Freeze coring of soft surface sediments at a water depth of several hundred meters

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Abstract

A freeze corer was developed specifically for the sampling of unconsolidated surface sediments by *in-situ* freezing. The new device which is presented here is designed to be used to a water depth of up to 1000 meters and was successfully tested at a depth of 200 m. The corer consists of a high pressure resistant housing with a vacuum insulated jacket for the ethanol which can be chilled by separate cooling agents, adjustable stabilizing legs, an electrical pump and a freezing wedge of 100 cm length. The freeze coring can be performed from a platform or a boat by using only a single cable to pull it up or to lower it. All other equipment is inside of the resistant housing. The core sample can easily be cut into two distinct slabs by use of the freeze-protectors on the small sides of the freeze wedge.

Introduction

Concerning lake sediment coring, a few difficulties arise due to the very high water content of the uppermost sediment layers. First of all, one may often fail to recover the uppermost layers. In sediments rich in organic material, the possibility of gas ebullition must be taken into account. Additionally, it is almost impossible to obtain undisturbed samples of sediment layers less than 0.5 cm thick using a gravity or piston corer because of their water content. Thus, *in-situ* freezing techniques have been developed (Shapiro 1958; Huttunen and Meriläinen 1978; Wright 1980; Renberg 1982; Renberg and Hanson 1993; Miskimmin et al. 1996; Lotter et al. 1997; Verschuren 2000)

Precisely dated paleoclimate records from the last 1000 to 2000 years are needed to validate numerical climate models (e.g., KIHZ, <http://kihz.gfz-potsdam.de>). The synergy of numerical modeling and precisely dated high resolution archives is essential to improve our understanding of the climate of the past

and its temporal and spatial variations. This could lead to a better understanding of future climate evolution.

Annually laminated (varved) lake sediments, as well as ice cores, tree rings, and corals, have been the focus of paleoclimate research as well as recent environmental pollution topics. Varved sediments offer the unique possibility to date sediments by counting their laminae without resorting to other methods (e.g., radiocarbon dating) which allows for the best possible precision in terms of dating.

The first freeze corers were made for sampling from the ice surface and were limited in terms of their maximum attainable water depth (at that time 30 m). The reason for this was mainly that the freezing process could not be kept completely under control. Freezing began immediately after the corer was filled with coolant, resulting in the build-up of a coating of ice on the freezing wedge as the corer was lowered down through the water column. This led to an enormous loss of efficiency as well as increasing the

possibility of disturbances during the penetration of the corer into the sediment. Moreover, problems exist adapting the coring device to different types of sediment (e.g., terrigenous, biogenic) and their differing densities. In some cases the corer over penetrates the sediment resulting in a failure to sample the uppermost surface sediments.

Commonly, a mixture of dry ice and alcohol is used as the cooling agent which is only efficient when the two ingredients are mixed in the correct ratio. However, subsequent addition of cooling agents cannot be undertaken accurately because of unknown residuals in the cooling chamber. To avoid this problem one can always use fresh ingredients which is very expensive, and an additional logistical problem associated with the larger amount of material transported to the field site. Sometimes liquid nitrogen was used (Pachur et al. 1984; Klee and Schmidt 1987), but its handling can be precarious with this type of equipment.

Most freeze corers developed within the last years are limited in terms of water depth, equipment transport, controlling the start of the coring process, and the availability of cooling methods. All these limitations make field work difficult, expensive, and in remote regions nearly impossible. To overcome all of these problems, a new freeze corer was constructed.

Technical features

The new freeze coring instrument (Figures 1 and 2) provides the possibility of sampling the uppermost ca. 100 cm of fluffy watery surface sediments by *in-situ* freezing at water depths of 1000 m or potentially more. The freeze corer consists of a high pressure resistant housing with a magnetic switch (through the wall) integrated into the lid as well as a small pump and a battery. The lower two-thirds below are vacuum isolated for 20 to 30 l of chilled alcohol. On the bottom of the housing are two isolated connectors (inlet and outlet for the chilled alcohol) for the freezing wedge. It consists of an aluminium plate 1.0 cm thick, 10 cm wide, and one meter long. Channels on the inside compartment of the wedge permit the circulation of the alcohol. Three adjustable legs are fitted on the outside of the corner to stabilize the equipment and prevent over penetration of the freezing wedge. The weight of the corer is ca. 110 kg in the air and ca. 45 kg under water, so it is possible to

sample from a boat or from a platform down to 1000 m water depth.

Dependence on the availability of energy for cooling and especially for the need to overcome logistic limitation and constraints during the field operation, the new freeze corer was developed to be set up by four different methods for cooling on board of a raft, a ship or on the surface of an ice-covered lake.

Method 1) The simplest and most effective method illustrated in Figure 1 consists of a stainless steel chamber filled with alcohol (19) into which a cooling coil (16) is inserted. Liquid nitrogen is circulating through the coil using compressed air. A portion of the nitrogen regulated by a valve is being bled directly into the bottom of the alcohol chamber to aid in circulating alcohol around (13, 14). The resulting circulation leads to a highly efficient energy exchange with alcohol temperatures in order of -100°C .

Method 2) Cooling of the alcohol chamber by the use of dry ice tablets 10 cm in diameter and 7 cm thickness that are contained in an immersed stainless steel basket. The dry ice tablets can be produced at will on board using a CO_2 -gas bottle and additional small equipment. Using this method temperatures of -70°C can be produced, no additional circulation is required in the chamber and the logistics and handling of the dry ice are easier.

Method 3) Cooling the alcohol chamber by an electrical immersion cooler which requires the availability of electrical energy of AC 220 V net or a generator. Depending on the type of cooler used alcohol temperatures from -30 to -80°C can be achieved.

Method 4) The same applies for the fourth method where the alcohol (stored in canisters) is chilled in a deep-freezer and decanted immediately into the corer. Temperatures of -70 to -80°C as seen in method 3 are possible with standard laboratory facilities. Method 3 and 4 are easy to handle and one may have fewer logistic problems but the disadvantage is that it takes up to 15 h for cooling.

The main problem of former developed freeze corers using dry ice and liquid nitrogen as a cooling agent within the closed resistant housing is that their gasification results in a large volume change (1 kg dry ice is equivalent to 540 l CO_2 -gas and one liter of liquid nitrogen is equivalent to 860 l N_2 -gas). Pressure relief of the alcohol chamber is regulated by one-way valves to vent the gas and to prevent water from entering the system to avoid an explosion of the corer. As a result of the very cold gas ($\sim -70^{\circ}\text{C}$ for CO_2

Figure 1. Cross section of the new freeze corer. (1) cable attachment and release weight, (2) release hook for the flexible protection tube, (3) Mounting cable for the flexible protection tube, (4) magnetic switch, (5) magnetic contact, (6) accumulator with relay, (7) cap and cap nuts, (8) pump 12 V DC, (9) suction tube, (10) pressure line of the pump, (11) acryl glass lid, (12) liquid nitrogen connector, (13) outlet valve, (14) outlet tube, (15) nitrogen-gas outlet, (16) copper coil, (17) outer stainless-steel high-pressure resistant housing, (18) vacuum, (19) inner stainless-steel canister with alcohol, (20) flexible protection tube with steel spiral, (21) end ring of the mounting cable for the flexible protection tube, (22) return tube for the alcohol, (23) adjustable support legs and base-plates 33×33 cm, (24) screws to fasten the freezing wedge to the high-pressure resistant housing, (25) insulated inlet coupling (valve inside), (26) insulated outlet coupling (valve inside), (27) freezing wedge ($100 \text{ cm} \times 10 \text{ cm} \times 1 \text{ cm}$), (28) PVC-plates ($3.5 \text{ cm} \times 1 \text{ cm}$) on both sides of the freezing wedge, (29) cooling channels for the alcohol.

Figure 2. a) Schematic sketch of freeze coring from a raft, b) Picture of a recovered freeze core, the freezing wedge, and its plastic sides.

and $\sim -190^\circ\text{C}$ for N_2) just a single drop of water could freeze immediately on the cold metal, and put the valve out of commission. If the valve is blocked, the pressure inside the corer could possibly rise to critical levels, threatening the stability of the resistant housing of the corer and resulting in a dangerous situation for the personnel as the corer is brought up to the water surface. Additionally, if water penetrates the corer it can block the pump and if it should freeze, it can destroy the battery and other electric parts, thus preventing a successful coring. Furthermore, it would require a prohibitive amount of time for the removal of all water from the corer and its repair. These problems increase with water depth and in order to overcome all these problems due to a critical gas pressure buildup inside the corer housing, the alcohol is cooled on e.g., a raft while the corer is open.

In term of reproducibility the new freeze coring system has been tested by a comparison of two cores taken in Baldeggersee/Switzerland. One was taken

with the new freeze corer in 2000 and the other with a different system (Lotter et al. 1997) in 1993. Using photographs they show an excellent correlation by means of distinct layers, like marker varves and turbidites.

The new corer is suitable for sampling under cold, windy, and even arctic conditions, because it is no problem to keep the small batteries for the pumps warm which are the only crucial parts under such weather conditions. Rain fall during the set up and cooling period is more sophisticated because one has to avoid that water gets on the sealings or in the pumps and the alcohol cycle.

Depending upon its configuration the approximate cost for the freeze corer is 19,000 US \$.

Use of the freeze corer

Coring

Assembly of the freeze corer takes place on a boat or a raft. Generally, a freeze corer is never been utilized before other corer devices are attempted. Thus, the constitution of the sediment is taken into account, when its legs are mounted to the freeze corer body preventing it from sinking too far into the sediment (Figure 2a). Then the freezing wedge is fixed on the bottom of the core body. The ethanol which is stored in the cooling box at -10 to -20°C is decanted into the body of the freeze corer. Residual air is removed out of the pump-wedge system and the ethanol is cooled using one of the four methods mentioned above to -70 to -100°C . At lower temperatures the ethanol starts to gelatinize/crystallize and the pump may have problems pumping the cooling agent through the freezing wedge.

After assembling the battery onto the freeze core body, a pump is turned on for a minute to check the circulation of the cooled ethanol through the couplings, wedge, and pump. If water freezes on top of the wedge immediately, then proper circulation is verified.

Before assembling the body and head of the corer to the inside magnetic contact, the head should be tested by switching it on and off. Now the corer can be assembled with the head, but one should test the integrity of the two rubber sealings by applying air-pressure in the space in between (see detail Figure 1). If there is no loss of pressure, the housing of the corer is absolutely watertight.

The freeze corer is placed into the water and lowered to just a few meters above the sediment surface. Once the corer reaches this position the final leg of the descent must be done slowly and steadily. At the moment that the corer touches down onto the sediment (Figure 2a), the loss of tension in the lowering rope initiates an electrical contact, providing power to the pump. The pump will then circulate cold ethanol continuously throughout the wedge. Also, at this point, the flexible protection tube is released. After 30 to 45 minutes of freezing, it is hauled up to the raft and the unfrozen sediment is scraped off of the frozen sediment (Figure 2b). Then the wedge is taken off of the corer. Valves inside the couplings of both corer and wedge prevent drainage of the alcohol. The frozen sediment can easily be removed from the metal by pumping warm ethanol through the wedge.

Whether the topmost layers have been sampled or not and how they are preserved can be verified by looking at the uppermost frozen material of the core that should be a layer of almost clear ice.

Freeze coring at 200 m water depth

For deep water coring, this newly developed freeze corer was tested at 200 m water depth both in Zuger See/Switzerland and Traunsee/Austria and worked very well. We recovered a 75 cm long laminated sediment core (see Figure 3). Its shape is different to freeze cores taken from an ordinary water depth of 30 – 50 m. Frozen and unfrozen sediment, which is found at the uppermost segment of the core, is effectively removed by both water friction and melting, due to its exposure to the relatively warm lake water during its lengthy ascent to the water surface. The lower half of the core remains almost unaffected and even has a cover of unfrozen sediment. This is the first time that it was possible to recover a freeze core from a 200 m deep lake from a small boat or a raft. To improve the technical features of the corer and to overcome problems as soon as possible, UWITEC (Umwelt- und Wissenschaftstechnik) is collaborating closely with the scientists who are working with the new equipment on lakes. Since the friction and melting problem was known, UWITEC has developed a highly effective protective cover (see Figure 4) to solve the problem.

Storing

A big advantage over former constructions is the

Figure 3. Freeze core taken in Zuger See at 200 m water depth.

ability to protect the small sides of the freeze wedge with PVC (see Figure 2b) resulting in two distinct slabs of frozen sediment which needs only to be cut at the bottom. This minimizes the risk of breaking the core during cutting.

Each half of the freeze core is laid onto a $120 \times 20 \times 3$ cm styrofoam plate, sealed in a plastic wrap, and stored as soon as possible in a cooling box together with a few kilograms of dry ice. Airtight sealing is very important especially using dry ice because the sediment freeze-dries quickly under such conditions. A cooler, powered by a car-battery or alternating current, as well as dry ice, can be used to keep the temperature of the cooling box below 0°C .

Sampling and sediment preparation

The sediment is sampled in a cold room at about -10°C . One half is used for preparation. Because of the use of PVC to separate the two slabs from each other during coring, an approximately 3 cm thick bar of the sediment plate is sawed off longitudinally and rejected. This rejection is necessary to factor out disturbances and contamination of the sediment laminae,

Figure 4. Freeze corer and the protective cover. (a) before the coring, (b) after coring with a core inside of the cover.

especially on the edges of the core. For thin sections, two 1.5 cm thick bars are sawed off longitudinally. Both 1.5 cm thick bars, which can be as long as 100 cm, are cut into pieces of 10 cm in length, but the second is sawed from 2 to 12 cm sediment depth to have an overlap of 2 cm from one sample to the other. All samples were freeze-dried for 48 hours, then injected with Araldite resin under vacuum (modified after Merkt (1971)). For geochemical and sedi-

mentological analyses, sampling of single annual layers is possible by scraping the sediment with a thin blade (Lotter et al. 1997).

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References

- Huttunen P. and Meriläinen J. 1978. New freezing device providing large unmixed sediment samples from lakes. *Ann. Bot. Fenn.* 15: 128–130.
- Klee R. and Schmidt R. 1987. Eutrophication of Mondsee (Upper Austria) as indicated by the diatom stratigraphy of a sediment core. *Diatom Res.* 2: 55–76.
- Lotter A.F., Renberg I., Hanson H., Stöckli R. and Sturm M. 1997. A remote controlled freeze corer for sampling unconsolidated surface sediments. *Aquat. Sci.* 59: 295–303.
- Merkt J. 1971. Zuverlässige Auszählungen von Jahresschichten in Seesedimenten mit Hilfe von Groß-Dünnschliffen. *Arch. Hydrobiol.* 69: 145–154.
- Miskimmin B.M., Curtis P.J., Schindler D.W. and Lafaut N. 1996. A new hammer-driven freeze corer. *J. Paleolim.* 15: 265–269.
- Pachur H.-J., Denner H.-D. and Walter H. 1984. A freezing device for sampling the sediment-water interface of lakes. *Catena* 11: 65–70.
- Renberg I. 1982. Improved methods for sampling, photographing and varve-counting of varved lake sediments. *Boreas* 10: 255–258.
- Renberg I. and Hanson H. 1993. A pump freeze corer for recent sediments. *Limnol. Oceanogr.* 38: 1317–1321.
- Shapiro J. 1958. The core-freezer - a new sampler for lake sediments. *Ecology* 39: 758.
- Verschuren D. 2000. Freeze coring soft sediments in tropical lakes. *J. Paleolim.* 24: 361–365.
- Wright H.E. 1980. Coring of soft lake sediments. *Boreas* 9: 107–114.