A carbon fibre composite (CFC) Byelorussian peat corer

L.G. Franzén[1] and T.L. Ljung[2]

[1]Department of Earth Sciences, University of Gothenburg and [2]SU/Ortopedteknik, Gothenburg, Sweden

SUMMARY

The design specification, development and manufacture of a Byelorussian (Russian) peat corer constructed from carbon fibre composite (CFC) are described. The availability of this new composite material introduces new possibilities for constructing field instruments that are as strong as, or stronger than, equipment made from steel and other metals. One advantage is a significant weight reduction. A 10.5 metre coring set in standard stainless and soft steel weighs around 16 kg, whereas the total weight of a similar CFC set is 5.2 kg, giving a weight reduction of almost 70%. The CFC sample chamber is 500 mm long with internal diameter 65 mm, and so contains almost twice the volume of peat that can be collected with a standard 45 mm diameter steel corer. The diameter of the rods is 30 mm, which improves ergonomics, and the CFC has better thermic properties for winter use. Another advantage is that the contamination of samples (notably by chromium and nickel) associated with the use of steel corers is eliminated. The CFC sampler works well in soft peats such as *Sphagnum* and *Carex* types. It is less suitable for little-decomposed fibrous and forest peats (e.g. *Polytrichum* type) and those containing hardwood remains, especially in the more compacted bottom layers. It should be totally satisfactory for organic lake sediments, but probably not for stiff and coarse mineral deposits.

KEY WORDS: lightweight corer, metal contamination, over-sized, peat sampling, Russian peat corer.

INTRODUCTION

The standard Byelorussian (or Russian) peat corer has been used widely for peatland and lake sediment investigations since it was first introduced in the mid-20th century (Belokopytov & Beresnevich 1955, Jowsey 1966, Faegri & Iversen 1975). It is a semi-cylindrical filling shuttle type sampler, typically made from stainless steel with a chamber 45 mm in diameter and 500 mm long. Standard 1.5 m soft steel rods are normally used for extension. Versions in other metals such as aluminium and titanium alloys are also common.

The great advantages of the steel Byelorussian corer are its simplicity, high strength and reliability when used in soft soils and sediments. A significant disadvantage is its weight. The standard field equipment required to obtain a sample from 10.5 m depth comprises the corer unit, six extension rods and a T-bar handle. The whole set is normally stored and carried in a poly canvas case, and the weight of the entire outfit is about 16 kg. It is sometimes helpful to add a few movable jacking handles or even a ball-lock lifting head unit, which increase the weight further. The researcher usually has to walk to the sampling location carrying all of this steel, and then return with an additional load of wet peat samples - which can be tiring, troublesome or even hazardous. The steel peat sampler set is also a significant (and expensive) addition to personal luggage when travelling to field locations by air.

The idea of constructing lightweight equipment arose when carbon fibre appeared as a reinforcing material for acryl and epoxy resins. It was initially expensive, but has now become affordable. On the other hand, some peat researchers felt intuitively that it could not replace metal in soil sampling equipment because it would be too soft, or would crack and be irreparable if damaged in the field.

A further incentive for developing a non-metallic corer was the unsuitability of steel sampling equipment for the study of cosmic signals in peat stratigraphies (Franzén & Cropp 2007). This required measurements of trace elements including chromium and nickel. Standard stainless steel is made from iron, chromium (12–30%), nickel (7–30%) and sometimes molybdenum (<3%). ICP-MS (Inductively Coupled Plasma Mass Spectrometer) measurements on peat ash dissolved in Aqua Regis revealed a strong contamination signal in peat samples collected with a steel corer. Elevated chromium and nickel readings were obtained for the top sample of every 0.5 m core section. The geochemistry of the entire peat profile thus plotted as a saw-tooth graph with these elements peaking at intervals of 0.5 m (Figure 1). This could be

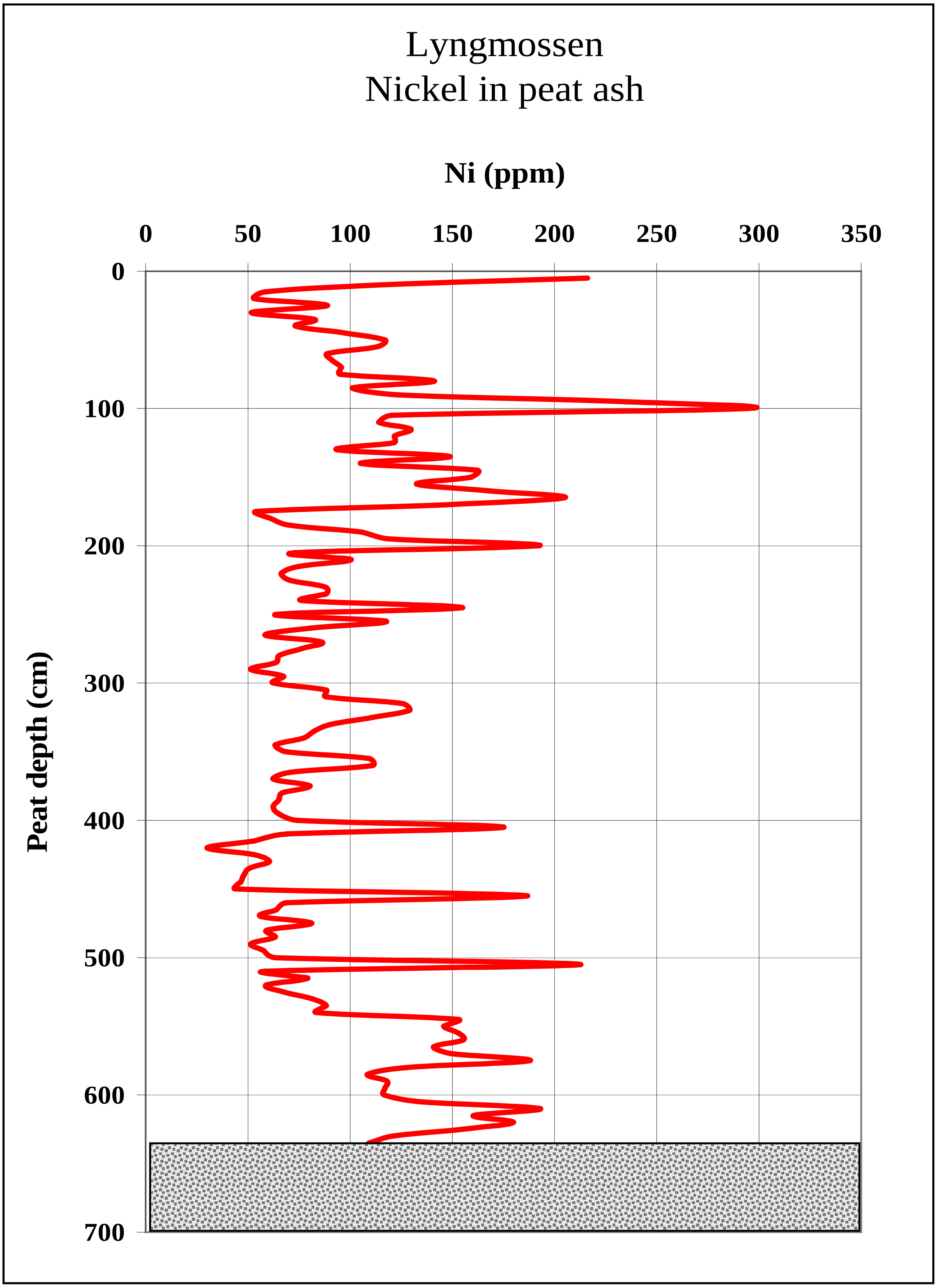

Figure 1. ICP-MS profile of nickel expressed as a fraction of the total content of 72 recorded elements, for the raised bog Lyngmossen in south-west Sweden. The peat samples were taken with a standard stainless steel Russian corer. The sharp peaks at 0.5 m intervals, becoming more pronounced with depth, coincide with the upper ends of the 0.5 m core sections and are attributed to contamination from the corer.

explained only by contamination. Iron, which is fairly abundant in most peat types, was not affected in the same way due to the relatively low contamination bias of this element. The contamination is most likely to arise from abrasion of the chamber's nose and anchor plate as each new 0.5 m peat layer is penetrated. A trace of material from the corer is consequently concentrated at the top of each section of the core, and the effect tends to increase with depth because the more compacted bottom layers offer higher frictional resistance than the soft surface peats.

The analyses required samples from 50 mm depth intervals and a minimum sample volume of 80 cm^3. If a corer with the standard chamber diameter of 45 mm was used, two parallel cores were required, and these must be taken from locations no more than *ca*. 25 cm apart to avoid stratigraphical dislocations. If a sufficiently wide single core could be obtained, the time required for field sampling would be halved. When large samples have been required previously, 'over-sized' chambers have been constructed, e.g. by Barber (1984). The sample volume would be almost tripled if the internal diameter of the chamber was 75 mm, and almost doubled if the diameter was 65 mm.

In this technical note, we describe the development of a lightweight over-sized carbon fibre composite (CFC) peat sampler for our geochemical research, and compare its performance with that of conventional equipment.

THE PROTOTYPE

The corer described by Jowsey (1966) was used as a model, although it was necessary to add reinforcement at several points to reproduce the strength of the original metal. The CFC parts for the prototype were produced by a local company (SCD)[1] which manufactures sports equipment including canoe paddles. It proved expedient and cost effective to use their standard canoe paddle shaft material (30 mm diameter tubing) for the upper part of the corer unit and the extension rods.

To join the rods together, we chose stainless steel push-fit male/female couplings secured with Allen lock screws, rather than threaded connectors. These would be well above the sampling depth and so could not give rise to contamination. They were made by the authors at the Department of Earth Sciences in Göteborg. The different parts of the couplings were joined together with TIG (Tungsten Inert Gas) point-welds only (although it turned out later that this was a fatal mistake). They were then sent to SCD, who attached them to the extension rods with expanding epoxy resin. The corer unit was supplied with the chamber similarly glued to its rod, but with only one layer of reinforcing carbon fibre cloth wound around the neck joint (this turned out to be the second fatal mistake).

The anchor plate (Figure 2:3c) could be made detachable for servicing, or permanently moulded to the body of the chamber. We chose the latter method, which meant that the plate's pivot pins and the supporting bearing bushes (Figure 2:3b) had to be fixed in exactly the right positions to allow free but tight movement of the plate through 180 degrees within the chamber (Figure 2:3). Red lines were painted at 50 mm spacing on the "peat side" of the anchor plate to indicate where the samples should be divided in the field. Finally, the interior of the chamber and the anchor plate were covered with a thin layer of acrylic resin to create a smooth and glossy surface.

The T-bar handle was made by TIG welding a short length of stainless steel tube transversely to a female coupling, then inserting a CFC bicycle handlebar (supplied by SCD). The handlebar was glued into the tube and fitted with two soft plastic grips (Figure 2:1).

The prototype corer was first tested at Komosse, a raised bog in south-west Sweden (Franzén 2006), where the uppermost 2–3 metres of the profile consist of weakly decomposed wet *Sphagnum* peat (H2–3, *ca*. 95% water). The first three half-metre core sections were obtained before the chamber broke loose from its rod at the neck joint (Figure 2:3a). After repair and further reinforcement of the joint, the corer worked well, and a full sampling campaign in southern Sweden was completed without further problems.

However, when samples taken with the prototype corer were analysed, it was found that those taken from the centres of the core sections had systematically higher bulk densities than those closer to the ends of the chamber. This problem arose from slight bending of the anchor plate during filling of the chamber, due to the pressure exerted by the peat. This meant that more peat was caught in the middle than towards the ends of the chamber when it closed.

The corer was then taken to Tierra del Fuego, Argentina, to sample the well-known Harberton Bog (e.g. Heusser 1989). Another team worked in parallel with ours, using a standard steel corer.

[1] "Svensk Kompositutveckling AB" (Swedish Composite Development Ltd.), Uddevalla.

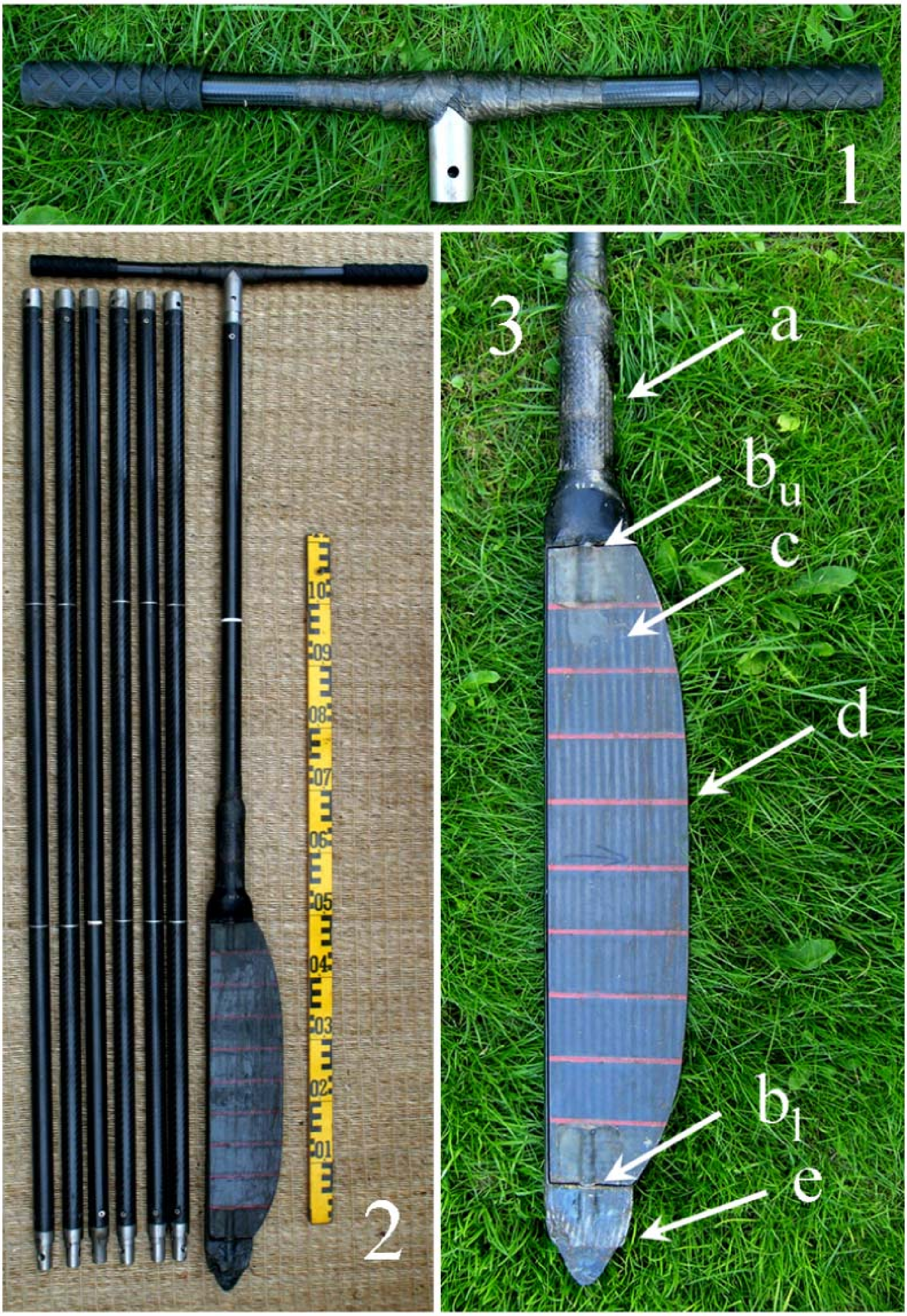

Figure 2. The CFC peat corer. 1: T-bar handle; 2: field coring set; 3: close view of the chamber showing reinforced neck joint (a), upper (b_u) and lower (b_l) anchor plate bearings, anchor plate (c) with red lines (d) at 5 cm intervals, and corer nose (e). The chamber lies beneath the anchor plate.

Sampling with the CFC corer was initially much faster than with the steel one, although its large diameter made it difficult for one person to penetrate stiff peats. However, when all the extension rods were being used at a depth of 9.5 m, it proved impossible to turn the chamber through a full 180º even by turning the handle through more than 360º. Finally, a snapping sound was heard. The equipment was brought to the surface and we found that both the coring unit and the deepest extension rod were missing, because the point weld securing the central tap at the male end of that rod had snapped. The remaining samples from Harberton Bog were collected with the steel corer, revealing that the peat at the depth where the CFC corer had broken was a very hard and coarse fibrous "*Polytrichum"* type. The lost equipment could not be recovered.

THE IMPROVED VERSION

Manufacture

The five remaining extension rods and the handle were used as the starting-point for restoring the CFC corer. This time, the material for the rods was purchased from SCD and the authors carried out all manufacturing procedures using the workshop facilities of the medical centre where Ljung works as an orthopaedic engineer.

The chamber was vacuum cast from six layers of 45° carbon fibre cloth stocking, giving a thickness of 5 mm. Only four layers of cloth had been used in the prototype, so this increased the weight by a few hundred grams but gave considerably higher torsional strength. An aluminium former was lathed for the chamber, which was again 500 mm long but had an internal diameter of 65 mm. A 150 mm cone-shaped neck (Figure 2:3a) was added to house one end of the coring unit rod. A thin soft plastic tube was mounted over the aluminium former, which was then dressed with the six layers of stocking. A second thin plastic tube was placed over the stockings and closed at the bottom end. Holding the whole arrangement vertically, the outer plastic tube was filled with a mixture of resin and hardener, then its upper part was connected to a vacuum pump and all air removed. After complete curing, the aluminium former was removed and the chamber finished in a cutting machine. This involved cutting out the front opening of the chamber and extending 20 mm square grooves from its upper and lower edges to accommodate the bushes of the anchor plate bearings (b_u and b_l in Figure 2:3). The rod of the corer unit was attached with expanding epoxy glue, and several layers of carbon fibre cloth strip impregnated with acrylic resin were wound around the joint. The cutting edge was then sharpened.

The anchor plate was cut from 3 mm thick CFC sheeting. The two pivot pins were 70 mm lengths of 10 mm diameter stainless steel rod. A 3+ mm slit was cut through the axis of each pin for 50 mm of its length, leaving *ca.* 20 mm intact at one end to give a 'tuning fork' shape. One pin was then mounted on each end of the anchor plate by inserting the plate between the prongs of the 'fork', positioning carefully and fixing with glue. The prongs on the front side of the plate were covered with a few layers of impregnated carbon fibre cloth, moulding in extra cloth to streamline the 'step' at the end of the upper pin (to the left of the head of arrow 'c' in Figure 2:3) so that this discontinuity would not result in surface material being caught and dragged downwards during insertion of the corer. This time, the anchor plate was stiffened by adding a fin to its rear side, as suggested by Jowsey (1966). The fin was a 20 mm wide strip of the 3 mm CFC sheeting, cut to fit within the length of the chamber and recessed to fit over the pivot pins. One edge of the fin was glued to the centre line of the anchor plate so that the plane of the fin was perpendicular to that of the plate, and each side of the join was covered with a 30 mm wide reinforcing strip of impregnated carbon fibre cloth, attaching half of its width to the fin and half to the plate. A sleeve (*ca.* 20 mm length of 10 mm i.d. stainless steel tubing) was then placed over the protruding end of each pivot pin, and the anchor plate mounted on the chamber by gluing the sleeves (bushes) in precisely the correct positions within the previously cut grooves and covering them with layers of impregnated carbon fibre cloth. The anchor plate and chamber were painted and coated as for the prototype.

The male and female rod couplings were assembled from stainless steel materials of standard dimensions. The inner tube of each coupling was made from a 65 mm length of 26.70 mm o.d. (outside diameter) x 2.11 mm w.t. (wall thickness) tubing which was lathed down to 26.00 mm o.d. and 22.05 mm i.d. (inside diameter). At one end, the wall of the tubing was cut away around half of its circumference to create a 10 mm curved ('semi-lunar') lug. This was done with a precision cutting machine, since the lugs on the male and female couplings must articulate with each other exactly to prevent rotational movement of the joints under torque. To form a female coupling, a 32 mm length of 30.00 mm o.d. x 2.0 mm w.t. tubing was lathed to 25.05 mm i.d. and TIG welded around an inner tube so that one of its ends was flush with the top of the lug. For a male coupling, the outer ring was a 22 mm length of the same tubing, which was machined similarly and welded around an inner tube so that the 10 mm lug (b in Figure 3) protruded. These outer rings (tubes) partly protect the lugs, and function as guides when joining the rods. To complete a male coupling, a 100 mm length of 22 mm diameter rod (the central tap) was inserted and TIG welded so that one of its ends was flush with the end of the inner tube that had no lug. A hole for the (M10) Allen lock screw (d in Figure 3) was drilled 20 mm from the protruding end of the tap and threaded. After assembly, a radial hole was drilled through all three parts of each male coupling to accommodate a 6 mm stainless steel securing pin (Figures 3 and 4), which was TIG welded in place; and an 8 mm hole was drilled through each female coupling in the correct position to give access to the ends of the Allen screw when assembled with a male coupling (Figure 4).

Each extension rod was made by cutting the correct length of CFC tubing to make the total length of the finished rod (including the outer tubes of a pair of couplings) exactly 1500 mm, and gluing a male coupling into one end and a female coupling into the other. Three countersunk stainless steel screws were then threaded through each end of the CFC tubing into the underlying steel as ‘insurance’ against failure of the glue (Figures 3 and 4).

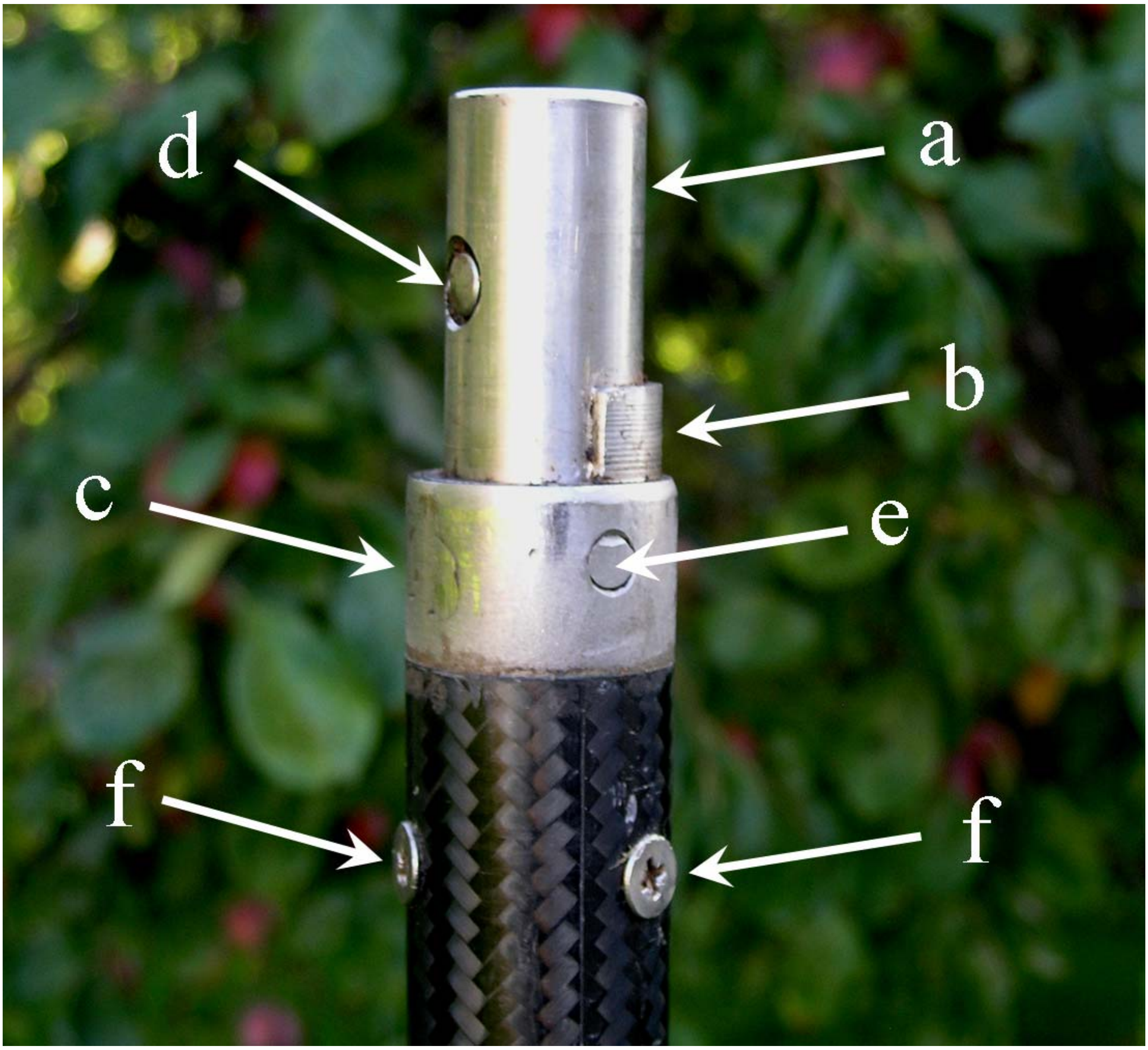

Figure 3. Male end of an extension rod showing details of the coupling: central tap (a), lug of inner tube (b), outer tube (c), Allen lock screw (d), securing pin (e) and two of the three securing screws (f).

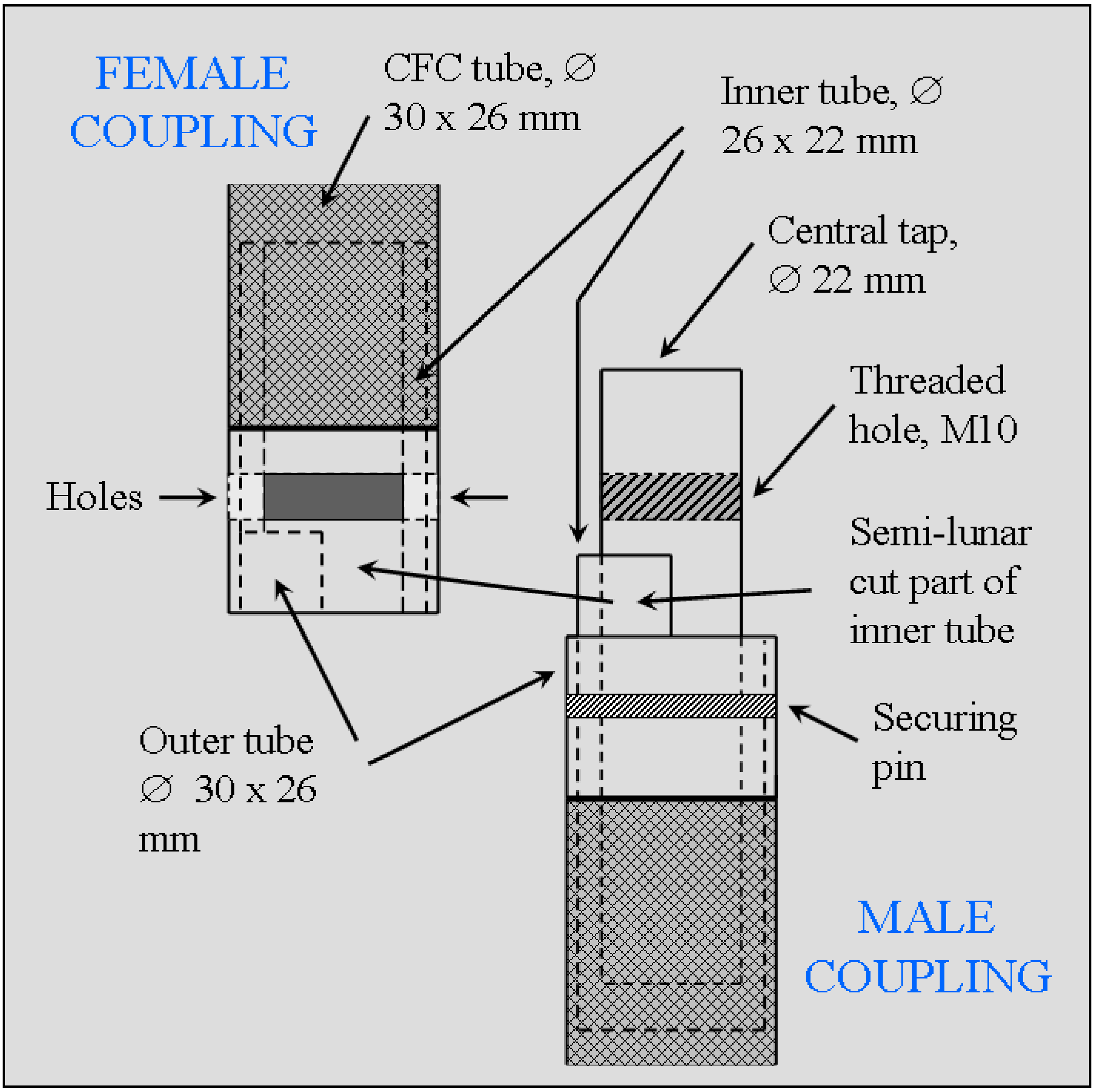

Figure 4. Diagrams showing how the male and female couplings were constructed and attached to the rods.

Cost

In 2007, the cost of the 30 mm CFC tubing was *ca*. 100€ (euro) per metre, or *ca*. 150€ for one extension rod. The cost of producing the CFC parts of the corer unit was 300€ for the aluminium former, carbon fibre cloth (stockings and strips) and acrylic resin, plus 100€ for CFC tubing. For a coring set with six extension rods, the metal components cost *ca*. 100€ and the total cost without labour or Value Added Tax (VAT) amounted to *ca*. 1,300 €.

Testing

The sampler was used successfully to core several peatlands in New Zealand (Figure 5), where very stiff fibrous minerotrophic peat was found in the bottom layers of the deepest (7.5 m) site. On one occasion, a sample including *ca*. 20 cm of sandy sediment in addition to peat was secured, but for this the handle had to be turned through 270° before the cutting edge finally completed its 180° rotation.

Advantages

1. The total weight of a set consisting of CFC coring unit, handle and six extension rods is 5.2 kg, compared with *ca*. 16 kg for a standard steel set, giving a weight reduction of almost 70%.
2. The 30 mm CFC rods are ergonomically better than the 15–18 mm steel rods of standard corers

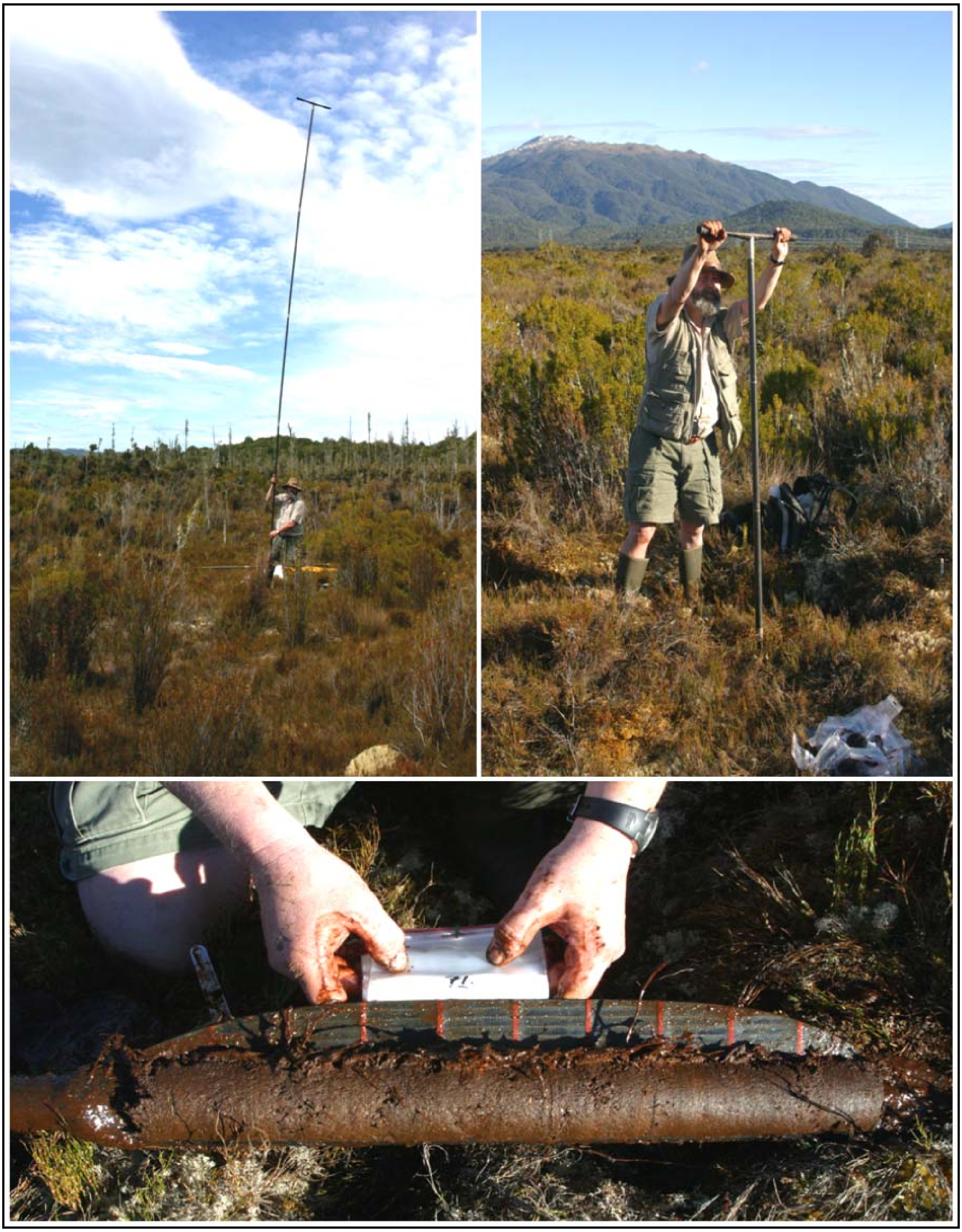

Figure 5. Sampling with the CFC corer on Dean Burn Bog at the southern tip of South Island (Southland), New Zealand, in late 2007.

because they allow a firmer grip and are warmer to the touch. At least when new and un-worn, the large-circumference plastic surfaces repel water, eliminating the problem of ice forming on the rods when used in freezing conditions. The steel couplings do suffer from icing, however.
3. The rods can be coupled together quickly, and the links between rods are very secure.
4. For geochemical work, the CFC produces no detectable elemental contamination. The carbon fibre is pure graphite (Vaccari *et al*. 2002) and the resin is a polymer containing carbon, hydrogen and oxygen (Gallot-lavallée *et al*. 2006). Only the elements mentioned above could be detected when a small sample of the CFC material was subjected to SEM-EDX (Scanning Electron Microscope - Energy Dispersive X-ray) analysis.
5. The elasticity and deformation resistance of the rods make them suitable for use as temporary bridges (e.g. 3 x 2 coupled rods for a 3 m span) for crossing deep drainage ditches.

Disadvantages

1. The corer does not perform well in very stiff deposits such as fibrous "*Polytrichum*" peat or weakly decomposed sedge peat in compressed layers at depth. Nor is it suitable for peat with high mineral content such as that found in the loess regions of north-west China and Tibet, where mineral contents of up to 75% make sampling difficult even with the standard steel corer (Yu *et al*. 2006).
2. The orientation of the carbon fibres in the rods means that they do not bend readily, but behave elastically under torsion. This makes closing the chamber in stiff peat types difficult, especially when all of the extension rods are attached.

Future improvements

For the next generation of corers, a special order will be placed with SCD to manufacture CFC tubing with increased torsional strength. It is envisaged that this might be produced by either altering the orientation of the carbon fibres or adding another layer of carbon fibre cloth. The latter solution may marginally increase the total weight of the field coring set.

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Author for correspondence:
Professor Lars G. Franzén, Department of Earth Sciences, University of Gothenburg, P.O. Box 460, SE-405 30 Göteborg, Sweden. Tel: +46-31-7861958; Fax +46-31-7861986; E-mail: lars@gvc.gu.se