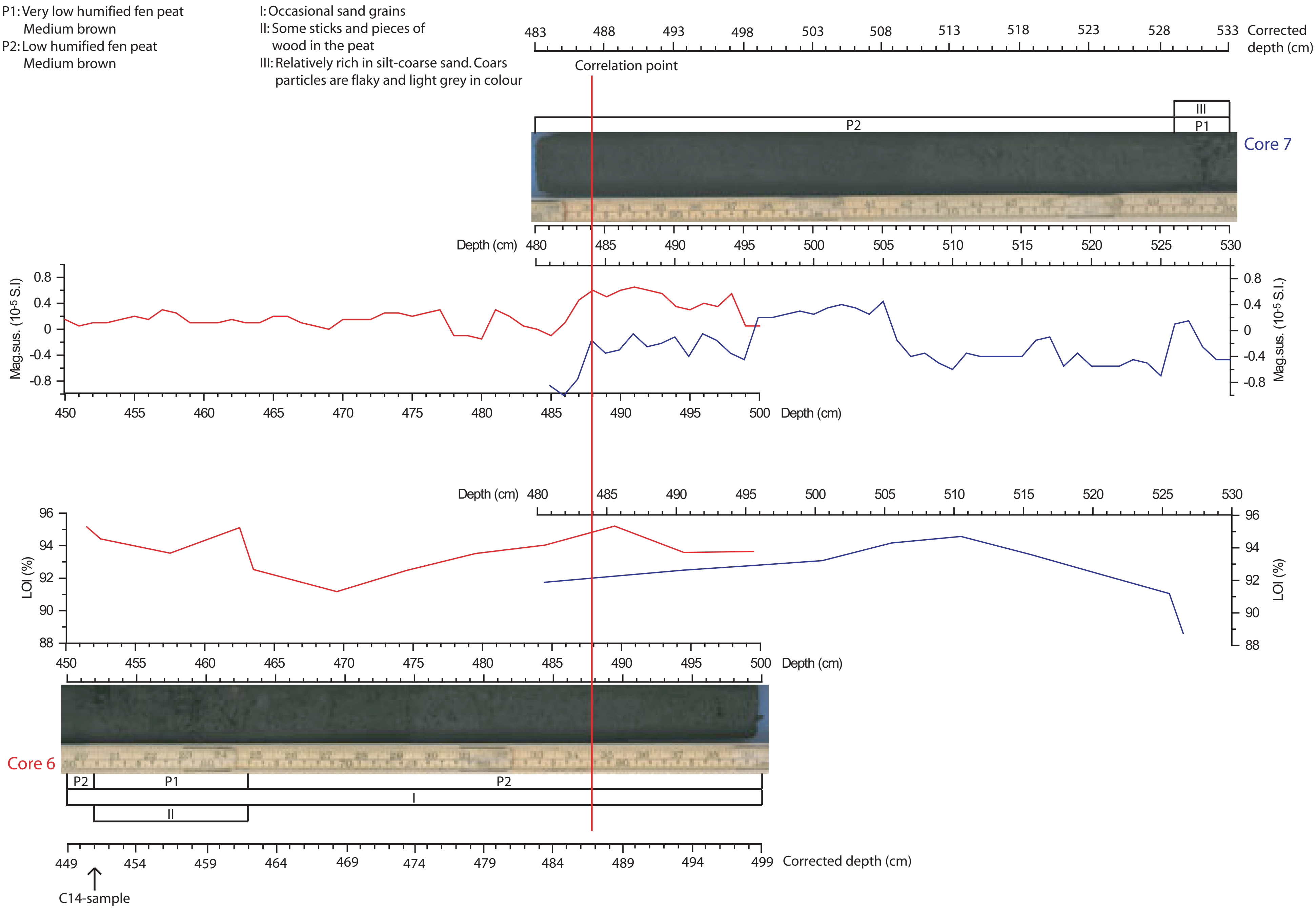
I: Relatively rich in silt-fine gravel. Coarse particles are flaky and light grey in colour.
II: Relatively rich in silt-corase sand. Corase particles are flaky and light grey in colour.



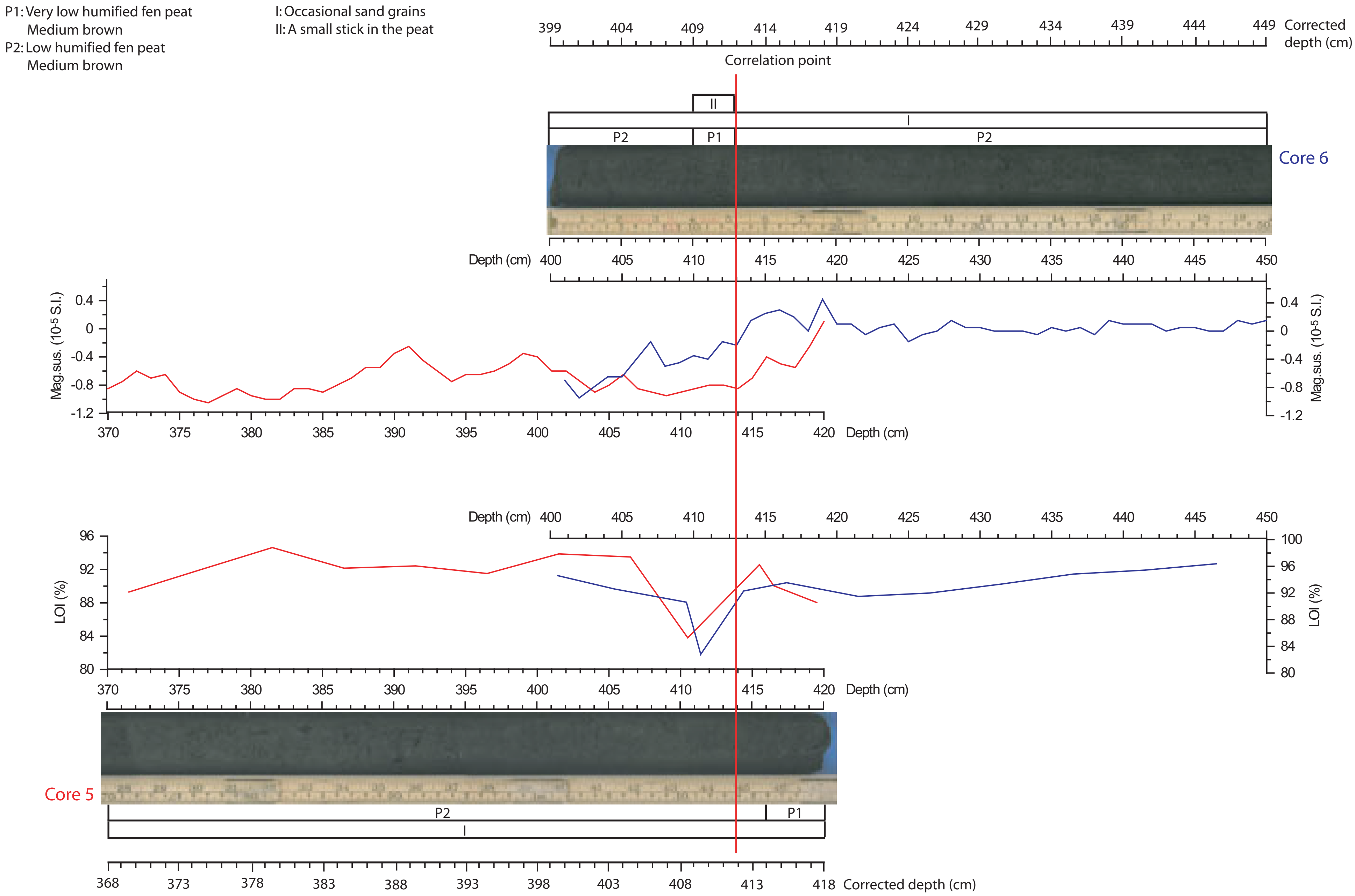
Appendix 7. Core 8 and 7



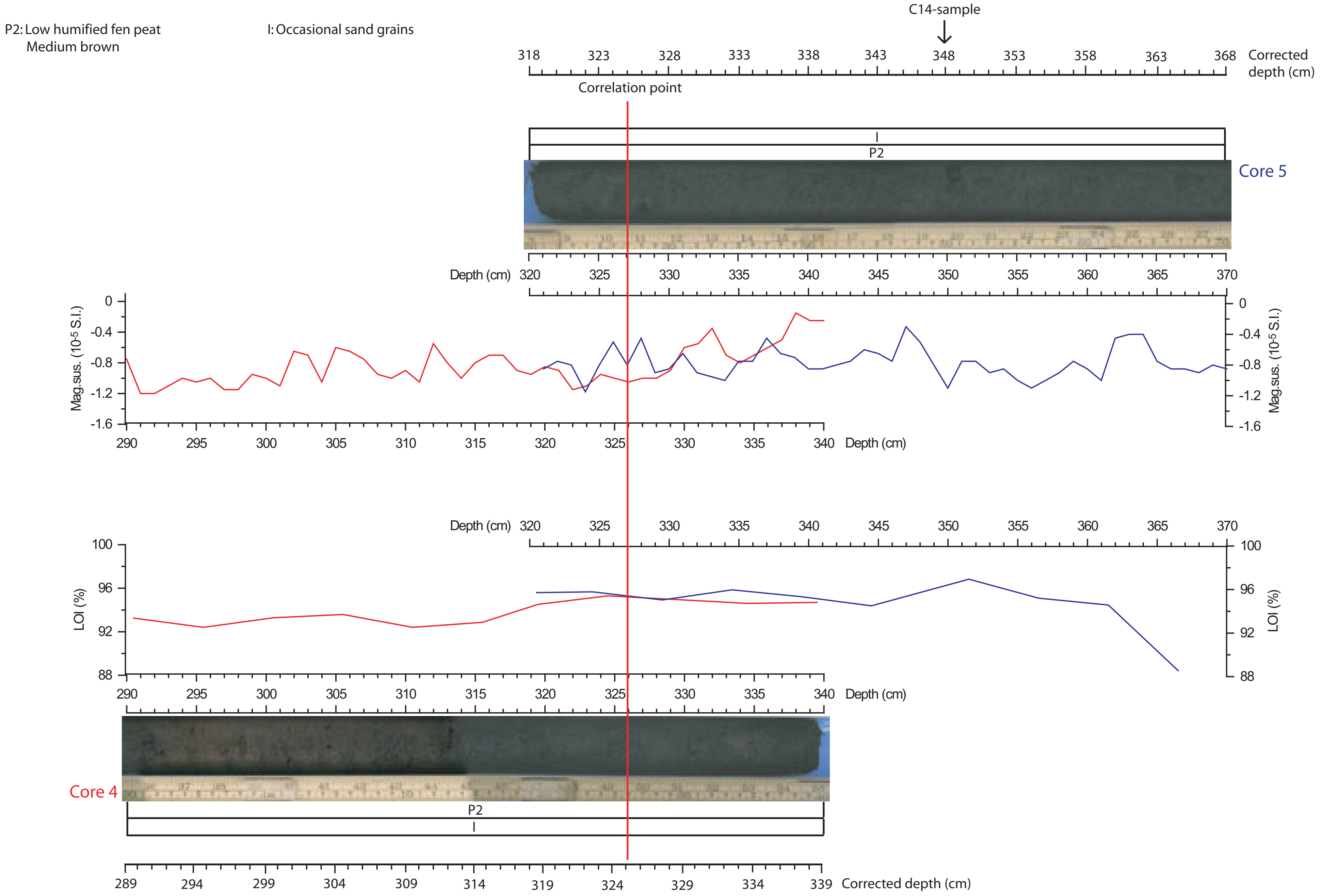
Appendix 8. Core 7 and 6



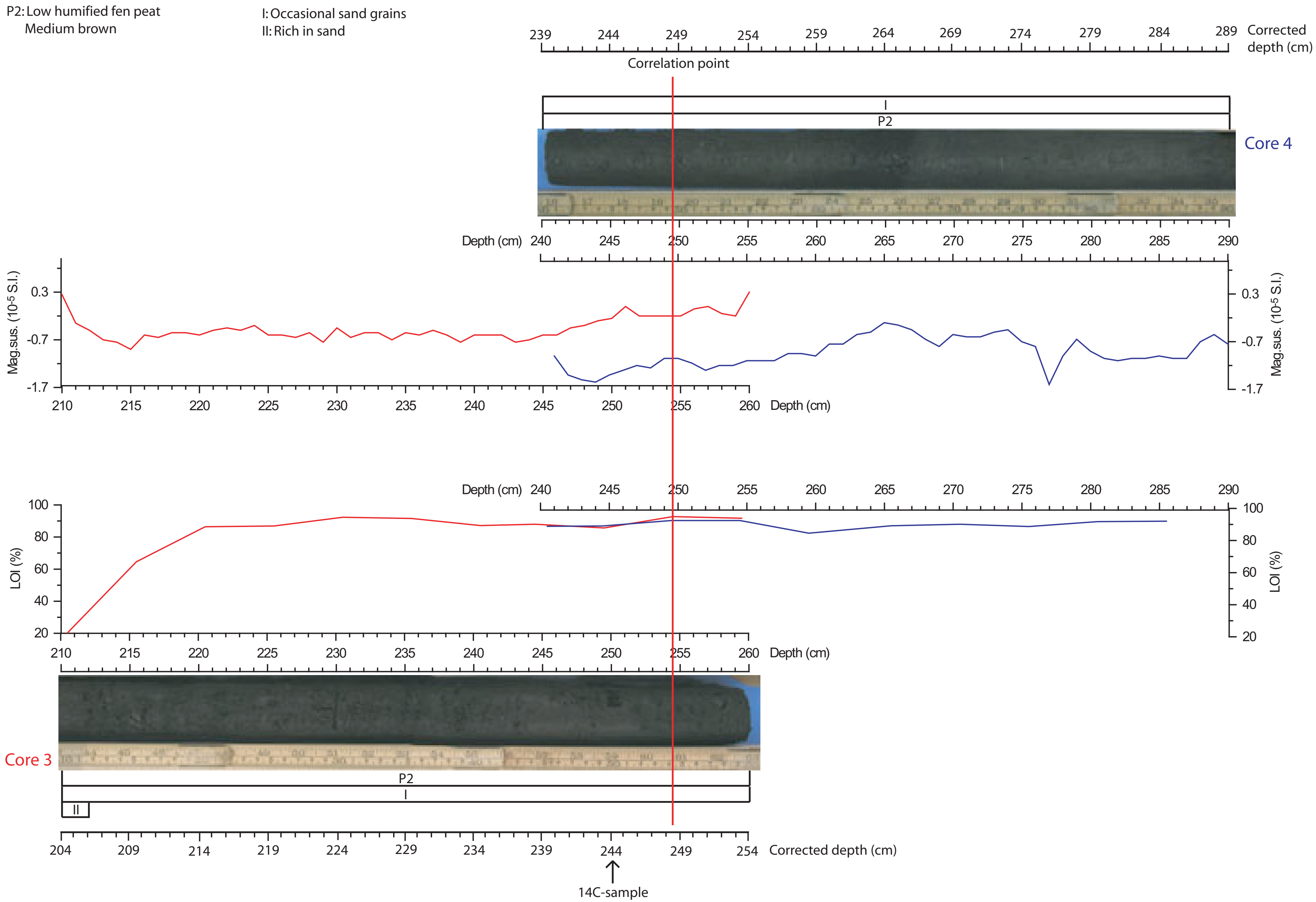
Appendix 9. Core 6 and 5



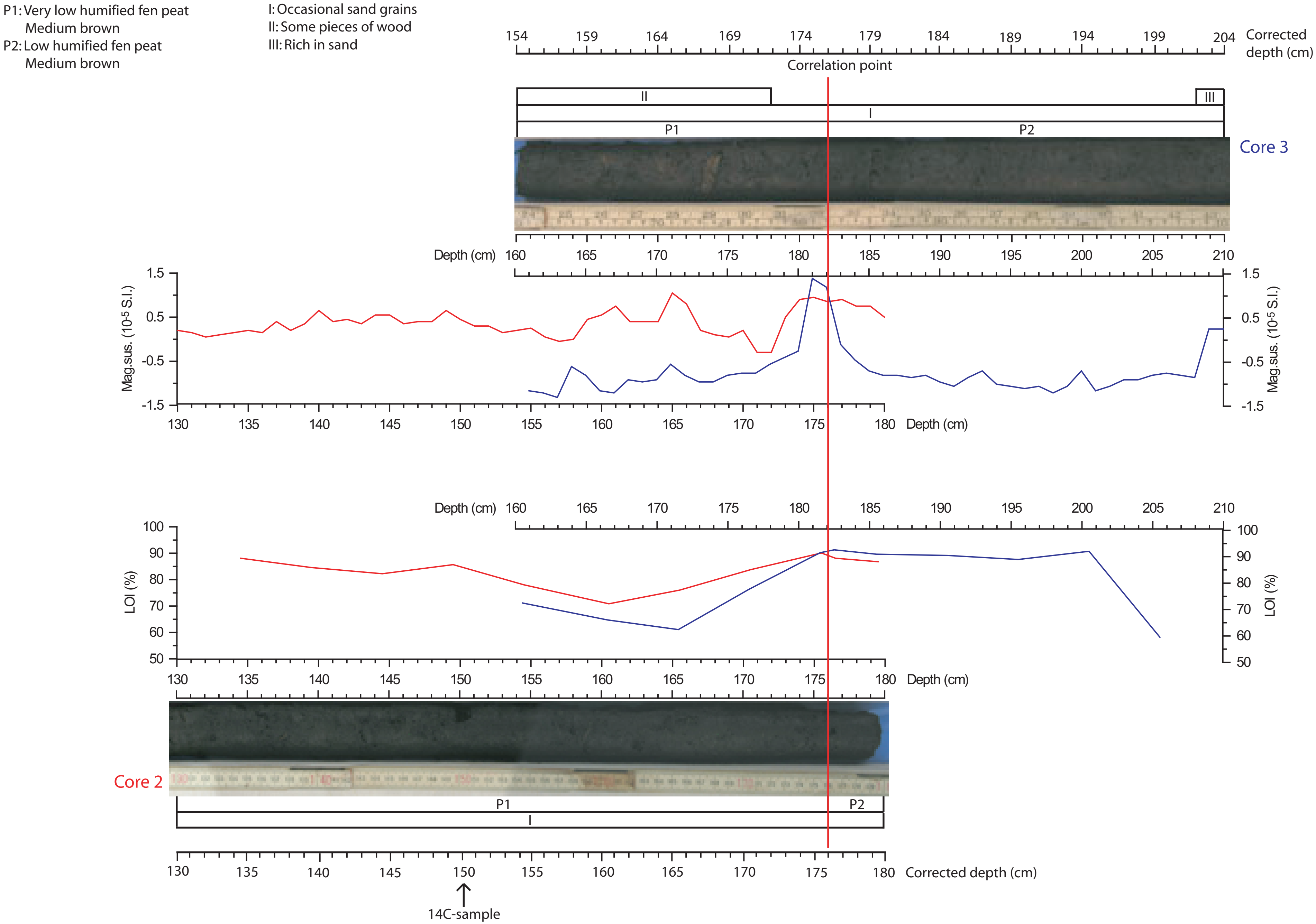
Appendix 10. Core 5 and 4



Appendix 11. Core 4 and 3



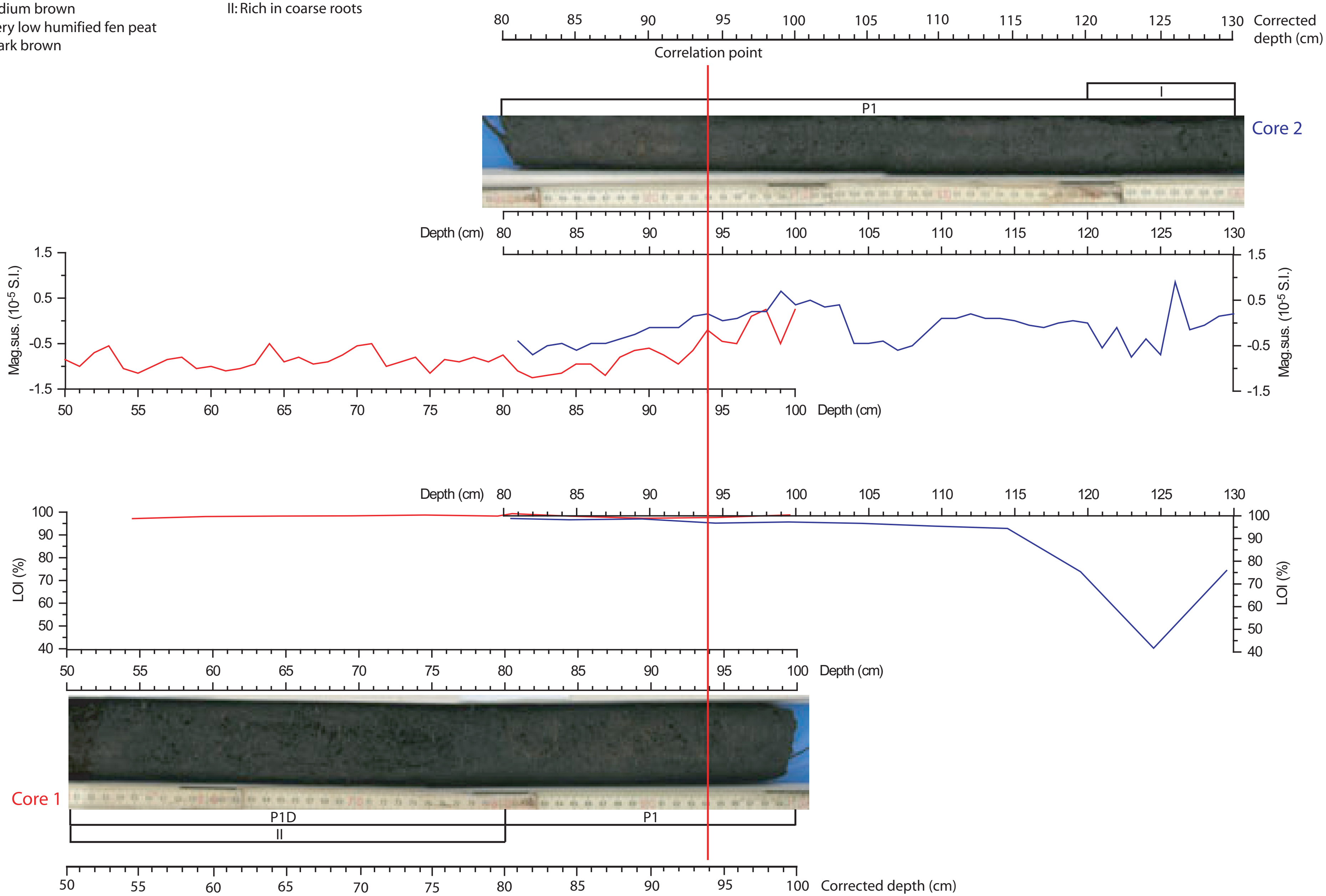
Appendix 12. Core 3 and 2



Appendix 13. Core 2 and 1

P1: Very low humified fen peat
Medium brown
P1D: Very low humified fen peat
Dark brown

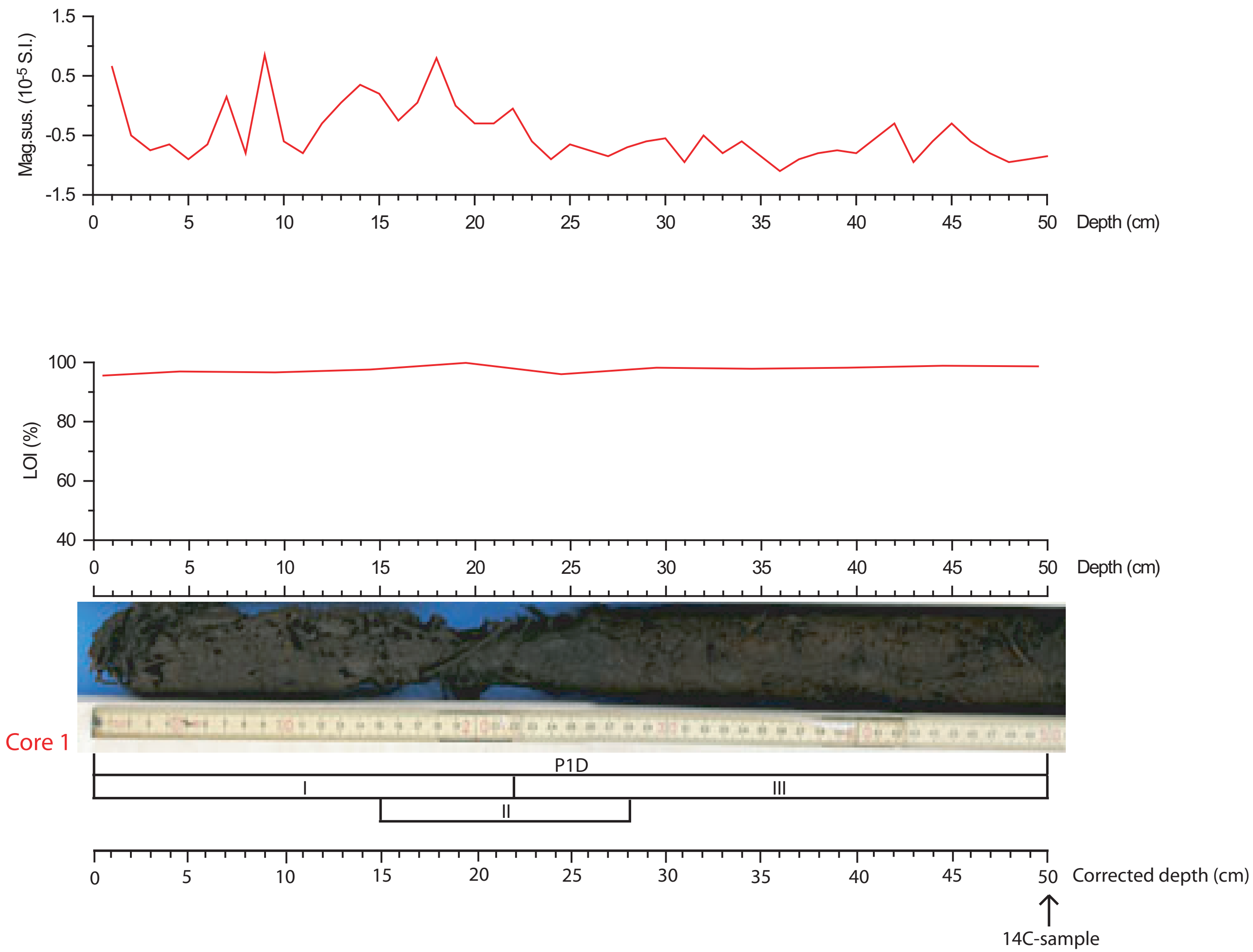
I: Occasional sand grains
II: Rich in coarse roots



Appendix 14. Core 1

P1D: Very low humified fen peat
Dark brown

I: Very rich in coarse roots
II: The core gets thinner
III: Rich in coarse roots

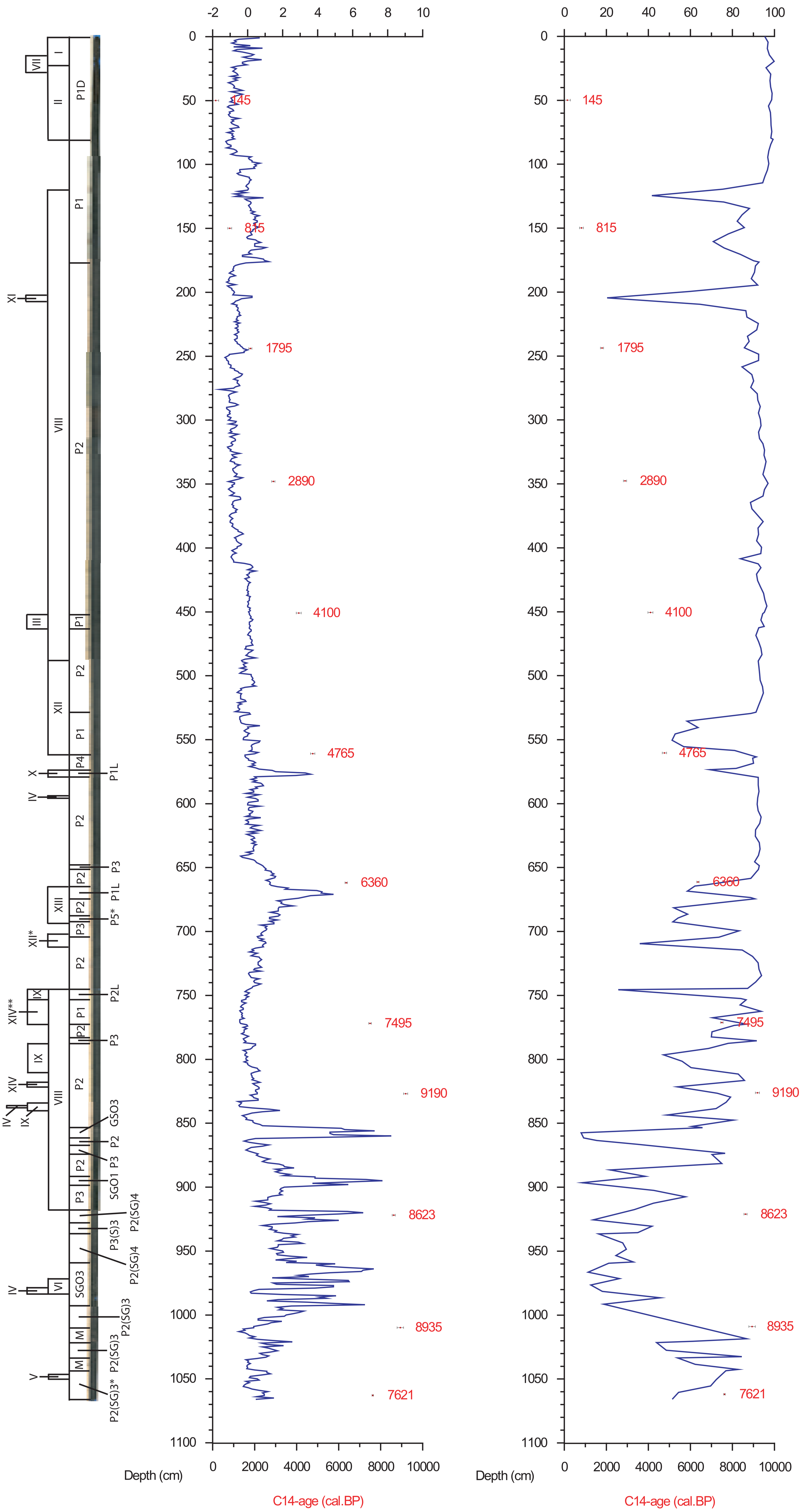


Appendix 15. The complete sequence from Taniente Palet bog

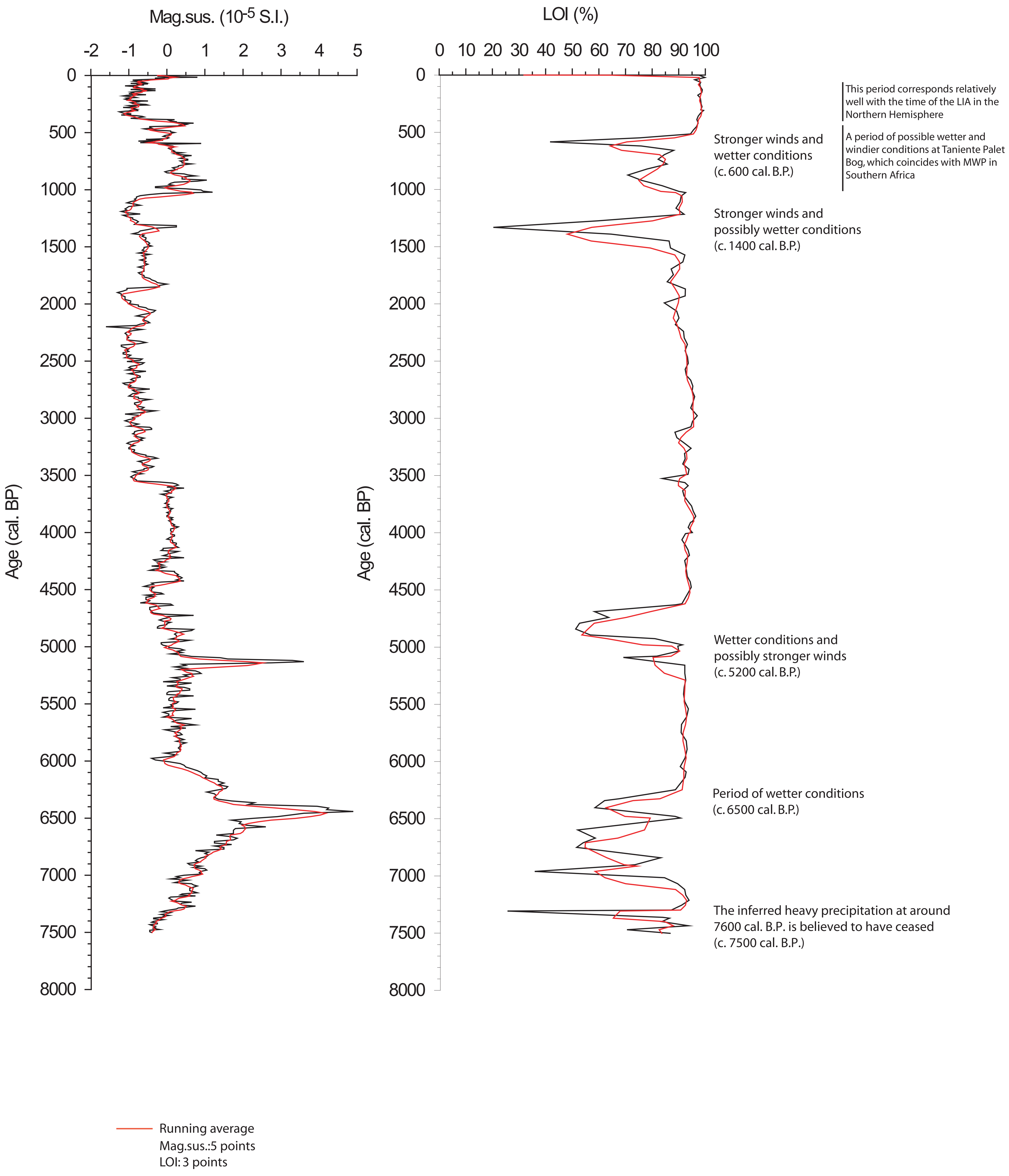
P1: Very low humified fen peat
Medium brown
P1D: Very low humified fen peat
Dark brown
P1L: Very low humified fen peat
Light brown
P2: Low humified fen peat
Medium brown
P2L: Low humified fen peat
Light-medium brown
P3: Medium humified fen peat
Medium brown
P4: High humified fen peat
Medium brown
P5: Very high humified fen peat
Medium brown
P2(SG)3: Low humified fen peat rich in sand and gravel
Medium brown
P2(SG)4: Low humified fen peat very rich in sand and gravel
Medium brown
P3(S)3: Medium humified fen peat rich in sand
Medium brown
GSO3: Gravely sand rich in organic material
SGO1: Sandy gravel with some organic material
SGO3: Sandy gravel rich in organic material
M: Wood

* Might also be drift gyttja

I: Very rich in coarse roots
II: Rich in coarse roots
III: Some sticks and pieces of wood in the peat
IV: A piece of wood
V: Pieces of wood
VI: Pieces of wood and stones
VII: The core gets thinner
VIII: Occasional sand grains
IX: Relatively rich in silt-sand
X: Rich in silt
XI: Rich in sand
XII: Relatively rich in silt-coarse sand. Coarse particles are flaky and light grey in colour (possibly schist)
XII*: Relatively rich in silt-coarse sand. Coarse particles are flaky and light grey in colour (possibly schist). It is mostly sand in this unit
XIII: Relatively rich in silt-fine gravel. Coarse particles are flaky and light grey in colour (possibly schist)
XIV: More wet
XIV**: More wet, and rich in big pieces of wood and other organic material



Appendix 16. Magnetic susceptibility and LOI records shown with interpretations of the sequence



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