Core drilling of Quaternary sediments for luminescence dating using the Dormer Drillmite™

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(Received 14 March 2011; in final form 27 April 2011)

Abstract
The coring of buried Quaternary deposits using a Dormer Drillmite™ auger permits the extraction of samples for luminescence dating from depths of up to 20 m. The unit is powered hydraulically and features portability as one of its main advantages. While a range of other power drilling methods have been used successfully for sample collection in a number of luminescence dating studies, there is a dearth of literature that describes such drilling methods in detail. The absence of such information belies the importance of sampling methods in luminescence dating. This contribution aims to play a role in addressing that deficit. The basic operational features of the Drillmite™ are outlined and we share some experiences we have had coring with the unit. Adaptations that can be made to the equipment to suit different circumstances are explored. The advantages and drawbacks of core drilling at depth for luminescence dating are also briefly examined.

Introduction

A primary requirement for sediments intended for luminescence dating is that the mineral grains to be analyzed should not be exposed to light from the time they are initially buried up till the point they are exposed to the stimulating source during measurement. This restriction necessitates the adoption of special precautions during sample collection and a number of procedures have been devised over the years. Such measures include sampling at night (e.g. Aitken, 1998; Lian and Roberts, 2006), but this inconvenient. In settings where the sediment is sufficiently indurated, an alternative approach is to cut out a block of sample from the depositional unit being investigated for subsequent sub-sampling in light-controlled conditions (Aitken, 1998; Lian and Roberts, 2006, Ó Cofaigh et al., in press). A sampling approach that has become a method of choice because of its ease and relative guarantee for retrieval of an unadulterated sample is to insert an opaque pipe made of metal or plastic into a freshly prepared profile face (Aitken, 1998). Once retrieved, the pipe is immediately capped on both ends with an opaque and preferably moisture-tight seal. At the laboratory, sediment at the ends of the pipe is removed and the sample for OSL measurements is taken from the central portion of the pipe.

A feature that characterizes all these methods, however, is that the profile face being sampled has to be directly accessible. There are numerous advantages to working from exposed sedimentary profiles; the lithostratigraphy can be readily recorded, lateral continuity of the units being sampled can be checked, and samples can be taken precisely from locations that either avoid specific problems (e.g. evidence of bioturbation) or target certain features (e.g. sand lenses). There are occasions, however, when direct access to the entire sedimentary profile under investigation may not be possible and studies of aeolian dunes for paleoenvironmental reconstruction provide good examples of such cases. In central and northern Alberta, Canada, for instance, several luminescence dating investigations have been completed on aeolian dunes that mantle the postglacial landscape (e.g. Wolfe et al., 2002, 2004, 2007; Munyikwa et al., 2011). The dunes in the region attain heights of up to 20 m (Halsey et al., 1990) but, in the majority of cases, sample extraction has been confined to the upper 2-3 m. Consequently, reconstructions performed using the results can only be viewed as partial records of the chronology contained in the aeolian deposits.

Because natural full-depth sediment exposures in unconsolidated sandy sediments are often scarce, researchers have frequently sought alternative approaches. In many regions, road cuttings in Quaternary sediments have become prime locations for sampling (e.g. Bateman et al., 2004; Spencer and Owen, 2004; Porat and Botha, 2008; McIntosh et al., 2009). Alternatively, investigators have excavated pits to gain access to buried depositional units (e.g. Stokes et al., 1997; Wolfe et al., 2004; Munyikwa et al., 2011), but with obvious practical limitations to the depth that can be attained in sand. Occasionally, backhoe diggers have also been used (e.g. Lomax et al., 2003) to cut open profiles but this approach can be costly and is potentially damaging if practised in environmentally sensitive areas.

The most obvious solution to these problems would be to sample remotely down augered boreholes and recover intact sediment, suitable for luminescence dating. A study of the literature will show that a range of devices have been employed to drill holes to extract samples for dating. Very few of the operational procedures used, however, have been described in detail, making it difficult for new investigators who face similar situations to benefit from the experiences of others. This contribution focuses on the use of one such sampling device: the Dormer Drillmite^{TM} auger. We describe field experiences we have had over a number of sampling seasons using the system in order to provide practical advice for other workers who might be interested in using the unit or a comparable method. We also assess the merits and drawbacks of the system compared to other methods of sample collection.

Extracting samples for luminescence dating by drilling

The extraction of coarse grained samples for luminescence dating by drilling is not a new concept. Early attempts include studies by Nanson et al. (1992, 1998) who used a hand auger to collect aeolian dune and playa sediments from depths of up to 8 m. In these studies, samples were recovered by quickly placing the auger bit with the sample into an opaque plastic bag where the sample was removed and packed (Nanson et al., 1992, 1998). A potential problem associated with this approach is the possibility of exposing the sample to light during transfer from the hole to the opaque container. Subsequently, other users (e.g. Rodnight et al., 2005; Tooth et al., 2007) overcame this problem by fixing a sampling tube to the auger once the required sampling depth had been reached. Wallinga and van der Staay (1999) described a hand operated device (the Van der Staay suction-corer) for extracting samples from waterlogged sands which also addressed the risk of exposure to light. With the Van der Staay corer, samples are extracted from depths of up to 7 m in a removable coring tube which is sealed afterwards and transported to the lab for analysis.

Vibracorers, which penetrate sediment through a vibratory motion as opposed to rotary or percussion action employed in conventional drilling, have also been used to collect samples for luminescence dating in some studies (e.g. Rittenour et al., 2003). Normally, vibracoring retrieves samples as continuous cores in hollow tubing and this shields the sediment from sunlight upon extraction from the hole.

A mechanized bailer-drilling unit originally described by Oele et al. (1983) has been used in a number of luminescence dating studies to extract sediment cores from depths in excess of 35 m (e.g. Törnqvist et al., 2000; Wallinga et al., 2004; Busschers et al., 2008). Cores obtained using the mechanical bailer are retrieved in 1 m long PVC pipe sections which ensures that the sediments are not exposed to sunlight above ground. Working at greater depths, Preusser et al. (2002) utilized a large drilling rig to drill a triple-lined hole and attained a depth of 140 m in very large linear dunes of the Wahiba Sands of Oman. Sample recovery from the cores in that study, however, was limited to 50 - 80%.

In a study that sought to adapt the drilling method to the depth of drilling in order to maximize sample recovery in aeolian sequences, Bristow et al. (2005; 2007) employed a combination of drilling rigs to extract luminescence dating samples from various positions within the interior of an aeolian dune. In the upper 10 m, a percussion auger mounted on a truck was used. For dune depths beyond 10 m, however, a Dormer sand auger equipped with an auger flight housed in a counter rotating core barrel was found to be more appropriate (Bristow et al., 2007). Other vehicle mounted rigs that have been used to extract samples for luminescence dating include the Geoprobe® Systems coring outfit (e.g. Zlotnik et al., 2007). Geoprobe® rigs generally operate on a direct push mechanism which is a variant of the percussive drilling mode. As with other methods described above, the Geobrobe® samples are extracted from the ground in opaque tubing in which they may be transported to the lab.

A number of recent studies (e.g. Chase and Thomas, 2006, 2007; Telfer and Thomas, 2006, 2007; Telfer et al., 2009; Stone and Thomas, 2008; Burrough et al., 2007; Burrough and Thomas, 2008), have provided very brief accounts of the usage of a lightweight, portable, hydraulic auger: the Dormer Engineering Drillmite™. This system combines three important characteristics of a convenient sampling technique which can be inferred from the different methods described above, viz.: portability, operational ease, and the ability to extract samples from depths beyond a few metres. Its use as well as that of the other drilling methods cited above demonstrates that any method that extracts samples intended for luminescence dating by coring at depth has to address three attendant problems:

- the method has to avoid exposure of the samples to sunlight during transfer from the drilled hole to the container;
- it has to be possible to determine the stratigraphic context and precise depth at which the sample is being collected;
- there has to be some means available of ascertaining the integrity (for dating purposes) of the sediment at the base of the hole prior to sampling.

All three topics are discussed below with reference to the Drillmite™.

Sample extraction by augering with the Dormer Drillmite™ auger

Manufactured by Dormer Engineering (www.dormersoilsamplers.com) of New South Wales, Australia, the Dormer Drillmite™ is a portable 6 HP diesel or gasoline driven hydraulic unit for powering augers (Fig. 1 and Fig. 2). The unit weighs around 60 kg and, hence, operating it far from a vehicle would generally be ill-advised. The system is manoeuvrable by two people but if only one operator is available to auger, it should be noted that the sand drill bit provided with the kit can be operated manually without hydraulic power very successfully, and depths of at least 8 m have been attained by a single operative (Telfer, in press).

The Drillmite™ outfit comes with components specifically designed for luminescence dating. However, as discussed below, some adaptations may need to be made to suit specific circumstances. Drill bits can be selected for soil, sand or clay substrate (Fig. 3b and c). The targeted depth is reached by augering and removing successive sediment cores of about 30 cm at a time. As the working depth increases, the drill stem is extended by attaching additional aluminum or steel extension rods (Fig. 3f and Fig. 4a).

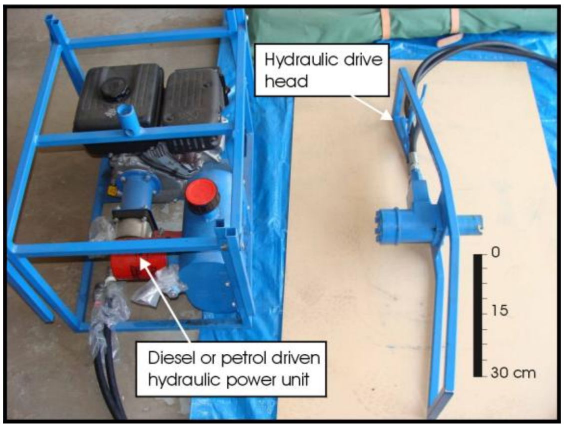

Figure 1. *The Dormer Drillmite™ hydraulic power unit and drive head.*

Figure 2. *Though the Drillmite™ can be operated by a single person, it is often convenient for two persons to work in partnership.*

Generally, as long as the working depth is above the water table, holes drilled in moist dune sands maintain their walls well. Telfer et al. (2009) utilised a Drillmite™ to auger into the clayey silt and sand pan floor sediments at Witpan, southwestern Kalahari, which included the extraction of at least 1 m of sediment below the water table; it seems unlikely such a strategy would work so well in unconsolidated dune sands. Conversely, in very dry, fine sands, a hole collapse is possible, and if this occurs at depth, there is the risk that an auger or sampling head may be lost. If extraction of sands with the auger head proves difficult (i.e. the drill bit fails to retain the sediment load), Stone and Thomas (2008) successfully mitigated the problem by pouring water down the hole to moisten the sands to improve cohesion. Although this strategy inevitably results in some movement of sediment down the hole, if allowed sufficient time (usually overnight) to percolate into the dune, successful extraction of both

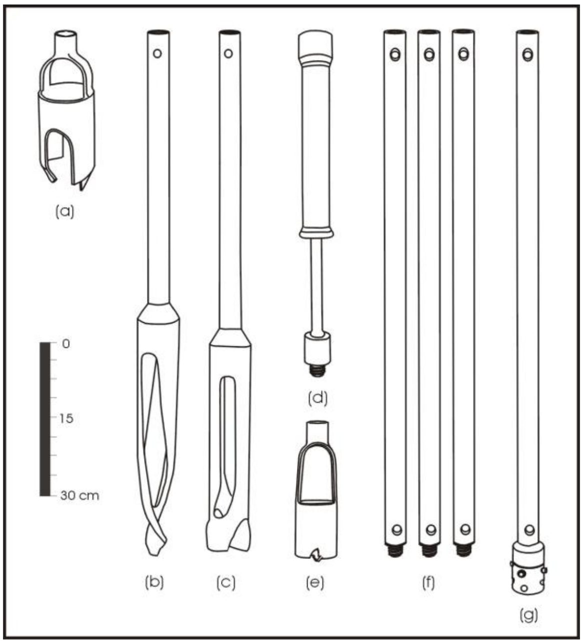

Figure 3. *Depending on the scope of the intended work, a range of accessories for the Drillmite^{TM} can be acquired from Dormer, including: (a) a large diameter drill bit; (b) a drill bit for clayey formations; (c) a drill bit for sandy formations; (d) slide hammer for driving sampling modules into the ground; (e) hole shaver for cleaning the bottom of the hole; (f) extension rods for increasing the working depth, and (g) adaptors for attaching sampling modules (see Figure 5) at the end of the drill stem.*

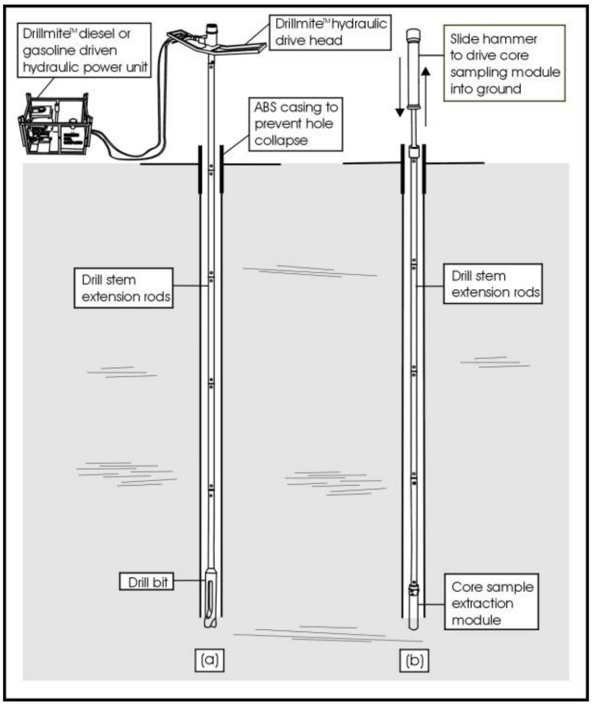

Figure 4. *(a) The desired working depth is reached by removing successive sediment cores of about 30 cm at a time followed by reinserting the drill stem into the hole and drilling further. Once the desired depth is reached, the drill bit is replaced by a hole shaver which is used to remove loose sediment from the bottom of the hole. (b) A sampling module is then attached at the end of the drill stem and hammered into the ground using a slide hammer. The sample is extracted from the hole by pulling the drill stem vertically upwards.*

the detrital material and intact sands was eventually possible. In even moderately dry dune sands, digging a working platform into the damper sub-surface sands (at ~1 m depth in the southwestern Kalahari) from which to auger helped reduce the effects of hole collapse. Experience in both the Kalahari and Canada has also shown that it may be advantageous at times to case the upper 20-30 cm of the hole using a large diameter acrylonitrile butadiene styrene (ABS) plastic pipe (Fig. 4). This provides a firm working lip and prevents fallback from disturbed sediment during the repeated insertion and retrieval of the drill stem from the hole.

Extracting a core sample without exposure to light

Once the desired sampling depth is reached, samples for luminescence dating are collected using stainless steel push tubes supplied by Dormer (Fig. 5a). The tubes were designed following suggestions from John Magee (formerly Australian National University), Gifford Miller (University of Colorado) and Gerald Nanson (Wollongong University). A drive adaptor (Fig. 3g and Fig. 5) couples the push tube to the bottom extension rod (Fig. 4b) and a slide hammer (Fig. 3d) is used to drive the sampling tube into the ground as illustrated in Fig. 4b.

The reusable sampling push tubes, as provided by the manufacturer, are convenient, but they may have a number of significant disadvantages for some users. They are heavy once filled with sediment, and even allowing for the discarding of light-contaminated ends, the amount of material collected is excessive in sand-rich sediments. Given the increasing focus on intensive sampling strategies (e.g. Telfer and Thomas, 2007; Telfer, in press), this imposes serious logistic limitations, particularly if international transport is required. For investigators who do not have their own dating lab, the use of reusable sampling tubes would necessitate the transfer of the samples to other packaging prior to dispatch to the dating lab. To avoid such laborious routines,

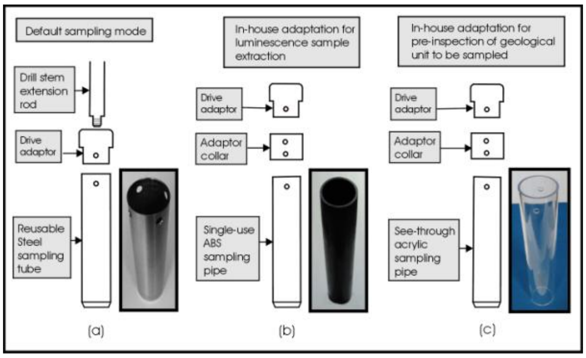

Figure 5. *Sample extraction modules are attached at the end of the lowermost extension rod using a drive adaptor as illustrated above. (a) Dormer supplies re-usable stainless steel pipes for use in sample collection. (b) Because it is sometimes necessary to send collected samples to other labs for analysis, it may be more practical to collect samples using single-use ABS plastic pipes. (c) To permit on-site pre-inspection of a subsurface unit, a see-through acrylic pipe can be attached at the end of the drill stem and a sample extracted as in (b).*

Munyikwa and Knight (2010) have fashioned a disposable push tube using a 6 cm diameter by 30 cm long ABS plastic pipe (Fig. 5b). With a wall about 4 mm thick, the pipe is rigid enough to withstand the force imparted by the slide hammer. To enhance penetration into the substrate being sampled, the ABS pipe can be sharpened. Shorter pipes can be used to reduce weight if desired. To attach the ABS push tube to the drive adapter which attaches to the drill stem, an additional collar may need to be designed (Fig. 5b). The push tube is fixed to the collar using a detachable through bolt. When the sample is retrieved from the hole, the push tube is detached by removing the through bolt after which the tube is sealed on both ends. Field experiences show that both the steel and ABS sampling tubes are generally efficient and, unless waterlogged or extremely dry, the sediment stays firmly in the tube during extraction from the hole.

Alternatively, in the quartz sand dominated dunes of the southwestern Kalahari, Telfer and colleagues (Telfer and Thomas, 2006, 2007; Telfer et al., 2009; Telfer, in press) have subsampled from the steel sample head with a 5 cm diameter by 12.5 cm length black plastic pipe in the field in a large opaque plastic bag. After discarding the outermost sediment in the steel sampling head, the plastic tube can be pushed into the sampling head by hand, and is then carefully extracted when full. This subsample is then capped, and treated exactly as a sample taken from an exposure would be; that is, the ends are still considered light-contaminated and discarded.

Determining the stratigraphic context of a sample

The most significant drawback for sampling by deep coring is that the investigator is not able to see, in-situ, the depositional unit being sampled, nor its immediate stratigraphic context. This is significant not only in terms of ensuring that the correct unit is being sampled, but also because, ideally, samples for luminescence dating should be collected from a substrate that is homogenous within a radius of at least 30 cm (Aitken, 1998). This is particularly important if in-situ dosimetry is not available.

At the most basic level, stratigraphic positioning is achieved by careful monitoring of the depth that the sample is taken from. This is easily attained by counting extension rods, and it may prove useful to mark the individual rods with tape at suitable intervals (e.g. 20 cm) to aid measurement. The Drillmite^{TM} kit comes with a shaver which can be used to retrieve loose sediment from the base of the hole (Fig. 3e). Shaving the hole base enables the determination of the precise depth at which samples are extracted.

Telfer and Thomas (2007) attempted to minimize any potential complications to dosimetry imposed by the blind nature of sampling down a borehole by measuring dose rate in-situ with a gamma spectrometer lowered down the borehole. This has been done by constructing a steel casing for a 2” NaI gamma scintillometer (necessitating a separate calibration of the instrument to reflect the changing geometries of measurement), which allows the probe to be lowered to the base of the hole.

Ascertaining the integrity of the sample

It is critical that the auger or sampling head is inserted into the borehole cleanly; this becomes increasingly challenging with depth as it becomes necessary for practitioners to lower the auger in several separate stages. Any contact with the sidewalls during the lowering of the auger or sampling unit will result in sediment dropping to the base of the hole. Evidence that this does indeed occur comes from the slow widening of the hole evident at the surface, as well as a slower rate of penetration at depth (as the removal of material knocked down the hole reduces the overall rate of augering). Such down-hole contamination threatens the integrity of the luminescence sample.

To determine the degree of disruption of the sample, Munyikwa and Knight (2010) have devised a transparent detachable push tube that can be attached at the end of the drill stem in place of the sampling push tube (Fig. 5c). A sample is extracted by driving the transparent tube into the subsurface unit using the slide hammer and pulling it out. While this method may preserve stratification in some compact sediments, it has been noted that the penetration of the pipe into the formation sometimes disrupts fine bedding. Increasing the internal diameter of the sampling tube appears to help preserve the stratification better. Dormer also supplies a similar sampling module which comprises a steel tube with a removable internal transparent plastic sleeve for extracting samples for pre-inspection. Alternatively, a split tube sampler can be used to achieve the same objective.

Single-grain studies on samples removed from auger holes suggests that down-hole incorporation of young grains is minimal if augering is conducted carefully (Telfer, in press), and if hole collapse does occur, careful examination of dose distributions may be useful in identifying the problem (Telfer and Thomas, 2007). It is advisable, however, to avoid windy days for augering, as it becomes increasingly difficult to ensure that the auger and extensions rods are held vertically before lowering into the hole.

Advantages and drawbacks: case examples of the Drillmite^{TM} in use

Canada

Munyikwa and Knight (2010) have used the Drillmite^{TM} extensively in central and northern Alberta, Canada to extract samples for luminescence dating in aeolian dunes from depths up to 20 m. It is well accepted that the region was glaciated by the Laurentide Ice Sheet during the Last Glacial Maximum (Dyke et al., 2002, 2003). However, the scarcity of radiocarbon bearing material has rendered the timing of the retreat of the ice sheet from the region difficult to constrain. Wolfe et al. (2007) and Munyikwa et al. (2011) have proposed the use of luminescence chronology from postglacial aeolian dunes in the region as an alternative time constraint for the retreat of the ice sheet. The rationale of this approach is that eolian deposition denotes an ice-free landscape and that dune emplacement commenced in the immediate aftermath of the recession of the ice sheet, prior to colonisation by vegetation. Accordingly, sampling using the Dormer Drillmite^{TM} has been targeted at the bottoms of the dunes.

Results show that sampling with the Drillmite^{TM} can be performed rapidly, with hole completion rates of 10-15 m in a day being easily attained. The manufacturer specifies that the Drillmite^{TM} can drill to depths of up to 60 m, but work in Alberta shows that a limiting factor is the mechanism employed to hoist the drill stem in and out of the drill hole. With manual hoisting, one can work down to a depth of 15-20 m. Beyond this depth the weight of the drill stem becomes prohibitive and a powered hoisting system becomes necessary. Also worth knowing is that occasionally, especially when working in clayey substrates, the sampling module can become stuck. As advised by the manufacturer, an effective remedy in such cases is to use a car jack to provide vertical leverage to the segment of the drill stem projecting at the surface.

Southwestern Kalahari

Prior to the application of the Drillmite^{TM} during field campaigns in 2002 and 2004, sampling of the huge semi-active southwestern Kalahari linear dunefield in southern Africa had only been possible via surface pits and occasional road-cuts (e.g. Stokes et al., 1997), or even scarcer deep exposures resulting from mine workings (Bateman et al., 2003). Such studies confirmed the homogenous nature of most Kalahari dunes, with stratigraphy often absent or very poorly preserved. The crucial drawback of sampling at depth, namely that intact internal stratigraphy cannot be observed, is thus perhaps less critical in this area than it might be in some other regions. However, the Drillmite^{TM} offered the opportunity for full-depth profiling of dunes selected by criteria other than convenience, and as a result intensive, localized sampling was carried out to re-assess the implications of the more opportunistic sampling that had gone before. Over 100 samples were collected from a small region, and these revealed previously unconfirmed spatial variation in preservation of dune sediments (Telfer and Thomas, 2006, 2007). For the first time, full-depth profiling of the dunes allowed studies that would simply not have been possible without the use of a rapid augering system capable of working in unconsolidated sandy substrates. The studies enabled a rigorous assessment of the preservation potential of linear dunes of the Kalahari over timescales longer than the most recent major period of dune mobilization (at around 15 – 9 ka). More recently, systematic augered OSL sampling of dunes has also been used to test geomorphic models of dune formation, sometimes in combination with Ground-Penetrating Radar (GPR) (e.g. Hollands et al., 2006; Telfer, in press).

The rapidity with which sampling can be carried out has some implications for the use of technologies such as the Drillmite^{TM}; the rate of augering possible during fieldwork, and hence the numbers of samples collected, probably far outstrips the capabilities of many laboratories for subsequent analysis. An efficient team of two field operatives might comfortably collect more than 100 samples in a week's fieldwork; a work schedule which might subsequently keep many laboratories busy for up to a year. Although laboratory procedures such as standardized growth curves (Roberts and Duller, 2004) have been explored for handling such large volumes of samples (e.g. Telfer et al., 2008), those planning large scale augering surveys are likely to have to consider issues of quantity and quality more carefully than ever.

Summary

A cursory literature review will show that, on many occasions, luminescence dating investigators have been confronted with situations when remote sampling of geological units that are not directly accessible has been imperative. In such instances, drilling to reach the targeted units has offered an attractive solution and a range of drilling devices have been employed. The Dormer Drillmite^{TM} presents a viable alternative for such sampling work because of its field portability as well as its ability to sample deeper than many other outfits of comparable size. The system comes with equipment specifically designed for extracting samples for luminescence dating and various adaptations can be made to suit specific circumstances.

In addition to being capable of sampling deeper than would be possible unaided, sampling devices such as the Drillmite^{TM} are also able to yield large numbers of samples over relatively short periods of time. The high sample acquisition rates will hopefully encourage the development of accelerated analytical protocols if excessive backlogs are to be avoided in luminescence dating laboratories.

All in all, these possibilities widen the prospects for paleoenvironmental studies that use records from Quaternary deposits.

Acknowledgements

The Natural Sciences and Engineering Research Council of Canada (NSERC) and Athabasca University are thanked for funding through grants to KM. Gratitude is extended to Jakob Wallinga for reviewing this paper and providing invaluable comments.

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