A Paleolimnological Study of Past and Present Pollution at Loe Pool, Cornwall

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45 credits

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‘There was no fishing in the Cober, but when it reached the Loe it seemed to deposit its refuse. It would have been a lovely river without the mines’

(National Trust, 2001)

Abstract

A paleolimnological study has been conducted on a 3m core collected from Loe Pool, Cornwall. The overall aim is to determine past and present pollution that has affected the lake and how pollution concentrations have changed over time. Different analyses will be performed in an attempt to provide an answer: Troell-Smith; Loss-On-Ignition; magnetic susceptibility; heavy metal analysis; phosphorus analysis; particle size analysis; C137; SCPs; and statistical tests. A chronology has also been produced by combining some of these analyses with literature research to provide a temporal aspect to the results. A large proportion of focus throughout this dissertation has been placed on a desktop survey, including an in-depth literature review and two interviews. This research will be used to imply potential sources of Loe Pool pollution; however further studies into the catchment area would need to be undertaken to make definite conclusions.

1. Introduction

1.1 Why study pollution?

Studying pollution is crucial due to its detrimental environmental impacts, which effect both society and the economy (Brown, 1981). Pollution is a global issue because of this environmental deterioration and understanding its underlying controlling processes is essential. Paleolimnology, the study of lake sediments, provides the opportunity to observe past pollution (O'Sullivan et al., 2004 and Thevenon et al., 2011) and analyse regional and local environmental signals (Smol, 2002).

Although mining only accounts for 0.9% of land use in England (Bloodworth et al., 2009), it can create enormous, long lasting alterations to nature (Passariello et al., 2002). Mining introduces numerous potentially hazardous trace elements into the environment, and had substantial impact during the British industrial revolution (Yang et al., 2005), when anthropogenic pollution dramatically increased with the expansion of the manufacturing industry (Thornton, 1996). Mining is notorious for causing soil contamination (NSCA, 2006); river channels and floodplains in many parts of the world have been contaminated by heavy metals, threatening the health of humans (Macklin et al., 2006).

Modern regulations are reducing the impact of mining (Kwolek, 1999) but more recently, pollution caused by sedimentation, agriculture and waste facilities have become prominent. One tenth of the Earth's surface is assigned to agriculture (Brown, 1981), accounting for 71% of the UK's land (Bloodworth et al., 2009). During the 1950s, use of chemical fertilizers on crops expanded, increasing the world's food output by 33% (Brown, 1981). However, effects to wildlife have caused widespread concerns about their possible ecological impacts (Morairty, 1983). These fertilizers contain three main nutrients; nitrogen, phosphorus and potassium (Brown, 1981) which have a non-uniform distribution (Morairty, 1983), therefore making their environmental impact harder to measure. These nutrients are also released by sewage treatment facilities, presenting a major challenge to catchment management (Dinsdale, 2008).

1.2 Why study pollution in Loe Pool, Cornwall?

Around the 19th century, Cornwall was renowned for copper, tin, arsenic and lead mining; the last mine, South Croft, was closed in 1998 (Spalding, 2005). Mining has destroyed over 100km^2 of countryside in Devon and Cornwall (Mellanby, 1992). Furthermore effluent from sewage systems is seen as a primary source of water pollution within the South West (Dinsdale, 2008). This presents the problem of eutrophication; higher concentrations of limiting nutrients which lead to accelerated algae growth that can overrun lake systems (Mellanby, 1992). Phosphates and nitrates in rivers have increased in the last 40 years, with sources from both agriculture and sewage works. Loe Pool is the largest natural lake in Cornwall and has been strongly influenced by the effects of mining, agriculture and sewage facilities. This combination of pollution sources makes Loe Pool a good study site within the UK.

1.3 Aims:

The aim of this dissertation is to investigate the pollution history of Loe Pool and determine the different types of pollution by conducting a high resolution paleolimnology study. It will extend the current pollution record of Loe Pool (Coard et al., 1983) by using new tests and more analyses than previously.

1.4 Research Questions:

The following questions have been proposed for this dissertation:

- What types of pollution has Loe Pool been subjected to?
- Which of these types of pollution have been most prevalent throughout the core?
- What pollutants are currently affecting Loe Pool?
- How has the pollution concentrations altered in the lake over the last three decades?
- Have recent management schemes had an apparent effect on the pollution levels in Loe Pool?

1.5 Objectives:

To answer these research questions the following objectives will be undertaken:

- To conduct a high resolution paleolimnology study on the historical pollution of Loe Pool by analysing a three metre core from within the lake.
- To determine the types of pollution by conducting experiments such as heavy metal analysis, phosphorus and particle size, and comparing this to catchment data, such as mining history and agricultural practices.
- To create a detailed chronology of the core using C137, SCPs, magnetic susceptibility and Troell-Smith, to define a timescale enabling changes of pollution levels over time to be determined.
- To compare this core record with previous studies to establish a more complete overview of the pollution at Loe Pool.

- Research, via a desktop survey, will be conducted to explore the progress of management schemes conducted in the past few decades.

1.6 Study site:

Figure 1.1: *Site map of Loe Pool, North of Helston West of RNAS Culdrose.*

(Google Earth, 2013.)

Loe Pool is the largest natural lake in Cornwall (Coard et al, 1983). The lake is situated 1km south of the town of Helston (Figure 1.1), which has a population of ~10,000 people. RNAS Culdrose military base, which lies to the East of the lake, was commissioned in 1947, and now has a population of 2500 (Coard et al., 1983).

It is thought that the Pool was formed when Loe Bar, on the coast of Mount's Bay, formed during the medieval period, closing off the former estuary from the sea (Toy, 1934).

Increased sedimentation has reduced the original size of the lake, which now covers 55.6ha (Pickering, 1987) and a deepest point of 10m (O'Sullivan, 1996). The area is managed and run by the National Trust (National Trust, 2002) and has recently been designated UK Grade 1 Site of Special Scientific Interest (SSSI) (O'Sullivan, 1992).

1.7 Project rationale:

This dissertation will utilize techniques not used in this area previously, such as SCPs and additional heavy metals analyses as well as extending extend the record by 30 years. This high resolution study will significantly contribute to work done by such groups as the Environmental Agency and the Loe Pool Forum, providing useful additional information. Other studies, such as Flory et al (1993), have shown how the pollution in Loe Pool can be monitored; however, no previous study has collectively observed all forms of pollution within the lake. The intense mining impacts and other pollution sources have led to investigations within this area by many organisations, including the National Trust and South West Water. Lake sediment will be analysed instead of water quality because of its ability to reconstruct past pollution records over a longer time scale.

2. Literature Review

This chapter includes an overview of global pollution studies and a detailed analysis of Loe Pool and its catchment. Information has been collected from various sources including a review of previous studies; an in-depth desktop survey; two interviews; and other published literature.

2.1 Loe Pool geology

Loe Pool is the largest freshwater lake in Cornwall (Blame, 2007) and is a designated Site of Special Scientific Interest (Dinsdale, 2008). The maximum depth of the lake is 10m; depth increases from the Northern end seawards, with a lake area of 56km² and mean water residence time of 57 days (O'Sullivan, 1992).

2.1.1 River catchments

Four rivers run into Loe Pool: Penrose stream (NW), Carminowe Stream (SE), Chyvarloe stream (SE) and the River Cober (NE) (O'Sullivan, 1992). 90% of water entering the lake is from the River Cober and therefor its catchment shall be considered when discussing catchment characteristics. The River Cober drains from Porkellis moor (Barton, 1965), and has a catchment area of 40km², which contains two main settlements, Helston and RNAS Culdrose (EA report, 2003). Two thirds of Cornwall is arable or pasture land (Carey, 1911), with trees also forming a large section of this catchment (Healy, 1996).

Cornwall is formed of killas and granite, with lobes in a North-South direction carrying lead and East-West lobes bearing tin and copper (Carey, 1911). Figure 2.2 displays the region's geology (Balchin, 1983). The River Cober catchment runs through three main rock types; Cammenellis granite, Mylor and Gramscatho (Pickering, 1987). The northern half of the catchment mainly contains Cammenellis granite, and was the former site of many mines that produced cassiterite (SnO_2) (Coard et al 1983).

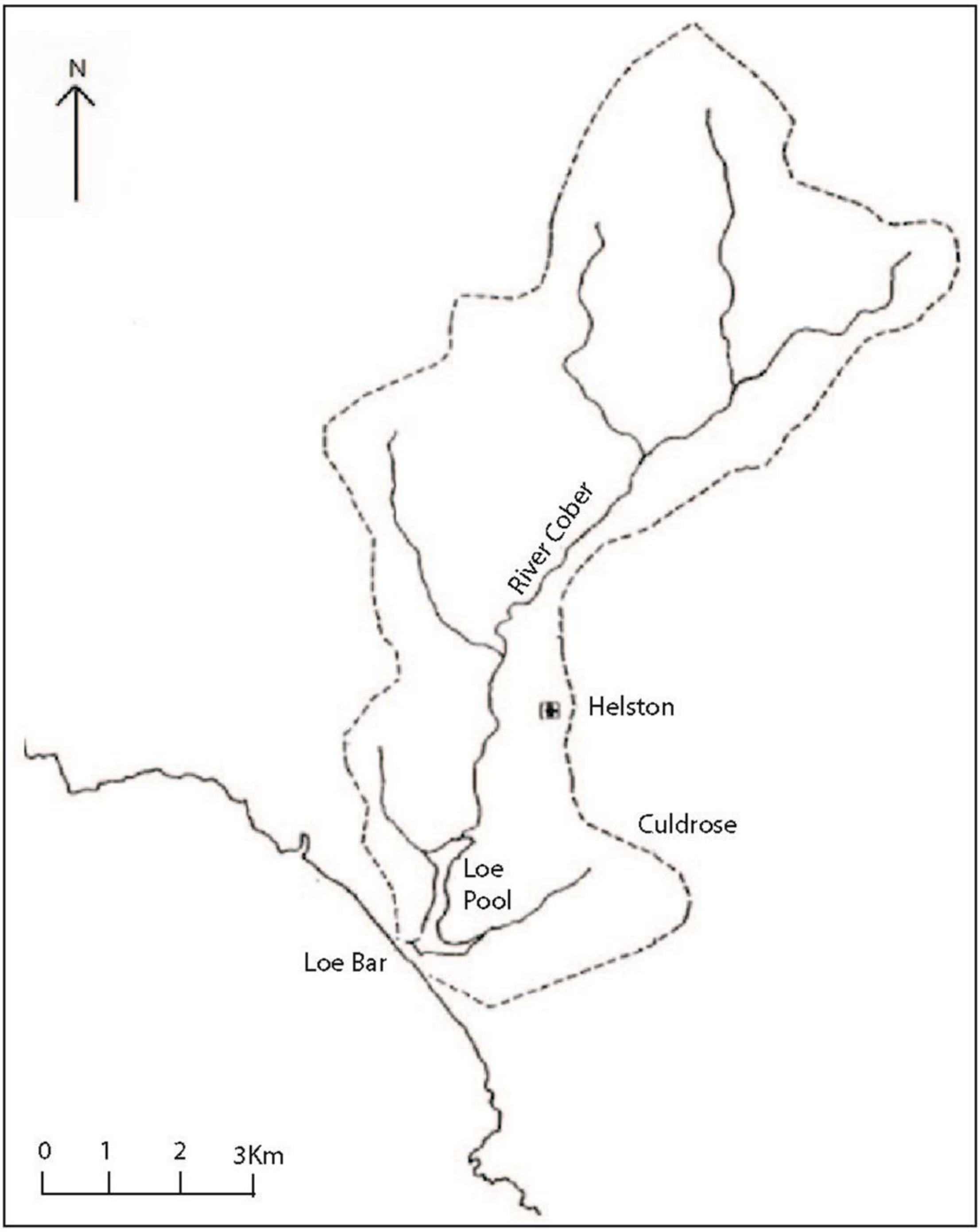


***Figure 2.1:** Map showing Loe Pool's catchment area, including the River Cober and the position of Helston and Culdrose (adapted from O'Sullivan 1992.)*

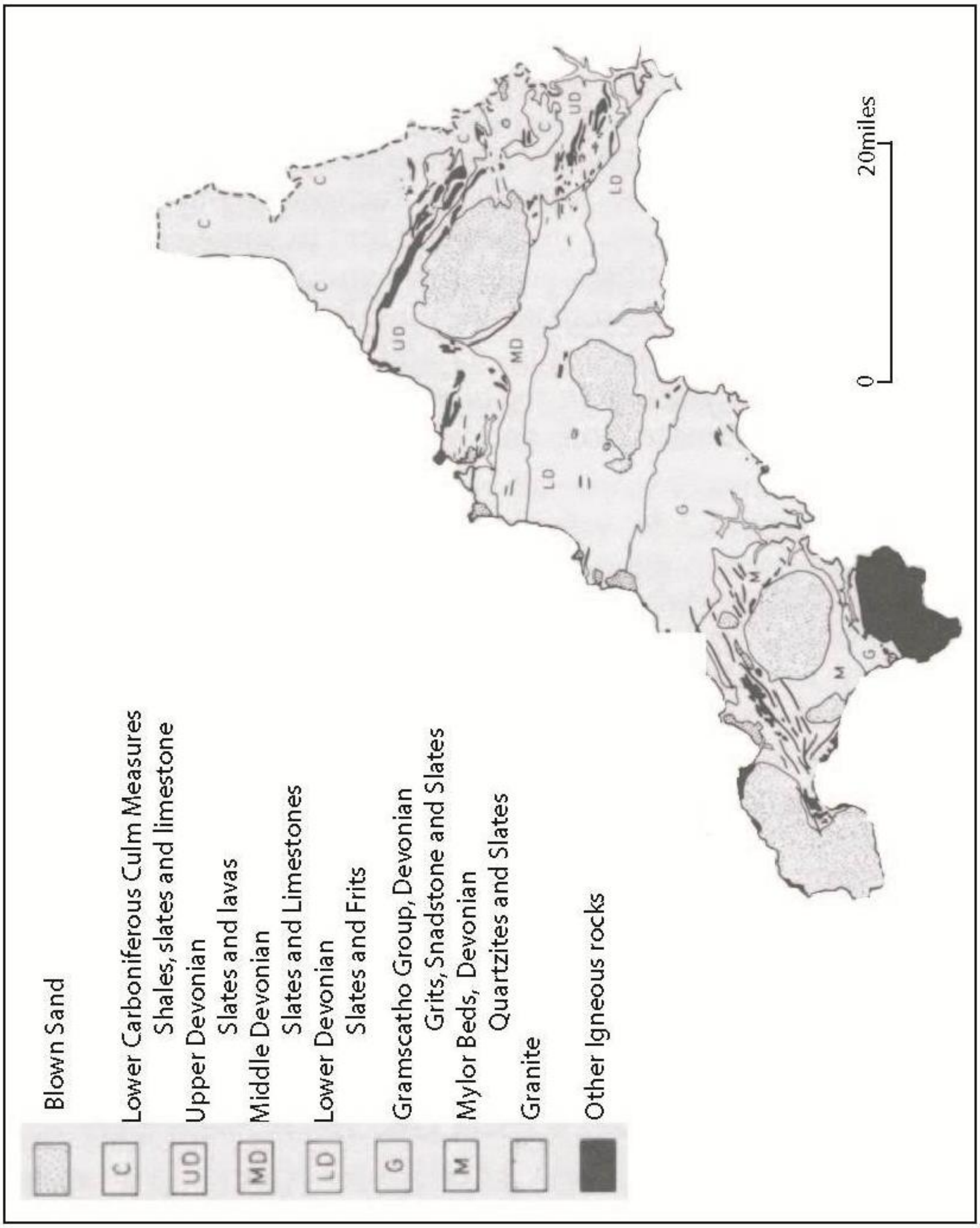


Figure 2.2: *Map of Cornwall showing the dominant underlying rock types in the region (Balchin 1983).*

In 1946 a section of the River channel, just below Helston, was straightened and then substantially re-profiled in 1988. This has led to the river being confined to its channel and disconnected from its floodplain. Furthermore, since 1988 de-silting of the channel has been carried out every six years (Dinsdale, 2008), in an attempt to reduce flood risk in Helston. This resulted in improved water flow; however sediment was now dropped into the lake bed rather than the marshes (Balme, 2007). Helston still experiences flooding and flood waters deliver high levels of nutrients and fine sediments to Loe Pool, impacting on water quality (Dinsdale, 2008). The river's daily average flow is 1m^3/s, with flood events, such as in 1979, reaching peaks of 11m^3/s (EA, 2003), illustrating the huge amount of water that can reach Loe Pool.

2.1.2 Formation of Loe bar

There is much debate over how and when Loe Bar formed, turning the Loe estuary into Loe Pool. The present length of the bar is 250-400m and is approximately 250m wide (EA, 2003).

One explanation for the formation of Loe Bar is that spits developed, through a combination of long shore and onshore drift, at either end of the coast line, meeting to close off the bar (Toy, 1934). It is thought that it was finally blocked by a series of storm events (National Trust, 2002); enormous waves produced by Atlantic weather systems can deposit hundreds of tonnes of new material (National Trust, 2001). This process of bar formation across an estuary has been observed in many places on the East Anglian Coast, such as Norfolk Broads (Toy, 1934).

Loe Bar is made of shingle, which is 86% chalk flint (National Trust, 2002); the nearest inland site of this material is over 120 miles away. It is believed that the main source of the bar's sediment is an undersea ridge of chalk flint located out to sea in the Western approaches (Balme, 2007).

The formation, maintenance and movement of Loe Bar are controlled by sediment supply, relative sea-level rise and wave climate (EA, 2003). It can be seen that Loe bar is migrating inward due to sediment passing over the bar crest in high energy storms (Figure 2.3). It is estimated that the bar will migrate

Figure 2.3: *Map showing the inland movement of Loe Bar since 1867 and the predicted position in 2053 (O'Sullivan 2013, pers.comm., 13 Feb).*

between 25 and 74m landward over the next 50 years (EA, 2003). As this occurs, the height of the bar could increase due to the maximum angle on the sea side (O'Sullivan 2013, pers.comm, 13 Feb).

Older studies show contradiction over when the bar closed off the sea and formed Loe Pool (O'Sullivan, 1996). Some resources state how the bar was created during the 13th Century (Toy, 1936), whereas others claim that geological evidence suggests that the bar was formed thousands of years ago (National Trust, 2002). It is unclear from the literature which of these is correct, but diaries from the 13th Century show that the bar existed then, despite some writers, such as Defoe, claiming it was a port around this time (O'Sullivan 2013, pers.comm., 13 Feb). It can therefore be assumed that sediment within the lake is from at least the 13th Century, if not before.

2.1.3 Bar breaching:

Flooding is a constant issue for Helston, due to the fact that it was built on the Cober's floodplain. This has led to a history of 'bar breaking'; cutting the bar to release excess water into the sea. By the mid-18th Century, bar breaking was well established, with the last manual cut in 1867-68 (Toy, 1934). In 1979 and again in June of 1984, South West Water used machinery to break the bar to allow millions of gallons of water to flow into the sea. This drained the lake to practically mud (Balme, 2008), and the impact of this can be seen today with gap in the vegetation apparent on Loe bar (Figure 2.4). Saline conditions persisted in the lake for several weeks, even after the bar had re-established itself (O'Sullivan, 1996).

In the middle of the 19th Century, Wheal Pool, a silver mine just below Helston, made an adit through the rocks on the west of the bar (Figure 2.5), allowing surplus water to drain away (Toy, 1934). This was created to prevent mines from flooding and was later improved by the Environmental Agency in 1986 (National Trust, 2002). During storms and heavy rain events the adit can become blocked (Balme, 2007), such as the tidal wave in January 1924 (Toy, 1934).

2.2 Mining:

The mining of mineral ores is one of many human activities which influenced the physical appearance of the countryside (Johnson, 1978). Around one tonne of waste results from one tonne of ore mined (Merefield, 1993), highlighting the huge influence mining can have on an area. An example of this is Lake Orta, Italy, which has been affected by direct discharge from untreated effluent from surrounding industries, leading to environmental damages caused by copper toxicity (Smol, 2002). Mining can cause different amounts of metal pollution, depending on the nature of the underlying mineralised rock and the mining activity itself (Li and Thornton, 1993). It is therefore important to refer to the geology of an area when assessing mining impacts.

2.2.1 Cornwall:

Cornwall has a history of metalliferous mining dating back to the Bronze Age. Although hampered by a lack of coal (Carey, 1911), Cornwall was the world's largest producer of copper during the 1800s (Camm et al., 2004). It can be seen that, within Cornwall, copper played a bigger role than tin (Barton, 1965). Cornish mining peaked during the early 19th century, when over 340 mines

Figure 2.4: *Photograph of Loe Bar, showing reminisce of last bar breaking in 1984 (red arrow) and the position of the adit (blue arrow) (source: Author).*

Figure 2.5: *Photograph of adit on the North West end of Loe Bar, now maintained by the Environmental Agency (source: Author).*

operated, with an annual output of 181,470 tonnes of copper and 10,000 tonnes of tin, employing approximately 40,000 workers (Barton, 1965). Cornwall also produced a lot of China clay, with an output of 80,000 tonnes during 1855; it was thought that this was the most important mineral product of the county (Carey, 1911).

Tin streaming was a common practice in Cornwall since the Bronze Age (Buckley, 1999), producing a higher quality tin due to its higher specific gravity, making it easier to separate from soil (Carey, 1911). Underground mining emerged in the 15th Century, with the majority of early mines being open-cast. Copper mining only started to accelerate during the 16th Century; since then it has dominated Cornish mining (Buckley, 1999).

Arsenic recovery, with arsenic occurring naturally in tin and copper lodes, became more extensive from the 1860s, when its importance was realised. This recovery is strongly linked to tin mining and between 1860 and 1900, Cornwall became the world's major producer of arsenic (Camm et al., 2004).

Cornwall has become a geochemical hot spot for arsenic, which can be seen in Figure 2.6 (Thornton, 1996). The concentration of Arsenic in soil is gaining increasing attention due to its potential toxicity to humans, fauna and flora. According to Camm, 11.9% of the soil and streams in South West England are currently contaminated by this heavy metal (Camm et al., 2004).

As copper began to be mined worldwide, Cornish copper production started to decline, with the copper crisis occurring in 1866 (Barton, 1965). Cornish tin mines also started to close in the late 1880s, with production fluxuating until 1914. Less than twenty mines survived the First World War, but the 1930s tin crisis, along with foreign countries undercutting the English price of tin, forced most of these to close, despite the government's attempt to save the industry by injecting four million pounds into tin mining (Barton, 1965; House of commons, 1985).

2.2.2 Wendron mining district

The River Cober catchment lies within the Wendron mining district, a tin production area that is five miles by three miles (Barton, 1965). Compared to other Cornish mining districts, Wendron is small. However for over 100 years, 30 mines operated in this district (National Trust, 2002), with the upper parts of the River Cober used for tin streaming (Toy, 1936). Figure 2.7 show the locations of the mines and tin streaming sites within the Cober Catchment. From the 17th century onwards lob mining continued side by side with alluvial streaming (Jenkins, 1978). Wendron produced 3.3% and 0.1% of Cornwall's total tin and copper respectively, showing how tin mining was in fact more important within this area. It is thought that alluvial deposits from these mines led to a 14.4% reduction of Loe Pool's total area (National Trust, 2001). Unfortunately much of the information about many of the mines in the catchment is no longer available (Dines, 1956).

The history of mining in this area is thought to be linked to why the river is highly silted (Dinsdale, 2008). The River Cober served as a power source for ore-washing as well as a disposal facility for the mining industry (O'Sullivan, 1996); with tin streaming being common practice (Balme, 2007). This resulted in huge amounts of material travelling downstream into Loe Pool. During 1906 to 1938, 2 to 3 km^2 of Loe Pool was filled with mine waste, making the majority of the sediment in the lake of terrestrial origin (O'Sullivan, 1996). The effect of this

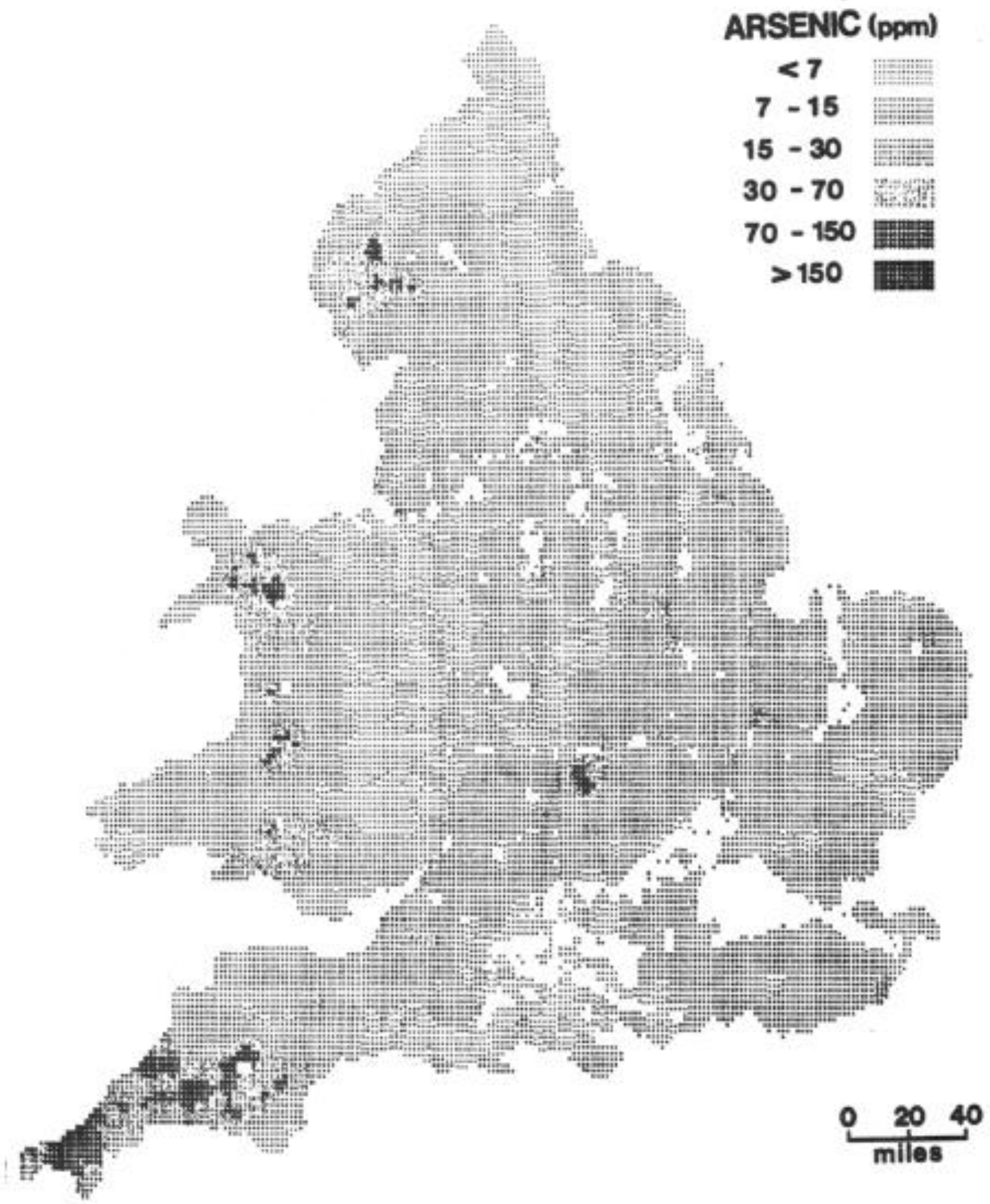


Figure 2.6: *Map of England and Wales showing the distribution of arsenic concentrations found in soil samples (Thornton 1996).*

waste was evident to those in the 19th century; ‘the Cober was stained a deep rusty red and covering the bottom and shore of the lake with a deposit’ (Balme, 2007).

The main mine within this district was Porkellis mine, which opened in 1750 (this was later changed to Basset and Grylls in 1860 and can be seen in Figure 2.7). This mine started to decline in 1870 but was successively working between the 1920s and 1930s (Barton, 1965). Weir Pool is also thought to have affected the sediment entering Loe Pool, which had its peak in 1865 (Barton, 1965). It is thought that Porkellis mine was the main source of sediment into the lake as Weir Pool may not have been big enough(O’Sullivan 2013, pers.comm., 13 Feb). Furthermore, haematite has been found in the core, which can be found in the underlying rock from one particular load of tin at Porkellis mine (O’Sullivan 2013, pers.comm., 13 Feb).

2.3 Agriculture

Two thirds of Cornwall is arable or pasture land (Carey, 1911), with roughly 50% as permanent grassland, 21% temporary grassland, 10% rough grazing, 6.4% cereals, 3.5% arable and 3% woodlands (O’Sullivan, 1992), highlighted in Figure 2.8. The lower area within the Cober catchment is more agriculturally intensive (National Trust, 2001). Agricultural disturbance by ploughing (Camm et al., 2004), emphasised by steep slopes in the area (National Trust, 2001), has resulted in nutrient runoff, including arsenic contamination within some soils. In recent years, Loe Pool has experienced increased eutrophication because of nutrient runoff caused by agricultural intensification and by incoming sewage effluent (O’Sullivan, 1992).

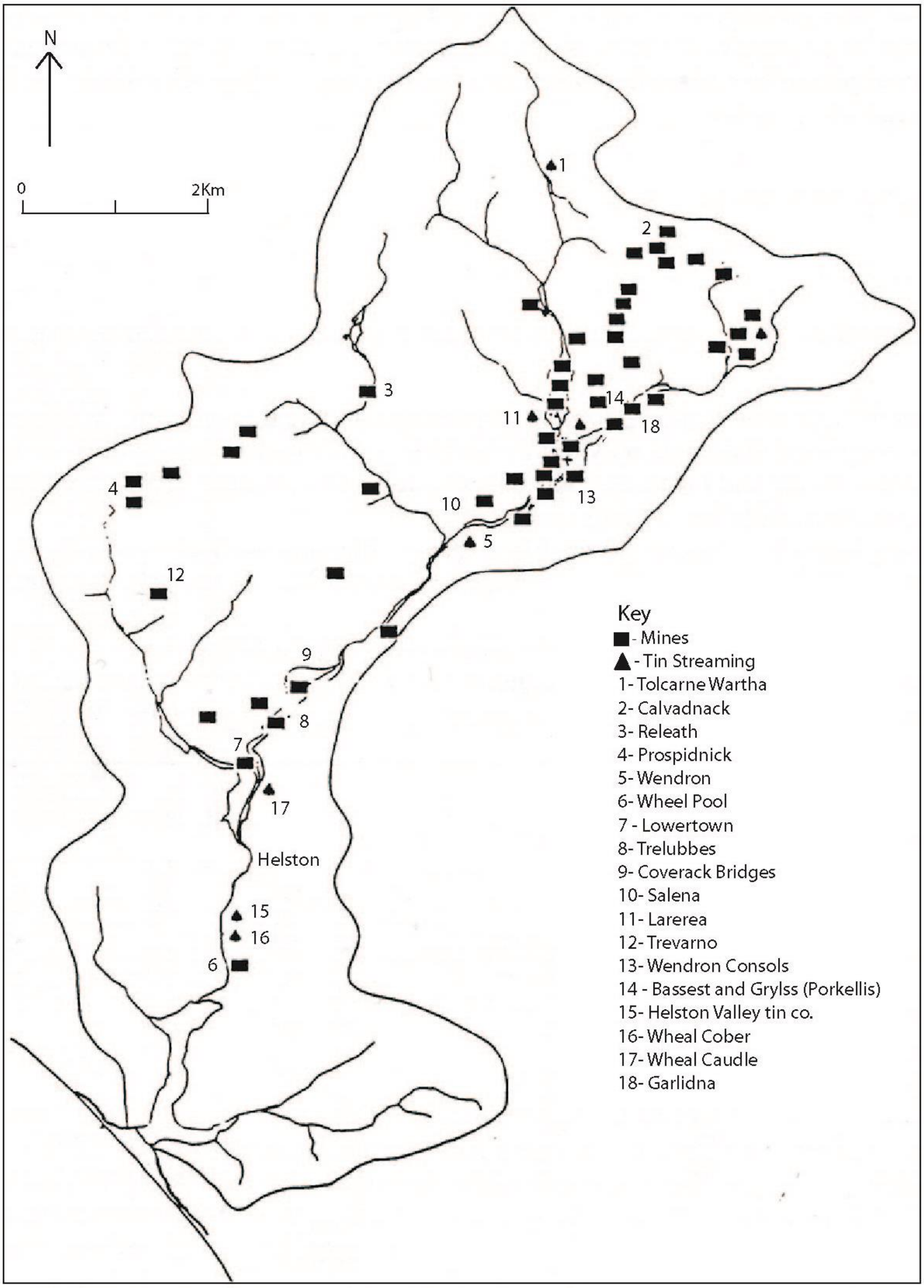


Figure 2.7: *Map of mines and tin streaming sites within the Loe Pool catchment area, with the location of Helston added (adapted from O'Sullivan, 1996).*

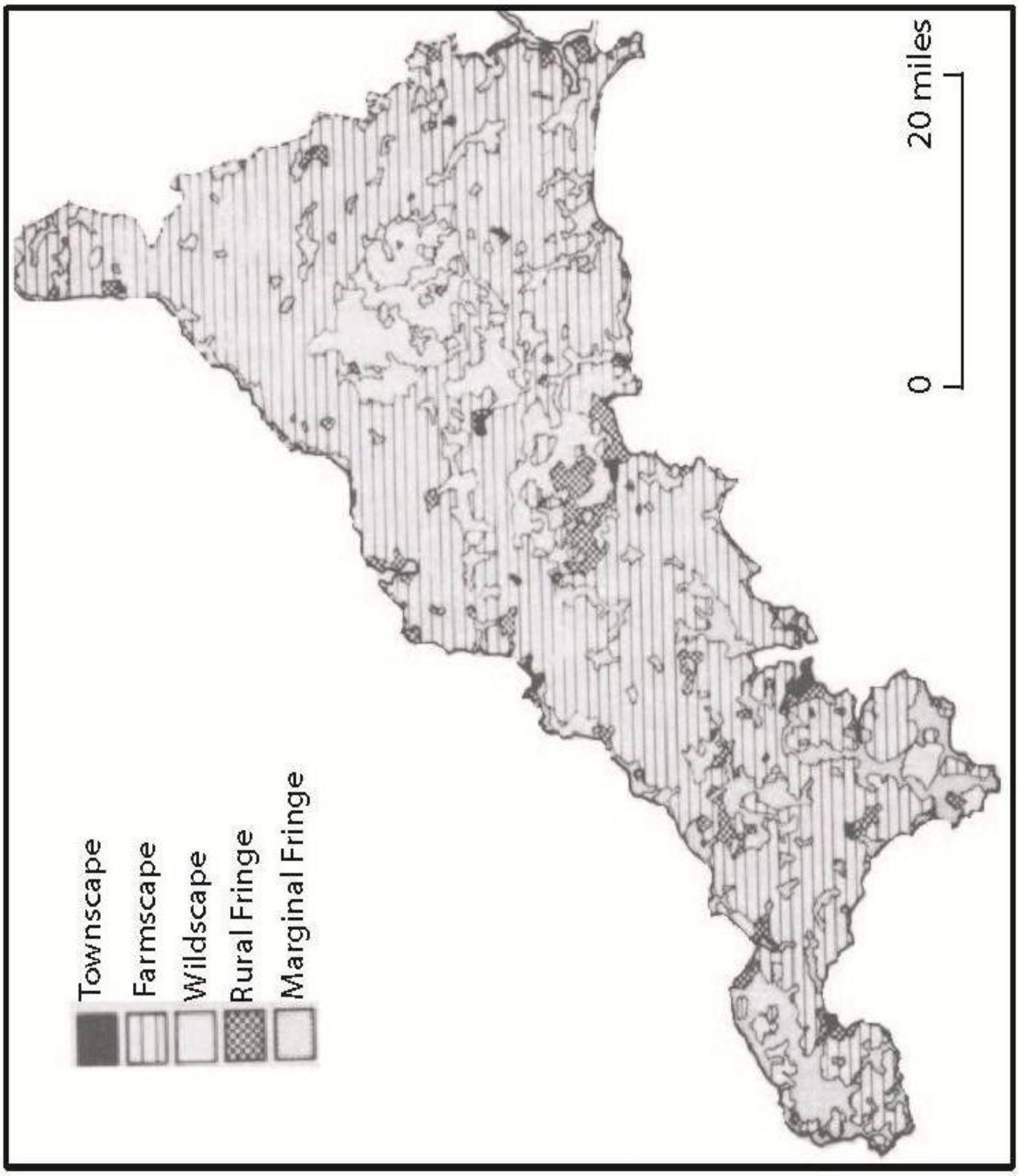


Figure 2.8: *Map of dominant land uses throughout the Cornwall region (Balchin 1983).*

2.4 Sewage works

It is thought that 80% of phosphorus in Loe Pool is sourced from two sewage treatment facilities in the area, Helston and RNAS Culdrose (Coard et al., 1983). The water quality of the area is slowly declining (Balme, 2007) with incidences of hydrodictyon (green algae) covering 24% of the lakes in 1993 (Flory et al., 1993). This fast growing algae has appeared in the lake each year since 1989 (Flory et al., 1993).

In 2003, Helston sewage works started phosphorus removal which (The Loe Pool Forum, Undated), combined with agricultural improvements, has resulted in a four-fold reduction in average annual phosphorus concentrations between 1997 and 2004 (Dinsdale, 2008). The waste treatment works at RNAS Culdrose is now required to start reducing their phosphorus output, as it currently contributes around 22% of the total phosphorus to the lake (Dinsdale, 2008).

2.5 Protection in the area

Due to the high amounts and multiple sources of pollution in the area, Loe Pool and the River Cober catchment have been placed under environmental protection. Loe Pool and its sediment are now designated an SSSI (O'Sullivan 2013, pers.comm., 13 Feb) and the area is part of the Cornish Mining World Heritage Site (National Truest, 2012).

Addressing problems caused by nutrient and sediment run-off is the current priority(Dinsdale, 2008); the Loe Pool catchment has become a Countryside Stewardship target area, giving local farmers grants to promote more sustainable farming (The Loe Pool Forum, Undated). These agri-enviromental schemes helps protect soil and reduces water pollution (Courtney et al., 2013). Other schemes and policies include the Common Agricultural Policy Reform, Catchment Sensitive Farming and Nitrate Vulnerable Zones (Dinsdale, 2008).

River water quality is also monitored and is now surveyed using the general Quality Assessment Scheme (NSCA, 2006). The River Cober has been given a Class 1 classification, with a pH of 6.5 (Johnson, 1978). Laws such as the Water Framework Directive (2000) have now been introduced to try and help (Collins et al., 2008). Loe Pool is one of only four lakes in the South West to be assigned 'surveillance' water body status, being classified as ecologically and chemically 'poor' (Dinsdale, 2008). One shortcoming of the Water Framework Directive is a failure to account for the potential effects of climate change. Predictions from UKCIP02 include wetter winters and more frequent storm events, however due to the complex relationship between diffuse pollution from agriculture and climate change it is hard to predict what may occur in the future (Collins et al., 2008).

Lake rehabilitation programmes are trying to reduce the amount of nutrient loading and improve fish populations (such as the native brown trout (The Loe Pool Forum, Undated)) and plant species in the lake (Dinsdale, 2008). During the medieval period the lake was known for its trout, but in 1943 Rudd was introduced upstream to eat unwanted weeds. However these escaped and overtook the trout population within the lake (National Trust, 2002).

The following three groups are influential in the protection and management of Loe Pool, but are not the only groups involved with the lake.

2.5.1 National Trust

A site visit was conducted to the National Trust offices at Loe Pool, where a meeting with Nick Gordon was held. The following information is from resources received from Mr Gordon.

The National Trust cares for many areas of importance within the Cornish Mining World Heritage Site (WHS), which is now one of the largest world heritage sites on the UK mainland (National Trust, 2012). The WHS consists of 10 landscape areas between West Cornwall and West Devon, including the Wendron mining district (Cornwall Council, 2011).

The Penrose estate, in which Loe Pool is situated, was given to the National Trust by the Rogers family in 1974 (National Trust, 2002). Additionally, the Rogers family also bought the rights to Porkellis mines so that they could never be used again (National Trust, 2001).

2.5.2 Environmental Agency:

The Environmental Agency has a key interest with Loe Pool, especially due to the issues surrounding flooding within Helston. The current solution is to pump water into the sea over Loe Bar to keep the lake at the required 5m (O'Sullivan 2013, pers.comm., 13 Feb). Work is being conducted to find a better solution, including the maintenance of the adit on the north side of the bar.

2.5.3 Loe Pool Forum

The Loe Pool management Forum was established in 1998 to address problems at Loe Pool and manage the catchment appropriately (Dinsdale, 2008). It aims to rehabilitate Loe Pool to a state of ecologically stability, with eutrophic standing waters being a priority habitat under the UK Biodiversity Action Plan (UKBAP, 2005 in Dinsdale, 2008). The Forum considers other issues, such as the impact of septic tanks, coronation lakes and urban drainage (Figure 2.9) (Dinsdale, 2008).

Figure 2.9: *Photograph of water drainage in Helston (urban drainage) (source: Author).*

3. Methodology

This chapter outlines the methods used to collect and analyse the core from Loe Pool. For this dissertation, a considerable desktop survey was undertaken followed by laboratory analysis. And during this the 'steps in sampling' by Smol 2002 were referred to (see appendix for details).

3.1 Desktop Survey:

A desktop survey was conducted before Loe Pool was chosen as a coring site (see literature review). Permission to core at this site was then obtained, with interviews conducted with the National Trust, Dave McKeown and Patrick O'Sullivan.

3.2 Site Selection:

Figure 3.1 shows the section of the lake where the core was collected. This position was chosen as the majority of previous cores have been collected further north, expanding the spatial extent. It also lies within a section estimated at 8m deep, therefore a 3m core could be obtained.

When collecting a core there are three main goals; no disturbance of structure, no change in water content and no change in constituent or chemical composition (Smol, 2002). Physical forces such as friction and sampling mechanism can deform the core (Smol et al., 2002) and therefore the collection of the core was done with great caution and was then stored properly.

3.3 Coring:

A Mackereth Corer was used to collect a 3m core from the lake by lowering it from a boat into the water. Compressed air forces the inner core barrel

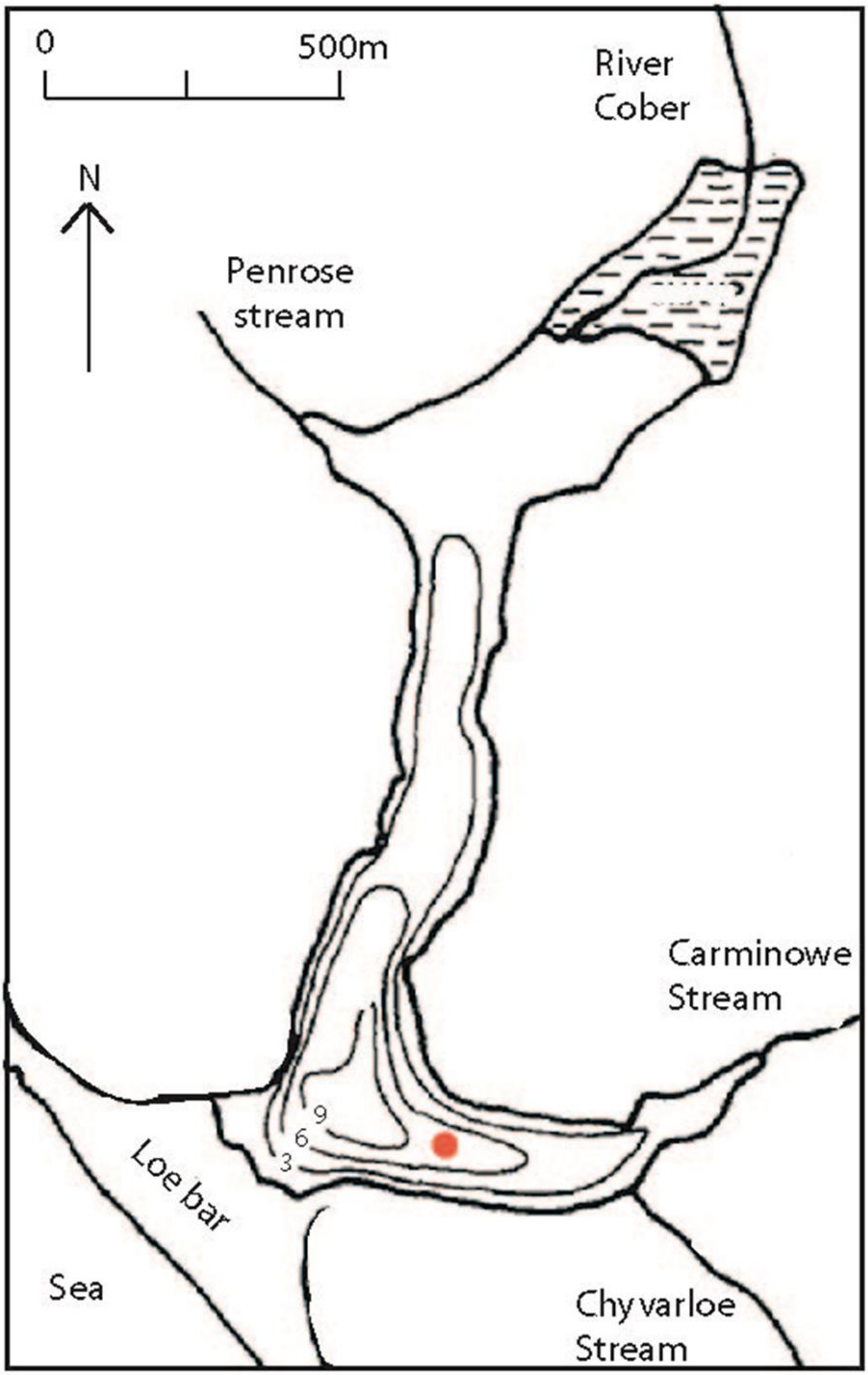


Figure 3.1: *Map of coring position (red marker) taken in the South East section of Loe Pool (adapted from O'Sullivan 1992).*

downwards through the lake sediment, which then fills with compared air allowing the corer to return to the water surface (University of Minnesota, 2011). This core was transported back to Exeter and stored in the cold room. The core was cut into two 1.5m sections which were cut into semicircles. When the core was opened it became apparent that the bottom 60cm of the core was water, therefore the actual length of the core 242cm. The core was cleaned using slides to reduce smearing of the top layer, which may have been caused during cutting.

3.4 Troell-Smith:

The modified Troell-Smith method assesses the appearance and physical properties of the core by eye; this provides a considerable amount of information (Smol, 2002), including highlighting potential geochemical changes in the sediment. The colour, determined using a Munsell colour chart, helps determine the composition of sediment; e.g. red suggests the presence of iron oxides, whereas a darker colour implies more organically rich sediment. However this method is time consuming and errors can occur when using the Munsell charts due to illumination and spectral responses of the human eye (Smol et al. 2002). Other methods, such as Minolta spectrophotometer, could improve accuracy (Smol et al., 2002) but equipment for this was unavailable. Multiple pictures were taken for later reference. However, a potential source of uncertainty is light distribution and stacking errors (Smol et al., 2002).

3.5 Magnetic susceptibility:

Magnetic susceptibility is the “ability of a substance to acquire magnetisation when an external magnetic field is applied” (Evans and Heller, 2003). Iron oxides and sulphides are normally the most significant sources of magnetisation when using this method (Smol, 2002). Therefore, this method primarily depicts the quantity of iron-bearing minerals, which occur in the catchment through erosion or pollution, and potentially determining the source (O'Sullivan, 2004). This is an expedient way to analyse and show potential changes in lake sediment. It is a non-destructive method that is fast, easy and reveals useful trends.

Every centimetre of the core was marked and passed through a Bartington MS2 system. The loop sensor for this is stationary and the circumference is close to the core size to reduce error (Smol et al., 2002). This test was run three times and an average was taken to get the most accurate reading.

Error may occur in these results because the layers of sediment are angled, whereas the device measures perpendicular to the core. To avoid this 'slumping' affect, discrete sampling could be used as this has better spatial resolution. However, due to time constraints this option was not taken (Smol et al., 2002).

Errors could also occur due to instrumental drift if the temperature of the core is not in equilibrium with the ambient temperature of the laboratory (Smol et al., 2002). To avoid affects from background magnetic and temperature change, the device does a zeroing at the start and end of the sample tested to correct any changes.

3.6 Sub Sampling:

To undertake the remaining laboratory techniques the core required sub sampling; 1cm thick slices were taken every 4cm. Around 30cm down the core the sediment layers became angled. This could be disturbance of sediment during the coring method or due to the position of the core, i.e. taken on the edge of a shelf. To account for this, samples were taken to the right of the 1cm markers at the angle of that particular layer. Sampling began at 12cm (sample 4) due to the 10cm top being sent away for C137 analysis. 61 samples were taken, which was later increased by taking samples every 2cm; taking sections of 'high interest'; and including the top 10cm. In total, there were 132 samples.

3.7 C137 samples:

C137 is a by-product produced from nuclear testing and can be used as a dating technique by defining certain peaks. This is a non-destructive, easy method and can establish some dates quickly and cheaply. Therefore this technique has been chosen and the top 10cm have been analysed for this core.

A potential issue with this method is a distorted pattern caused by post-deposition C137 mobility, meaning that the record could extend further than expected, although the 1963 peak is normally recognisable (Smol, 2002).

3.8 Loss-on-ignition:

Loss-on-ignition is the estimation of the organic matter content by burning sediment at 550^{o}C. This is a simple method which can provide valuable information about the composition of the sediment. However factors such as sample size and position of samples in furnace can cause uncertainties within the results (Heiri et al., 2001). Caution will be taken to reduce these errors. 128 samples were analysed to produce a high resolution graph.

Figure 3.2: *Photograph of a section of core with angled sediment bands (source: Author).*

Figure 3.3: *Photograph of a section of the core marked as 'high interest' (source: Author).*

3.9 Partial size:

Deposited material can be characterised by particle size; the lightest particles (silt and clay) are deposited downstream (Beasley, 1972). Particle size can infer the processes and sources of sediment. For example clay suggested more erosion, whereas sand suggests more energy within the system (Smol, 2002). 128 samples were taken within the core.

3.10 Heavy metals:

Heavy metals can be analysed to assess the amount of metal contamination in sediment. 35 samples were taken, which were run through an Atomic Absorption Spectrophotometer, to look for arsenic, cadmium, calcium, chromium, copper, iron, tin and lead concentrations.

A potential issue is the differences in mobility and solubility between different heavy metals, e.g. Zinc is known to be more readily mobilised from sediments in more acid water (Haworth et al., 1991), resulting in artificial disparities.

3.11 Phosphorus:

Phosphorus is a nutrient found in fertilizer and is used as a neutraliser in sewage treatment works. Within the top 70cm of this core 24 samples were collected, measuring total and inorganic phosphorus, with organic obtained after.

Care must be taken to reduce the errors during preparation as exact amounts of each chemical are required otherwise large disparities within results can occur.

3.12 SCPs:

Spheroidal carbonaceous particles (SCPs) are combustible matter that was not burned during the combustion process. They have no natural source and are a simple way to add to the chronology, as three main dates can be gained; start of industrial era, rapid increase for World War 2 and a peak during late 20th Century (Rose, 2011). However this does have its limitations, such as the potential for displaced within the core (Swindles, 2010).

24 samples were taken throughout this core to try to determine the rough depth of the three dates.

3.13 Statistically tests:

Statistically tests can be used to determine correlations between two sets of data (Ebdon, 1985). A link between particle size and certain heavy metal concentrations has been suggested within the literature and therefore this relationship will be tested. The data will be tested for normality on SPSS and then with a parametric or non-parametric test will be used (Pearson’s or Spearman’s).

4. Results and Analysis

4.1 Troell-Smith:

Figure 4.1 shows the combination of Troell-Smith and photographs to produce a visual representation of the core. This will be compared to other studies in the discussion section below to produce a chronology.

4.2 Magnetic susceptibility:

Figure 4.2 shows the average results from the magnetic susceptibility test. The lower half of the core has a relativity low magnetic susceptibility, with only slight fluxuations. A dip occurs at 162cm, possibly due to the transition between the core sections. At around 110cm the susceptibility starts to increase rapidly, peaking at 93cm, followed by a short decline, then successive peaks at 70cm and 46cm. Another small decline is then followed by a small rise, averaging around 0.00020 (SI). The upper 1m of the core has a much higher magnetic susceptibility than the bottom. This would suggest that a change in composition of the sediment entering the lake changed at around ~1m in the core.

4.3 C137:

Figure 4.3 shows results from the C137 analysis. The top 6cms produced no results, with a small peak occurring at 7cm, which dropped again at 9cm. The activity levels are much lower than expected and it was predicted that the top of the core would have produced results. This could be due to many factors, such as bioturbation, and therefore these results shall not be used for dating the core.

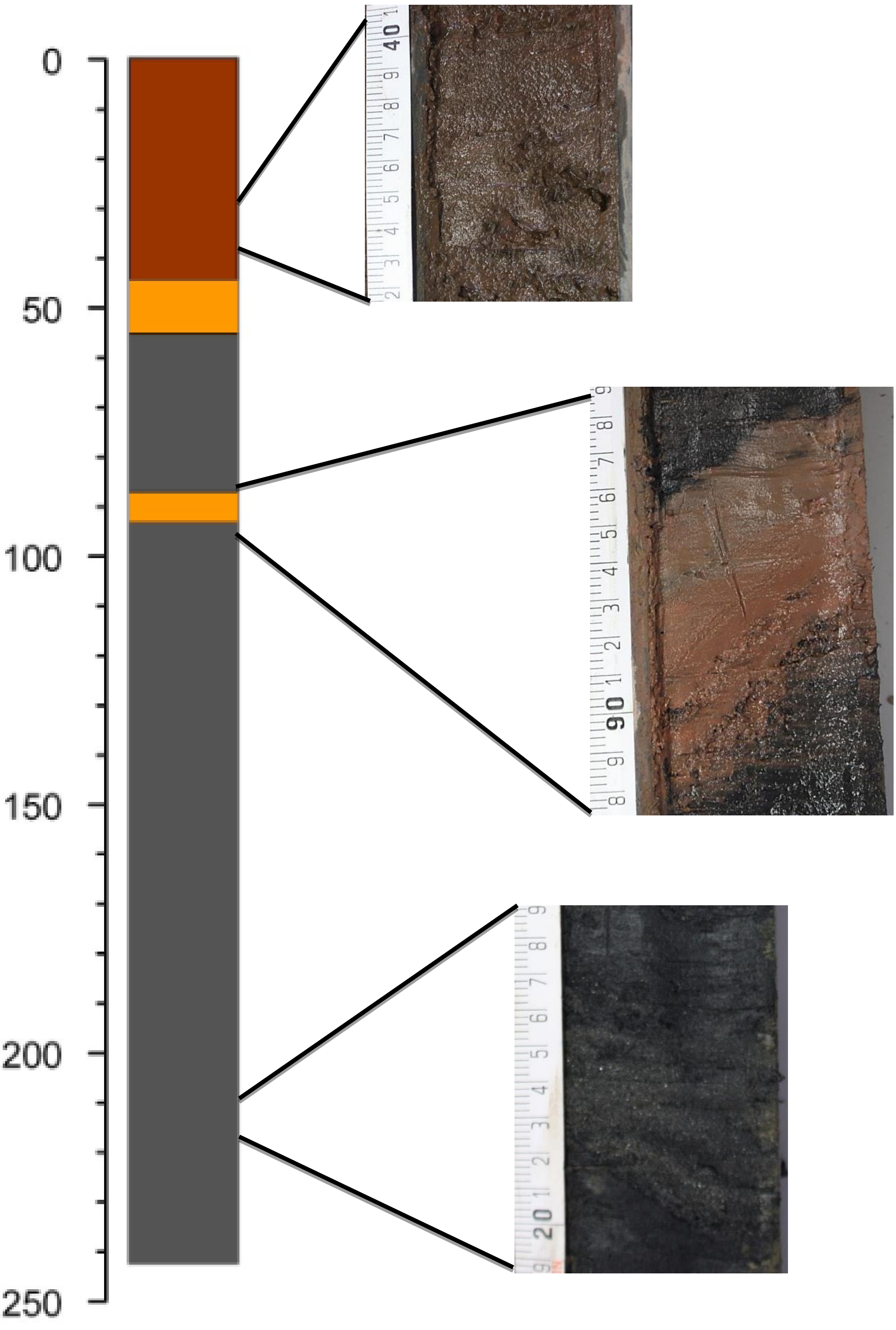


Figure 4.1: *Diagram of visual depiction of Troell-Smith, accompanied by photographs of the core a picture, illustrating the different sections.*

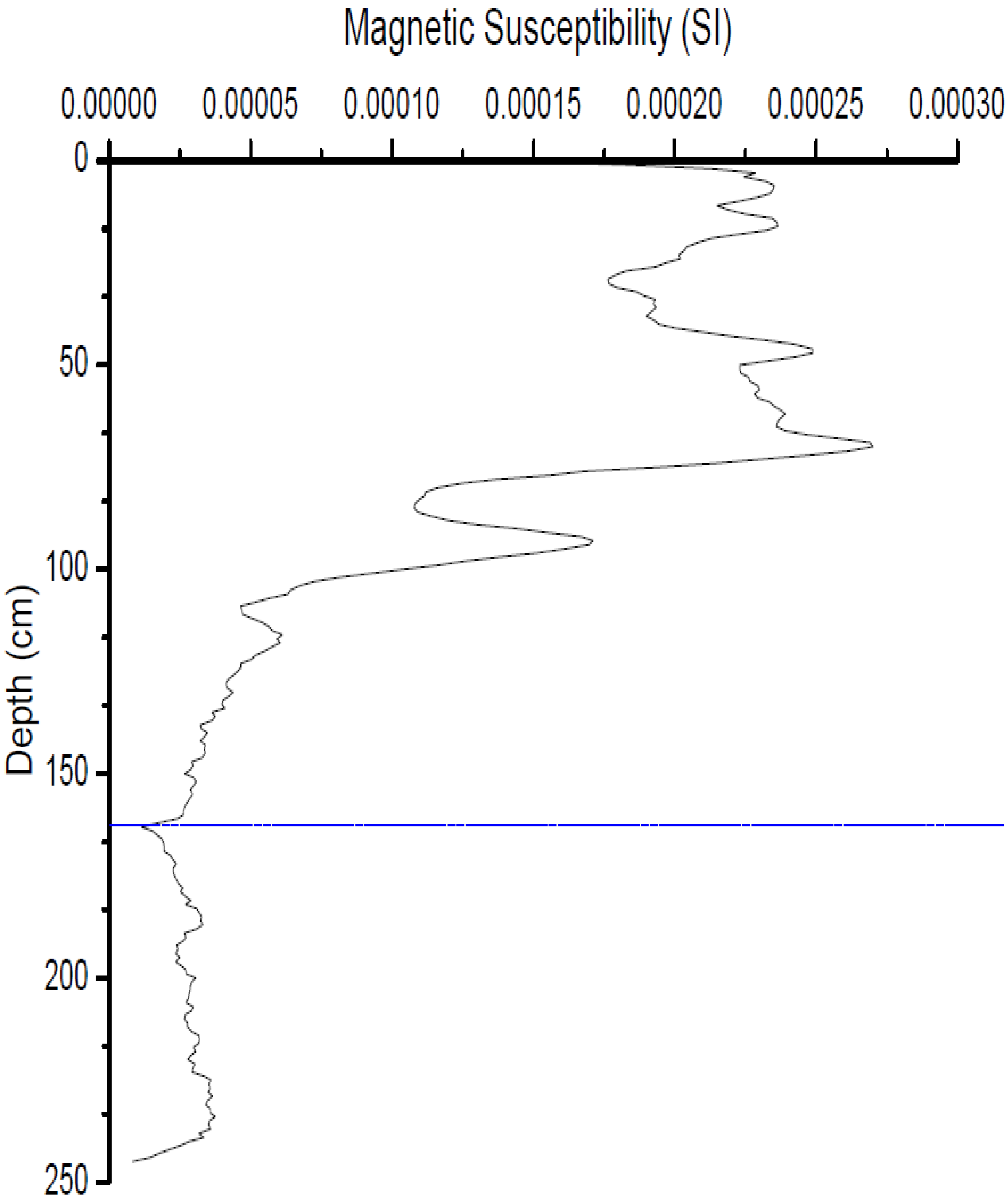


Figure 4.2: *Graph of Magnetic Susceptibility results, with blue dashed line indicating the position that the two sections of core were swapped.*

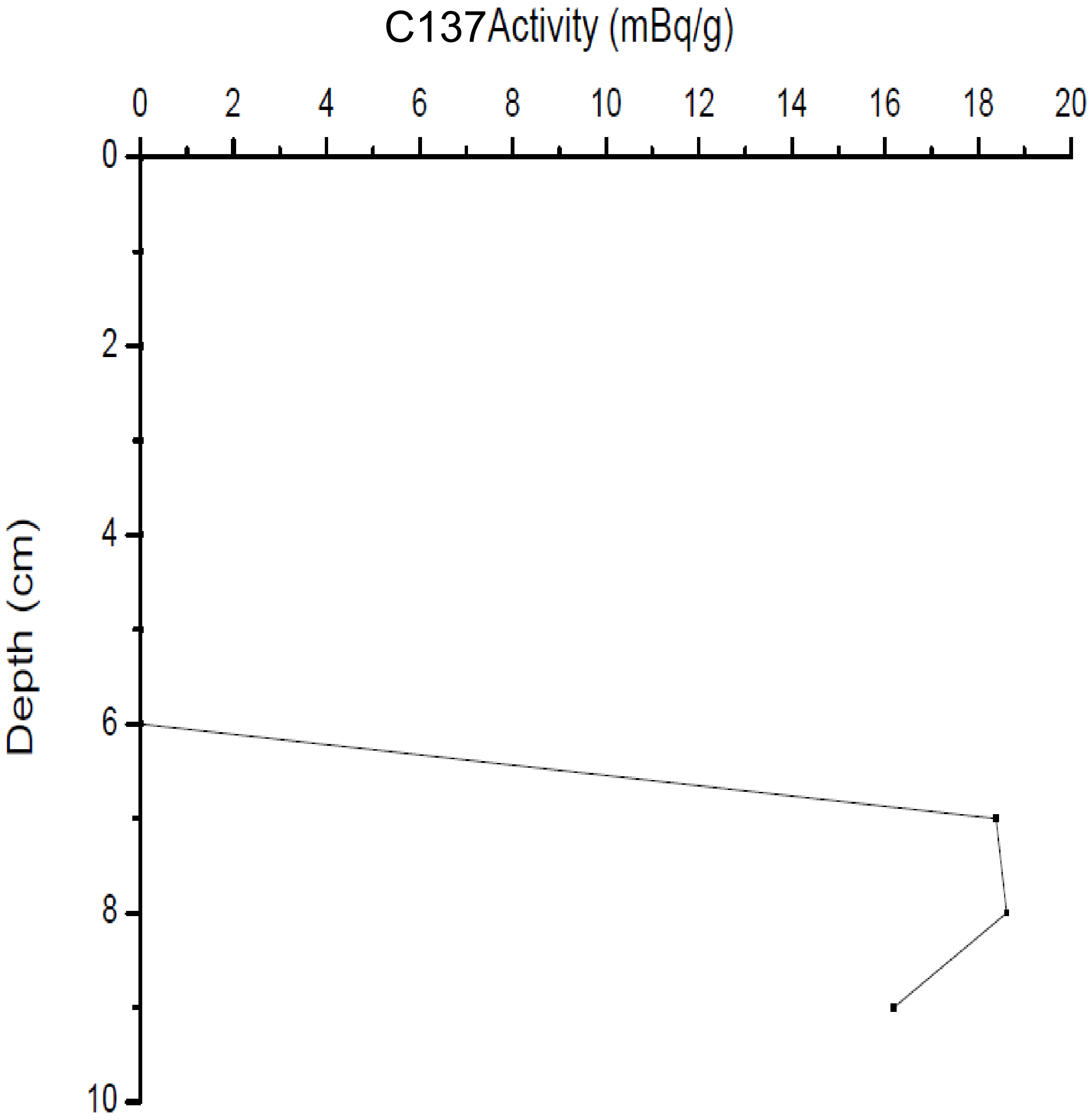


Figure 4.3: *Graph of the C137 results. Notice how top 6cm have produced no activity, with only a slight peak occurring at 7-9cm.ssing results in the top 6cms.*

4.4 Loss-On-Ignition (LOI):

Figure 4.4 shows the percentage of organic matter lost within each sample; with areas of high LOI suggesting high organic content. The graph shows that the lower section of the core has relatively low LOI (less than 10%). At 209cm there is a slight peak (19.4%) and then again at 164cm (16.57%) and 136cm (16.09%). A larger peak occurs at 107.5cm (23.54%), followed by a sharp drop to 2.96% (104cm). The LOI then steadily increased to a maximum of 19.3%. Results for the first 10cm of this core are missing due to time constraints after the C137 analysis. In general, the composition of the lake sediment changes in the top 1m of the core, corresponding to the same change seen in magnetic susceptibility (Figure 4.2).

4.5 Particle size:

Figure 4.5 shows the percentage of sediment which lies within the three sub-categories of particle size; sand, silt and clay.

The sand content shows a fairly noisy record. In the lower core until 75cm there are multiple peaks in concentration (maximum 60%). After 75cm the majority of samples have 0% sand, with a maximum of only 5%.

The silt content also produces a fairly noisy record, but with all results above 20%. The silt content becomes more consistent around 75cm, suggesting that there could be a potential change in the source of the sediment at 75cm.

The clay content in the core remains fairly low, with only one peak reaching near 40% (75cm). There is a small upward trend in the amount of clay moving up the core, but this remains under 20%.

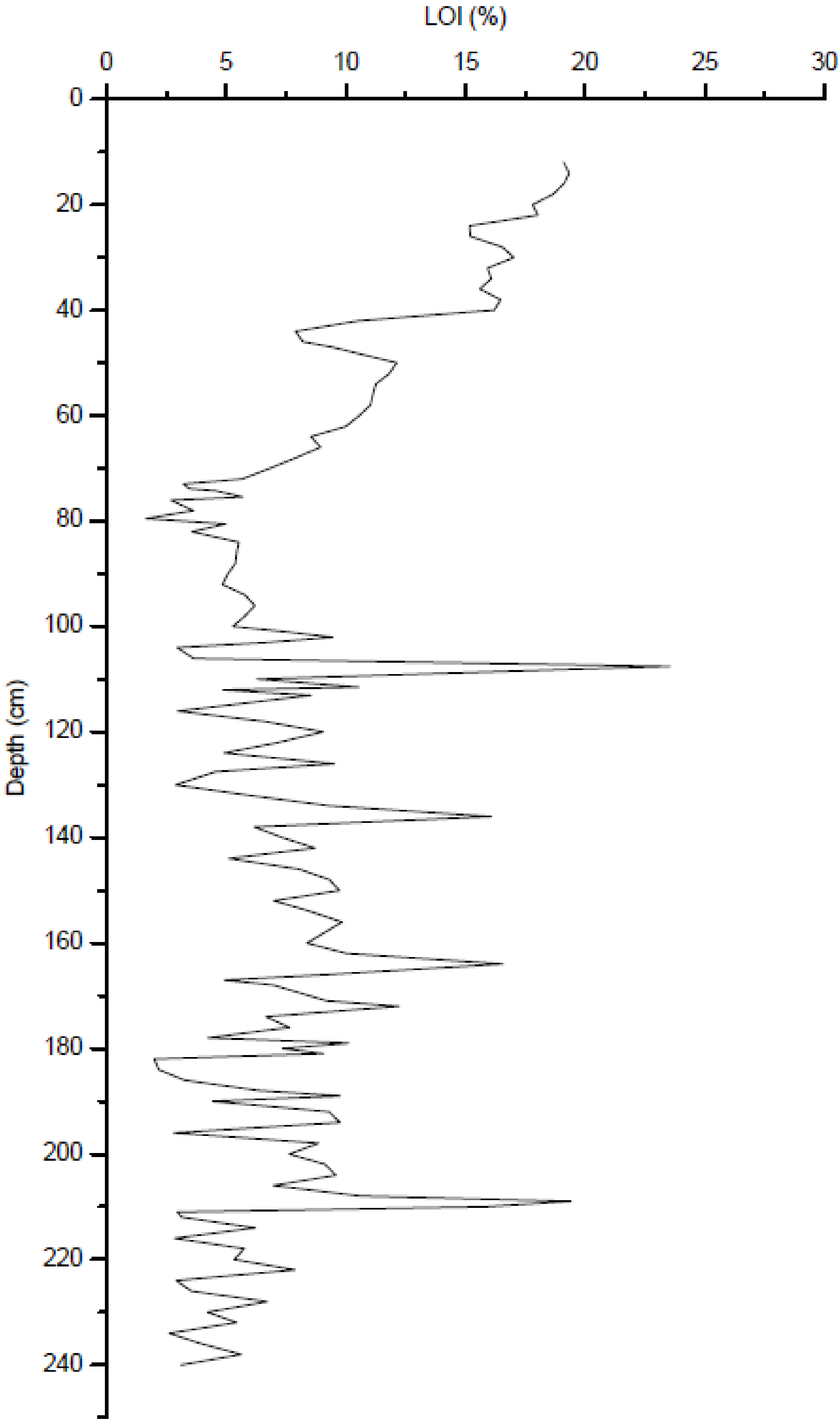


Figure 4.4: *Graph of the Loss-On-Ignition results. The top 10cm of this core was not measured during this experiment.*

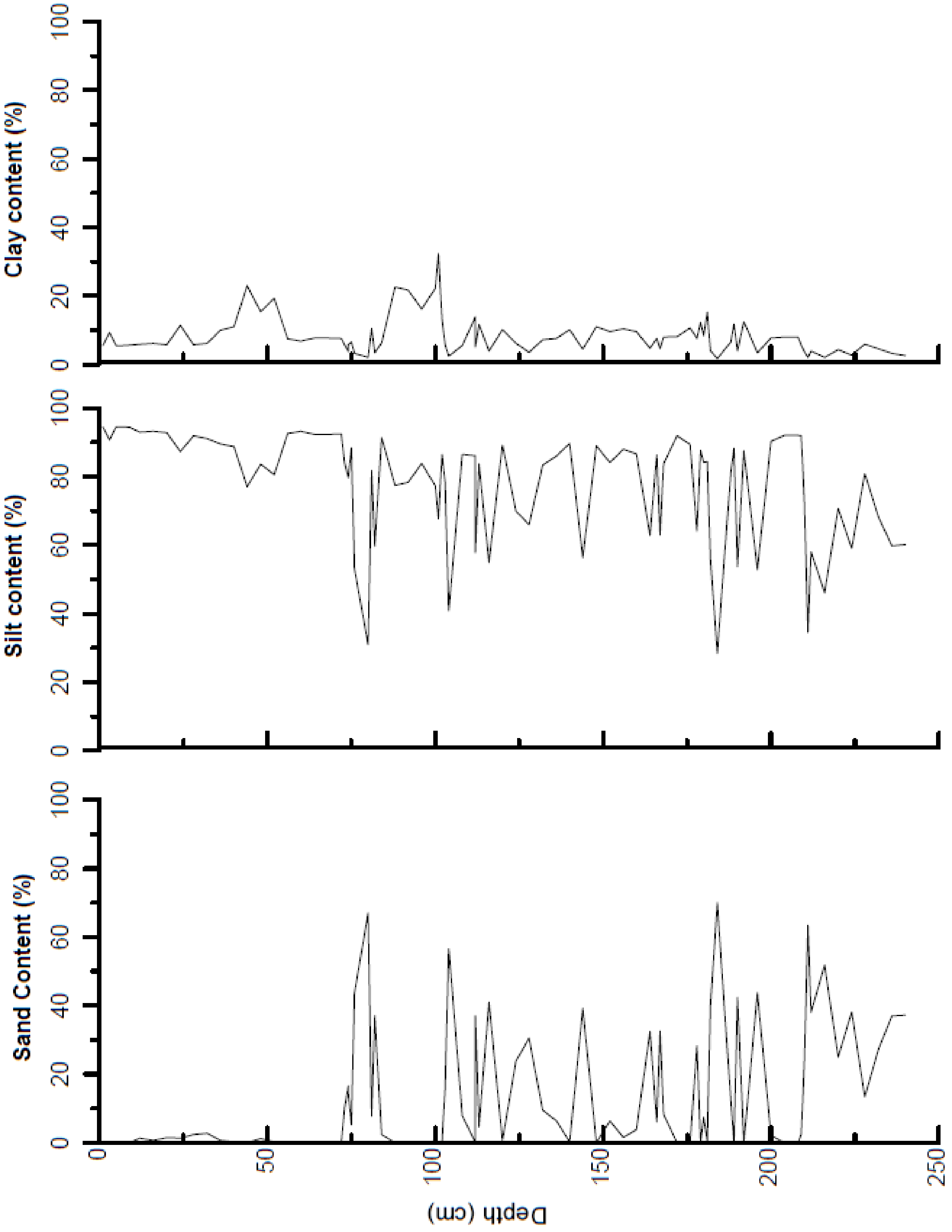


Figure 4.5: *Graph of Particle Size content analysis, split into sand, silt and clay content (%). This experiment was taken throughout the core.*

4.6 Heavy metals:

Eight heavy metals were tested, although only Arsenic, Calcium, Copper, Iron and Tin produced results (Figure 4.6).

The arsenic record shows low concentrations until 107.5cm, where the first spike occurs (1783.9ppm). After this there are two smaller peaks (84cm and 60cm) followed by a declining trend towards the top of the core.

Parts of the calcium record required re-diluting due to the large range in concentrations. Large peaks occur until 84cm, when the concentration dramatically drops to around 300ppm, which coincides with the decrease in arsenic.

The copper record has two small peaks at 204cm and 180cm, with the concentration starting to substantially increase at 100cm. Three successively larger peaks occur after this with a maximum of 1780ppm. Concentrations start to decline at 20cm with a maximum of 500ppm.

The iron record has greater concentrations than the other heavy metals, with a more erratic pattern. Two large peaks occur in the lower section of the core and until 75cm this pattern fluxuates between 10,000 and 50,000ppm. At 50cm the fluxuations start to even out at around 40,000ppm.

The tin record produced very low concentrations. An initial peak occurs at 175cm with 200ppm, with the last peak occurring at 75cm, followed by a steep decline, fluxuating near the top of the core.

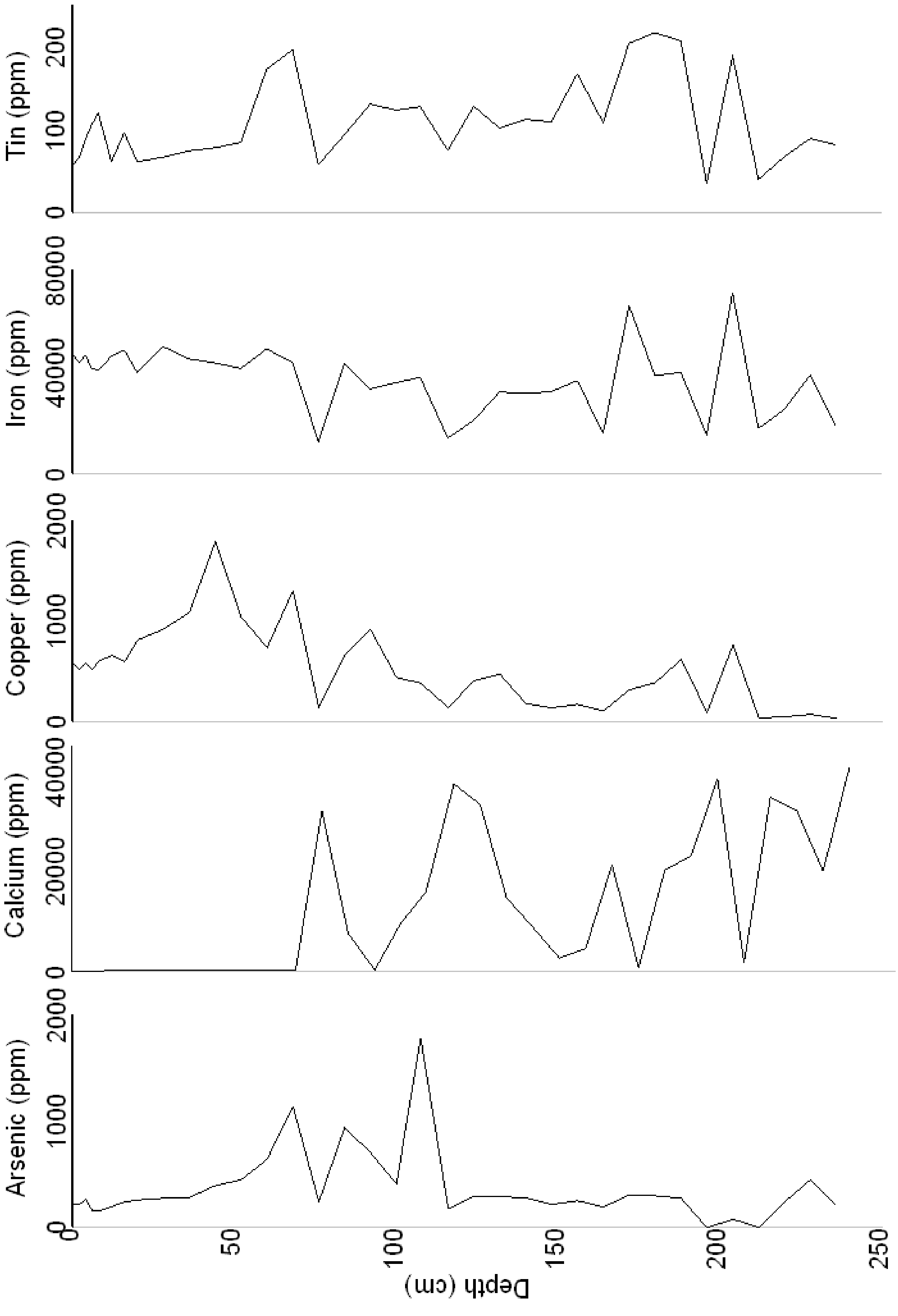


Figure 4.6: *Graph of heavy metals analysis results, showing the concentrations for arsenic, calcium, copper, iron and tin (ppm).*

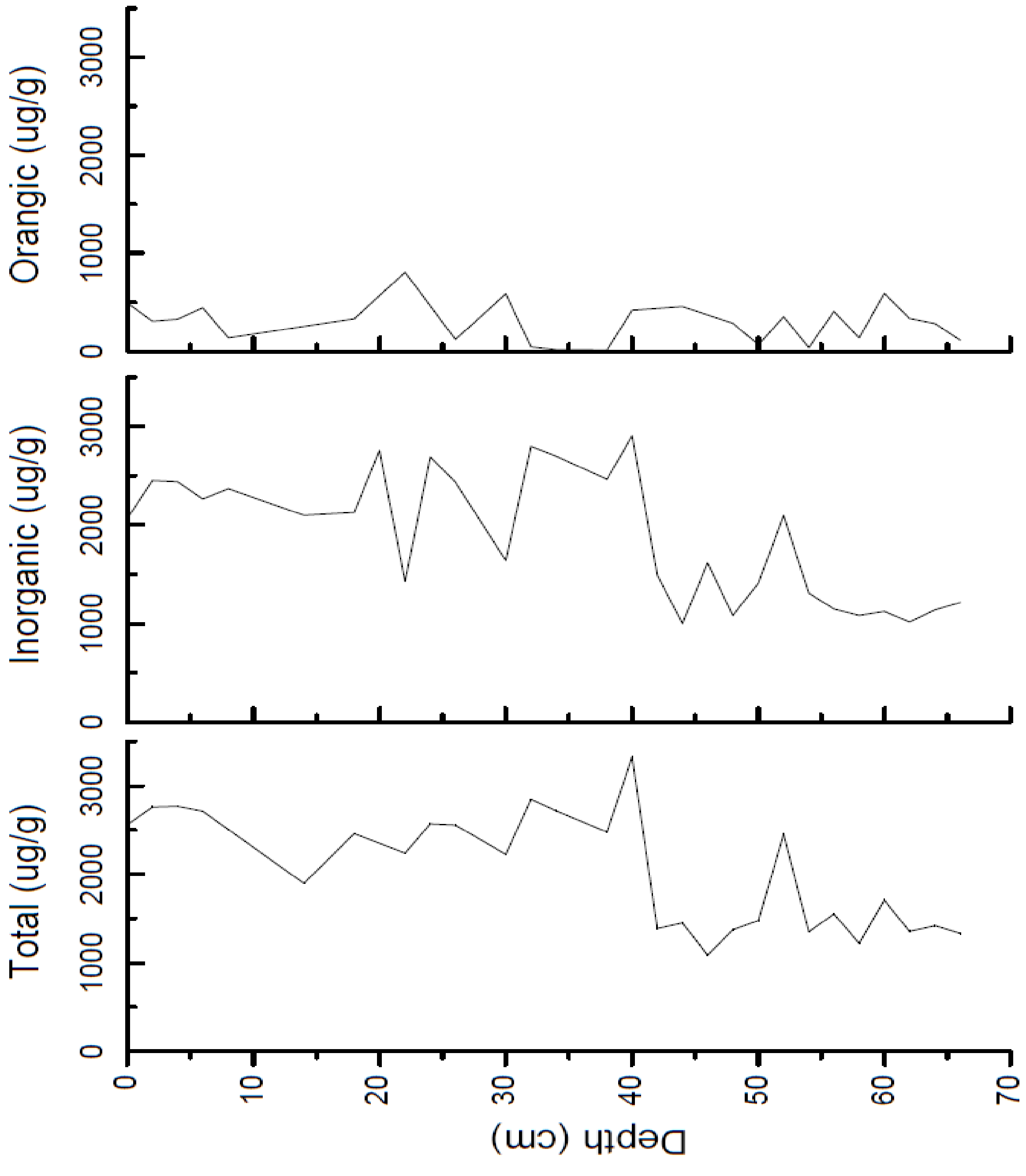


Figure 4.7.1: *Graph of phosphorus concentrations, split into total, inorganic and organic for the top 65cm of the core*

4.7 Phosphorus:

Figure 4.7.1 shows the phosphorus record for the top 65cm of the core. A few points were omitted due to suspected error. This could be caused by numerous reasons, such as the accuracy of the pipette used during the experiment. Furthermore, the samples were tested in two batches, with the standards used in each experiment made as close as possible. Figure 4.7.2 equations used in calculations are comparable between the two.

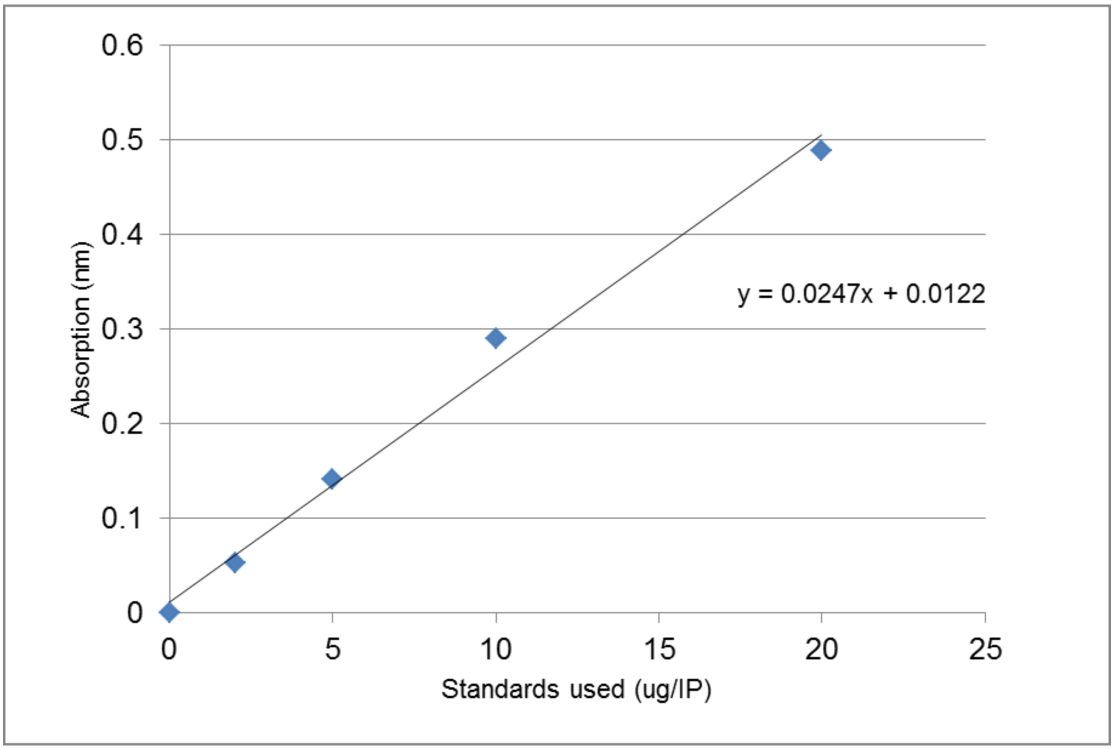
Total phosphorus concentrations start relatively low around 65cm, with the first peak occurring at 55cm. A major peak arises at 40cm (~3500ug/g) followed by fluxuations around 3000ug/g. A decline is observable at 15cm, before increasing back to 3000ug/g. Subsequently, a final decline occurred in the top few centimetres.

The inorganic and total phosphorus levels have a similar pattern; large fluxuations occur between 45cm and 20cm with a maximum of 3000ug/g. After 20cm (2500ug/g) there is an incline until 2cm, after which a small decline is noted.

Organic phosphorus has comparatively very low concentrations, suggesting that inorganic phosphorus is the dominate form of phosphorus in the core. This signal is noisy and shows no clear pattern until around 5cm when an increase starts to occur.

4.8 SCPs:

After all samples were analysed under a microscope it was determined that no recognisable SCPs were present in this core.



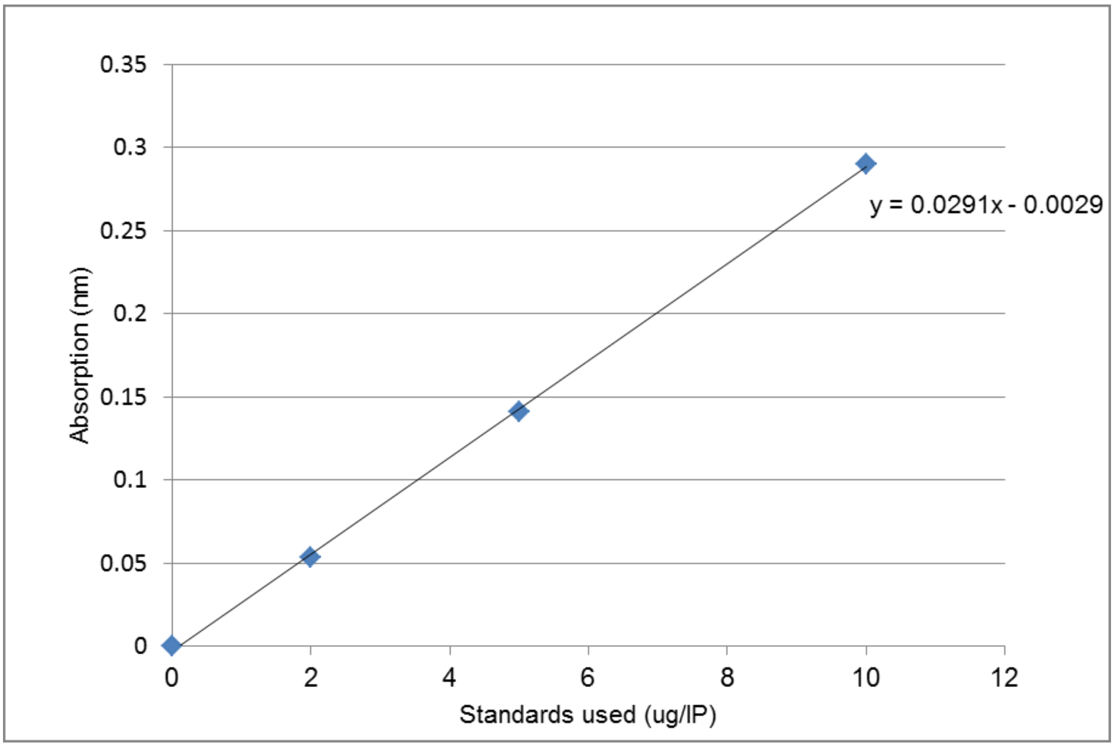


Figure 4.7.2: *Graph of standards used in phosphorus calculations with associated equations, highlighting the similarities between the two.*

4.9 Statistical tests:

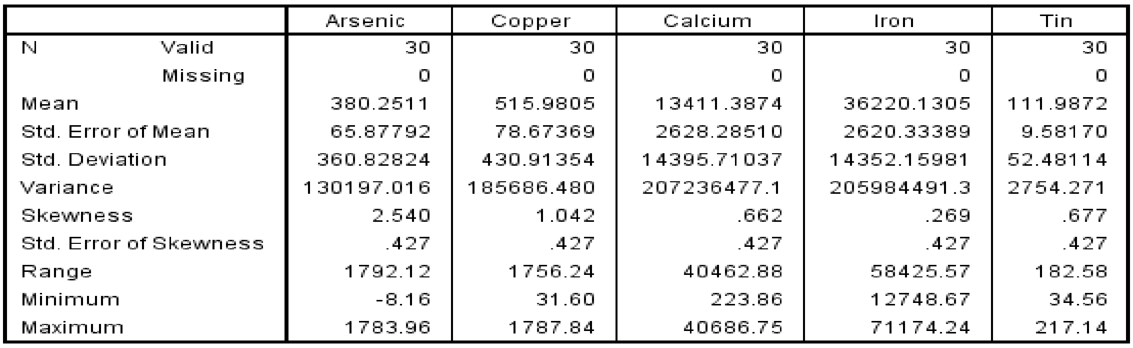
A test for normality was run, which showed that the data for heavy metals was not normally distributed (see Figure 4.8) and therefore a non-parametric test (Spearman's) was used to calculate correlations between particle size and heavy metal concentrations. The results are described below, with R representing the Spearman's rank correlation coefficient and p representing the significance level.

4.9.1 Heavy metals in Particle size:

Figures 4.9.1 to 4.9.5 show the excel results and their associated table of SPSS results. These could imply potential sources of heavy metal pollution; however the actual source cannot be fully determined as a catchment survey would need to be undertaken.

These results show a strong positive correlation between calcium and sand ($R=0.826$, $p<0.05$). There is also a fairly strong negative correlation between calcium and clay ($R=-0.633$, $p<0.05$). This suggests that the majority of calcium will be transported in sand sediment. Copper also had a strong negative correlation ($R=-0.671$, $p<0.05$) with sand and a modest positive correlation with silt ($R=0.543$, $p<0.05$) and clay($R=0.582$, $p<0.05$), suggesting that it is unlikely to occur within sand.

Iron has a strong positive correlation with silt ($R=0.83$, $p<0.05$) and a strong negative correlation with sand($R=-0.7$, $p<0.05$); therefore it would be expected to occur in more silty sediments. Tin and arsenic have weak correlations with clay and fairly modest negative correlations with sand, but the significance of these was low and therefore suggests these are not as dominated by particle size than the other heavy metals.



		Arsenic	Copper	Calcium	Iron	Tin
N	Valid	30	30	30	30	30
	Missing	0	0	0	0	0
Mean		380.2511	515.9805	13411.3874	36220.1305	111.9872
Std. Error of Mean		65.87792	78.67369	2628.28510	2620.33389	9.58170
Std. Deviation		360.82824	430.91354	14395.71037	14352.15981	52.48114
Variance		130197.016	185686.480	207236477.1	205984491.3	2754.271
Skewness		2.540	1.042	.662	.269	.677
Std. Error of Skewness		.427	.427	.427	.427	.427
Range		1792.12	1756.24	40462.88	58425.57	182.58
Minimum		-8.16	31.60	223.86	12748.67	34.56
Maximum		1783.96	1787.84	40686.75	71174.24	217.14

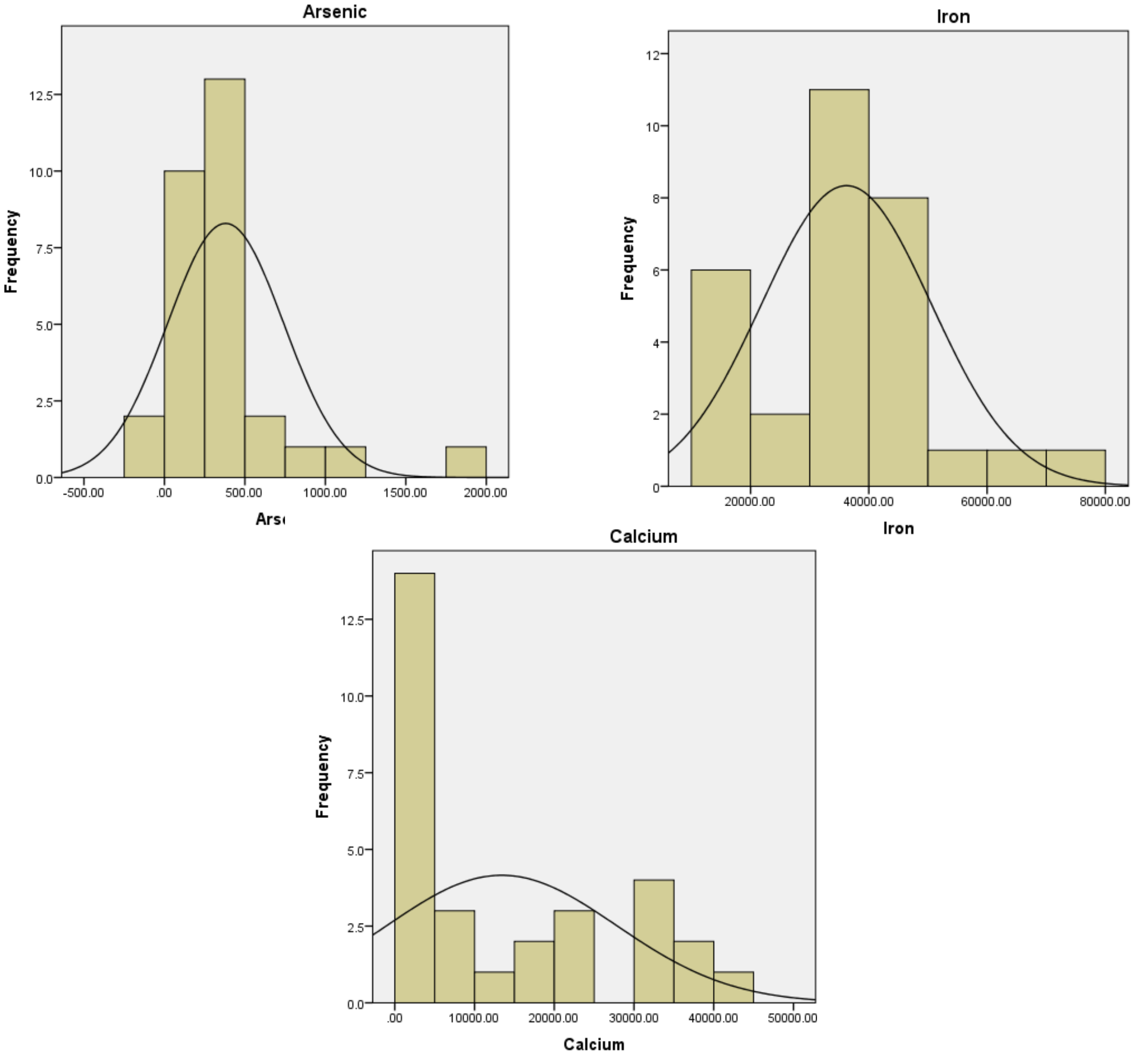
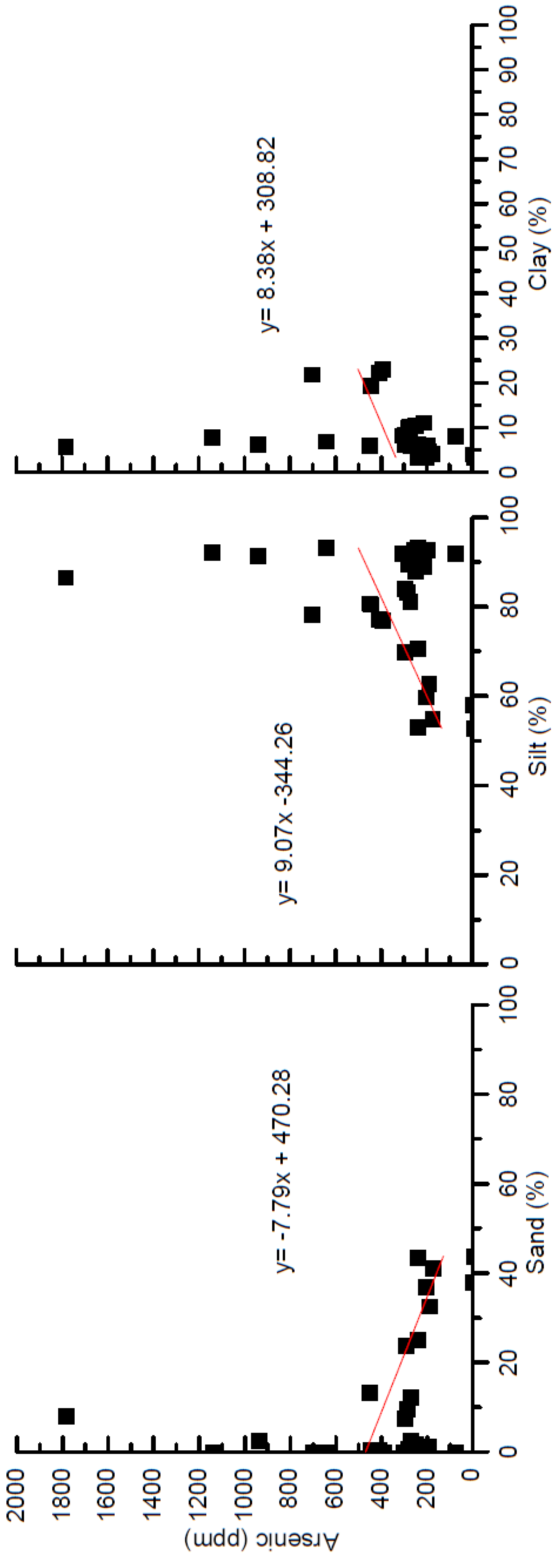
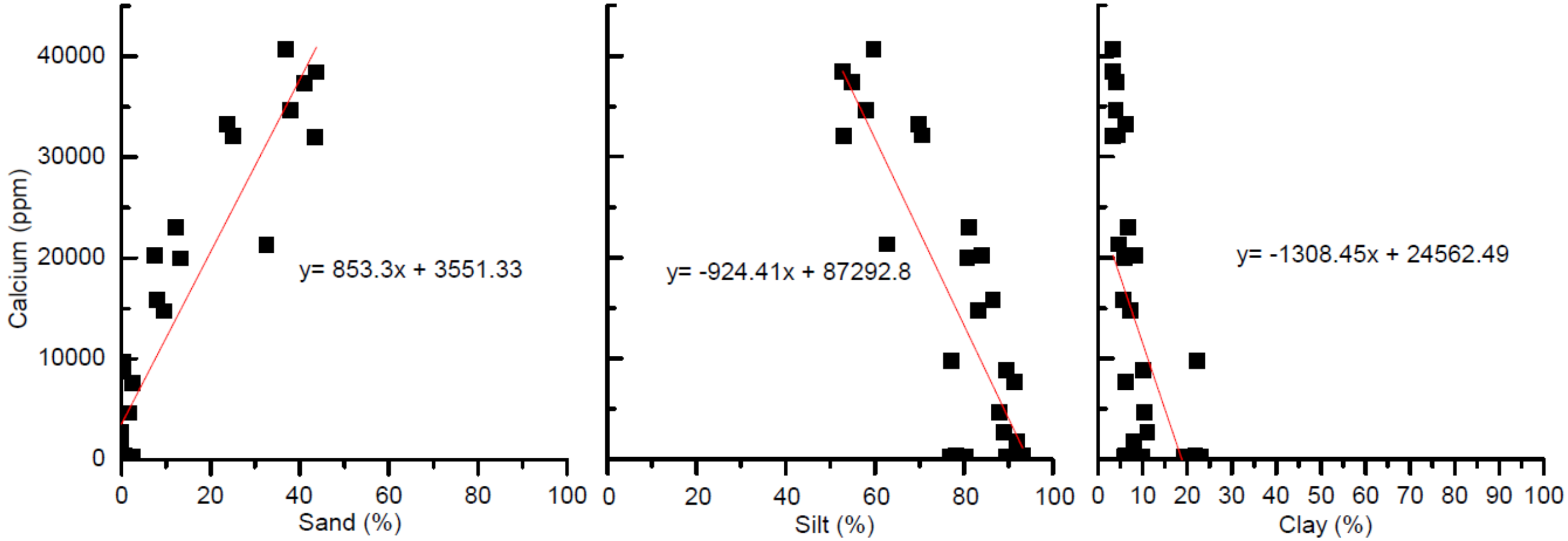


Figure 4.8: *Graphs from SPSS normality test performed, with associated table, showing how data was not normally distributed.*



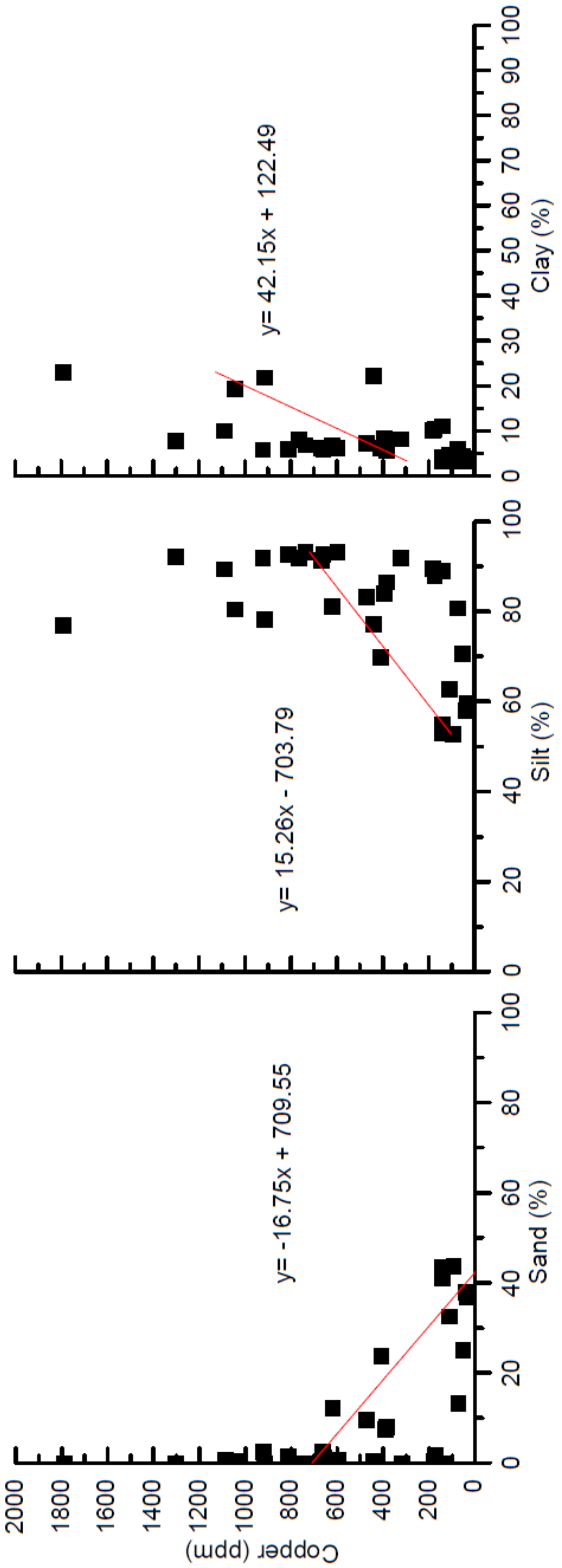
Heavy Metal	Sand	Silt	Clay
Arsenic Correlation	-0.449	0.271	0.503
Arsenic Significance	0.013	0.147	0.005

Figure 4.9.1: *Graphs of arsenic compared with different particle sizes (sand, silt and clay), including line of best fit and equation. Table underneath are values produced in SPSS.*



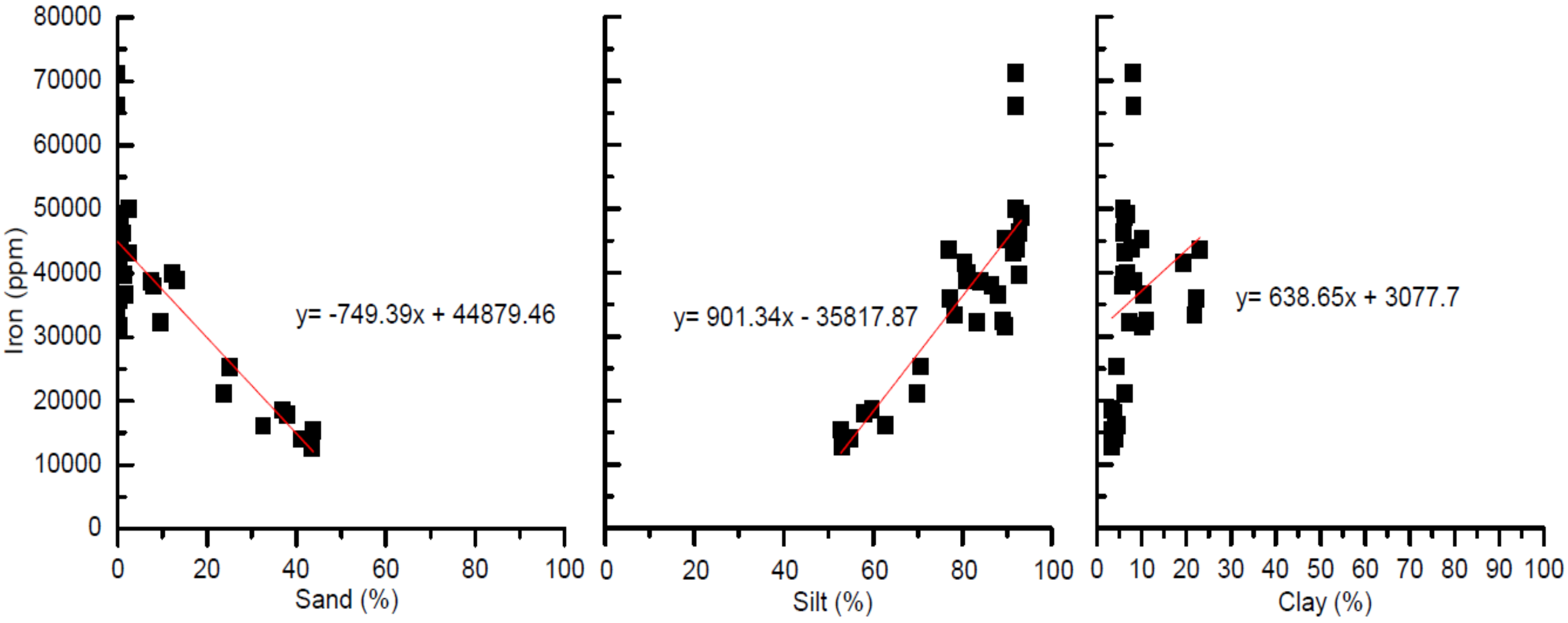
Heavy Metal	Sand	Silt	Clay
Calcium correlation	0.826	-0.72	-0.633
calcium significance	0	0	0

Figure 4.9.2: *Graphs of calcium compared with different particle sizes (sand, silt and clay), including line of best fit and equation. Table underneath are values produced in SPSS.*



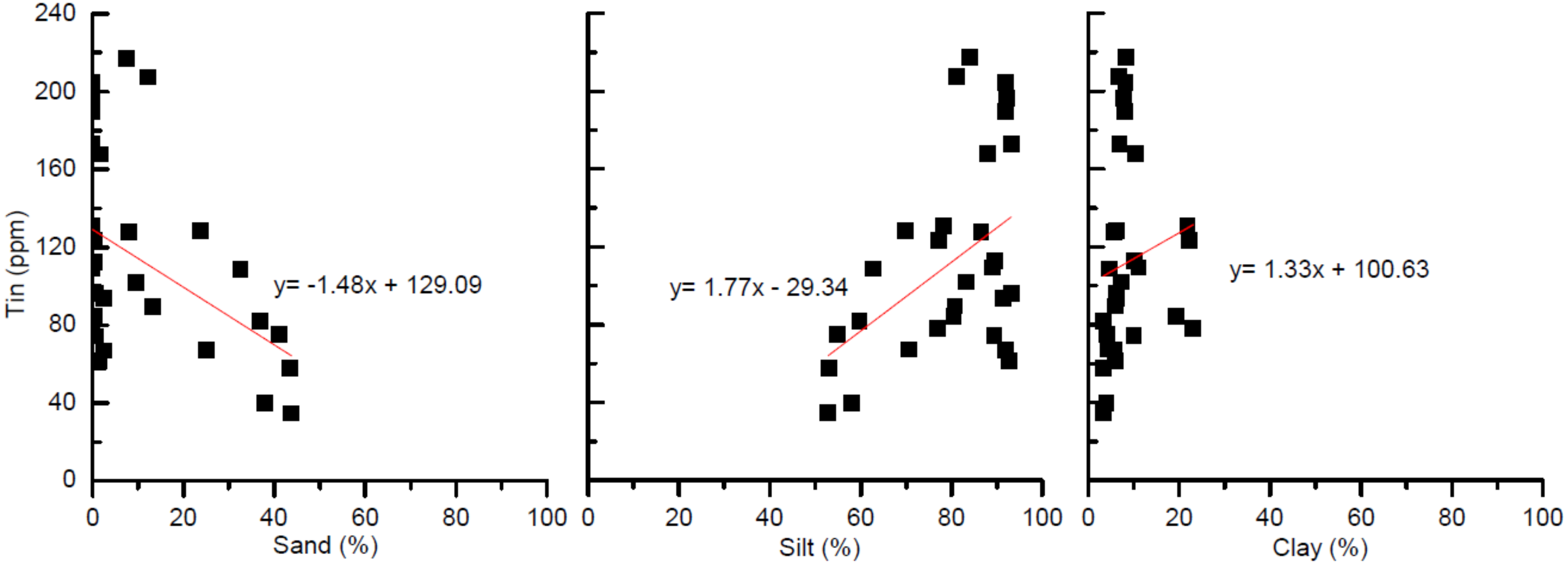
Heavy Metal	Sand	Silt	Clay
Copper Correlation	-0.671	0.543	0.582
Copper significance	0	0.002	0.001

Figure 4.9.3: *Graphs of copper compared with different particle sizes (sand, silt and clay), including line of best fit and equation. Table underneath are values produced in SPSS.*



Heavy Metal	Sand	Silt	Clay
Iron correlation	-0.7	0.83	0.454
Iron significance	0	0	0.012

Figure 4.9.4: *Graphs of iron compared with different particle sizes (sand, silt and clay), including line of best fit and equation. Table underneath are values produced in SPSS.*



Heavy Metal	Sand	Silt	Clay
Tin correlation	-0.422	0.313	0.535
Tin significance	0.015	0.093	0.002

Figure 4.9.5: *Graphs of tin compared with different particle sizes (sand, silt and clay), including line of best fit and equation. Table underneath are values produced in SPSS.*

5. Discussion

5.1 Core Chronology:

Figure 5.1 shows the age-depth model creating a chronology produced using Troell-smith, photographs and magnetic susceptibility compared to literature on Loe Pool. Previous recordings of the upper 3m of sediment at Loe Pool have shown a general stratigraphy pattern being dark brown clay-gyttja (top 20-40cm) above a thicker layer of red and grey clay (Coard et al., 1983). These previous studies provide a few dates; 1928 and 1938. The top of the core can be dated as 2012, as this is when it was collected.

Red layers have been observed in all cores taken from Loe Pool, including this study (Figure 5.2). The presence of haematite can explain these red layers and can be directly linked to the mining activity at Porkellis mine; cassiterite ore (from which tin is produced) was embedded within ground rock containing haematite (Coard et al., 1983).

Porkellis mine was closed in 1938, coinciding with the last red layer in Loe Pool cores. In addition, the most active phase of the mine was between 1928 and 1938 and it has been assumed that the majority of haematite would have been deposited within this period (O’Sullivan et al., 1992).

Figure 5.3 compares this study’s results with previous data to show that peaks in magnetic susceptibility correspond with the presence of these haematite layers (Coard et al., 1983). This shows that 1928 corresponds to 93cm and 1938 to 46cm. Verifying these positions of haematite layers enables the chronology to be matched with previous studies to within 1cm.

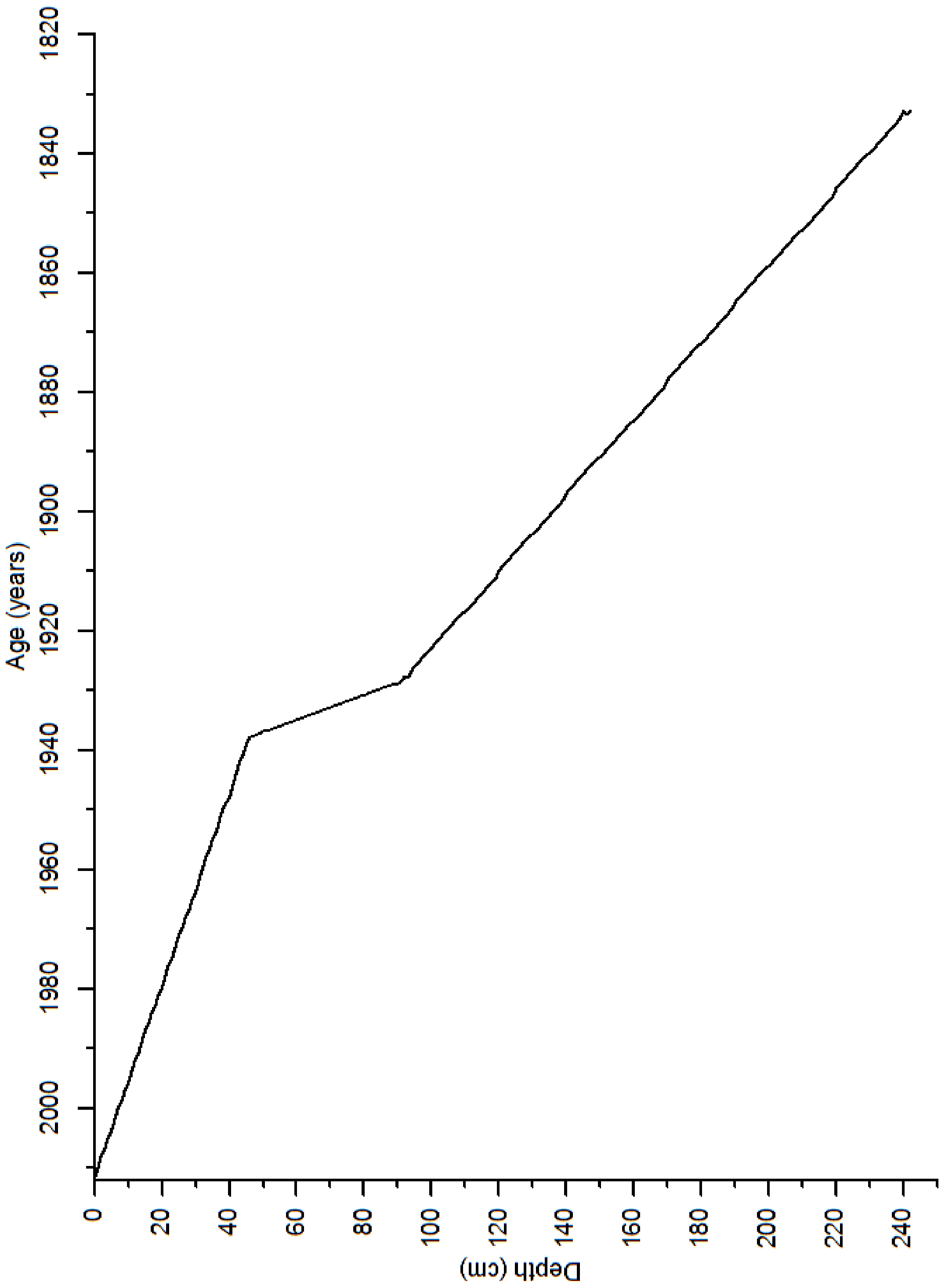


Figure 5.1: *Age-depth model showing the relationship of age of sediment compared to depth. This has been used through-out the discussion to produce approximate dates. 0cm=2012; 242cm=1833.*

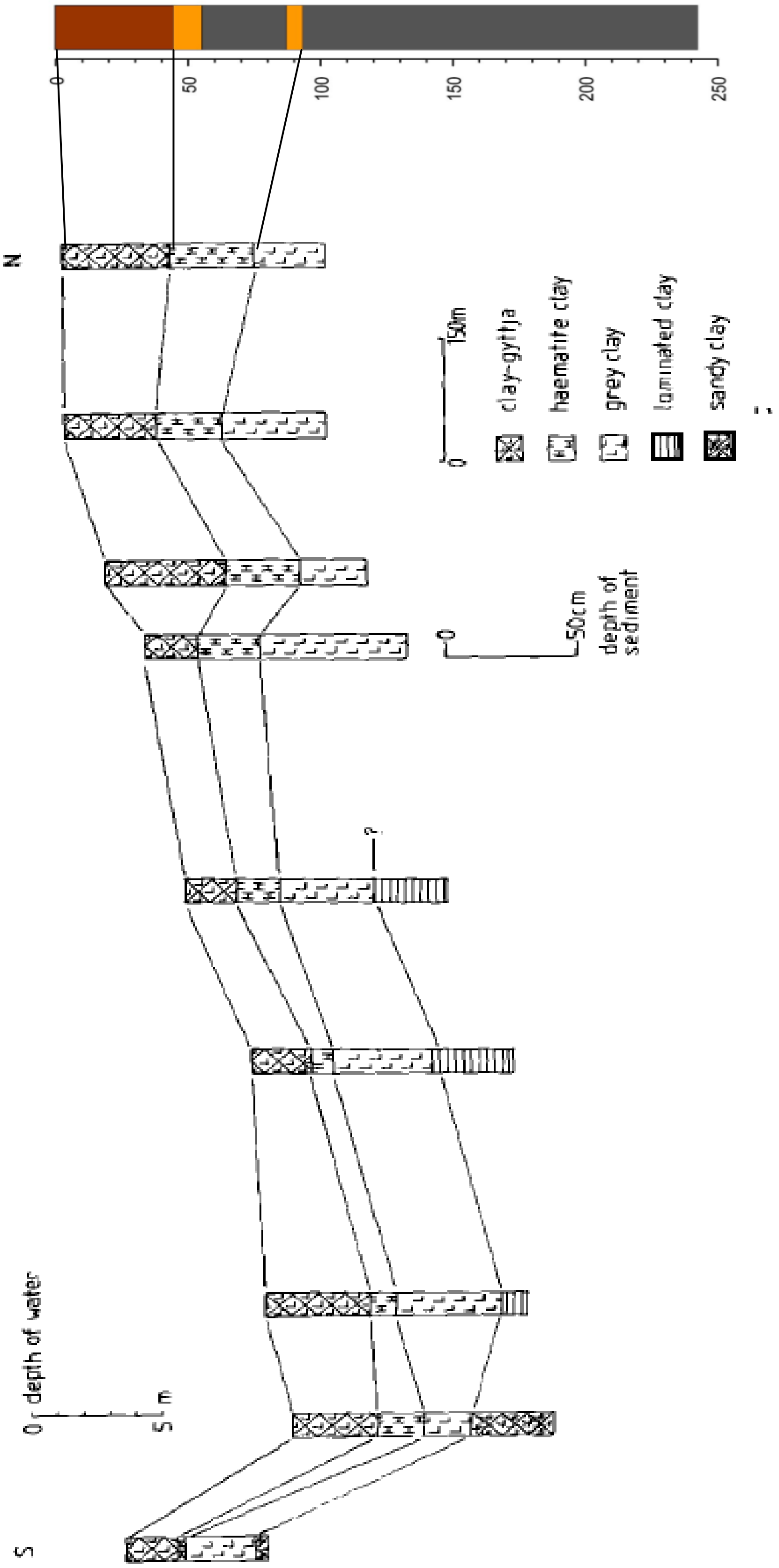


Figure 5.2: *Comparison of occurrence of haematite layers from O'Sullivan, 1999 with this study's core added. Scale has been matched as best as possible. Three segments for which sedimentation rates were calculated can also be seen.*

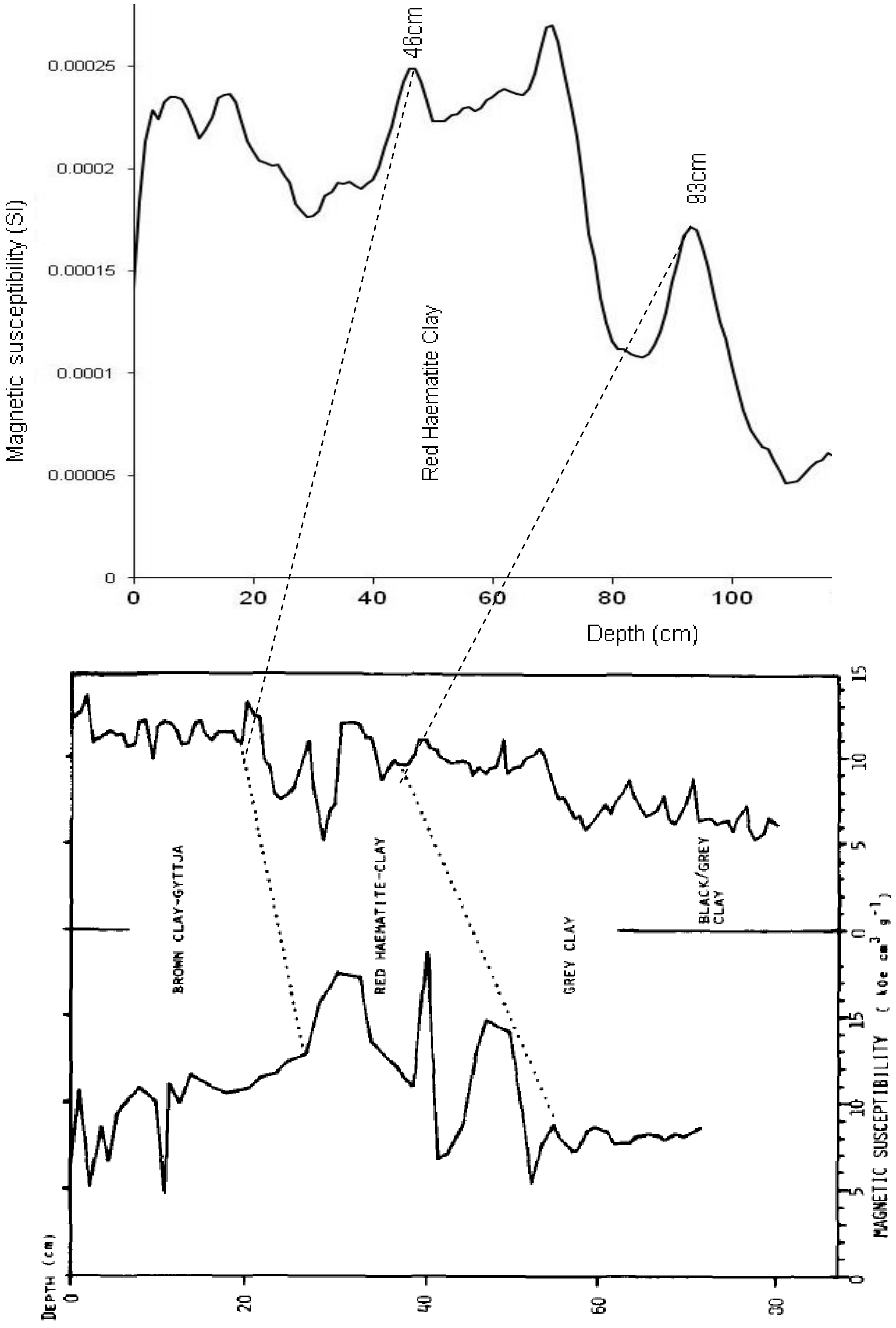


Figure 5.3: *Comparison of magnetic susceptibility of the red haematite clay layers; results from Coard et al., 1983 (bottom) and this study (top).*

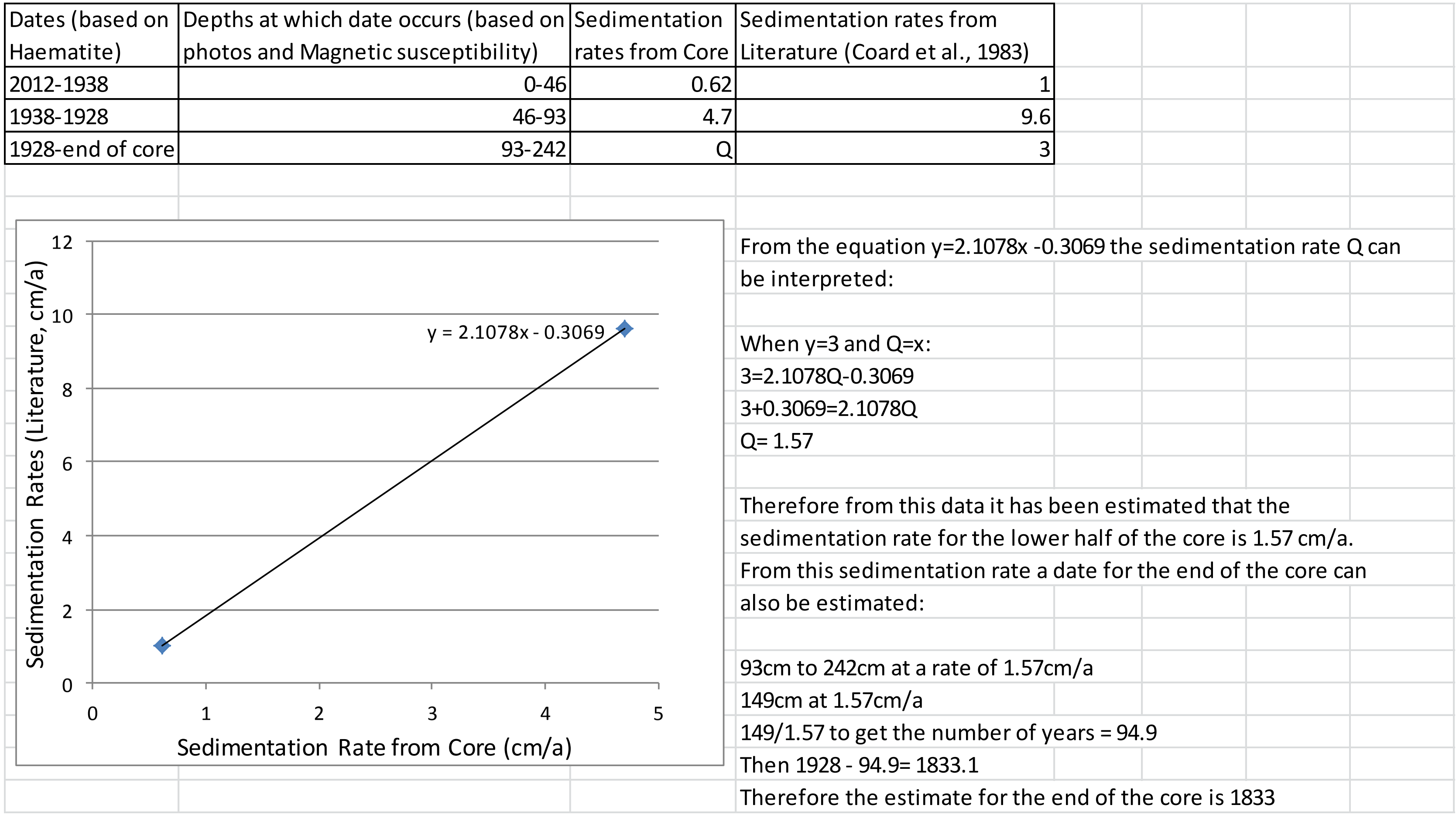
With these three dates (1928, 1938 and 2012) the chronology can be extended. Previous studies have produced general sedimentation rates for different segments (Figure 5.2) within Loe Pool cores (Coard et al., 1983). Two sedimentation rates can be calculated for this study's core by using the dates acquired. By comparing sedimentation rates, the rate for the bottom half of this study's core can be estimated (see Figure 5.4), producing an estimate for the base of the core as 1833. Using this, dates through the whole core have been calculated (see appendix) and will be used throughout the discussion.

These dates have been calculated with the information and time available. However, there is a large margin of error due to the lack of C137 and SCPs in this core, therefore the chronology had to be formulated by other means. This alternative method can be affected by other factors described below, which could further reduce its accuracy.

One factor is that studies have found laminations within Loe Pool, suggesting it is a very dynamic system. Laminations reflect changes within the lake's ecosystem or variations in the intensity of catchment erosion, thought to be strongly linked to human activity (Simola, et al., 1981). Studies conducted at Loe Pool have shown that these are varve laminations, which reflect summer and winter periods. Between 1870 and 1920, the main cause of these laminations is thought to be the steady inflow of mining waste with recent laminations attributed to increasing eutrophication in the lake (Simola et al., 1981). A dynamic system could reduce the chronology's accuracy by introducing several uncertainties, such as irregular sedimentation rates.

Another factor is the potential impact of a bioturbated layer. In some previous studies, bioturbation occurred in the 1960s (Coard et al., 1983), and it could be argued that it has affected this study's core. Distortion in the C137 graph could be evidence for this (Figure 4.3), but the remainder of the core would require analysis to confirm this. This again highlights the dynamism of this system and its potential to increase uncertainties within the dating techniques. In addition, mixing and distortion can also be caused by factors such as winds and inflowing rivers (Smol, 2002).

Finally, the practice of bar breaking may affect the sediment record of Loe Pool. This causes mass drainage of the lake, and an influx of sea water can potentially disturb the sediment. In the bottom of the core, bands of sand can be seen (appendix), which correlates to the sharp peaks in the sand content graph (Figure 4.5). The source of these sand bands is unknown but a link with bar breaching is possible, with the last breach in 1984 by South West Water. However, from the chronology, some sand layers seem to occur at similar times to tidal wave events in Mounts Bay, occurring in 1859, 1868 and 1924 (Figure 5.5) (Davies, 1999). These events throw massive amounts of shingle on and over the bar. As this core was taken close to the bar this could be a source of some of the sand layers, but further research into the composition and dating of these layers would need to be undertaken to make any conclusions. This emphasises the dynamism of Loe Pool, with multiple potential sources of sediment, therefore making it difficult to formulate conclusive statements on exactly how, where and when different sediments entered the lake.



Dates (based on Haematite)	Depths at which date occurs (based on photos and Magnetic susceptibility)	Sedimentation rates from Core	Sedimentation rates from Literature (Coard et al., 1983)
2012-1938	0-46	0.62	1
1938-1928	46-93	4.7	9.6
1928-end of core	93-242	Q	3

From the equation y=2.1078x -0.3069 the sedimentation rate Q can be interpreted:

When y=3 and Q=x:
3=2.1078Q-0.3069
3+0.3069=2.1078Q
Q= 1.57

Therefore from this data it has been estimated that the sedimentation rate for the lower half of the core is 1.57 cm/a. From this sedimentation rate a date for the end of the core can also be estimated:

93cm to 242cm at a rate of 1.57cm/a
149cm at 1.57cm/a
149/1.57 to get the number of years = 94.9
Then 1928 - 94.9= 1833.1
Therefore the estimate for the end of the core is 1833

Figure 5.4: *Diagram showing the workings in excel for inferring sedimentation rates and the date for the bottom of the core.*

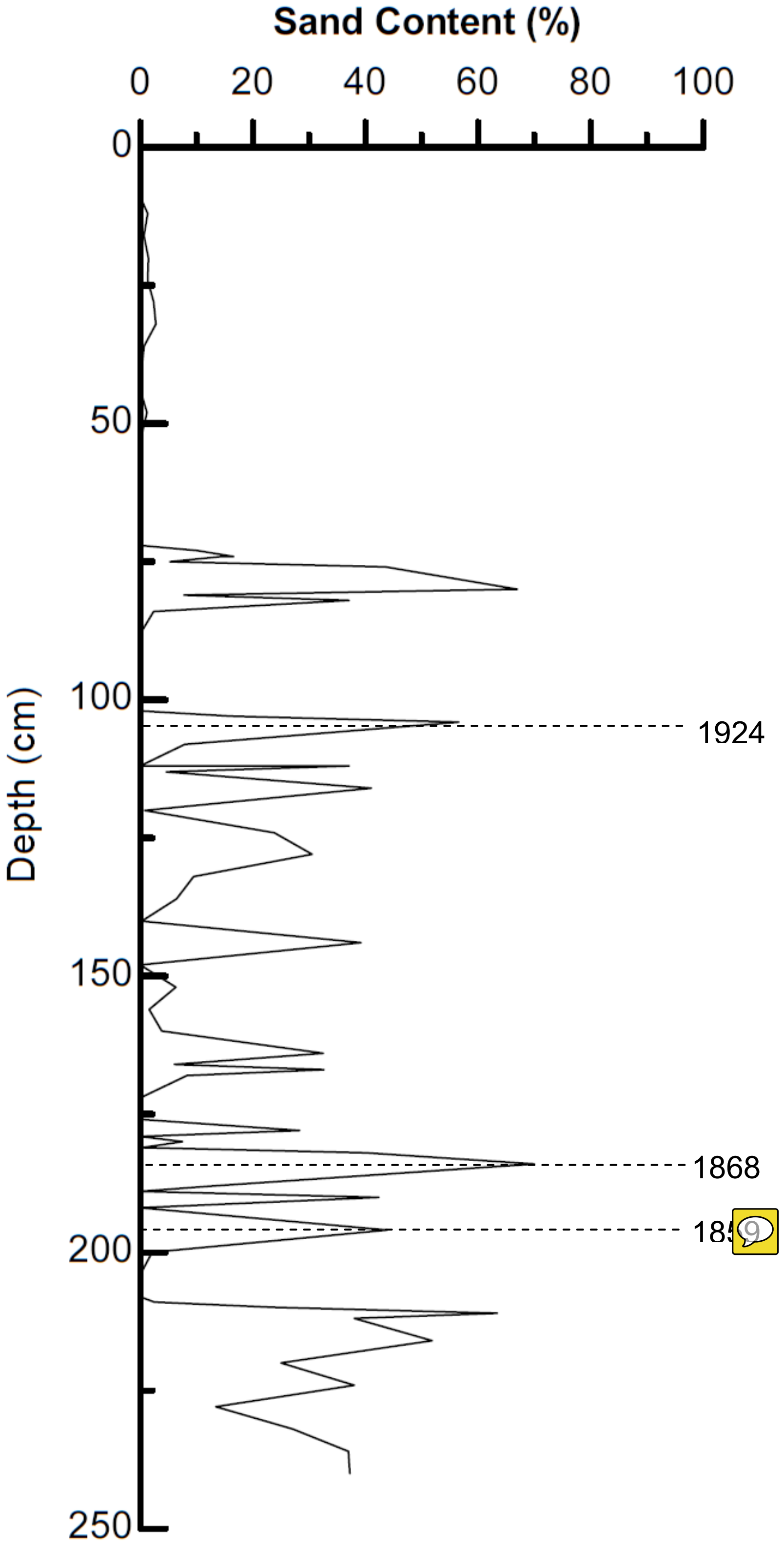


__Figure 5.5:__ Graph showing the sand content of this dissertation's core, with the rough position of the 1924, 1868 and 1859 tidal wave events.

5.2 Types and potential sources of pollution in Loe Pool sediment:

From the results collected it can be seen that Loe Pool has been subjected to many different types of pollution over the past few centuries. Heavy metal concentrations are high within the core as well as an elevated amount of phosphorus. Pollution from increased sedimentation causes several problems: namely, deterioration in the quality of streams and lakes; reduced downstream capacity of channels; and an increased flooding risk (Beasley, 1972).

Certain man-made activities can increase sedimentation rates within a system, with mining and agriculture assumed to be the most influential factors in the Cober catchment (O'Sullivan et la., 1992 and Dinsdale, 2008). Most of the material within Loe Pool is thought to be allochthonous: table 1 shows sedimentation rates and their potential sources in the catchment (O'Sullivan et al., 1982). These results suggest that intense mining increase sedimentation rates more than agriculture, however agriculture does appear to have a significant impact.

Date	Sedimentation rate (km^2/a)	Potential cause
1938-1981	12	Agriculture
1937-1938	361	Intense mining and agriculture
1930-1936	421	Intense mining and agriculture
1860-1920	174	Less intensive mining and agriculture

Table 1: *Table showing sedimentation rates within the Cober catchment during certain periods and the potential cause for the extreme magnitude of the values (O'Sullivan et al., 1982).*

Other studies also show increased sedimentation rates in relation with mining activity, such as the Fal estuary in Cornwall where historical evidence has shown that rapid sedimentation and metal deposits are directly linked to mining activity (Pirrier et al., 2002).

5.3 Most prevalent pollution type:

The results collected suggest that the most prevalent type of pollution is increased heavy metal concentrations. Evidence for this includes a reduction in organic matter; increased concentrations of several heavy metals; sections of elevated magnetic susceptibility; and a discolouration of sediment layers. The literature implies that this has a strong association with mining activity in the area. It is thought that between 1870 and 1938 the main inflow of sediment was caused by mining waste, producing artificially high sedimentation rates, especially during the intense mining period of the 1920s and 1930s (EA, 2003). This link is also noted in other studies across the UK and Cornwall, including a study conducted in Wales which directly linked increasing mining activity to increasing heavy metal concentrations (Alloway and Davies, 1971). Studies in the Fowey estuary, Cornwall showed how clear tin pulses around 1880 originated from the former tin streaming and mining in the area (Pirrie et al. 2002).

It is thought that a minima in LOI is linked to an intense mining period between 1936 and 1940, as mining waste consisted primarily of inorganic debris (Pickering, 1987). The lowest trough in Figure 5.6 occurs at 100cm to 73cm, with another smaller decrease at 50cm to 44cm. Using the chronology it can be seen that these two sections coincide with 1923-1932 and 1937-1941, which,

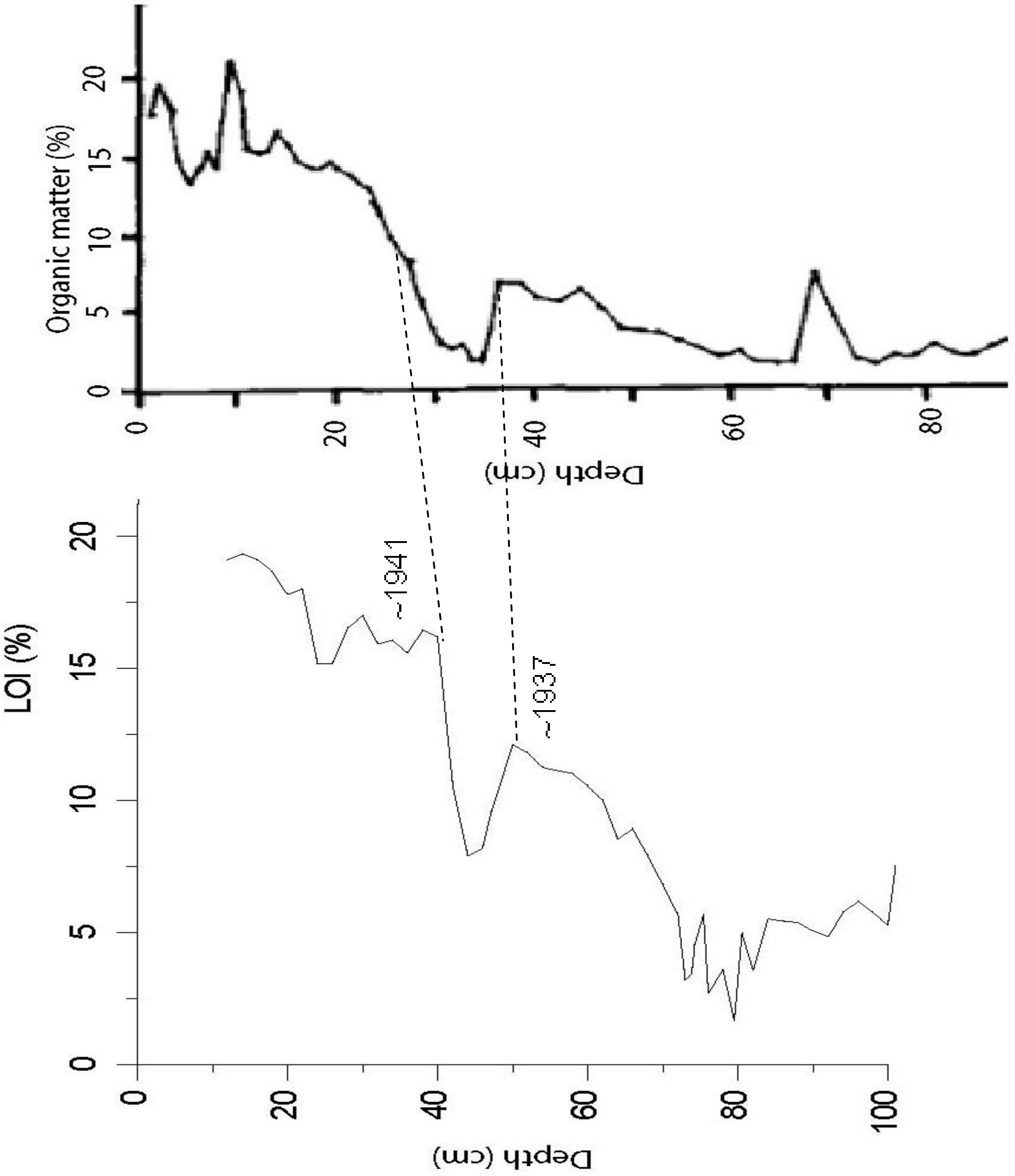


Figure 5.6: *Graph comparing organic matter content (%) (Coard et al., 1983) and Loss-on-ignition (%) to determine dip suggested between 1936 and 1940. This dissertation's core reaches 1996 at 10 cm and Coard's core reaching 1983 at 0cm.*

when compared to the literature, matches the intense mining periods in this region. Therefore, this data implies that mining during these times could have affected this section of Loe Pool, though further catchment analysis would be needed to confirm this.

Pickering explains how LOI has increased since 1940 -1987 (Pickering, 1987). Again, this agrees with this study's core, which increases from1940 (45cm) up until 1996 (10cm). Figure 5.6 supports these findings by comparing this study's results with results from Coard et al, which shows that the general pattern of LOI virtually agrees. This would suggest that in the last fifty years conditions within the lake have become more organically rich, which could be linked to the closure of the mines within the area, reducing the high proportion of inorganic sediment reaching the lake.

This pattern of a drop in LOI has been observed in other studies, for example the investigation into the rehabilitation of bauxite mining area in the Jarrah forest, which showed how mining operations altered the soil chemistry and microbial characteristics of the area (Banning et al., 2008).

Concentrations of certain heavy metals in this study's core have also changed over the last two centuries. Linking these results to the chronology, patterns and dates have been determined for Copper, Tin and Arsenic (Table 2).

Copper is dominate within Cornish mining. However the Wendron district only accounted for 0.01% of the total Cornish copper output and therefore most literature focuses on the effects of tin mining. Peaks in copper coincide with tin peaks, but further research into the history of copper mining in Wendron would be needed to draw fuller conclusions.

Depth (cm)	**Date**	**Occurrence**
44	~1941	Last peak in Copper, with major declines in Arsenic and Tin
68	~1933	Peak in Copper and last peak in Tin and Arsenic
84	~1930	Peak in Arsenic
107.5	~1918	Peak in Arsenic and first major increase in Copper
204	~1856	First peak in Tin and copper

***Table 2:** Depth and inferred dates from chronology of key peaks and declines of arsenic, copper and tin; the three main heavy metals mined in the Cober catchment.*

These patterns for Tin data can be compared with peak concentrations from Coard et al. (Figure 5.7). Peaks occur at 1925-1936 (6400ppm), 1900-1910 (35000ppm) and 1870-1896 (6000ppm), coinciding with mine activity in the catchment. The first two peaks in tin occur slightly earlier within this study's core, with the first peak at ~1856 instead of 1870-96, and the second peak occurring ~8 years late. The last peak of tin does lie within the range of 1925-1936 with a peak at 1933. There are multiple reasons for these discrepancies. Firstly, the coring site is different between the two studies, potentially resulting in a difference time of arrival of the heavy metal concentrations. However, the differences are fairly large and other reasons, such as the uncertainties associated with the chronology of this core, may be more probable. Differences in methodology may have caused the discrepancy. The results from the Coard et al. study were made using an X-Ray Fluorescence (XRF) machine whereas these results were measured using an atomic absorption spectrophotometer (AAS). This method only looks at the soluble component of the heavy metals whereas Coard et al measures the crystalline component (O'Sullivan 2013, pers.comm., 13 Feb).

Differences caused by methodology are evident when comparing the magnitudes of concentrations between the two studies; a maximum of 200ppm in this study compared to 35,000ppm (Coard et al., 1983). This difference could be because 90% of metal contaminants in the river are transported in particulate-associated form (Macklin et al., 2006). Furthermore, heavy metals are known to be persistent and non-degradable (Yang et al., 2009), and therefore less soluble, illustrating that the AAS method may produce comparably low concentrations. However the peak patterns do show some similarities and are useful for looking at pollution trends through the core.

Another heavy metal affecting the lake is arsenic. As discussed in the literature review, Cornwall is a geochemical hot spot for the heavy metal (Thornton, 1996), and arsenic mining has occurred in the area. Different types of arsenic can form: some are susceptible to transformations such as oxidation-reduction (Camm et al., 2004). The majority of arsenic is stored within the sediment; however changes in pH or oxidation state (caused by effects of eutrophication, for example) could have the potential to release it into the water system (Camm et al., 2004). This can prove detrimental to ecosystems and water quality. However, this study's core shows how arsenic concentrations have been declining since the last peak in 1933 (Figure 4.6), coinciding with the end of the mining era in the region, suggesting that the source of arsenic into the lake may have now stopped.

Two other heavy metals were found within the core; calcium and iron. Calcium is found almost everywhere in the terrestrial world and is essential for the life of plants and animals. It is present in the skeletons of animals and a small proportion is present in sea water (Lenntech, 2012a). From the results collected, it can be seen that from around the 1930s, calcium concentrations in the lake have declined over time to almost zero. A study of boreal lakes described how a decline of calcium in lakes is linked to a reduction in the exchangeable calcium concentrations in catchment soils (Jexiroski et al., 2008). This could suggest that weathering and soil degradation, caused by increase in agriculture in the Cober catchment, may be responsible for the decline in calcium. This could have a devastating effect on the marine wildlife within Loe Pool. Again, further experimentation within the catchment and Loe Pool would need to be undertaken to draw a fuller conclusion.

Iron is also essential to most living things and one form of this heavy metal is haematite (Lenntech, 2012b). This is normally associated with the production of steel but within this core, as previously discussed, haematite was released by tin mining at Porkellis mine. The high concentrations of iron could be linked to mining activity, but peaks and troughs do not coincide with periods of mining like arsenic, copper and tin. Therefore, haematite may not be the main form of iron present in the lake and mining is unlikely to be the main source of iron; further study would be required to determine its origins.

Cadmium was not found within this core. When zinc is mined, cadmium ratios tend to increase; an example of this process occurred in Shopham in South West England (Thornton, 1996). Cadmium may not have appeared because the Loe Pool catchment area was dominated by other forms of mining.

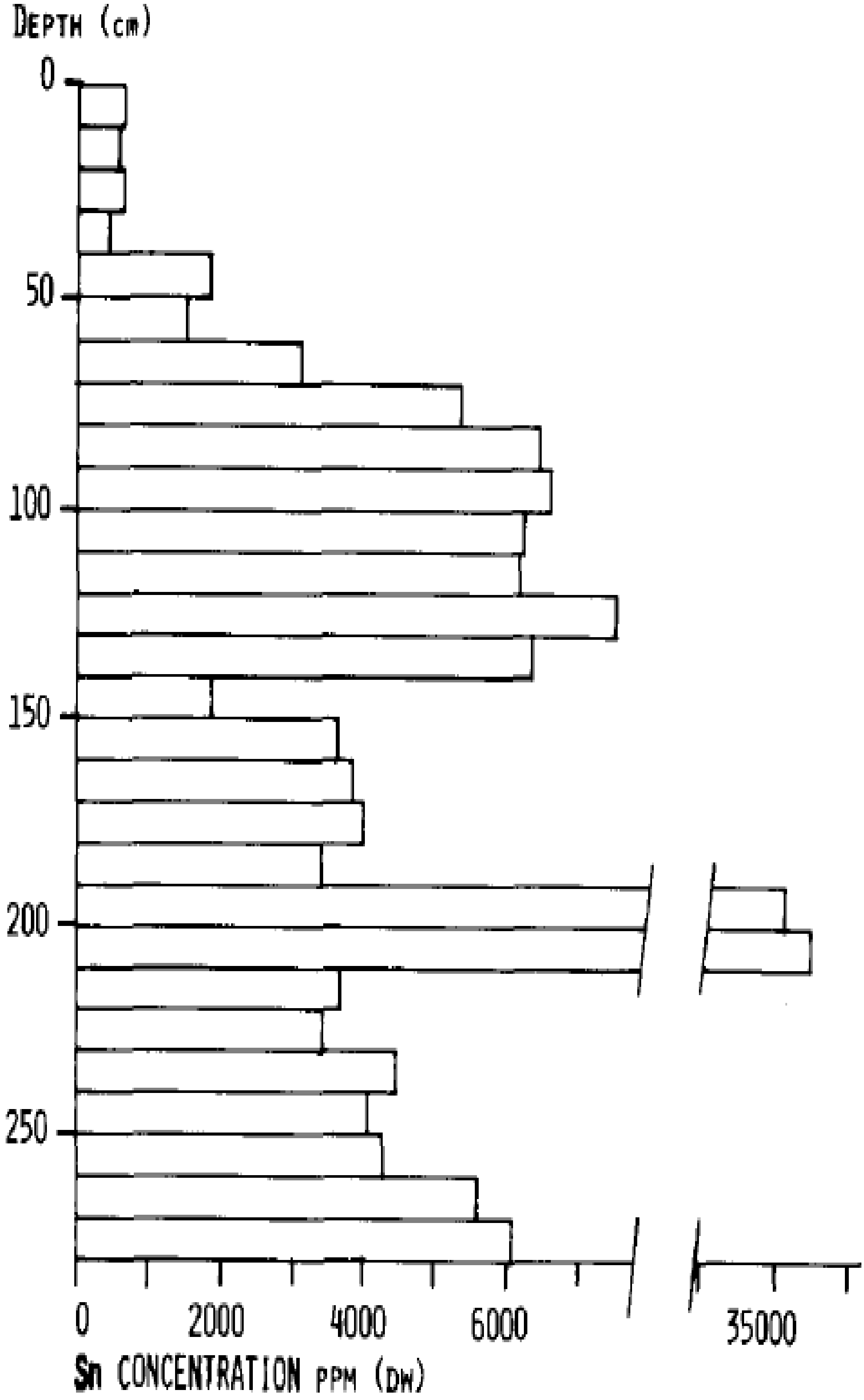


Figure 5.7: *Graph showing concentrations of tin (Sn) through a core collected by Coard (Coard et al., 1983).*

A link between heavy metals and particle size can be seen for this core (see 4.9.1 in results section). Previous studies also show links between the two, with the general consensus that heavy metals are typically found in the most mobile sediments within a river system: fine sand, silt and clay (Macklin et al., 2006 and Bird et al., 2005). For example, copper has been found in the clay, the finest fraction; iron concentrations increase with partial size; and tin was most abundant in the fine sand fraction (Merefield, 1993). When comparing this study's findings to Merefield's results, both show that copper concentrations have a positive correlation with clay. However in this study copper has the strongest relationship with certain silt fractions rather than clay. Tin had a positive relationship with clay, whereas Merefield suggests this should occur with sand. Furthermore, Merefield suggests that iron increases with particle size; however this study found a strong negative correlation between the two.

These disparities could, again, be due to differing methodologies for calculating heavy metal concentrations. However there are other influential factors; local geological conditions and hydrological linkages between mining and river systems can affect the magnitude and spatial extent of heavy metals (Bird et al., 2005). For instance, a study of Lake Geneva and Lake Luceme showed how levels of mercury and lead increased due to natural weathering in the surrounding area (Thevenon et al., 2011).

Another factor is catchment erosion, which can influence variations between sites due to spatially varied geology and geochemical processes (Yang et al., 2005). For example, a study in Derbyshire and the Mendips showed how natural weathered enrichments are enhanced by mining activities, increasing pollution in the watercourse (Li and Thornton, 1993).

There is also a high dependence on the ore being processed. For instance, in the Meza River, which was affected by the iron and steel industry, concentrations of arsenic and iron were embedded in the host rock and therefore released during mining (Gosar et al., 2011). This process occurs within this study with the presence of haematite.

These heavy metal concentrations within the core have been linked, using the literature, to mining activity within the catchment. However, although mining activity is a major supplier of heavy metals into river systems, it is not the only source (Merefield, 1993). Contributions from other industries (farming, waste disposal, water treatment and urban settlements) are also highly important and therefore a definitive source cannot be determined without further research.

5.4 Current pollution types:

Recently, as heavy metal concentrations have declined, the focus on Loe Pool has moved towards elevated phosphorus levels. Phosphorus, along with nitrogen, are limiting nutrients in most fresh water systems, and elevated amounts can cause undesirable processes, such as eutrophication (EPA, 2012). Organic phosphorus is associated with carbon-based molecules, i.e. it is found in plant and animal tissue. Inorganic phosphorus is anything not associated with organic material, and is the element that is essential for plant growth. Figure 5.8 shows a diagram of the phosphorus cycle, demonstrating how inorganic and organic phosphorus move around a lake system: (EPA, 2012).

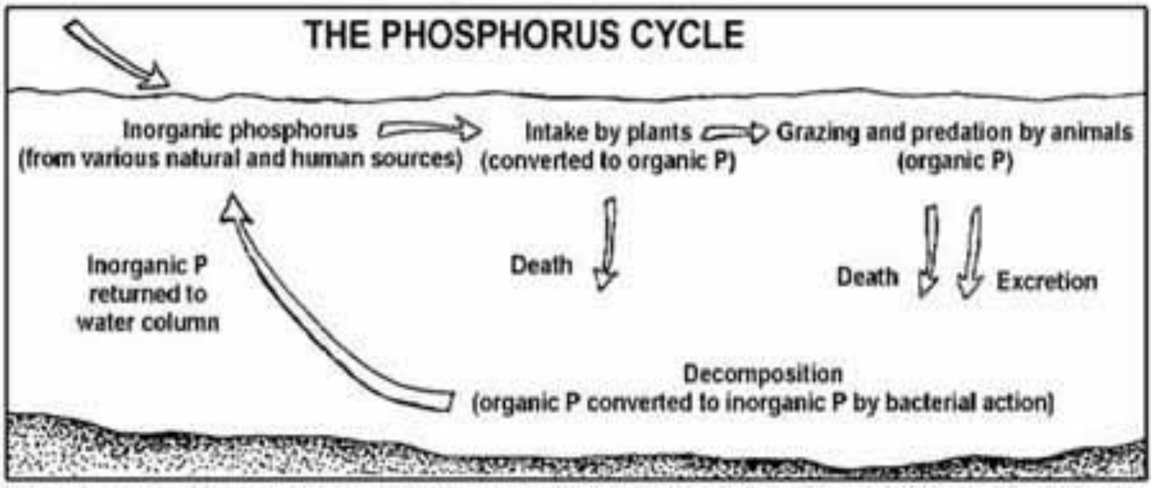


Figure 5.8: *Diagram showing the phosphorus cycle and the interactions between inorganic and organic phosphorus within a lake system (EPA, 2012).*

Loe Pool started to become eutrophic during the 1930s, the year when sewage treatment works in Helston were commissioned (O'Sullivan, 1992). Table 3 shows where the majority of the phosphorus within the catchment formed.

The effects following the opening of Helston sewage works will not be apparent in this study's results, because only the top 65cm (1934) were measured for phosphorus. However, the phosphorus results can be compared with a study by Coard et al (Figure 5.9). Since 1938, total phosphorus in the lake has increased significantly. The literature shows that inorganic fertilisers were introduced in the 1940s; Helston sewage works opening in 1930, then extended in 1959 and 1974; and RNAS Culdrose also had a separate work commissioned in 1947 (Coard et al., 1983). Comparing these with this study's results show some patterns of similarity. The first major peak occurs at 52cm (~1936) which is followed by a decline and then another peak at 42cm (~1944). This coincides with initial increases in phosphorus levels since 1938, as described by Coard et al. A small peak is observed around 1960 (32cm), which could potentially be linked to the extension of the Helston sewage works. However, what must be noted is that the concentrations seen in this data are the total soluble phosphorus, due to the methods used, and therefore do not represent all the phosphorus in the sample, but only a percentage of it (O'Sullivan 2013, pers.comm., 13 Feb).

Source	Amount (t Pa^{-1})
Agricultural (inorganic)	4.7
Agricultural (organic)	2.1
Agricultural (total)	6.75
Sewage	11.6
Background	0.57

***Table 3:** Table showing the source and amount of phosphorus lost from within the Loe Pool catchment (O'Sullivan, 1992).*

5.5 Last three decades and recent management schemes:

This study has been able to add 30 years to records of Loe Pool, and therefore it can be used to show any recent changes in pollutant concentrations. Using the dates calculated for the chronology, approximately the last 18cm of this study's core has accumulated in the past three decades and therefore this section will be discussed.

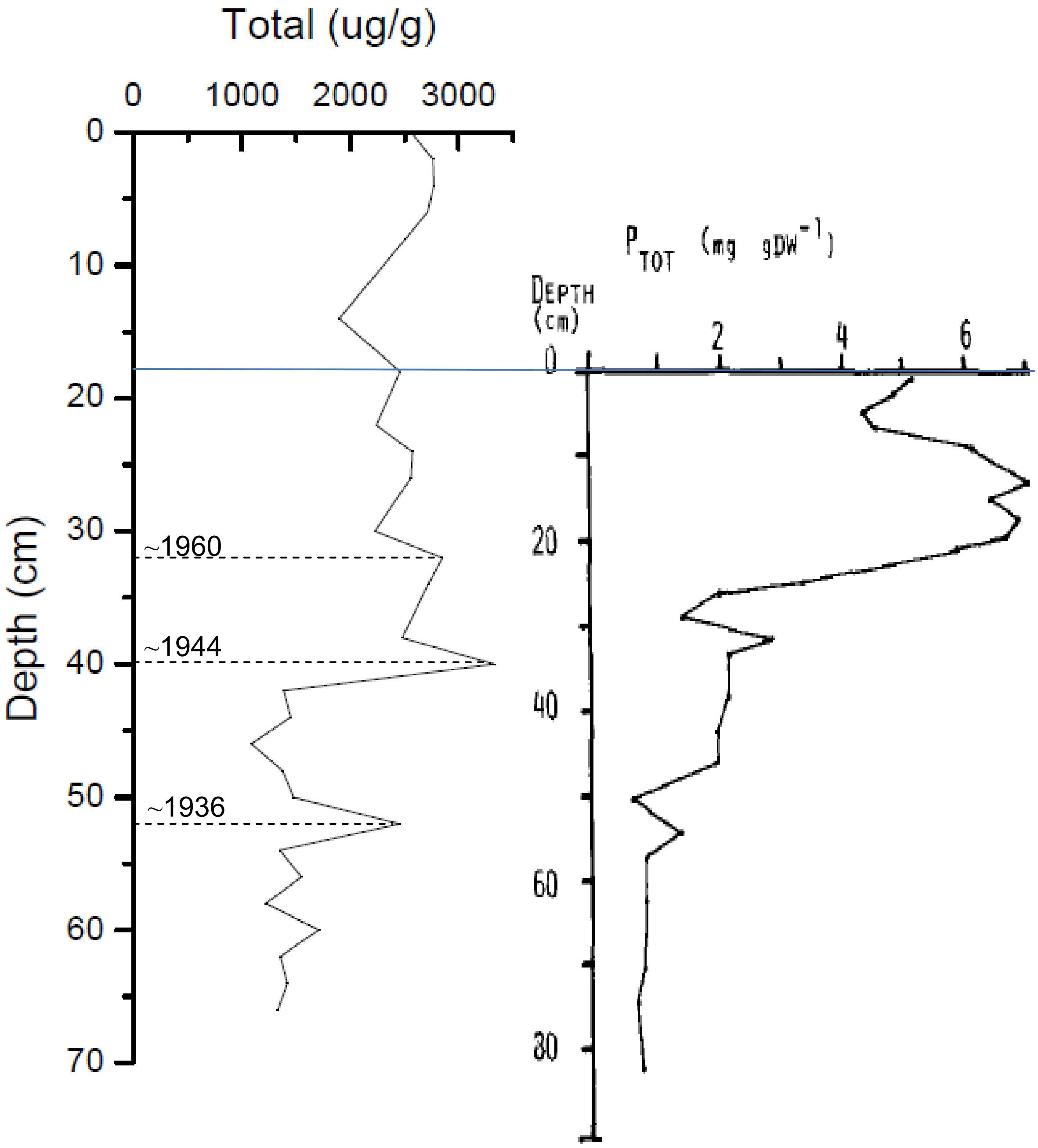


Figure 5.9: *Comparison of graphs of total phosphorus found in this dissertation's core and a core from Coard. The blue line shows the estimated point at which the Coard et al graph matches up (Coard et al., 1983). Major peaks are also marked on graph with estimated chronology date (dashed lines).*

Heavy metal concentrations have declined in recent years, but due to the prolonged residence time of heavy metals in sediment, some concentrations still persist today. Examples of this can be seen globally: for example, in the Aries River catchment in Western Romania (Macklin et al., 2005) and in the Moylouys Valley, Morocco (Iavazzo et al., 2011), where the on-going effect of mining can still be felt. Of more significance is evidence suggesting that overall phosphorus levels have declined.

During the past 30 years in this dissertation's core, there has been a slight increase in total phosphorus until 6cm (2002) where it starts to plateau, with a noticeable decline at 2cm (2008/9). Previous studies show that phosphorus levels have declined over the last few decades. Figure 5.10 shows there has been a four-fold reduction in the total phosphorus levels between 1999 and 2004 due to the removal of phosphorus at the Helston Sewage works in 2003. In addition, projects to reduce the runoff from agriculture have been implemented (Dinsdale, 2008). This dissertation's results show that, approximately, in 2002 the concentration of phosphorus stabilised and then in 2009 began to decline. The reductions and times are slightly less than in Figure 5.10, possibly because that study measured water quality as opposed to lake sediment.

Another factor could be that phosphorus can be sediment-bound or dissolved, but dissolved phosphorus only occurs in small concentrations and is available for biological uptake, with sediment-bound generally containing 95% of the overall concentration (Sharpley et al., 1999 and Hem, 1985). This could suggest that a large amount of phosphorus entering the water system is sediment-bound; therefore water records of phosphorus would be significantly lower. This highlights a potential problem with phosphorus restoration as it can still be released from the bed load sediment long after the supply has been stopped (Mellanby, 1992). This suggests that Loe Pool sediment could become a significant source of phosphorus during the lakes rehabilitation. However the results seen in Dinsdale are extremely encouraging as they currently show that phosphorus concentrations in the water are low. It is theorised that phosphorus is remaining stably bound within the sediment due to the high iron content from the historic mining activity within the catchment (Olosunde 2002 in Dinsdale, 2008). This is supported by this dissertation's results, as iron concentrations in the lake remain high (around 40000ppm up until the top of the core), suggesting that there could be enough iron available to keep the phosphorus stable in the sediment.

However another factor causing disparities could be the large proportion of total phosphorus coming from RNAS Culdrose, which uses the Carminowe stream to drain its effluence (South East side of Loe Pool). This is seen in Figure 5.11 (Dinsdale, 2008), with 22% of the total phosphorus coming from this stream. Due to the location of this dissertation's core, it may be highly affected by phosphorus input from this stream, compared to the rest of the river. Yet the location of the water samples is unknown so further research would be required for confirmation.

Overall, it can be argued that phosphorus concentrations over the last few years have started to decline, and this coincides with the reductions in phosphorus inputs into the lake. The results and literature suggest that the sewage works

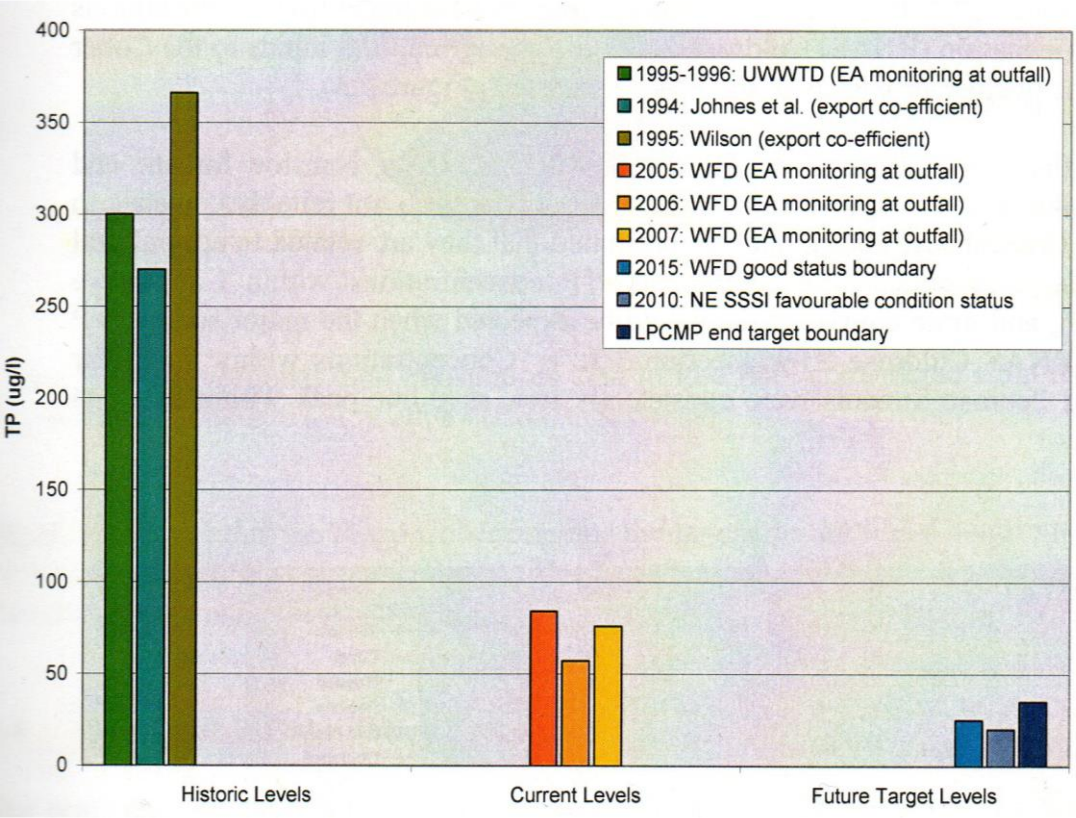


Figure 5.10: *Graph showing the main rivers transporting the total phosphorus concentrations to Loe Pool (Dinsdale, 2008)*

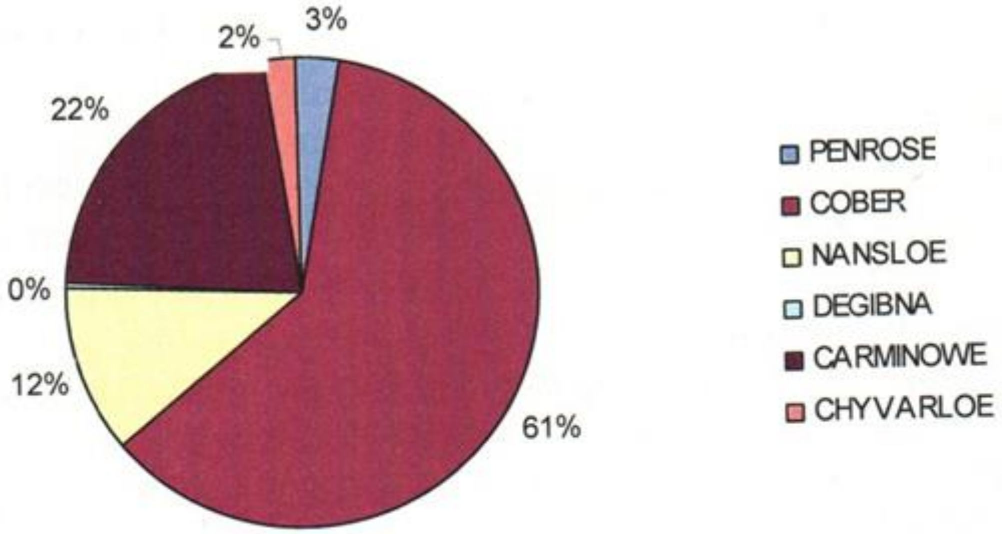


Figure 5.11: *Graph showing the historic, current and target total phosphorus concentrations for Loe Pool, taken from water samples in the lake (Dinsdale, 2008)*

are the main source of phosphorus into the lake, but a catchment survey would be required to confirm this.

From the discussion and data above, it can be seen that recent management schemes have affected pollution levels in Loe Pool: from a reduction in the heavy metal concentrations, to an increase in the organic matter and a reduction in phosphorus levels.

5.6 Other factors affecting Loe Pool pollution levels

There are other factors that must be examined before it can be concluded that the pollution in Loe Pool is reducing.

Atmospheric pollution has not been analysed in this study, however it can affect the amount of heavy metals which enter the lake. An example that highlights the importance of this factor was seen in the Morococha mining region, Peru: two lakes were studied in the region and showed high pollutant levels, comparable to some of the most polluted areas in America and Europe. Although neither lake studied was in the mining water course, both were highly polluted, highlighting the impact of atmospheric pollution (Cooke and Abbott, 2008). A similar case was studied in Lake Constance, central Europe, which found that lead had been atmospherically transported into the lake sediment (Kober et al.,1999). Therefore, atmospheric pollution should be studied within the Loe Pool catchment area.

Other case studies found a link between flooding and heightened contamination of water systems. As described in the literature review, the Environmental Agency is currently concerned about the potential risk of flooding within Helston

(O'Sullivan 2013, pers.comm., 13 Feb). Flooding could also have a dramatic effect on the ecosystem in the area and pollution levels within Loe Pool.

Floods are an important factor in the delivery of heavy metals into river systems (Bird et al, 2005), with the suggestion that 29-44% of mining waste that enters river systems is previously stored in the floodplains (Macklin et al., 1997). This could mean that, although pollution in Loe Pool is currently decreasing, a significant flood event may potentially wash pollutants into the water course from the floodplains. This could have a devastating effect on the rehabilitation of the lake and its ecosystem. This has been seen in a case study near the North Sea, where historical mining waste has been transported in pulses under flood conditions, acting as a major secondary source of metal pollution for many centuries (Macklin et al., 1997).

It is though that flooding is likely to get worse as the global climate changes, with extreme events becoming more common. The millennium floods in Europe during the winter of 2000-2001 have been described as a "wake-up call" highlighting the potential risk of climate change (Macklin et al, 2006).

While this study has analysed the effects of human activity using lake sediment evidence, further studies should be conducted. These would need to look at how the pollution levels within Loe Pool will be affected in the future, through further pollution within the catchment, secondary pollution and effects caused by climate change.

6. Conclusion

In conclusion, this dissertation has attempted to answer the proposed research questions by taking multiple samples throughout the core, producing a high resolution study. A rough chronology was created using the available information; further research should focus on improving the chronology to produce more accurate evaluations.

Loe Pool has been subjected to many different types of pollution with this core being dominated by heavy metals and increased phosphorus levels. This has been shown through the use of heavy metal analysis, Loss-On-Ignition experiments, magnetic susceptibility and phosphorus analysis.

The most prevalent type of pollution throughout this core has been heavy metal pollution. However, the pollution concentrations within Loe Pool have shifted over time, which has been observed in the upper section of the core. In the lower-middle section of the core, heavy metal concentrations increase, causing a deficit in organic matter and certain heavy metals affecting the magnetic susceptibility record. Yet the upper part of the core shows heavy metal concentrations in decline. Phosphorus levels within this section are high; eutrophication within the lake has been attributed to this. Extending the phosphorus record further down the core would be of interest to determine how levels have changed over a longer time scale.

Loe Pool is currently most affected by increased phosphorus levels: over approximately the last 30 years heavy metals within the lake have declined, with the exception of iron. From the literature it has been suggested that phosphorus levels have also declined since 2004. This can be seen in the top few centimetres of the core, implying that phosphorus has recently started to decline within the sediment.

These pollutants can potentially be attributed to several different sources. Mining is thought to be the largest source of heavy metals entering the lake, with peaks and troughs in pollution concentrations coinciding with mining activity, whereas enhanced phosphorus levels have been linked to sewage facilities at Helston and RNAS Culdrose. Declines were noticed in the literature and this core following phosphorus removal initiatives at Helston sewage works.

Loe Pool has become highly contaminated due to the last few centuries of pollution. This has affected wildlife as well as the water quality of the lake, resulting in monitoring by several organisations including the Environmental agency, National Trust and the Loe Pool Forum. These groups are making a noticeable effort to reduce pollution reaching Loe Pool and restore the lake to its natural state.

Nevertheless, there are considerations for the future that should be pursued. This includes the potential impacts of climate change, increased flooding risk and secondary pollution from lake sediments. All of these could reduce the health of the lake in the next few decades.

Overall, this paleolimnological study of the past and present pollution of Loe Pool has shown how the lake has been strongly affected by many different types of pollution from within its catchment. Loe Pool is a dynamic system with a vast pollution history that has been strongly influenced by different factors from multiple sources.

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8. Appendix

8. A1 -Methodology

8.A1.1-Diatoms analysis preparation:

Following the subsampling of the cores for microfossil purposes, the sediments underwent a series of preparation techniques that enabled the diatom assemblages to be recorded. The method used for diatom preparation is outlined below and was modified from (Renberg, 1990):

Stage 1

Small sub-samples (3-5mm^3) were taken and placed in glass test tubes (120x11mm). To each sample 1ml 30% H_2O_2 was added and the individual tubes were covered. The tubes were placed in a metal test tube rack and then immersed in a water bath.

Stage 2

The water bath was heated to 85°C and the samples were left for 1 hour. Throughout the hour the samples would be checked and lightly shaken to make sure they had not dried out.

Stage 3

After the first hour, a further 1ml 30% H_2O_2 was added and the samples were placed back into the water bath for another 1-2 hours until digestion has taken place.

Stage 4

Following digestion, the samples were removed from the water bath and filled with distilled water and then placed into a refrigerator overnight.

Stage 5

After chilling, the supernatant was removed and the samples were refilled with distilled water. The individual tubes were shaken and the turbid sample was placed onto a circular cover slip and topped up with distilled water. The sample was then left to air dry overnight.

Stage 6

Once dry, the sediment-covered cover slips were mounted using Naphrax, a high reflectivity mounting agent, onto a microscope slide. Counting was carried out using a high powered microscope at 1000x magnification, with critical identifications being made using a phase-contrast unit.

8.A1.2: Heavy Metals analysis preparation:

Method

1. Accurately weigh 0.5 - 1.0 mg of sediment into a 100 ml beaker.

2 Add 3ml of conc. nitric acid and mix with a separate glass rod for each sample.

3. Warm to dryness on a hotplate.

4. Remove from the hotplate and add 3ml of conc. nitric acid and 0.5 ml of conc. hydrochloric acid. 5. Warm until the appearance of the nitrogen dioxide brown fumes.

6 Remove from the hotplate to cool.

7. The contents of the beaker are then transferred with as little distilled water as possible to a 25mlcentrifuge tube

8. Centrifuge at 2500 rpm for 20 minutes.

9. Decant supernatant into a 25 volumetric flask.

10. Wash residue with a small amount of distilled water.

11. Centrifuge at 2500 rpm for 20 minutes.

12. Add supernatant to the volumetric flask.

13. Make up to volume with distilled water.

14 Retain solutions for analysis on the Atomic Absorption Spectrophotometer.

An air/acetylene flame is used for all the elements, except for Chromium, where we use an acetylene/nitrous oxide flame

Calculation

$$\text{ppm in sediment} = \frac{\text{volume} * \text{ppm of solution}}{\text{weight of sediment in mg}}$$

8.A1.3 Loss on ignition preparation:

1. Take crucibles out of 105 °C oven.
2. Cool in desiccator for 30 minutes.
3. Weigh empty crucible (W_C)
4. Add sample, say about half full
5. Dry crucible + sample in oven (preferably 105 °C overnight)
6. Cool crucible in desiccator & reweigh (W_S)
7. Place crucible onto the furnace tray and put tray (remember to have the hole nearest you in order to use the extraction tool later on) into furnace at 550 °C for 4 hours
8. Using the special tool, extract furnace tray, and place tray onto heat resistant sheet for at least 5 minutes to initially cool, before placing crucibles in a desiccator to fully cool
9. Reweigh crucible + ash (W_A)
10. If carbonate estimate is to be done, return samples to furnace at 925 °C for 1 hour, cool as above and reweigh (W_{CA})

Calculation: Loss on ignition $= \dfrac{(W_S) - (W_A)}{(W_S) - (W_C)} * 100\%$

Calculation: Carbonate $= \dfrac{(W_A) - (W_{CA})}{(W_S) - (W_C)} * 100\%$

8.A1.4 Particle size analysis preparation:

Reagents – 100vol hydrogen peroxide

Method

This method is a simplified method of the previous method above where removal of organic material is required prior to particle size analysis by instruments such as the Saturn Digisizer (screening at 1000μm) and the samples are known to be less than 1000μm Label all tubes and beakers.

1. The soil is first air-dried and then sieved at 2mm.

2. 1- 2 gm (depending on estimated sand content) is then put into a clean dry glass beaker. About 10 ml of water is then added to each sample + 5 ml of the hydrogen peroxide. It is often necessary to wait and observe the reaction and to control the effervescence by addition of a few drops of IMS.

3. After 2-3 hours, if the frothing has ceased a further 5 ml of hydrogen peroxide is added and the sample allowed to stand overnight. (More peroxide is added if a higher organic content is suspected)

4. The beakers are now warmed on a hotplate (starting at 80 ^{0}C and gradually increasing the temperature to 100 ^{0}C) until the reaction is complete and there is a clear supernatant above the sample.

5. The whole of the beaker contents are now carefully transferred to a centrifuge tube, using a policeman on a rod to clean the sides of the beaker. The tubes are centrifuged at 2500 rpm for 1 hour.
6. The supernatant is discarded.

8.A1.5 Phosphorus analysis preparation:

Materials

Chemicals

Ammonium molybdate	1.5g to 50ml distilled water
Potassium antimony tartrate	0.017g to 25ml distilled water
0.5M Sulphuric acid	27ml to 1 litre distilled water
0.25% p-nitrophenol indicator	
5M Sodium hydroxide	200g to 1 litre distilled water
1000 mgP/litre	0.4394g Potassium di-hydrogen phosphate/litre
1ppm P solution	0.5ml of 1000ppm stock soln to 500ml distilled water

Colour Reagent

Sulphuric acid	21ml conc H_2SO_4 in 150ml
Ammonium molybdate	50ml
Potassium antimony tartrate	25ml
Ascorbic acid	2.7g in 50ml

Make up fresh for each analysis.

Method

With this method 24 samples must be analysed over 2 days although steps 1-7 can be done in advance.

1.Switch on extractor fan and furnace (550C)

2 Label centrifuge tubes with sample ref for Inorganic and Total phosphorus

3.Put crucibles onto furnace tray, making note of crucible I.D’s

4. Follow method for LOI

5. Weigh for LOI.

6. Weigh 0.5g of burnt sample into labelled centrifuge tubes. This is for Total phosphate measurement

7. Weigh out approximately 0.5g of unburnt sample accurately on 4 fig balance for Inorganic Phosphorus directly into the labelled centrifuge tubes. Record weight

Day1

8. Add 45ml of 0.5M Sulphuric acid to all the samples and vortex.

9. Arrange sample tubes in racks on shakers so they are not touching each other and shake overnight. (16 hours)

Day 2

10. Next morning centrifuge samples for 10mins at 3000rpm.

11. Label 25ml volumetric flasks (48 for samples, 1 blank and 4 standards)

12. Pipette between 0.1 ml and 10ml of supernatant into labelled volumetric flasks (taking care not to disturb the sediment at the bottom).

13. Add 5 drops of 0.25% p-nitrophenol indicator to each flask then neutralise by adding drops of 5M Sodium hydroxide solution. Colour change is from clear to bright yellow.

14. Add 4ml of colour reagent to each flask. Then make to the mark with more distilled water.

15. Treat the blank (just 0.5M sulphuric acid) in the same way as the samples (pipetting, neutralising and adding colour reagent)

16. Make up standards by pipetting from the 1 ppm stock solution the required amount for each into their respective flasks (eg 1ml for 1ppm standard, 2ml for 2ppm and so on). Then to each flask add 4ml of colour reagent and make up to the mark.

17. Use standards that are within the range of phosphate expected in the samples i.e from 0.5 to 10ml

18 Switch on spectrophotometer.

19. Allow colour to develop at room temperature in daylight for 30 minutes

20. Measure absorbance at 880nm using disposable plastic 1cm cuvettes

8.A1.6 SCP extraction preparation (Rose, 1994):

Reagents

Nitric Acid (concentrated) Hydrofluoric Acid (40%) Hydrochloric Acid (6M) – 500 ml HCl to 1 l with distilled water Distilled water Napthrax

Safety Notes

The method involves Hydrofluoric acid (HF). This is a VERY HAZARDOUS substance and so must only be used under supervision and in a fume cupboard in the Clean Laboratory, with full personal protection (gloves, facemasks, etc.) and having the antidote gel available.

Nitric acid / Hydrochloric acid also pose normal acid hazards and so gloves / eye protection must be worn and all operations carried out in the fume cupboard

Method

1. Weigh 0.1 – 0.15 g of dry sediment accurately into a 12ml centrifuge tube
2. Add 1.5ml conc. nitric acid – leave overnight in fume cupboard
3. Add further 1.5 ml nitric acid and heat in water bath at 80 – 90^{0}C for 2 hours
4. For every sample have a second test tube with a lycopodium tablet. Dissolve the tablet in dilute HCl then spin and decant, fill with water spin and decant
5. Fill tubes with distilled water and centrifuge at 1500 rpm for 5 minutes – discard supernatant
6. Add 3ml of HF and heat at 80 – 90^{0}C for 3 hours
7. Centrifuge at 1500 rpm for 5 minutes – discard supernatant
8. Add 3ml of 6M HCl – heat at 80 – 90^{0}C for 2 hours
9. Add the dissolved lycopodium (one to each test tube) fill to top with distilled water.
10. Centrifuge at 1500 rpm for 5 minutes – discard supernatant
11. Add distilled water - Centrifuge at 1500 rpm for 5 minutes – discard supernatant
12. Repeat stage 9
13. Wash residue into labelled vial with distilled water – this can then be stored
14. Pipette out known amount of sample onto a slide and evaporate to dry – mount with Canadian Balsam

8.A1.7 Troell-Smith analysis sheet:

Site: **Transect Number** **Core Number:** **Distance from site edge:** **Date:**

Level (cm)		Physical features							Components (Total = 4)																Comments
		0 - 4																							
Upper	Lower	Darkness	Stratification	Elasticity	Dryness	Colour (Munsell)	Structure	Upper boundary	Mosses	Woody plants	Herbs	Woody detritus	Herb detritus	Fine detritus	Charcoal	Organic lake mud	Humus	Organosilicates	Carbonates	Iron oxides	Clay	Silt	Sand	Gravel	

8.A1.8 Magnetic susceptibility:

Measuring cores using the MS2C sensor

The MS2C core scanning sensor is designed to make volume susceptibility measurements (κ) of environmental materials in plastic or other diamagnetic tubes or liners. It is not possible to make measurements with aluminium, brass or other metal tubes even in half-section. The core is passed through the sensor, and measurements are taken at different intervals. The internal diameter of the MS2C sensor can be purchased in a variety of diameters ranging from 45-160 mm. It is recommended that a sensor is chosen which is 5 mm wider than the outer diameter of the core.

Setting-up

Setting-up the MS2C sensor requires a means of passing the core through the sensor in a controlled and repeatable way. Bartington Instruments can provide details of automated core conveying systems. Alternatively, it is straightforward to construct a series of wooden rollers on either side of the sensor that can be adjusted in height to allow for small variations in core diameter. The sensor and track should be positioned on a long flat surface, like a laboratory bench, but do not forget to evaluate the operating environment as described above. It is recommended that the base of the sensor is fixed to the flat surface. The sensor can sit in a simple rectangle of wooden or plastic strips glued or screwed (small brass screws) to the bench, or alternatively the feet can stand in small cut-outs. Before measuring, make sure that the core can run freely through the sensor without touching it. Pay particular attention to the manual control of the core as its end passes through the sensor. The sensor should not be touched while measurements are made.

Some users have passed the core vertically through the sensor. The sensor is held horizontally at the edge of a bench and the core is passed upwards or downwards through the sensor. This is particularly useful when measuring cores of sediment where the sediment-water interface must not be disturbed. Except with very short or narrow cores it is difficult to hold the cores steady by hand, and some kind of mechanical platform is required.

Evaluate the drift in the sensor by running continuous measurements of air. This is important because the final sequence of measurements requires an interpolated air reading for each measurement interval. Normally, the sensor should be switched on for about ten minutes before measurements are made. Most users mark a measurement interval on the core with felt pen or other marker, and make a measurement when the mark is immediately below one edge of the coil.

Measurements are made on the 1.0 or 0.1 range, and in button mode.

The measurement procedure is as follows:

1. Zero the sensor with the Z button before starting and take a first air reading with the M button.
2. Then pass the core along to the first measurement point, and push the M button. Note the κ value.
3. Pass the core to the next measurement point, and push the M button. Note this κ value.

4. Repeat at each measurement point until the core is clear of the sensor.
5. Finally take a second air κ reading with the M button.

Differences between the first and second air measurements mean that the sensor has drifted during the set of measurements. The simplest way of adjusting each sample measurement for drift is to plot the drift as a linear curve on graph paper and to reduce each measurement by the estimate of the 'air reading' at each measurement point (Fig. 4.5).

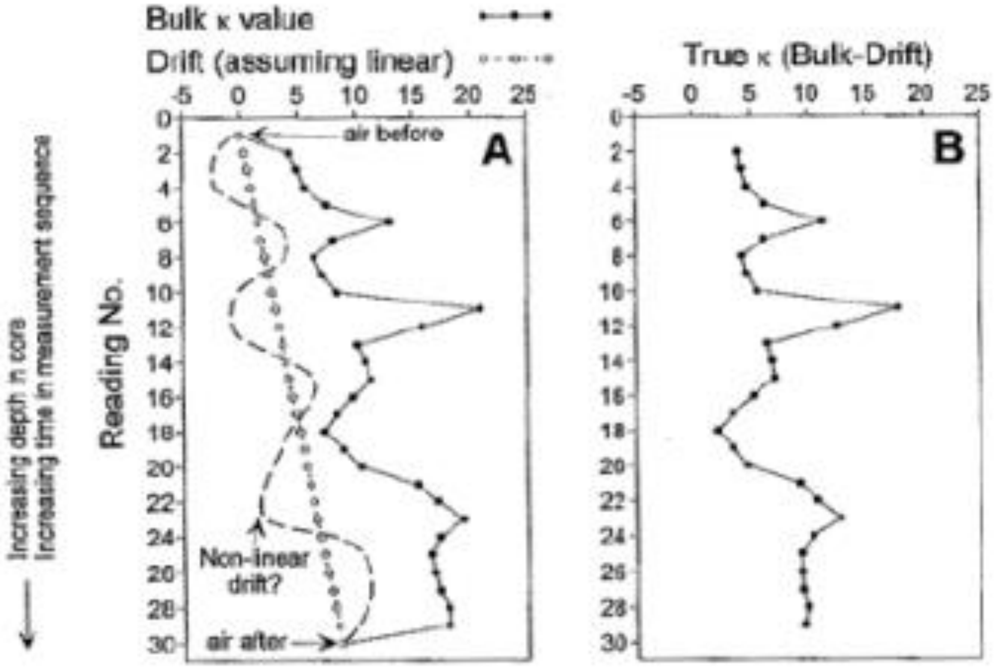


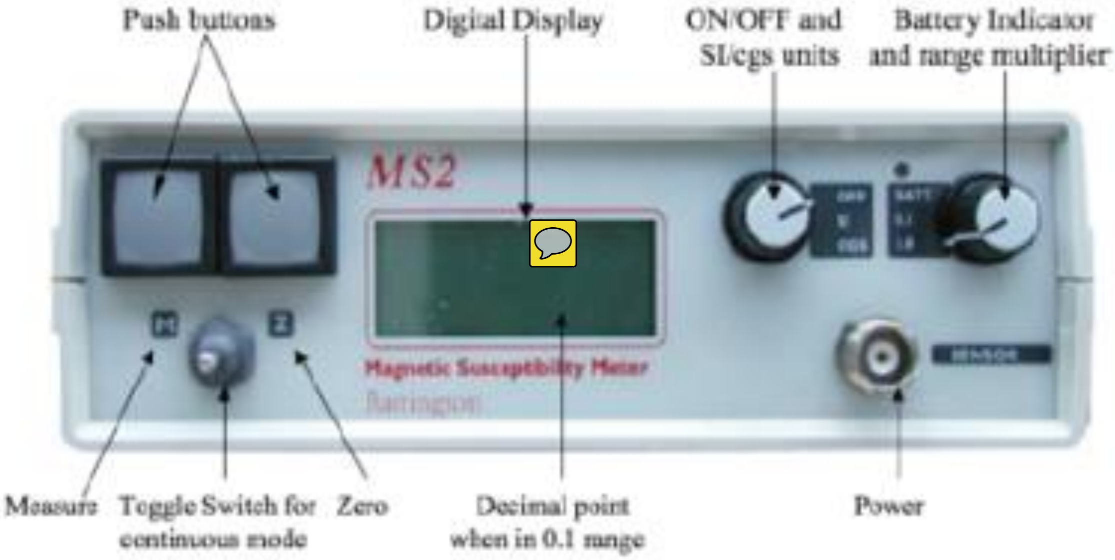
Fig. 4.5 Measuring continuous core susceptibility in the presence of significant equipment drift in air readings; a) measurements of air (before and after) and core intervals, showing interpolated air readings; b) corrected core readings (reading minus interpolated air reading assuming linear drift).

Choice of measurement interval is important and depends on the core material, the diameter of the core in relation to the sensor, and the nature of the study. In practice, optimum intervals between measurements are 30-50 mm; very small intervals will provide a highly smoothed and possibly meaningless data set. A graph in the manufacturer's instructions (Graph 2) shows the response to a section of core passing through a sensor. A couple of points are worth noting. The sensor may be sensitive to material up to one coil diameter away from it, thus for a 60 mm sensor, material over a 120 mm section may contribute to the reading. There is an optimum length of core where the coil is sensitive to 70% and more of the material's susceptibility (as shown in the graph) which is about a quarter of the coil diameter, i.e. 15 mm for a 60 mm sensor. But this data assumes homogeneous materials and a core which is 0.85 of the coil diameter. Overall, the user should try different measurement intervals and evaluate the effectiveness of each.

Different diameters of cores measured on the same sensor will give different results, even if the material is identical. If you need to compare data in different diameter cores, graph 1 in the manufacturer's instructions will help. It shows, for instance, that κ values for a core which is 0.65 of the diameter of the sensor coil will be half those for a core which is 0.85 of the coil diameter.

A final point to consider are the end-effects. Readings will normally reduce towards the end of a core because the sensor will be measuring both core and air. Inspection of Graph 2 in the manufacturer's instructions shows that a measurement made with the sensor over the last 10 mm of core will be reduced by 50%. This is the maximum error. However, it is difficult to estimate mathematically the effect for sections near the end of the core in non-homogeneous material. Graph 2 suggests, and experience confirms, that accurate measurements cannot be made within a zone of core length equivalent to one half of the sensor's diameter from the end of the core. For example, with a 60 mm sensor, measurements should not be made within 30 mm of the end of the core. Rarely, where the core is composed of strongly diamagnetic material, such as wet peat, there may be an increase at the end of the core as the diamagnetic effect is lost.

The MS2 meter display panel



8.A2- Additional information:

8.A2.1 Steps in Sampling (Smol, 2002):

1. Choice of study site- based on a specific problem such as contamination.
2. Selection of coring sites- only a few, analysed in detail. Must be representative= best areas are deep, flat and central.
3. Collection of sediment cores- choice in equipment will depend on site.
4. Section the sediment core- how will sediment be appropriately sectioned into temporal slices?
5. Dating the profile- radio carbon dating or looking at geological trends from other records?
6. Proxy data – physical , chemical, biological.
7. Interpreting proxy data- construction of transfer functions, using surface sediment calibration or training sets.
8. Presentation of data- professional and effective.

8.A2.2 Notes from interview with O'Sullivan and David McKeown:

- Flood risk – St johns road.
- Currently they pump water out of Loe pool into the sea in heavy events. Pool less than 5m is required.
- Toy- 102 petition for king to use grewick to tin – had been or years and year and therefore by 1302 Helston had already been silted up long before this.
- Bar is composed of alternating coarse and fine layers of shingle. Granular material. Bar could therefore be a storm event.
- 1400 breaching cycle every 4 to 6 yeas/
- 1795- Tunnel in pool was cut. This also release a lot of sediment with results in the bar from not being permeable. Can see layers of haematite in the bar.
- 180 Cornish mining. Porkellis united mine main source of sediment. Weir pool may not have been big enough.
- As bar migrated in land it can get higher due to the max angle on the sea side. Still migrating in land at the moment.
- 1758 account- just before mining began mining sediment – filled in North side – started to fill in the deeper side.
- Haematite does come from Porkellis. - One particular load of tin.
- Big effect of mining has made the bar as big as it is.
- Sediments in Loe pool is an SSSI due to the laminations.
- Potential future tin mining as values of tin is shooting up.
- Hematite layer is thicker at the north than near the bar as sediment is coming from the bar in this section as well. It is like sedimentation in a reservoir/. Catchment to area ratio is huge.
- When they stopped cutting it would grow better. Bar then became such that it didn't naturally breach.
- Black layer- non-oxidation.
- Grey layer- mixing.
- Sediment change when lake was deep enough to be stratified. 1988/89 upgraded the tunnel by SSW. 2012- Work done by EA.
- Pumping in the long term may not be effective. History of bar breaching would be useful. 1984 breach by the machine was a lot bigger- left a bold patch on the bar.
- Build the houses on the floodplain in the early 19th century.
- By the bar is really dangerous part of swimming area as can't get out.
- Must keep discharge down as when it builds up it floods Helston.
- They would breach the bar but now can't due to being an SSSI.
- Sea only goes until 'step' exevation by the sea. My core is after a step on the other side- hence why I managed to get 3m.
- Total soluble phosphorus.
- Heavy metals- can't directly compare due to different methods- looks only at soluble component. Crystalline not measured.

8. A2.3 Inferred dates

Dates for every cm of core using the statistic described in the discussion:

Depth	Date	Depth	Date	Depth	Date	Depth	Date	Depth	Date
0	2012	49	1937.37	98	1924.16	147	1892.52	196	1861.16
1	2010	50	1937	99	1923.52	148	1891.88	197	1860.52
2	2008/9	51	1936.95	100	1923	149	1891.24	198	1859.88
3	2007	52	1936.74	101	1922.24	150	1891	199	1859.24
4	2005/6	53	1936.53	102	1921.6	151	1890.36	200	1859
5	2004	54	1936.32	103	1920.96	152	1889.72	201	1858.36
6	2002	55	1936.11	104	1920.32	153	1889.08	202	1857.72
7	2000/1	56	1935.9	105	1919.68	154	1888.44	203	1857.08
8	1999	57	1935.69	106	1919.04	155	1887.8	204	1856.44
9	1997/8	58	1935.48	107	1918.4	156	1887.16	205	1855.8
10	1996	59	1935.27	108	1917.76	157	1886.52	206	1855.16
11	1994	60	1935	109	1917.12	158	1885.88	207	1854.52
12	1992/3	61	1934.85	110	1917	159	1885.24	208	1853.88
13	1991	62	1934.64	111	1916.36	160	1885	209	1853.24
14	1989	63	1934.43	112	1915.72	161	1884.36	210	1853
15	1987/8	64	1934.22	113	1915.08	162	1883.72	211	1852.36
16	1986	65	1934.01	114	1914.44	163	1883.08	212	1851.72
17	1954/5	66	1933.8	115	1913.8	164	1882.44	213	1851.08
18	1983	67	1933.59	116	1913.16	165	1881.8	214	1850.44
19	1981	68	1933.38	117	1912.52	166	1881.16	215	1849.8
20	1980	69	1933.17	118	1911.88	167	1880.52	216	1849.16
21	1978	70	1933	119	1911.24	168	1879.88	217	1848.52
22	1976/7	71	1332.75	120	1910	169	1879.24	218	1847.88
23	1975	72	1932.54	121	1909.36	170	1878	219	1847.24
24	1973	73	1932.33	122	1908.72	171	1877.36	220	1846
25	1971/2	74	1932.12	123	1908.08	172	1876.72	221	1845.36
26	1970	75	1931.91	124	1907.44	173	1876.08	222	1844.72
27	1968/9	76	1931.7	125	1906.8	174	1875.44	223	1844.08
28	1967	77	1931.49	126	1906.16	175	1874.8	224	1843.44
29	1965	78	1931.28	127	1905.52	176	1874.16	225	1842.8
30	1964	79	1931.07	128	1904.88	177	1873.52	226	1842.16
31	1962	80	1931	129	1904.24	178	1872.88	227	1841.52
32	1960	81	1930.65	130	1904	179	1872.24	228	1840.88
33	1958/9	82	1930.44	131	1903.36	180	1872	229	1840.24
34	1957	83	1930.23	132	1902.72	181	1871.36	230	1840
35	1955/6	84	1930.02	133	1902.08	182	1870.72	231	1839.36
36	1954	85	1929.81	134	1901.44	183	1870.08	232	1838.72
37	1952	86	1929.6	135	1900.8	184	1869.44	233	1838.08
38	1950	87	1929.39	136	1900.16	185	1868.8	234	1837.44
39	1949	88	1929.18	137	1899.52	186	1868.16	235	1836.8
40	1948	89	1928.97	138	1898.88	187	1867.52	236	1836.16
41	1946	90	1929	139	1898.24	188	1866.88	237	1835.52
42	1944	91	1928.53	140	1897	189	1866.24	238	1834.88
43	1942/3	92	1927.89	141	1896.36	190	1865	239	1834.24
44	1941	93	1928	142	1895.72	191	1864.36	240	1833
45	1939/40	94	1926.72	143	1895.08	192	1863.72	241	1833.6
46	1938	95	1926.08	144	1894.44	193	1863.08	242	1833
47	1937.79	96	1925.44	145	1893.8	194	1862.44		
48	1937.58	97	1924.8	146	1893.16	195	1861.8		