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Coring and sub-sampling of peatlands for palaeoenvironmental research

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SUMMARY

Every palaeoenvironmental, palaeoecological and palaeogeochemical study of a peatland begins with coring or section sampling and sub-sampling. This first step in a peat-based palaeoenvironmental study is the most crucial, as a high-quality investigation can be achieved only from a foundation of high-quality stratigraphic sampling and sub-sampling. Various techniques for coring, sampling and sub-sampling are described, aiming to: (a) provide the reader with an overview of existing approaches and techniques; (b) offer guidance on good practice for achieving high-quality results efficiently; and (c) standardise the methodology in order to achieve comparable sequences and samples for future multiproxy, multi-site and multi-core projects.

KEY WORDS: ombrotrophic mires, peat, peat monoliths, sample contamination.

1. INTRODUCTION

Every palaeoenvironmental, palaeoecological and palaeogeochemical study on a peatland begins with coring or section sampling and sub-sampling. This first step in a peat-based palaeoenvironmental study is the most crucial, as the quality of the stratigraphical sampling and sub-sampling lays the foundation for the quality of the whole investigation. Various techniques for coring, sampling and sub-sampling are detailed here, not only to provide the reader with an overview of existing techniques, but also to standardise the methodology in order to achieve comparable sequences and samples for future multiproxy, multi-site and multi-core projects. We suggest that anybody wishing to carry out such a study should apply the standards outlined here; not only to guarantee clean work, high efficiency and quality, but also to establish a better basis for comparisons between studies.

2. SITE SELECTION

Site selection is crucial in palaeoenvironmental studies. This section provides background information about site features, together with some pointers for selecting a suitable site and the best location within a site. However, the locations from which peat samples are ultimately collected must be chosen on a case-by-case basis because every site is different.

The composition of peat is highly variable (Clymo 1983). It is generally composed of at least 65% organic matter (dry weight basis) and less than 20–35 % inorganic material (Clymo 1983, Charman 2002), and may be up to 95–99% organic. Some of this variety arises from differences between peatland types. On the basis of genesis, vegetation and hydrological functioning, peatlands can be divided into two main categories, namely “ombrotrophic peatlands” and “minerotrophic peatlands”; these are also known, respectively, as “bogs” and “fens”. Of course, many intermediate types can be found. For example, a mire forming at the edge of a lake may develop hummock complexes and thus become partly ombrotrophic with zones corresponding to different stages of succession: from the shoreward ombrotrophic area, through a minerotrophic area including floating vegetation mats, which finally give way to open water. Ombrotrophic peatlands are isolated from any supply of groundwater and/or streamwater, and so are fed exclusively by atmospheric inputs such as rain, snow, fog, dust and ash unless these are supplemented by faecal material and urine from grazing animals. Their vegetation is generally dominated by *Sphagnum* species and includes other bryophytes, monocotyledons and dwarf shrubs; although in some parts of the world they have very different vegetation, as in the Restiad-dominated peatlands of New Zealand (e.g. Clarkson *et al*. 2004) and the tropical peatswamp forests of south-east Asia (e.g. Shepherd *et al*. 1997). They are acidic, with a pH range of 3–5.5 (Wheeler & Proctor 2000), and the ash content of their peat is <5% of dry weight. Minerotrophic peatlands similarly receive inputs from the atmosphere, but these are augmented by streamwater and/or groundwater which has been in contact with soils and/or rock in the surroundings and thus may have acquired some chemical buffering capacity. Compared with bog peat, the ash content of fen peat is often higher (up to 35% of dry weight), as is pH (range 5.5–8). The vegetation of fens varies widely. For example, the vegetation of some north-west European fens is characterised by the quasi-absence of *Sphagnum* and has instead abundant *Equisetum* spp., *Carex* spp., *Menyanthes trifoliata* and *Molinia caerulea* (Charman 2002); whereas others are dominated by *Sphagnum* spp. and sedges (e.g. Lamentowicz *et al*. 2007) but remain hydrologically dependent on groundwater (e.g. Dempster *et al*. 2006).

Ombrotrophic peatlands are efficient particle traps for materials originating from the atmosphere such as dust, pollen and volcanic ash. This makes them excellent archives of past climatic, environmental and/or anthropic changes. Moreover, the slow decay of vegetation under anoxic conditions guarantees that most of the plant material comprising the peat is in a sufficiently good state of preservation to be identified. Numerous studies have demonstrated their potential as records of vegetation succession in terms of palaeoecological (e.g. Vincens *et al*. 2003, Davis & Stevenson 2007), palaeoclimatic (e.g. Finsinger *et al.* 2006, Tinner & Lotter 2006) or fire (e.g. Asselin & Payette 2005, Davis & Stevenson 2007) indicators.

Because of the characteristics outlined above, ombrotrophic peatlands should always be preferred to minerotrophic peatlands when one intends to carry out a (multi-) proxy climate or human impact reconstruction.

Once the site has been selected, it is important to determine the precise location(s) where coring will be carried out. The surface of a bog is often far from uniform, and its micro-scale variability can play a significant role in determining the sensitivity of a peat record. The two most readily identified surface microforms are hummocks and hollows. Hummocks characteristically lie above the mean surface level and are composed of terrestrial and/or fast-growing *Sphagnum*, plus sedges and dwarf shrubs (a typical assemblage for the circumboreal zone is *S. fuscum* with *Calluna vulgaris*, *Eriophorum* spp., *Vaccinium oxycoccus*, *Erica* spp. *etc.*). They are generally isolated from the water table and any surface runoff. Hollows are depressions that are often wet, and sometimes present as pools containing standing water in which aquatic plants and other species adapted to these conditions (e.g. *Sphagnum* Section *Cuspidata*) can grow. Generally, the locations of individual hummocks and hollows change little through time (Barber 1981, Van der Molen & Hoekstra 1988), but their interfaces do vary, becoming wetter and drier in response to fluctuations in climatic conditions (Figure 1). Therefore, the most sensitive stratigraphical record will be found between a hummock and a hollow; and cores should, ideally, always be taken from such locations.

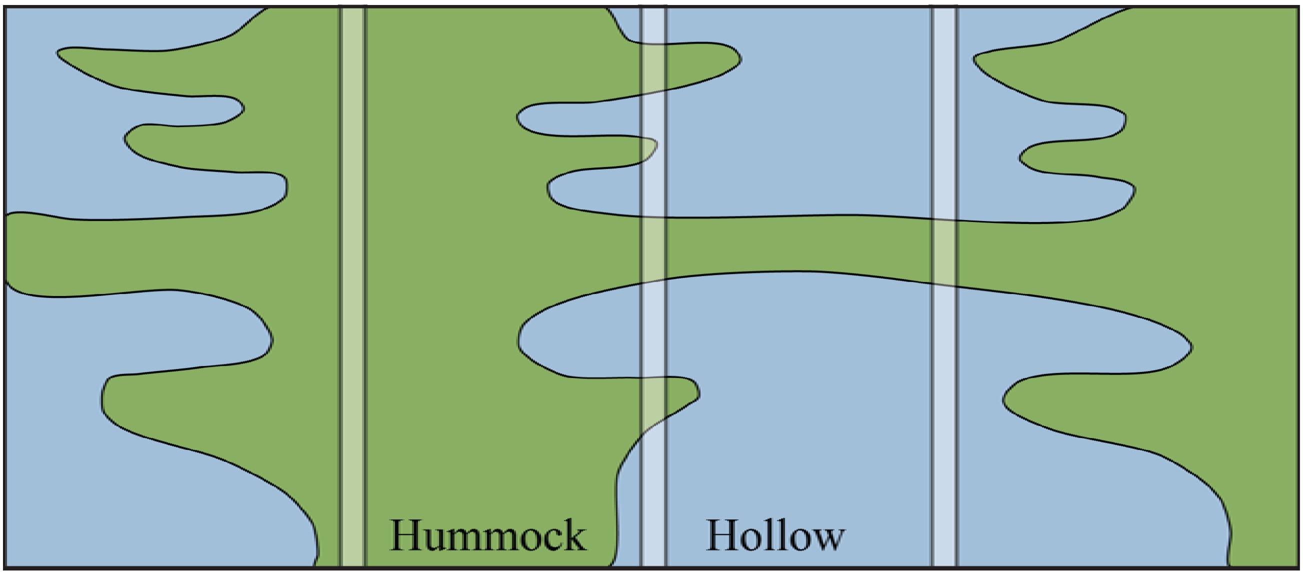

Figure 1. Evolution pathways of hummock and hollow microforms through time (vertical axis) and space (horizontal axis). Of the cores (vertical white rectangles) shown, the one that offers the most sensitive record of change is the one taken from the interface zone between hummock and hollow (after Aaby 1976).

3. CORING OF SUPERFICIAL LAYERS

Coring of the superficial peat layers (*i.e.* the first 50–100cm, which will include the acrotelm and the upper part of the catotelm) must be achieved with the greatest care in order to retrieve a perfectly shaped core without any compaction. This is an important step towards an accurate estimate of sub-sample volume and, therefore, of bulk density.

A good method for retrieving the acrotelm and subjacent peat is to use a stainless steel Wardenaar peat corer (Wardenaar 1987). This corer is a double-blade cutter designed to retrieve peat monoliths in undisturbed condition (Figure 2). The standard monolith dimensions are 10 cm x 10 cm x 100 cm, but corers can be home-made to extract cores of other sizes, e.g. 15 cm x 15 cm x 100 cm (Givelet *et al.* 2004). Another corer based on the same principle, known as the Malcolm sampler, is described by Cuttle & Malcolm (1979). The main differences from the Wardenaar design are that one blade is smaller than the other and flat, so that it acts as a lid which is removed to reveal the core after retrieval; and the standard core dimensions are around 5 cm x 5 cm x 75–100 cm, although Malcolm samplers can also be quite easily manufactured in different sizes. The cutting edges of the Wardenaar or Malcolm blades should be sharpened, especially if roots or fibrous layers are present and prove difficult to penetrate, as the core will be compressed if such material is not cut effectively before proceeding. Shallow fibrous material may be dealt with by making a ‘starter incision’ with a long-bladed knife (e.g. bread knife) before inserting the corer, and/or running such a knife round the corer’s outer wall at later stages of insertion. It is strongly recommended that a double-blade sampler, rather than the Russian corer (see Section 4), should be used to retrieve material from the acrotelm, because the Russian corer is not designed to cut the living plant mat cleanly and will strongly compress the core.

To obtain a sample using a double-blade corer, the two blades are separated and one of them is pushed vertically into the peat to the required depth, cutting round only part of the monolith’s perimeter so that it is still partly supported by surrounding peat whilst the first cut is being made. The second blade is then inserted so that it cuts the remaining side(s) of the monolith; then the two blades are lifted together, with the monolith enclosed between them.

Figure 2. The two main types of corer that are used for sampling peat profiles. On the left, the Wardenaar corer and the peat monolith that can be retrieved with it. On the right, the Russian D-corer and the semi-cylindrical sample that it delivers.

Once retrieved, the corer should be laid horizontally and opened by carefully removing the upper blade. To avoid any compression of the monolith, the recommended steps in packing are as follows:

1. Whilst the monolith is still lying on the lower blade, cover all of its exposed sides with plastic film.

2. Position a solid box, of appropriate size to accommodate the monolith, upside-down on top of the plastic film; then carefully lift blade and box together and invert, so that the monolith lies inside the box.

3. Cover the remaining exposed surface(s) of the monolith with plastic wrap and close the box for transport.

It is important that there should be no free space in the box in order to avoid movement of the monolith during transport. Any space should, ideally, be filled with plastic bubble-wrap before the box is closed, and the box should always lie horizontally. As no two monoliths ever have exactly the same dimensions, it is recommended that boxes should be manufactured to provide a loose fit for the largest core expected, with dimensions perhaps 1 cm more in width and 3–4 cm more in length than those of the corer itself.

If a double-blade corer is not available, good samples of the acrotelm can be obtained using a sharpened metal monolith tin. The tin is inverted over the peatland surface at the location selected and pushed down until it contains a monolith of the required length. A trench is then excavated to expose enough of the tin to allow a metal sheet to be inserted horizontally beneath, so that it cuts through the peat at the base of the monolith and covers the open end of the tin. The tin, monolith and metal sheet are then lifted out together. This is a useful and highly cost-effective sampling method for the uppermost few centimetres of the profile and can work well down to 0.5–1m. However, because this method becomes increasingly destructive as sampling depth increases, its use for extraction of monoliths more than a couple of decimetres long should be avoided if at all possible, and it cannot be recommended at all for sensitive or protected peatlands.

Other types of surface corers, e.g. auger and gouge corers, are not recommended; firstly because they cannot recover wet surface peat, and secondly because they disturb and compress the sample.

4. CORING OF DEEPER LAYERS

The coring of layers beyond the depth range of the Wardenaar corer is generally achieved using a semi-cylindrical ‘D-section’ corer which is commonly known as “the Russian corer”, but also as the “Belarussian”, “Byelorussian” or “Jowsey” sampler (Figure 2, Belokopytov & Beresnevich 1955, Jowsey 1965, Aaby & Digerfeldt 1986). The diameter and length of the core chamber may vary, respectively, from *ca*. 4 cm to 10 cm and from 25 cm to 100 cm. Long cores are obtained by collecting contiguous samples at successively greater depths, adding extension rods to the handle of the corer as necessary. There are two ways to retrieve a long core, using either one borehole or two boreholes. The one-borehole technique is not recommended because it is impossible to avoid sample disturbance. Disturbance may be reduced by exactly aligning the corer with the blade facing in the same direction every time it is inserted. However, each time a sample is collected, the nose of the corer will disturb the layer of peat directly beneath, from which the upper part of the next sample should be taken. Thus, if one-borehole sampling is conducted, the uppermost few centimetres of each sample are likely to be unsuitable for analysis. The preferred two-borehole technique involves taking alternate, overlapping samples from two different boreholes. The boreholes should be no more than 1 m apart, and ideally much closer. This technique has the advantage that the collection of one sample does not disturb the next, but an easily measurable proxy (e.g. water content, bulk density or ash content) is required to allow correlation of the two discontinuous cores and the construction of a composite log. In any case, special care must be taken in calculating the target depth for each sample. Overlaps of 10, 20 or 30 cm are commonly used. Table 1 gives a sampling scheme for achieving 10 cm overlaps between parallel boreholes using a Russian corer with chamber 50 cm long. It is important to note that, in order to match a composite core, both the upper and lower overlaps within each sample should be included in the subsequent analyses.

After each sample is extracted, it should be carefully packed. This involves opening the corer chamber, covering the core with plastic film, and placing it in a length of rigid plastic half-tube (e.g. guttering or longitudinally sliced plastic tubing of suitable internal diameter) to protect it from damage and compaction during transport. Thick plastic film (or multiple layers of kitchen-grade film) of width at least five times the diameter of the sample chamber is recommended, and this should be cut into sheets 50% longer than the length of each sample. It is important that there should be a layer of easily removable plastic film between the sample and the plastic half-tube, as the peat will otherwise stick to the half-tube.

To avoid any problems in removing samples from the corer or from the plastic half-tube, the recommended procedure for sample transfer is as follows:

1. Open the corer.

2. Place the sheet of plastic film over the sample with its edges overlapping both ends equally, but with one side of the sheet overlapping a long edge of the sample by only a few centimetres and a much larger overlap on the opposite side.

3. Position the half-tube over the plastic-covered sample.

4. Carefully rotate the corer chamber and/or blade whilst holding the half-tube, so that the sample is transferred to the half-tube.

5. Roll the long overlap of plastic film over the flat side of the sample and around the half-tube.

6. Fold the plastic film overlaps at the ends of the sample onto the curved outer wall of the half-tube and tape them in place.

After individual packing inside their half-tubes, pairs of samples may be assembled and taped with their flat sides together to make stronger packages for transport. Ideally, there should be separate coring and packing teams to reduce the risk of sample contamination; the packing team should also be responsible for systematically photographing the samples (see below).

Each sample should be provided with a clear water-resistant label. Although most waterproof pen marks can survive exposure to acidic bog water leaking around the plastic tube, the recommended method is to paint a number at the end of each half-tube that corresponds to the upper end of the sample, using red oil-based paint. This not only ensures that the label is resistant to contact with water, but also identifies the top end of each section of the core. A possible alternative or additional measure to ensure that the orientation of the sample is recorded is to place a piece of inert plastic at its upper end before wrapping.

Table 1. Scheme of depths for sample collection to obtain a satisfactory long core record using a Russian D-corer (chamber length 50 cm), applying the two-borehole technique with 10 cm overlap. Zero depth is set 10 cm above the bottom of the range of the Wardenaar corer (or other method) used for sampling the uppermost layers of the profile.

BOREHOLE 1	BOREHOLE 2
0–50 cm	40–90 cm
80–130 cm	120–170 cm
160–210 cm	200–250 cm
etc.	*etc.*

It is also important to photograph and make a stratigraphical description of each sample in the field, as oxidation and colour changes can occur within minutes, and few of the colour differences present when the sample is extracted will still be visible by the time the material is examined in the laboratory.

5. OTHER HAND CORERS

5.1 Large-capacity corers

If time and labour are available, the mire is intact, and the peat is neither too wet nor too dry, instead of using the Wardenaar and Russian samplers it is possible to use a large-capacity hand-operated corer (Smith *et al.* 1968) to extract successive cores of length 0.75 m or 1.5 m. This corer requires a scaffolding rig to be erected and pinned into the bog surface at the coring location (Figure 3). The corer is cylindrical with a cut-away wall, which both reduces internal friction in the core tube and allows one side of the core to remain connected to adjacent peat whilst the corer is being driven to the required depth. The corer is then rotated to sever the vertical connection. With luck, rotation will also ensure that the base of the sample is retained within the core tube. The corer is then raised, with the sample inside, using chain hoists which act against the anchorage of the pinned rig.

The corer contains a plastic liner, which is extruded through the core head with the peat inside it by attaching mole wrenches to the liner and pulling. The retrieved liner and peat are then laid in a length of plastic guttering for wrapping and transport. The core hole is reamed with a post-hole auger between drives.

This system works tolerably well, but some compression is common. As the principal cause is

Figure 3. The large-capacity hand corer of Smith *et al.* (1968). Above: general view of the rig and corer in use; below: plastic liner containing a minimally compressed peat sample.

failure of the corer to penetrate the vegetation mat, it is recommended that the surface layers should be removed (i.e. sampled, as described in Section 3) before commencing the drive.

Other types of corers have been used to sample peat with varying degrees of success. One example is the modified Livingstone corer (Livingstone 1955), which is probably best avoided owing to problems with contamination and compression of wet peat samples.

5.2 Corer for frozen peat (permafrost)

A substantial proportion of the world's peat is located in regions with permafrost, which renders classical peat coring methods useless. However, it is possible to core frozen peat using special equipment, such as the simple one-person motorised peat cutter developed by Nørnberg *et al.* (2004). This allows the retrieval of up to 10 m of continuous frozen peat core, in sections 70 cm long and 9.7 cm in diameter. The corer is a rotating titanium alloy tube with a sharpened head. Once the tube has penetrated down to 70 cm, the engine is stopped, then reversed for a single rotation. This releases two small spring-loaded blades from the head, and these first cut and then support the base of the core during retrieval of the tube. The core is then extruded. The whole device is fairly lightweight and easy to use. Coring down to 10 m can be achieved by adding metal extension rods, and a manual recovery system is included for use in case of engine failure. However, the device is relatively expensive.

6. OUTCROP SAMPLING

With suitable equipment, it is relatively easy to take a peat monolith from an exposed vertical face such as a peat outcrop or cliff (see e.g. Robichaud & Begin 2009), or the face of a drainage ditch. If several monoliths are collected to make up a longer sequence, it is good practice to include stratigraphical overlaps. A monolith box made from aluminium, metal alloy or strong plastic will be required for each sample collected. Before sampling, the face must be cut back with a spade or peat cutter to expose un-oxidised material that has not been affected by slumping or contamination. Then, a monolith can be obtained as follows:

1. Place a monolith box of dimensions 15 cm x 15 cm x 30–100 cm against the peat face.

2. Using a knife, score the peat surface around the perimeter of the box.

3. Remove the box; then cut into the peat face along the score lines, preferably using a specially designed peat cutter (Lageard *et al.* 1994, see Figure 4).

4. When the cuts are deep enough, push the monolith box into the face and separate the back side of the monolith by cutting vertically behind the box. If it is not feasible to cut from above (e.g. because the face is too high, or for other safety reasons), cutting can be done from the front, inserting the cutter at 45 degrees so that there will be a prism of peat projecting from the open side of the full monolith box when it is retrieved.

5. Run the cutter underneath the box, then lift it out with the monolith inside. Any prism of peat projecting from the box may be retained or cut back before the monolith, inside its box, is double-wrapped with tubular polythene sheeting.

Figure 4. Left: collecting peat in north-east Iceland, from an exposed surface containing tephra. Note the difference in colour between the long-term exposed peat face (lighter, more oxidised) and the darker, newly cut surface. Right: using the peat cutter of Lageard *et al.* (1994) to cut a trench in a peatland. This type of cutter can also be used on peat haggs.

7. SLICING

Slicing is a critical procedure, not only because it determines sample thickness, which is important for the calculation of volume, but also because slicing a peat core is difficult when it contains fibrous layers (e.g. of *Eriophorum* and *Scheuchzeria* spp.). There is no ideal method for slicing a peat monolith or core cleanly, and several methods are currently in use. Whichever is chosen, maximum care should be taken to minimise loss of material and cross-contamination.

A precise method is to measure the total length of the core/monolith section, then freeze it before cutting with a band saw. The dimensions of the clean slices obtained can then be measured quite precisely, which is important for accurate derivation of bulk density. If possible, the peat core or monolith should be laid on an incremental table that allows step-by-step cutting (Givelet *et al.* 2004). The band saw will quickly become soiled with small fragments of peat, and careful cleaning with deionised (mQ) water after separation of each slice is recommended. Light cleaning of the surface of each frozen slice, also with mQ water, will help to avoid cross-contamination. Directly after cutting each slice, its thickness should be measured using a Vernier caliper.

Not all laboratories use a band saw on frozen peat. Most often, the core or monolith is sliced in fresh condition in-house, using tools ranging from a simple kitchen knife to Teflon utensils and titanium knives. Scissors can prove useful when *Eriophorum* or matted sedge peat is encountered. Whatever tools are used, they should be cleaned after separation of each slice. Additional caution may be required depending on the proxy that will be studied. For example, titanium, plastic or Teflon-coated tools should be used if dealing with lead geochemistry to avoid any metallic contamination. Once again, it is important to ensure that the slices are of constant and reproducible thickness. Thickness should be measured exactly, using a Vernier caliper, soon after slicing. To facilitate this, if the samples have melted meantime, they should be re-frozen (without disturbing their shape) before measuring. This can be achieved in a normal domestic freezer.

A range of mini-cutters is available for fine-resolution work. These can provide samples just one or a few millimetres thick. They are excellent for obtaining samples for fine-resolution pollen analysis, for example, but work best in well-humified peat and are less effective in matted sedge-rich peat (see Cloutman 1987 and Amesbury *et al.* 2010).

8. SUB-SAMPLING

The sub-sampling should meet the needs of everybody working on the core. Therefore, needs should be discussed at the very beginning of the process to ensure that sufficient material is acquired for all of the analyses required. Also, as further analyses are always added, it is important to store a substantial part of each slice as an archive. In the case of Wardenaar cores, it is relatively easy to find surplus material for archiving. On the other hand, the majority of the material in a Russian core would probably be used in a multiproxy study.

There are several ways to proceed with sub-sampling. A simple approach begins with drawing a sketch of the ideal sub-sampling of a slice. This should be done bearing in mind that: 1) each sub-sample should be representative of the slice (*i.e.* homogenous); 2) sub-sample volume should be measurable afterwards, at least for the sub-sample designated for density determination (*i.e.* the dimensions of the designated sub-sample should be well-defined and precise); and 3) an appropriate quantity of material should be allocated to each analysis (Table 2).

Table 2. Minimum volume of fresh peat needed to perform the analyses described in this volume. Note than ^{210}Pb measurement and inorganic geochemistry can be non-destructive if performed, respectively, using gamma spectrometry and x-ray fluorescence.

Type of analysis	Volume (cm^3)
Macrofossil determination	5
Macrofossil for AMS radiocarbon dating	5
^{210}Pb measurement	10
Bulk radiocarbon dating	10
Pollen + NPP	1
Testate amoebae	2
Charcoal measurements	1–3
Inorganic geochemisry	5
Tephrostratigraphy	3
Spheroidal Carbonaceous Particles	1
Water content+Bulk density+Ash content	10
Humification	0.5
TOC, TIC	5
Stable isotopes	5

9. CLEANING

Cleaning is crucial at all stages of sample acquisition and preparation, as contamination is the primary source of uncertainty that can affect palaeoenvironmental studies. The most common reason for contamination arising during sampling and sub-sampling is working with tools that are not cleaned regularly. For example, failing to clean a corer between retrieving one core section and the next will lead to contamination of the second section by material retained on the edges and walls of the corer from the first section. Similarly, when slicing and sub-sampling a core section, material carried on the tools, knives, saw *etc*. can cross-contaminate samples. The degree of contamination may be limiting for some analyses. For microfossil analyses, the most common problem will be cross-contamination, or contamination by actual microfossils. The same applies for dating. For organic geochemistry, cross-contamination is again the main risk, but contamination by plastic tools and plastic film may constitute a further risk. For inorganic geochemistry, especially when metals are being studied, contact of the peat with a metallic corer is a further issue. Because many (multiproxy) studies employ several of the above-mentioned proxies, we recommend the following points of good practice:

1. Discard the outer surface of each core section because it may have acquired contaminants from the corer or by leakage of peat water and/or particles.

2. Clean any tool used for cutting and sub-sampling after every use, finishing by rinsing with deionised water.

3. For some studies (e.g. geochemistry), clean the corer as thoroughly as possible after retrieving each core section. This should be done with deionised water, so long as it is reasonably practical to carry water containers to the field sampling site.

4. If investigating inorganic geochemistry (see Section 8 above), use only plastic or Teflon-coated tools to minimise contamination by metals. If possible, use a corer made from non-ferrous material; for example, titanium alloy (Givelet *et al*. 2004) or carbon fibre (Franzén & Ljung 2009).

5. If investigating organic geochemistry (see Section 7 above), do not use plastic tools.

10. CONCLUSION

Coring and sub-sampling peat is a crucial step towards high-quality palaeoenvironmental reconstruction. The protocols suggested here provide an optimised way of proceeding. We suggest that anybody wishing to carry out such a study should apply them; not only to guarantee clean work, high efficiency and quality, but also to establish a better basis for comparisons between studies.

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