Polar Excavation Techniques and Technology

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ABSTRACT

Major archaeological excavations have been conducted at Scott's 1910–13 expedition hut site at Cape Evans, Ross Island, Ross Dependency, Antarctica, over the past three years. The work has involved experimentation and the use of a wide range of equipment for excavating in ice and permafrosted ground and to deal with specific problems encountered during archaeological fieldwork in a frozen environment such as Antarctica. The equipment, its operation, and advantages and disadvantages are described.

Keywords: POLAR ARCHAEOLOGY, ROSS SEA REGION, HISTORIC SITES, TECHNIQUES, EQUIPMENT.

INTRODUCTION

During the past three summers (1986–89), the author has spent over three months in Antarctica undertaking restoration, preventative conservation work, and archaeological excavations in and around the Scott and Shackleton expedition huts in the Ross Dependency, for the Antarctica Heritage Trust. The general nature of the sites, their history and associated artefacts, management proposals and problems have been detailed in several reports and publications (see Quartermain 1963; Harrowfield 1981; Turner and Harrowfield 1984; Ritchie and Simmons 1987, 1988; Ritchie 1988, 1989).

In addition to a wide range of management-related tasks, the work over the past three seasons has involved substantial archaeological excavations, particularly at Scott's 1910–13 expedition hut site at Cape Evans. Three seasons of sustained work on the one site enabled an annual review of the efficiency of each season's excavation work, and experimentation with 'new' technologies and techniques the following season (see Ritchie 1988, 1989). The various kinds of equipment, and insights into their operational merits and disadvantages are detailed below.

Within the Dependency there are four early British polar expedition base huts plus another 25 historic sites (field bases, scientific huts, shelters, food depots, cairns and memorials), which collectively constitute about 59 percent of the 54 currently ratified 'historic monuments' on the continent (Harrowfield 1988: 277–278; H.A.T.S. 1989). All the sites date from the so-called 'Heroic Era' of Antarctica exploration (1899–1917). The main expedition base hut sites in the Dependency are as follows (Fig. 1).

1. Living and storage huts at Cape Adare built by members of the 'Southern Cross' expedition led by C. E. Borchgrevink (1899–1900) (first to over-winter in Antarctica).

2. A substantial hut on Hut Point, Ross Island built by Captain R. F. Scott's 'Discovery' expedition (1902–04), used initially for polar exploration and seeking a route to the Pole, and as a staging base by the later Scott and Shackleton expeditions.

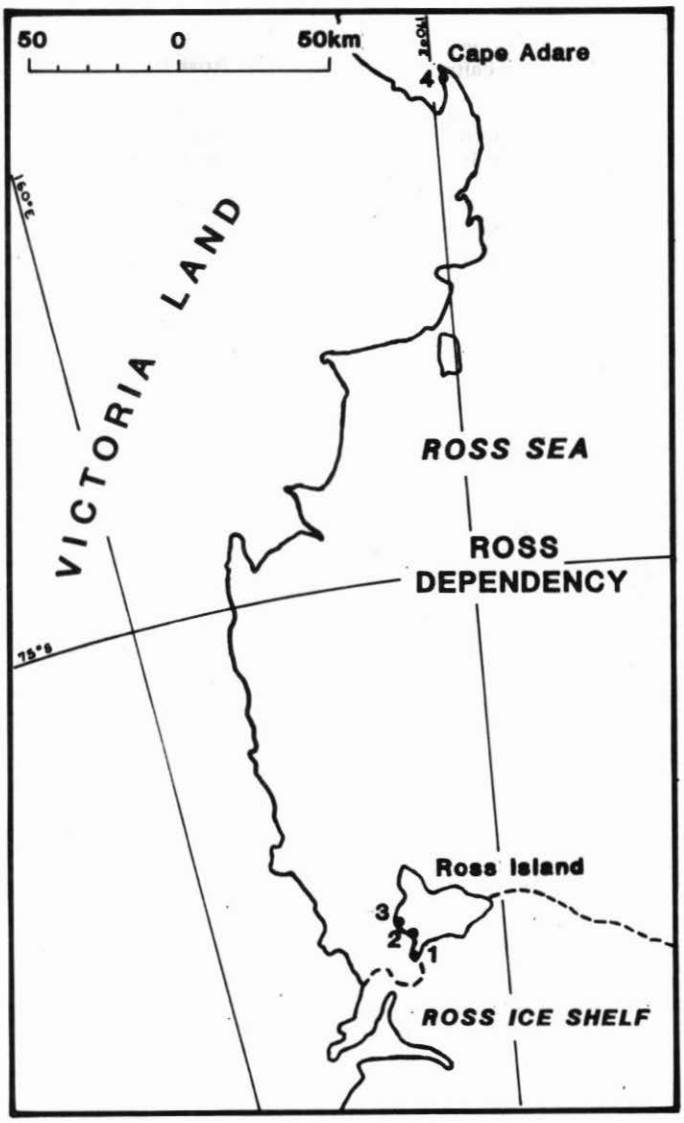

Figure 1: The locations of historic huts mentioned in the text. 1. Hut Point, 2. Cape Evans, 3. Cape Royds, 4. Cape Adare.

3. The overwintering hut erected at Cape Royds by Earnest Shackleton's 1907–09 'Nimrod' expedition (the base for their aborted Pole attempt). It was used again between 1914 and 1917 in the course of Shackleton's Imperial Trans Antarctic Expedition (the ill-fated 'Aurora' expedition).
4. Scott's hut at Cape Evans established during his 1910–13 'Terra Nova' expedition. Although Scott reached the Pole, he and his companions succumbed on the return journey. The hut was later used by members of Shackleton's 'Aurora' expedition. Unfortunately, no evidence remains of the distinctive Scandanavian-style 'Framheim', the base camp established on the Ross Ice Shelf by Roald Amundsen who beat Scott to the Pole in 1911.

The Scott and Shackleton huts are located on Ross Island where New Zealand's Scott Base and the American McMurdo base are located. These huts are relatively accessible to air or ship borne visitors and have been the main focus of the restoration, conservation and archaeological work to date. The 'Southern Cross' expedition hut and the living hut of Scott's 'Terra Nova' expedition (1910–13) Northern Party are on Cape Adare, about 300 km north of Scott Base. The 'Southern Cross' hut was cleared of snow in 1960 to provide an emergency shelter, and some further maintenance was undertaken in 1974 and 1982. Despite its relative inaccessibility and low visitation at present, plans for essential weatherproofing and restoration are in hand but further work has been deferred because of logistic difficulties (Harrowfield pers. comm. 1989).

BACKGROUND TO THE ARCHAEOLOGICAL WORK

Following their abandonment (before 1920), the expedition huts gradually filled with snow which gained entry through broken windows and gaps in the weatherboards. Within a short time the snow turned to ice. This accumulated material was removed from the three Ross Island huts in the early 1960s, in what is commonly described as 'the hut restoration period'. No archaeologists or restoration or conservation professionals were involved at this stage. Although the people involved kept minimal records and some artefacts were moved out of context, to their credit considerable efforts were made to do a systematic and professional job (Quartermain 1963). Before the 'restoration work' several northern hemisphere institutions were contacted (including the Smithsonian Institute, the U.S. Army Snow and Permafrost Establishment, the Museum of Canada, and H.J. Plenderleith) in order to establish the best means of extracting artefacts from ice and permafrost. They all recommended removing blocks of ice containing artefacts and placing them in the sun, so that the artefacts would be freed without damage as the ice melted (Quartermain 1960: correspondence).

By the early 1980s, the New Zealand Antarctic Division was becoming increasingly aware that many artefacts were deteriorating and decided it was time to involve specialists in an attempt to resolve the problems. It was on this basis that the author was asked to assist.

I acknowledge the role of David Harrowfield, a member of the New Zealand Archaeological Association, for his part in convincing the New Zealand Antarctic authorities that the historic sites and their contents could not be maintained in Antarctica in the long term without a more scientific approach to management and conservation. Harrowfield first worked on the huts programme (as a caretaker) in 1977–78. On the strength of the small test excavations he conducted then, it can be argued that he was 'the first archaeologist to work in Antarctica'. Since 1978, Australian archaeologists have carried out surveys and preliminary excavations in and around the Mawson expedition huts in the Australian Antarctic territory (see Ledingham *et al.* 1978; Ledingham 1979; Lazer 1985; McGowan 1987, 1988), and New Zealand based archaeologists have undertaken larger scale excavations at Cape Evans (Ritchie 1988, 1989). Roger Fyfe will be continuing work at Cape Evans in the 1989–90 season. Archaeologists have gained a foothold on the frozen continent, and it is essential that the profession maintain an active involvement in future field investigations and management of the historic sites on the continent.

In 1986, I was asked to assist with the identification, excavation, and recording of artefacts from areas which had 'not been excavated before' and advise on various long term management matters. When confronted with the prospect of excavating in ice and permafrosted ground, I sought as much information as possible on appropriate techniques and technologies. Formal texts on excavation techniques (e.g., Joukowsky 1980; Connah 1983) contain no discussion on polar excavation techniques or technologies.

Advice was sought from Parks Canada and the United States National Park Service in Alaska concerning publications on polar excavation techniques. I received several interesting but largely unhelpful reports on excavations and site surveys in the Canadian High Arctic.

With few exceptions (e.g., Janes 1982), the excavation description sections contained virtually no information on excavation techniques and ended with the same phrase "Excavation ceased when permafrost was reached" (e.g., Minni 1978). It appears that the inhabitants of such climes either did not lose or bury anything below the permafrost level or for some reason the archaeologists assume, on the basis of their field experience, that there is usually little of significance below the permafrost. Most of the recorded sites in the Arctic are surface scatters, cairns, or structural remains, usually on gravel beaches. Given the dearth of published information on polar excavation techniques and technology, we had to cope with the situation during the first season on the ice as best we could (Ritchie and Simmons 1987, 1988) but we learnt a lot from the experience.

The deficiencies of traditional ice excavating technology were soon apparent, as was the need for new approaches. Three years later, I have had the opportunity to experiment with about a dozen ice excavation techniques. None of them are perfect, but we have gained an increasing level of efficiency (and considerably less wear and tear on the excavators) by using various combinations of the techniques in situations where they have proven to be most appropriate. In the following discussion, the advantages and disadvantages of each technique are discussed.

Other techniques were evaluated but for various reasons discounted. These include techniques used by the goldminers on the Klondike goldfields to work frozen alluvial ground (Ball 1975) and methods such as explosives which are routinely used for the excavation/removal of frozen ground and ice in the course of engineering projects (see McCullough 1958).

The four main techniques used by the miners were fire thawing, steam thawing, and hot and cold water thawing. Obviously fire thawing was not possible within the confines of an historic site, and difficult for environmental reasons in Antarctica. Steam thawing had potential but required a steam generator and fuel. Hot water thawing also required bulky equipment and fuel. That left cold water thawing. It has long been recognised that pouring cold water on frozen ground or ice softens the surface, which can be scraped off if desired. The problem, of course, is that one needs a source of running water, not easily found in Antarctica. However, the technique can still be gainfully applied. By diverting even small amounts of meltwater, frozen ice (around artefacts) can be softened, lessening the likelihood that an artefact will be damaged during recovery.

ICE EXCAVATION TECHNIQUES AND TECHNOLOGY

There are two broad categories of ice excavation techniques: dry and wet. *Dry techniques* involve the use of manual or automated tools, which are used to pick or cut away ice from around structures, artefacts, or residues. Dry technologies include manual tools, mechanical percussive tools, and ice saws (manual and automated). Wet techniques involve the application of heat (in the form of solar energy, hot air, steam, or free-running water) to melt ice and thereby enable items to be extracted and documented. *Wet methods* include direct and indirect solar melting, using water (usually meltwater) to soften ice or permafrosted ground, and the application of heat to effect melting through the use of gas or electrical appliances including heat guns, blow torches, and air heaters. Melting can also be effected through the application of chemical de-icers.

The techniques vary from relatively simple to reasonably complex in terms of required technology. They also have specific advantages and disadvantages. Any artificial heat source requires a generator and/or fuel. While this is not a problem in some locations, it presents very real logistic difficulties in the Ross Dependency, if not other parts of Antarctica. In the Ross Sea region, New Zealand personnel are reliant on American helicopter transport. The Americans do not like conveying inflammable fuels in the helicopters, necessitating underslung loads or separate cargo loads, and also the draining and breathing of all fuel tanks on generators and other powered equipment. They also insist that all fuel drums leaving Scott Base are full, and are sealed and certificated by a safety officer before being loaded. Without the appropriate 'seal of approval' fuel is left behind. However, the greatest problems simply involve the lifting capacity of the helicopters and each field party's allocation of flying hours which are pre-approved. With a work crew of four and their food and survival equipment, the helicopters have about 350 kg of spare lifting capacity. As a consequence, it is not possible to take a complete arsenal of excavating equipment to a site, even if the necessary equipment is available.

The various excavation techniques are now discussed in order of increasing complexity of equipment.

MANUAL TOOLS

There are three main types of manual tools which can be used in various combinations in the course of excavating ice.

1. Percussive and picking tools such as ice picks, chisels, screwdrivers etc;

2. Cutting tools such as ice saws;

3. Levering bars (sometimes a sharp jolt will dislodge a robust object, such as a wooden crate, if it is frozen against another with little gap in between). De-icing chemicals (see discussion below) may also have application in these situations.

All the tools are used in conjunction with normal excavation equipment such as trowels, brushes, and hearth shovels. Snow shovels and tarpaulins are used for shifting large volumes of broken ice.

The main advantage of manual tools is that the equipment costs little and is very portable. The main disadvantages are that using them for prolonged periods is quite physically demanding (and painful; on wrists in particular), relatively slow, and messy (because of the constant splattering of fragments of ice, which are often contaminated with residues), which in turn presents some risk to eyesight and health. To avoid damage to eyesight it is necessary to wear goggles but they do not prevent bits of foul tasting ice getting in one's mouth or melting down one's collar. Despite these irritations, traditional manual excavation methods work, and cause relatively little damage to artefacts (so long as one works very slowly and carefully) but it is almost impossible to avoid some damage.

SOLAR MELTING

As mentioned earlier 'solar melting' was the method advocated by northern hemisphere institutions when Quartermain (1963) sought information on the best means of recovering artefacts from within the accumulated ice and snow in the Ross Island huts. The process can be speeded up if the ice (*in situ* if outside, or in blocks removed from the interior of structures) is covered with black plastic. Harrowfield (1978a: 99) reported that he used black plastic (heavy grade) to thaw the top few centimetres of ground outside the stables at Cape Evans in 1978, after which he was able to excavate in the normal way with a trowel. While there is no doubt that the method works, the rate of thaw is so slow that, in my view, it is of limited utility. However, we routinely use direct solar energy to free the contents of excavated containers, e.g., tin boxes containing fish hooks or cartridges, or for melting the ice inside excavated glass bottles.

DIVERTING MELTWATER

As noted, the presence of meltwater softens ice in the immediate vicinity, and can, on occasion, be gainfully used to facilitate the extraction of artefacts from ice. The disadvantages of meltwater softening are essentially the same as those associated with the other wet techniques, viz:

1. Ice stratigraphy is lost;
2. Organics rehydrate producing offensive smells;
3. The diversion or production of free running water is liable to damage or soak off product labels (so its use is restricted).
4. Hydro-engineering is constantly necessary to aggregate, divert, or drain away meltwater. While water can be used to soften ice, as in most archaeological excavations, it is messy and in polar climes can be uncomfortable if one's boots leak.

Naturally accumulated meltwater in a structure is, of course, quite undesirable from a conservation point of view. It increases relative humidity, and consequently dampness and oxidation damage.

The Australian archaeologist Angela McGowan (1987: 52), who conducted small scale excavations in Mawsons's hut in the Australian Antarctic Territory in 1986, claimed that wet techniques also destroy what she termed 'ice artefacts', which by her definition are in reality frozen residues. I think the term 'ice artefacts' is a misnomer, which also overstates their cultural significance and information potential. In an ice-filled structure, the source of the numerous residues (often intermixed) is usually readily apparent; leaking tins or broken bottles in the immediate vicinity or on a shelf above, or decomposing seal blubber, or penguin or husky carcasses, or portions of domestic animal meat cuts such as mutton or pork. If the nature of a residue is not immediately apparent it can become all too recognisable upon exposure and partial rehydration (through smell, and presumably taste if one is game enough). The use of meltwater for ice or permafrost melting is part of the assemblage of methods which any polar archaeologist should consider. Impounded or diverted meltwater effectively softens hard ice and can be used in non-critical locations (i.e., areas where there are no obvious cultural deposits) for softening ice around individual artefacts that are not prone to water damage, e.g., glass bottles without paper labels. Similarly, seawater can be used to melt ice in outside locations where it is obvious there are no vulnerable relics. Heated water also has limited applications, if for no other reason than that it can be easily directed from an appropriate container on to the ice around an object.

CHEMICAL DE-ICERS

Thus far, chemical de-icers have not been used during the Ross Island historic huts archaeological work, or elsewhere to my knowledge. Although untried as yet, commercially available chemical de-icers may be useful in limited situations during the course of polar excavation projects. The optimum, if not essential, requirements of de-icing chemicals for Antarctic historic hut work are that they are water soluble, biodegradable, and non-inflammable for personal safety, conservation, and transportation reasons. Following consultation with an industrial chemist, some experimentation will be undertaken at Cape Evans during the 1989–90 season (Fyfe pers. comm.) using three different de-icing products to aid artefact removal from ice and permafrosted gravels, namely:

1. Antifreeze (specifically glycols because they work in low concentrations);

2. De-icing chemicals — specifically, Calcium chloride (Dow-Frost, trade brand), which is non-corrosive and effective to minus 35° C. It is used for de-icing roads in North America);

3. Surf-actants (such as DOW multi-film). Surf-actants are biodegradable and safe compounds widely used in food preservation (an example is the waxy coating applied to apples). They reduce surface friction and extend anti-freezing capacity.

ARTIFICIAL HEAT SOURCES

Artificial heat sources are an essential part of all wet methods of excavation (except solar melting). They include the use of steam generators, heat guns, air heaters, and blow torches.

Steam Thawing

I have no personal experience of using steam as an archaeological excavation technique, and am unaware of any other archaeologists who have used it. However, as mentioned earlier, steam fed into ice or permafrosted ground via a pipe was used by the miners in the Klondike to soften the ground, and 'steam jets' have been used extensively for making small excavations (localised thawing) in the course of civil engineering projects in polar climes (Ball 1975; McCullough 1958). The technology has potential archaeological applications but I suspect steam thawing would be less efficient (much slower) than some of the alternative technologies. In the Antarctic situation it would require a petrol or electrically driven steam generator, both of which would require large volumes of fuel.

Gas Torches and Heaters

Archaeologists from the Canadian Northwest Territories Prince of Wales Northern Heritage Centre used propane gas blow torches for freeing artefacts during an excavation/conservation project on Kellett's storehouse, a provision depot established in the Canadian High Arctic by a British Naval Search Expedition in 1853 (Janes *et al.* 1979; Yorga 1979; Janes 1982: 371). In reports on the work, they neglect to comment on the effectiveness of the technique, but presumably the absence of negative comments means it works quite well. I have not used gas torches in Antarctica because we have been working in and around wooden structures and provision boxes (therefore there is some risk of incineration or charring), the supply and transport of gas presents some logistical problems, and the method would produce meltwater in situations where it was not desired. However, if used with care in appropriate circumstances, gas-powered blow torches or heaters would be both efficient and cost effective.

Heat Guns

For the past three seasons, we have used heat guns, which are small hand held appliances similar in appearance and operation to electric hair driers. Similarly, they produce a direct stream of hot air which can be used to melt ice around objects. They are particularly useful for melting ice around fabric, canvas, and leather. Care has to be taken that the heat is not concentrated on any one spot, or it will scorch the object.

They can be used to melt ice from around glass and tin containers, but must be used with extreme care. Any rapid application of heat will fracture glass (not a big problem if one is already dealing with fragments), and a concentration of heat on one spot can melt paint or wrinkle or incinerate labels. Like all electrical appliances used in the field they require a generator and fuel (Mogas). While this presents a logistical difficulty, it has not been a problem in the Ross Island situation because we routinely take a Honda portable generator into the field to power flood-lamps used to illuminate the interiors of the structures when we are working in them. A 1.5 kVA generator will power two appliances (just). The major disadvantage of heat guns is that the ice melts very slowly, making them quite inefficient for working large areas.

Air Heaters

In 1988 we used a portable petrol-engined air heater (an Andrews 1D 175) in the course of excavating within Bowers' storage annexe at Cape Evans. These machines are commonly used for heating workshops and warehouses. They produce a lot of warm air which can be directed through a hose on to the work area. Air heaters are definitely useful (in 1988, the Americans used several of their larger trailer-mounted Herman Nelson air heaters to excavate a LC130 Hercules which had crashed on take-off and been buried in the ice for 18 years) but they have a number of 'de-merits' about which it is necessary to be mindful. I have already outlined the main disadvantages of wet techniques, viz. loss of stratigraphy, rehydration and re-solution of frozen residues (with resultant smells), potential water damage to labels and paper, and the need for constant hydro-engineering to drain off melt water (which freezes again as soon as it runs beyond the heat source) to avoid creating icy bogs. With regard to stratigraphy, it is necessary to decide before using an air heater whether the ice layers are important. Often, it is fairly obvious that they are not (see later discussion). As in normal excavations, much can be learnt from small test excavations before one starts bulk removal.

The weight and bulk of air heaters are among the disadvantages and disincentives against their use in the Ross Sea region huts, although much smaller air heaters (and gas-fired) exist than the one which was available to us. The petrol driven air heater we used required a 2.5 kVA generator which weighs about 50 kg; the air heater itself weighed 127 kg, and a lot more when loaded to capacity with 100 litres of fuel. We mounted the equipment on a Nansen sledge (about 100 kg, lent by Greenpeace International) which we manoeuvred by hand. Even so it was still difficult to manoeuvre the equipment on rough or sloping ground. On the advantage side of the ledger, air heaters produce a lot of heat which can be directed on to specific areas via a reinforced rubber hose. We routinely covered areas where we wanted to melt the ice with a canvas tarpaulin and poked the air hose under it. This enabled us to do other chores while the ice melted. However, it is necessary to inspect progress regularly, in order to channel away the meltwater (which freezes as soon as it runs beyond the range of the warm air), and recover and document items. We were using the air heater outside; the use of air heaters inside would require more constant attention, and channelling of meltwater to avoid a chaotic situation developing.

Because an air heater in effect produces a warm wind, it is also necessary to be constantly mindful where the nozzle of the air hose is pointing, to avoid damaging fragile artefacts such as paper labels. They can easily rip or literally get blown off containers if one is not careful. On the other hand, the 'warm wind' makes working conditions very pleasant, especially when the temperature drops below -20° C.

PERCUSSION 'HAMMERS'

This season past, we introduced a new tool to our ice excavation arsenal, a percussion hammer-drill, which to my mind is the *pièce de résistance* of the ice excavating business. The specific model we used was a Ramset Dynadrill kindly lent by Ramset New Zealand Ltd. A Dynadrill is an electrically powered percussion hammer drill with a chisel-bit rather than a drill bit. Our machine had two chisel-bits, 20 mm and 40 mm wide. We found the wider blade was the more efficient for ice excavation. The Dynadrill proved particularly efficient for bulk ice removal and for cracking hard ice around artefacts. Because the chisel end only moves about 3 mm, the tool causes minimal damage if it comes into contact with artefacts (except glass, which is at risk with practically any percussion or thermal technique) or structural components.

Considering it is an automated tool, we found that it has a remarkably gentle and forgiving action, and has some very real advantages. Firstly, it enabled much greater volumes (at least 10 times more than other techniques) of ice to be excavated, with much less physical effort and strain than one experiences using manual percussive tools. The constant jarring when one is striking hard ice is particularly hard on wrists and shoulders. The second major advantage is that it cracks the ice with virtually no splattering of freed ice/water compared with manual percussive and chopping tools, making the actual work of ice removal considerably more pleasant and less messy, especially when working amid ice containing horse manure, human faeces, and food residues (as we were in places).

The third advantage of the tool is that it is lightweight (about 3 kg), very portable and highly manoeuvrable, so that it can be used with great dexterity, even by a first time user. Fourthly, it likes hard ice; the harder the ice, the more effective the tool is (the complete antithesis of manual ice-breaking).

As with other power tools, it is necessary to have a portable generator, to be mindful of the power cable, to use an isolating transformer at all times, and to be aware of the possibility of short circuiting (despite the double insulation) because of snow or meltwater getting into the tool. To avoid potential short circuiting problems operators need to be careful where they place electrically powered tools when they are not in use (the motor housing should not be laid directly on snow or ice). Those problems aside, the Dynadrill proved remarkably efficient and robust for ice excavation. Considering we would have put on more than a normal lifetime of use in the space of a week, either, by good fortune, we had a particularly robust machine, or it is indeed one of the better inventions (I suspect the latter). Furthermore, I believe Dynadrills have potential applications in other areas of archaeological excavation, such as in breaking out pit fills or indurated ash layers, in fact, in just about any situation where excavators are struggling with grubbers or spades, or trying to excavate rock hard soils with a trowel.

We also experimented with a small Kango hammer (lent by Greenpeace) during the 1988–89 season. A Kango (trade brand) is a small version of the pneumatic jack hammers which are used for ripping up road surfaces or breaking up concrete. Our Kango had a 70 mm wide blade. It was particularly efficient for excavating drainage channels through ice and frozen gravel, but its weight (about 30 kg) and ungainliness are such that I would not advocate its use for controlled archaeological excavation.

In 1978, Ledingham and party used 'a percussion chisel' to remove ice from the Australian Antarctic Expedition (A.A.E.) hut at Commonwealth Bay, Australian Antarctic Territory. They reported that "it worked well in hard ice and in tight corners where the ice was welded with debris, but it was unable to cope with medium soft snow" (Ledingham *et al.* 1978: 14). This is similar to our experience with pneumatic tools.

CHAINSAWS

An electric chainsaw was another new tool we introduced during the 1988–89 season. Obviously an electric chainsaw has considerable potential for mass destruction if used carelessly, but used carefully it proved particularly efficient for cutting 'artefact free' 'sugar-ice' into blocks for removal. 'Sugar-ice' has a sugar-like texture. Although it is relatively soft compared with 'hard ice', its removal by manual means still involves considerable exertion because it does not shatter or crack when struck. Instead, it tends to absorb the blow and usually snag the implement. However, it readily cuts with a chainsaw and can be efficiently removed in small blocks. The efficiency of a chainsaw (electric or petrol-powered) is directly related to how it is treated. The chains blunt rapidly if one is constantly cutting very hard or grit-impregnated ice. Regular sharpening maintains a high level of efficiency.

Ledingham and party used a chainsaw in 1978 to cut ice in the Australian Antarctic Expedition hut at Commonwealth Bay. They reported that "the chainsaw was valuable where the way ahead was known to be clear (e.g., passageways) but it could not discriminate between ice and wood. As a result, some minor damage was done in the early stages" (Ledingham *et al.* 1978: 14). Their experience highlights the need for care and caution when using a chainsaw within the confines of an historic polar hut.

CONCLUDING DISCUSSION ON TECHNOLOGIES

There is, in my opinion, no optimum method of ice excavation; each has advantages and disadvantages, and each involves an element of trial and tribulation. Ideally, when excavating a polar site, one would have virtually the full range of technologies at one's disposal. However, it is not possible to do this in Antarctica because of weight limitations and logistic factors. It is necessary to weigh up the availability of the equipment and the problems of getting particular technologies on-site, against their known or inferred efficiency and the requirement to get the job done within a reasonable time. The window of time when it is possible to work at the historic huts in Antarctica is very small — two months at the most, and usually only one month.

Of the polar excavation technologies that we have used on the Ross Island sites to date, without a doubt the Dynadrill is the most efficient, being in effect a 'reciprocating trowel' which breaks down the matrix (in this case ice) by vibration rather than scraping or gouging. It is a remarkably versatile tool, and the only thing that I am aware of which would be better is two Dynadrills (however, a 2 kVA generator, at least, would be necessary to power two at one time). There may be similar and better tools on the market, but I would be inclined to stick with the one I know, in the first instance.

When using machinery, it is also necessary to take into consideration the mechanical ability of the crew. This need not be substantial but it is a long way to a garage if one is relying on particular power tools and is unable to effect elementary repairs. It is essential to take basic spares and maintenance tools such as fuel funnels, fuel filters, spark plugs, screwdrivers, a crescent spanner etc. It is also important to keep track of these items as well as the tools and ensure they are under cover (if possible) when the crew is not working. A snow flurry when the crew is asleep will rapidly bury any exposed items, which may prove very difficult to relocate.

To conclude, ice excavation involves an element of trial and error, and often considerable physical exertion. I believe there is no optimum technique for ice excavation (although a Dynadrill comes close to it). Snow and ice have different physical properties depending on their antiquity, the topography of the site, and its location in relation to structural remains and other site features. Each site has to be looked at individually, and an assessment made based on its 'originality', the volumes of snow and ice and their nature, the known or inferred contents of the structure, and the resources available (including time, personnel, funding, equipment, and fuel).

ICE EXCAVATION TECHNIQUES

When excavating ice and permafrosted ground the normal principles of stratigraphic excavation are still valid. Excavation technology has to be tailored to the snow, ice, and ground conditions, the obvious or inferred likelihood of artefacts, and surrounding structural features.

It is important to ascertain as soon as possible whether the ice has been formed in recent years or whether it is of some antiquity. If a structure is not weatherproof, snow will gain access and new ice will form at least annually (if not more often). With a few test 'pits', it is usually possible to ascertain the extent of recent ice, which may be represented by many discrete layers. Recent ice usually contains few items of special interest and can justifiably be removed fairly rapidly. However, it is always necessary to be mindful of the possibility of encountering historic items which have fallen from ceilings or shelves. Generally there is a rough correlation between the age of ice and its hardness (related to compaction), but it varies a lot from place to place. Extremely hard ice shatters like glass or obsidian when struck. 'Sugar-ice' and other softer forms of ice and consolidated snow absorb blows. Soft (and usually very recent) snow can be cut with a trowel and excavated with a hearth shovel.

Regardless of its age, there are two main forms of ice which are likely to be found within a structure: ice formed from snow which has gained entry through gaps in the walls, roof, windows etc., and ice which has formed from the entry and freezing of melt-water. The former tends to build up in layers with a 'preferred orientation'; while the latter may form distinct horizons (if contained) or flow down to lower levels within the structure where it accumulates. En route, the running water freezes into sloping ice masses. The two types of ice have different characteristics. That formed from snow can be more readily broken out in layers (depending on the texture of successive layers), whereas ice formed from frozen meltwater tends to produce conchoidal fractures when struck and break out in a more irregular manner.

Impurities in ice act like a binder. Grit-impregnated ice can be extremely tough (i.e. resistant to blows), but by the same token, hard ice will sometimes shear cleanly along an interface (e.g., along a wall) if struck in the right place. Ice varies greatly in opacity. Some ice is crystal clear. You can clearly see items in it and can plan on that basis. However, most 'historic' ice is contaminated with dirt, grit, straw, food residues or manure, or contains chunks of paper, cardboard, plywood, rope, sacking, or canvas or other materials which obscure visibility and make it more difficult to excavate. It is in these situations, particularly, that one should experiment with different excavation technologies.

During the excavations I have conducted in Antarctica, I have not used conventional string grids. They get in the way, and are difficult to anchor securely. Instead, all exposed items are plotted relative to permanent structural features such as walls and interior divisions (e.g., the partitions in the stables). Normal stratigraphic sections are drawn, again relying on fixed structural features as a reference point.

With wholesale melting techniques, such as the use of air heaters, there is of necessity a compromise between the loss of ice stratigraphy (hence possibly significant information) and the ease of recovering items. It is necessary to evaluate the ice matrix before starting and decide whether it is likely to be critically important in any chronological or information sense. Historical records often contain information which is very relevant to such assessments. Once melting is underway, the process needs to be monitored and drainage maintained.

The lack of consistent conservation input into the Ross Island historic huts programme until relatively recently has been a major deficiency of the programme to date, although the situation, while regrettable, is understandable (cf. Hett 1985; Hughes 1986). New Zealand conservators tend to have expertise or skills in different media than those of the artefacts in the historic huts. Furthermore, there are few professional conservators who have indicated they or their employers can make the time commitment. However, moves are at present underway (through the Antarctic Heritage Trust) to redress this situation. It is absolutely essential that there is a sustained conservation programme in future, which is closely linked to further archaeological work.

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