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# 4.1.1. Coring Methods

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ABSTRACT: Coring operations are an essential element in studies seeking to complement surface landform evidence with a more continuous record of landscape change. Site assessment and the choice of coring location within a basin is an important first step in any coring task. A set of established tools and techniques are available for coring operations that seek to minimise the disturbance to material during extraction and maximise the potential for long and continuous records. The choice of tools will depend largely on the coring environment and remoteness of the site. Importantly, there is no universal tool available for any coring task and, commonly, multiple pieces of equipment are required to extract a continuous record. This contribution seeks to outline the process of planning a coring operation, detail the advantages/disadvantages of the various piston, gouge and Russian style corers available and highlight the various conventions used for the reporting of results.

KEYWORDS: coring, sediment Sampling, palaeo-environmental, reconstruction

## Introduction

The discipline of geomorphology is largely concerned with the understanding of earth surface process and the origin/interpretation of landform assemblages. Despite this, it is often the case that a more continuous record of landscape development is required. The accumulation of sediments and organic materials over time forms multiproxy archives of palaeoecological, sedimentological and/or hydrological change within a catchment or landscape. Additionally, detailed investigation of subsurface stratigraphic horizons can be used to understand the depositional settings and interrelationships of surface landforms. In the absence of exposed sedimentary cross sections, for example in river terraces or during construction works, suitable material must be retrieved by means of coring. A typical coring task involves careful planning, with the diverse range of environments suitable for coring activities each presenting a unique challenge in terms of operation and equipment selection. For example, coring in more remote locations is often limited in terms of achievable depth by the amount of equipment required and the feasibility of effectively transporting samples from the site, as is the case in many arctic or high altitude settings.

This paper aims to highlight the various challenges, and potential pitfalls of any coring task. The key stages of planning, equipment operation and transport of material will be addressed. The focus for this paper will be on coring in terrestrial and lacustrine environments. For marine, deep sea and ice coring, the reader is referred elsewhere.

## Site Assessment

### Geomorphological Assessment

In many studies, an important first step is to determine the potential sources of material accumulating within the depositional setting e.g. fluvial systems, talus cones, dirty snow avalanches, debris flows etc. Therefore, geomorphological mapping (See Otto and Smith 2014) of the immediate catchment is an important first task in any coring activity. To avoid disturbed records, sites close to steep slopes or obvious mass movements, avalanche tracks and across floodplains where evidence of meandering has taken place in the past should be avoided. Following this, the preservation potential of sediments can be estimated at sites within the chosen accumulation basin.

Another consideration for site selection is to ensure that access is granted from the relevant land owner and permission sought from the relevant agency if the site is designated as protected. It is vital to ensure that there is no risk of damaging any subsurface utilities (gas, electricity etc.). This can be done by consulting the relevant up-to-date local utilities map.

## Lacustrine Sediment Preservation

Preservation in lacustrine environments is governed by both biotic and abiotic processes. For reconstructing palaeo-environments from organic sediments, it is important to consider changes to the primary signal through degradation of material in the water column as well as post depositional diagenesis. In the water column, organic material is subject to degradation through oxidisation. Lehmann *et al.* (2002) show how the carbon and nitrogen isotopic composition of lake sediments, typically measured as palaeo-climate indicator, varies with oxygenation level whereby preservation is enhanced under anoxic conditions. Similarly, lipid biomarkers, such as alkenones often used to infer a wide range of palaeoclimatic conditions, can be affected by prolonged oxygen exposure and microbial degredation (Rontani *et al.* 2013). As such, investigations using such methods can benefit by targeting coring in certain depositional environments. For example, shallower settings with shorter residence times have greater potential for the preservation of organic deposits (Meyers and Ishiwatari 1993). As discussed below however, such shallow settings can be prone to sediment re-suspension, encouraging post-depositional oxidisation of material and further degradation. On the lake bed, sediments can be subject to bioturbation which involves the disturbance through the movement and burrowing of benthic organisms. Typically, this occurs within the top 10cm of deposits and can result in a temporal smoothing of the sequence as stratigraphic layers are overturned. Benthic organisms require dissolved oxygen to survive, meaning that anoxic conditions, largely found in eutrophic environments, significantly reduce the risk of biotubation in sediments (Meyers and Ishiwatari 1993).

In terms of abotic factors, wave action and wind driven turbulence within the water column play a key role in the redistribution of fine grained sediments on the lake floor. The significance of such processes depends on both wind speed and fetch (Meyers and Ishiwatari 1993). Basins protected by surrounding topography and those that are deep with small surface areas offer the greatest protection from wave action. Re-suspension also depends on the critical sheer stress of the sediment bed in question, with recently deposited material being re-suspended more easily than that which is more compacted. Such processes have been observed to produce highly variable sediment distribution in lakes. During storms, wind driven turbulence can be responsible for eroding near shore material and transporting it towards deeper parts of the lake (Bengtsson *et al.* 1990). Careful consideration of wind driven redistribution is therefore necessary on exposed lakes where sedimentary chronologies may be disrupted, even in accumulation zones. Colluvial processes such as slumping and turbidity currents also have the potential to disrupt lacustrine sedimentary sequences through the erosion and re-deposition of thick sedimentary units. Turbidity flows are benthic currents induced by dense inflows laden with high suspended sediment loads (Meiburg and Kneller 2010). The density difference between inflow and ambient lake waters can cause the inflow to continue as an erosive current along the lake bed. The current may subsequently separate from the lake bed at depth if the density of the ambient water becomes greater than that of the current. Shallower settings with steep sided delta faces are more prone to erosion through turbidity currents and are more common in settings that are fed by fluvial networks with a high suspended sediment load, such as pro-glacial environments.

The difficulties outlined above can be overcome in some cases by sampling at multiple locations to bridge erosional gaps in the sequence and gain a fuller understanding of sediment distribution throughout the basin. The number of coring locations targeted will be dependent on the logistical constraints of the site. However a single core approach is rarely sufficient to identify a representative stratigraphy. For larger lakes, sub-basins should be considered as part of a sampling strategy that targets wide, flat and deep areas that are distant to the lakeshore. Other processes such as the occurrence of dropstones or thick volcanic ash layers have the potential to introduce errors in the age depth relationship of a sequence, although these processes tend to occur more widely throughout the basin and are largely unavoidable. Ground penetrating radar (GPR; see Robinson *et al.* 2013) or seismic investigations make it possible to map the distribution of sediment within a basin, helping to determine the most suitable coring site. Analysis using radioisotopic profiles from short cores can provide an opportunity to assess the disturbance of recent sediments before a more comprehensive coring operation takes place, however this is not always practical due to time constraints.

### Preservation of Bog and Wetland deposits

Paus (2013) identify soil erosion as a major potential source of error in palaeoenvironmental investigations. In bog or wetland settings, soil erosion can be a consequence of deforestation, agriculture and peat cutting. The erosion, transportation and deposition of old sediments may introduce errors in the age depth relationship and as well as foreign or reworked proxy material. Soil erosion is substantially increased in areas with human presence, and as such, the study of sediments deposited since the mid-Holocene can be particularly susceptible.

Borehole transects using basic gouge auger tools (outlined in the next section) are often conducted to develop a three dimensional understanding of the subsurface stratigraphy prior to recovery of sequences for detailed analysis. This step is crucial for determining the most complete and representative sequence of deposits for analysis.

## Equipment Selection

Equipment selection is determined in large part by the coring environment (bog, floodplain, lake etc.), the nature of the material being extruded and site accessibility. A wide range of equipment available, each offering advantages in terms of transportability, operating depth and sample length (Table 1). Typical requirements for coring in remote locations include reliability, modular designs and air/sea freight capability (Kelts *et al.* 1986). The advantages and disadvantages of a range of equipment will now be described. For more detailed instructions regarding the operation of the equipment described here, the reader is referred to the references provided.

### Gouge Auger

Gouge augers are easily transportable tools that permit relatively quick survey of subsurface sediments in terrestrial environments. Sampling is particularly rudimentary and involves thrusting a semi cylindrical chamber into deposits and twisting the device using a handle at the surface to capture the sample. Consecutive drives are enabled by the addition of extension rods.

*Table 1: Summary of equipment available for coring tasks*

| Device | Number of operators | Max depth (m) | Section length (m) | Reference(s) |
|---|---|---|---|---|
| Gouge Auger & ‘Russian’ Corer | 2 | 10-15 | 0.5, 1 | Franzén and Ljung (2009) |
| Rod operated Piston Corer | 3 | <30 | 1-5 | Livingstone (1955); Kelts *et al.* (1986); Mingram *et al.* (2007) |
| Wire operated Piston Corer | 3 | >100 | 1-6 | Nesje (1992); Chambers and Cameron (2001) |
| Mackereth | 2 | >100 | 2, 3, 6 | Mackereth (1958); Barton and Burden (1979) |
| Surface samplers | 1 | >100 | ~1 | Wright (1980); Blomqvist (1985); Glew *et al.* (2001); Larsen *et al.* (2011) |

The retrieved sample is subject to significant disturbance as the open chamber is prone to resampling of material from depths above those required especially where sands underlie the softer organic material above. Additionally, more-consolidated material can force its way upwards over less consolidated horizons within the chamber. For these reasons, it is not recommended that the gouge auger is used to retrieve samples for analysis. However, such equipment is suitable for developing a first order approximation of the three dimensional stratigraphy of a sedimentary basin, bog or mire by conducting multiple boreholes in transect. This can be done rapidly over a wide surface area with a minimum of two operators.

## ‘Russian’ Peat Corer

The Gouge auger is often used in tandem with a ‘Russian’ peat corer which is capable of retrieving largely undisturbed samples from organic material or fine-medium grained clastic sediment. The corer consists of a half barrel which pivots around a flat ‘fin’ plate (Franzén and Ljung 2009). The chamber is inserted in an open position, relative to the ‘fin’ plate (Figure 1a), and subsequently closed at the required depth to capture the sample (Figure 1b). Care must be taken to ensure that the chamber is fully closed to avoid contamination.

Russian corers can be used in both unsaturated and semi-saturated environments, however overly saturated material is difficult to sample as the core is not retained in its own sample tube and instead must be transferred from the fin plate to a suitable container for transportation. Russian corers have been extensively used in terrestrial studies in peat bog, marshland and coastal environments (e.g. Dawson *et al.* 2004; Jordan *et al.* 2010; Long *et al.* 2011; Schofield and Edwards 2011; Long *et al.* 2012). The base 15-20cm of sedimentary basins can be difficult to sample due to the ‘nosecone’ of the Russian corer. Also, the system can be heavy making transport to remote sites difficult.

*Figure 1: Russian Peat Corer. (a) The corer in an ‘open’ position with detachable extension rods and sections of plastic guttering for transporting samples, (b) A sample collected with the chamber now in a ‘closed’ position. Photographs courtesy of S. Dawson*

## Piston Corer

‘Piston’ type corers are specifically designed for the extraction of saturated sediments without significant disturbance to the sample. Such corers are largely based on the Kullenberg design (Emery and Broussard 1956) used in marine coring. This involves driving a metal or plastic sample tube into sediment over a fixed-position ‘piston’ which acts to maintain a vacuum below it, reducing deformation and holding the sample in place as it is extracted (Figure 2). Several modifications to the Kullenberg design have

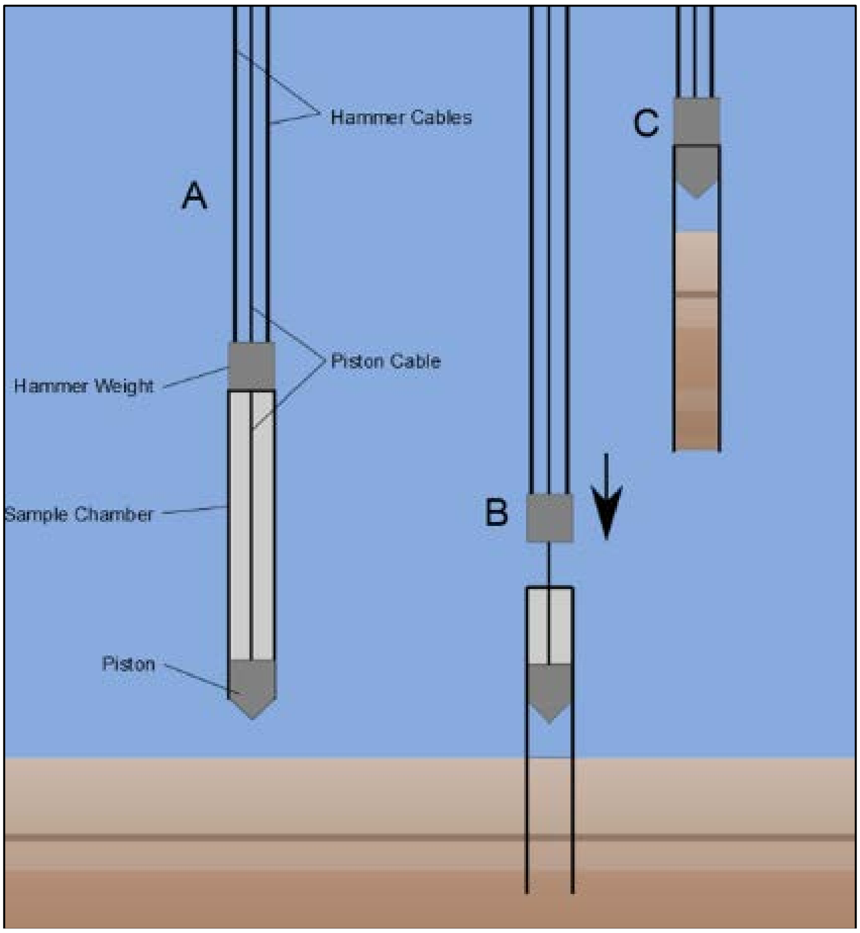


*Figure 2: Wireline piston corer operation. A) The device is submerged and lowered to a short distance above the sediment water interface. B) The piston wire is secured at the surface before the sample chamber is hammered into the sediment below the fixed position piston. C) The system is raised to the surface with the sample retained in a vacuum below the piston.*

been proposed over the years. Originally Livingstone (1955) adapted the marine corer for use in shallow lacustrine environments, using extension rods to manually drive the coring chamber below the fixed-piston.

Despite the success of this device, the use of extension rods increases the total weight of the system, making coring in remote locations difficult and limiting the reasonable operating depth to 20-30m. To overcome this, several wireline systems have been developed which use a weighted hammer that can be raised and dropped to drive the coring chamber into the sediment (e.g. Kelts *et al.* 1986; Fisher *et al.* 1992; Nesje *et al.* 2008) Such wireline systems are capable of retrieving samples in excess of 100m water depth, however this is generally limited to a single coring drive due to difficulties associated with penetrating the same bore hole at great depth multiple times. The length of sample retrieved using a single drive can be increased by lengthening the coring chamber, however this increases flexibility of the chamber, especially of those manufactured from PVC, meaning that much of the driving force is lost through flexing (Nesje 1992). The typical maximum coring drive for such systems is approximately 6m.

Piston coring systems have typically been used in lacustrine environments where they are capable of retrieving samples that maintain the integrity of fragile sedimentary structures, such as varves (e.g. (Moore *et al.* 2001; Snowball and Sandgrena 2002), as well as penetrating through thick sequences of glacio-fluvial diamicton and clay. Additionally, they have been used in terrestrial settings where the addition of a sharp cutting mouth at the end of the core barrel helps to penetrate through layers of wood and fibrous peat (Wright Jr *et al.* 1984; Mingram *et al.* 2007). Difficulties using piston corers typically involve the upward displacement of the piston during retrieval, causing the sample to be drawn upwards inside the core barrel resulting in sediment disturbance. Disturbed or compressed sequences are evident based on comparison between the length of sample retrieved and the recorded depth of penetration during the coring task. Several recovery systems that minimise the potential disturbance to the sample have been proposed (Chambers and Cameron 2001; Mingram *et al.* 2007). In deep-water environments, ridged casing can be used to prevent excessive bending of extension rods and to guide the corer to the borehole location for consecutive drives, however such casing is heavy, expensive and of limited use in remote locations (Livingstone 1955; Mingram *et al.* 2007).

A regularly cited advantage of piston corers is that they are capable of retrieving the sediment-water interface intact. However in most cases the excessive force required to sample longer sequences disturbs the uppermost sections of the sample. As such, piston corers are typically used alongside surface samplers, dredges and box corers that have proven to be more effective tools for this purpose.

## Mackereth Corer

Mackereth type corers use a Kullenberg style fixed-piston in a similar manner to the generic piston corers discussed above (Figure 2). However, the method of driving the coring chamber below the fixed-piston is fundamentally different. The Mackereth corer relies on a large cylindrical anchor drum to stabilise the system on the lake bed. The anchor drum is coupled to a main coring barrel, inside which, a retracted coring chamber rests (Figure 3). Compressed air is fed by the operator at the surface through high pressure tubes into the main barrel above the coring chamber. This increases pressure above the coring chamber, forcing the coring chamber below the fixed piston and into the sediment. Once the chamber is fully extended, the compressed air is then redirected into the anchor drum, creating buoyancy that lifts the entire system towards the surface. A key advantage of the Mackereth corer is that it can be used with relative ease in deep-water, limited largely by the hydrostatic pressure at the lake bed that must be overcome to return the equipment to the surface.

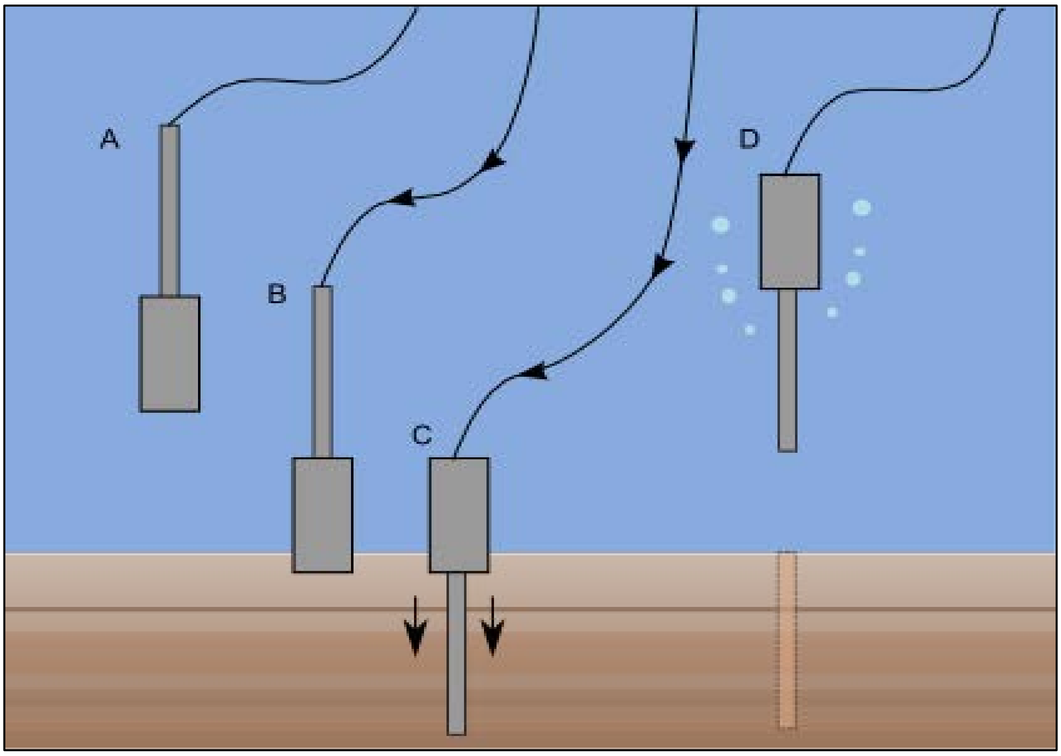


*Figure 3: Mackereth corer operation. A) The device is submerged and falls under its own weight to the sediment water interface B) The system anchors itself into place as the anchor drum penetrates the sediment. C) Compressed air used to drive the coring chamber below a fixed position piston. D) Once the chamber has fully extended, air is diverted into the anchor drum, creating buoyancy that lifts the system to the surface.*

Notable disadvantages are that the device is not always capable of capturing full sequences. This occurs when the frictional force of sediment on the coring barrel exceeds the force required to displace the anchor drum from the bed. This results in the full extension of the coring chamber from the main barrel, returning the system to the surface. The equipment is generally heavy, requiring multiple containers of compressed air and is therefore not suitable for extremely remote locations. However smaller, more portable versions are available.

## Surface Samplers

For sampling of the sediment-water interface, several tools are available. Nearly all surface samplers rely on gravity for penetration into sediment. Sampling in this way can be susceptible to fine grained sediment washout caused by the influence of bow waves as the device approaches the sediment water interface. For this reason, it is recommended that gravity driven surface samplers are lowered to a short distance from the sediment water interface before being allowed to fall under their own weight. However, some tools include diode type features that allow for water to pass through during descent with rubber flaps that act to maintain the sediment sample during ascent.

Grab samplers typically consist of a set of jaws that can be closed by triggering a release mechanism with a messenger weight to capture sediment at the surface. Similarly, Box corers are open sampling boxes that cut into the sediment and are closed from below as the sample is lifted (De Groot *et al.* 1982). Such tools are principally used for collecting large volumes of sediment over a wide surface area. Box corers have the advantage of retrieving samples in a relatively undisturbed state. However in particularly consolidated sediment, the locking mechanism on box corers may fail to close fully resulting in the loss of sample. Grab samplers are more suited to this purpose, with the downside however of significant sample disturbance. Due to the heavy combined weight of sample and device, large volume grab samplers require a substantial raft platform with suitable counter-balance for operation. Such samplers are only suitable for a general assessment of the sediments and do not preserve lithological boundaries.

Freeze coring offers an opportunity to preserve delicate sedimentary structures at the sediment water interface (Kulbe and Niederreiter 2003). Such corers commonly use a mixture of dry ice and ethanol that is circulated around the inside face of a stainless steel wedge to freeze the sediments *in-situ*. Freeze coring devices require a power source and a supply of cooling agents in the field as well as a cooling box for the transport of the frozen samples from the field to the laboratory. As such they are not suitable for remote sites.

Other surface sediment corers include designs that maintain the sample in a coring chamber through the messenger triggered deployment of a suction cup at the head of the device. This creates a vacuum, capable of holding fine grained, consolidated sediments. The waterlogged sediments can then be subsampled for transport using an extruder device (Figure 4). Such systems suffer similar problems in terms of the bow wave induced washout of surface fines, however they tend to be lightweight, modular and therefore more suitable for remote field sites.

*Figure 4: Subsampling of a surface core at Hämelsee, Germany, using an extruder device. Photography courtesy of W. van der Bilt.*

### Additional Equipment

In addition to the tools described above, it is advisable to be equipped with a series of cutting tools, tape measures, waterproof writing utensils and safety equipment. Sharp knives or cheese wire can be used to separate the core from the sampling plate when using the Russian Corer. A hacksaw can be used to cut lengths of PVC core liner pipe for the piston style corers. Waterproof gloves should be used to protect the hands from sharp objects and from getting cold. A back brace may also be necessary for heavy lifting.

When coring in lacustrine or shallow marine environments a raft or boat is often necessary, for which several designs are available. Many raft designs are also modular, meaning that they can be transported with relative ease to remote locations and assembled on site. Some rafts make use of foam blocks for buoyancy (e.g. Figure 5), while others are simply metal, wooden or plastic platforms strapped to a Zodiac-style inflatable boat. It is important to ensure that the chosen raft has sufficient buoyancy for the extraction of deep sediment cores, as the core can only be extruded when the force of the raft buoyancy exceeds that of the friction and vacuum-suction acting on the coring chamber. Many rafts are mounted with a tripod and winch system which can make the extraction of heavy samples easier.

*Figure 5: Coring from an isopore block raft platform, SE Greenland.*

Critically, there is no universally applicable tool that is suitable for any environment or coring task. As described above, the nature of the sedimentary material and accessibility of the site play a large part in the selection of equipment. More often than not, a combination of equipment is required to retrieve a full, undisturbed sequence.

## Coring Procedure

The coring procedure should follow a systematic approach. In lacustrine settings, the water depth should be measured using an echo-sounding device or weighted rope measure. In settings with a particularly diffuse sediment water interface, the true water depth can be difficult to judge. When coring, a duel or triplicate core approach should be used to cover boundaries between core sections. Care should be taken to accurately record the penetration depth which should be compared against the depth of material sampled to identify any compression/ loss of material. The location of boreholes should be measured with GPS and levelled according to a known datum if necessary.

It is good practice to photograph and record basic characteristics of key sedimentary horizons in the field while the sediment is fresh. This way any major disturbances during transport can be identified. There are several classification schemes for doing this, (e.g. Troels-Smith 1955; Barnston and Livezey 1987; Schnurrenberger *et al.* 2003). Often however, cores are maintained in their PVC casings until they are opened in the laboratory. Finally, it is important to know if the samples retrieved represent a full record of deposition at the site. Therefore it is important to record, and report in any publication, whether or not the base of the depositional basin is believed to have been reached.

For transport, cores collected in full PVC liners should be plugged at either end using ‘oasis’ floral foam or ‘sodium polyacrylate’ gel which will fill any excess water or air space in the core tube. The cores should then be sealed using a tight fitting cap and secured with waterproof tape. Importantly, core samples intended for further analysis, such as luminescence dating, should be collected in opaque core liners and not opened until in a light secure environment. Lacustrine sediments should be maintained in an upright position for as long as possible during transportation to minimise sediment disturbance (Figure 6). It is possible to freeze cores for transportation, however ice crystal growth can potentially disrupt fragile sedimentary features. For cores collected using a 'Russian' peat corer, the sample can be transferred into half sections of PVC guttering and secured with appropriate packing material (paper or plastic wrap if the samples are to radiocarbon dated) to soak up excess water before being wrapped in plastic wrap for transportation.

*Figure 6: Storage of cores in the field can be difficult. Here, cores are strapped to a boulder in an upright position in order to allow the sample to settle.*

## Conclusion

In conclusion, sediment coring represents an essential and useful technique to complement surface geomorphological investigations. A wide variety of tools have been developed to allow coring in increasingly diverse and remote locations. The choice of equipment will be governed largely by the nature of sediments to be cored and the accessibility of the site. The methods and tools available for coring will continue to evolve as we seek to develop longer and better preserved sedimentary records.

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