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Environmental pollutants from the Scott and Shackleton expeditions during the 'Heroic Age' of Antarctic exploration

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ABSTRACT. Early explorers to Antarctica built wooden huts and brought huge quantities of supplies and equipment to support their geographical and scientific studies for several years. When the expeditions ended and relief ships arrived, a rapid exodus frequently allowed only essential items to be taken north. The huts and thousands of items were left behind. Fuel depots with unused containers of petroleum products, asbestos materials, and diverse chemicals were also left at the huts. This investigation found high concentrations of polyaromatic hydrocarbons in soils under and around the historic fuel depots, including anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, fluorene, and pyrene, as well as benzo[a]anthracene, benzo[a]pyrene, and fluoranthene, which are recognized carcinogens. Asbestos materials within the huts have been identified and extensive amounts of fragmented asbestos were found littering the ground around the Cape Evans hut. These materials are continually abraded and fragmented as tourists walk over them and the coarse scoria breaks and grinds down the materials. A chemical spill, within the Cape Evans hut, apparently from caustic substances from one of the scientific experiments, has caused an unusual deterioration and defibration on affected woods. Although these areas are important historic sites protected by international treaties, the hazardous waste materials left by the early explorers should be removed and remedial action taken to restore the site to as pristine a condition as possible. Recommendations are discussed for international efforts to study and clean up these areas, where the earliest environmental pollution in Antarctica was produced.

Contents

Introduction

A little more than 100 years ago, the members of the British National Antarctic Expedition, led by Robert Falcon Scott, built a large wooden building, later to become known as the *Discovery* hut, at Hut Point on Ross Island. This hut was to serve as a shelter, workshop, and supply store for the expedition members for three years during their exploration and scientific investigation of the area (Scott 1905). In 1908 the members of the British Antarctic Expedition, led by Ernest Shackleton, built another hut on Ross Island at Cape Royds; this would house a shore party of 15 men (Shackleton 1909, 1919). The members of Scott's ill-fated *Terra Nova* expedition (1910–13) erected a large prefabricated hut at Cape Evans to provide accommodation and also built a smaller structure that was framed in wood and lined with asbestos sheeting for taking magnetic observations (Harrowfield 1995; Pearson 1992; Scott 1913). Although it can be argued that geographical goals were primary to all three expeditions, they also had important scientific objectives. Each of the expeditions had one or more biologist, geologist, meteorologist, and physicist to carry out scientific programs. Along with an enormous amount of stores and equipment needed for survival in Antarctica during several years of exploration, there were some unusual items such as motorized vehicles and tractors. This new mode of transport for the early twentieth century was to be used for hauling supplies across the ice, but they were not overly successful. Large volumes of petroleum products brought for the vehicles were not used and remained in storage containers near the huts (Dougherty 1985). A considerable amount of asbestos was also transported to Antarctica for use as insulation around scientific equipment to prevent interference during magnetic observations and for other purposes. Knowledge of potential health hazards and environmental pollution that could result from these compounds being indiscriminately released into the environment did not exist at the time. In addition to crude petroleum products and asbestos, a wide array of chemicals was also brought to Antarctica along with battery acid, paint, and other substances containing heavy metals.

When the relief ships arrived to transport the shore parties back, initially, to New Zealand, there was a fast exodus to avoid the possibility of the ship getting frozen in the pack ice. Many non-essential materials were left at the huts, including unused food stores,

scientific and technical equipment, and personal items. Unused tanks of petroleum, materials containing asbestos, chemicals for experimentation, and thousands of other items were left behind. Today, the historic huts and most of the artifacts remain, providing a remarkable view into the lives of the explorers (Harrowfield 1995, 1981; Quartermain 1963). The international community has recognized the immense historical significance of the huts and artifacts for many years. Provisions of the Antarctic Treaty require all governments to adopt all adequate measures to protect the buildings and objects of historic interest from damage or destruction. The Protocol on Environmental Protection to the Antarctic Treaty of 1991 forbids the damaging, removal, or destruction of the historic sites, and, more recently, the huts have been designated as 'protected areas' by the Antarctic Treaty Consultative Meetings held in 1997 and 1998. During the past several years conservators from the Antarctic Heritage Trust have carried out work to protect and restore the huts. The investigations reported here were carried out in collaboration with the Antarctic Heritage Trust to identify hazardous materials and areas contaminated by potentially toxic pollutants at the historic sites in the Ross Sea region.

The dry, cold Antarctic environment has helped to preserve the huts and artifacts, but during the past 9–10 decades considerable deterioration has occurred (Blanchette and others 2002). Non-biological as well as biological deterioration has taken a toll on the wooden structures, metal objects, textiles, food stores, and other materials. During investigations to assess the abiotic deterioration and unique microbial decay occurring at the historic sites, hazardous pollutants originating from the early explorers were found to be contaminating the Antarctic environment at several locations. Since these sites are some of the most frequently visited areas for tourists in the Ross Sea region, exposure of the pollutants to humans should be a concern as well as the potential effects on terrestrial animal populations, aquatic life, and the Antarctic environment in general. This paper documents areas of environmental pollution that were found and identifies the specific types of pollutants present at each site. Results from these investigations suggest that despite the historic origin of the materials, the toxic substances should be removed to return the Antarctic environment to as pristine a condition as possible.

Sampling methods and analyses

Samples of soil, wood, and materials suspected of being asbestos were obtained from within the historic boundaries of Hut Point, Cape Evans, and Cape Royds on Ross Island, Antarctica. Samples were obtained during the austral summers of 2001 and 2002 under Antarctic Conservation Act permit numbers 2001-015 and 2002-001, and in cooperation with the Antarctic Heritage Trust, Antarctic New Zealand program K021, and the National Science Foundation.

Soil samples were collected from two fuel depot sites at Cape Evans near the historic hut. One site, the 'lower fuel depot,' is located south of the hut. The second site is located at a higher elevation to the southeast of the hut and is referred to in this paper as the 'upper fuel depot.' Both depots have wooden crates enclosing metal tanks that stored the petroleum products. Samples were taken immediately adjacent to the containers and at one-meter intervals from the ground surface and at various depths (5–15 cm) down to the ice-cemented layer. Samples were placed in non-reactive containers and frozen until analyzed. Levels of total petroleum hydrocarbons were determined by extracting the samples in methylene chloride, then analyzing the extracts by capillary gas chromatography with a flame ionization detector, as outlined in EPA Method 8015 (US Environmental Protection Agency 1992). Samples contaminated with hydrocarbons were also analyzed by using accelerated solvent extraction EPA Method 3545, followed by capillary gas chromatography with mass spectrometry and selected ion monitoring quantification EPA Method 3540 and 3630 (US Environmental Protection Agency 1992).

Elemental analyses were completed on samples of historic woods using multi-elemental inductively coupled plasma atomic emission spectroscopy. Wood samples from the historic huts and artifacts were carefully collected by selecting minute segments of wood from inconspicuous areas that appeared to have deteriorated or were suspected of heavy-metal contamination. Samples were kept in sterile containers and frozen until used. Methods used to prepare and analyze the samples were previously described (Blanchette and others 1994; Munter and Grand 1981). Soil samples obtained for elemental analyses were also placed in sterile containers and frozen until used. Previously described methods for sample preparation (Munter and Grand 1981) and inductively coupled plasma atomic emission analyses were used for these samples (US Environmental Protection Agency 1992).

Materials suspected of containing asbestos were sampled and examined microscopically. Locations were documented within the huts or within the historic boundaries where asbestos was found. At the Cape Evans site, large amounts of fragmented asbestos material were found littering the area around the hut. To obtain additional information on how much asbestos was present at the site, a survey was done at three snow-free areas adjacent to the hut. Three different surveyors counted asbestos materials greater than 1 cm^2 that were found on the ground surface; each area was surveyed twice by each examiner. This assessment provided an estimate of the amount of asbestos on the ground but made no attempt to determine asbestos materials below ground or those covered by ice and snow.

Environmental pollutants at the historic huts

The buildings and artifacts left in Antarctica by the early explorers provide a wealth of important historical information that deserves to be protected and preserved

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long into the future. However, materials now considered to be environmental pollutants were also left behind, and these have a negative impact on the once pristine Antarctic environment. Aromatic hydrocarbons, asbestos, lead, and other potentially toxic materials contaminate the historic sites. Although these materials are part of the historic record of Antarctic exploration, their potentially harmful effects on the environment necessitate remedial action by the international community.

Petroleum-contaminated soils

Soil samples taken adjacent to historic petroleum containers and at 1- and 2-m intervals in two fuel depots located at Cape Evans hut (Figs 1 and 2) show that petroleum products have spilled or leaked from containers and have contaminated the area. At the lower fuel depot, high levels of total petroleum hydrocarbons were present adjacent to the containers from the soil surface to a depth of 15 cm, where the ice-cemented zone was located (Table 1). The contamination was also found at the soil surface and at a 5-cm depth located 1 m from the containers. A similar set of samples taken from the upper fuel depot immediately adjacent to the fuel boxes and at 1- and 2-m intervals showed that total petroleum hydrocarbons for C_7–C_9, and C_{10}–C_{14} were below the detectable limit. However, at the 5–10 cm depth soil sample, taken adjacent to the fuel container and just above the ice-cemented layer, 600 mg kg^{-1} of C_{15}–C_{36} compounds were present. All other soil samples taken away from the fuel containers at this depot had levels of hydrocarbons below the detectable limit. For both fuel depot sites, no attempt was made during this sampling to dig below the ice-cemented layer nor to move any of the containers since this would have resulted in excessive disturbance of the site. There appear to be few low molecular weight hydrocarbons present in these samples from the various locations tested (Table 1). The residual total petroleum hydrocarbons present at the site were unresolved complex material. Over the past decades these low molecular weight compounds may have been evaporated, leached, or transported out of the area. Since this is one of the oldest petroleum spills in Antarctica and the compounds have been in the soil for more than nine decades, some degradation by soil microbes could also have taken place. The high molecular weight compounds present in the contaminated soils at the lower fuel depot include high concentrations of phenanthrene, pyrene, chrysene, benzo[b]fluoranthene and benzo[a]pyrene (Table 2). Concentrations at this site are exceedingly high as compared to other petroleum spills in soils from around Scott Base, McMurdo Station, and the former Vanda Station (Aislabie and others 1999; Mazzera and others 1999). While naphthalene and or methylnaphthalenes predominated in samples from Scott Base and McMurdo Station in these previous investigations, they are absent

Fig. 1. Fuel depot at Cape Evans near the historic hut. High concentrations of polyaromatic hydrocarbons are in soils below and around the fuel containers.

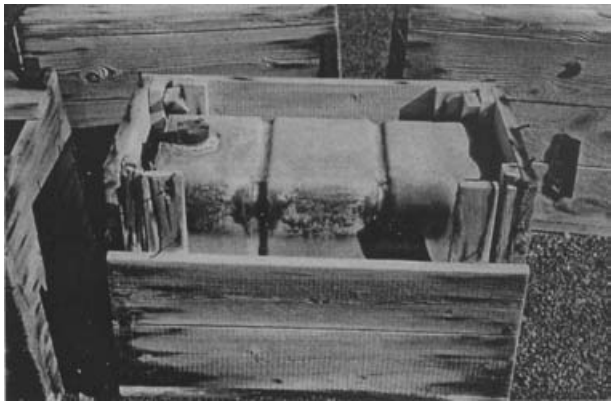

Fig. 2. Petroleum container at fuel depot showing a metal tank that contained the petroleum products enclosed in a wooded crate.

Table 1. Total petroleum hydrocarbons detected in soil from the lower fuel depot area at Cape Evans hut, Ross Island, Antarctica. Amount present is in mg kg^{-1} dry weight. * = soil samples taken adjacent to fuel container where soil appeared darkly stained and at 1 m (sample 2) and 2 m (sample 3) intervals out from the container. † = soil samples taken at ground surface–5 cm, 5–10 cm, and 10–15 cm. The lowest sample was taken from just above the ice-cemented soil. For sample 3, soil was taken only from a 0–5 cm depth. BLD = below level of detection.

Total petroleum hydrocarbons	Sample 1*			Sample 2			Sample 3
	0–5 cm†	5–10 cm	10–15 cm	0–5 cm	5–10 cm	10–15 cm	0–5 cm
C_7–C_9	BLD	BLD	BLD	BLD	BLD	BLD	BLD
C_{10}–C_{14}	80	44	48	9	15	BLD	BLD
C_{15}–C_{36}	36,100	21,200	25,200	9330	13800	760	BLD

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Table 2. Polycyclic aromatic hydrocarbons (PAH) identified in soil from the lower fuel depot area at Cape Evans hut, Ross Island, Antarctica. Amount present is in μg kg^{-1} dry weight. * = soil samples taken adjacent to fuel container and at 1 m (sample 2) and 2 m (sample 3) intervals out from the container. † = soil samples taken at the ground surface and at 5 and 15 cm below surface.

	Sample 1*			Sample 2			Sample 3
PAH	0–5 cm†	5–10 cm	10–15 cm	0–5 cm	5–10 cm	10–15 cm	0–5 cm
Chrysene	2950	1780	2120	942	1230	52	6
Pyrene	2170	1610	1770	664	954	42	11
Phenanthrene	1700	2460	2430	723	791	78	11
Benzo[a]anthracene	1230	890	1040	453	633	24	6
Fluoranthene	770	610	710	208	208	18	14
Benzo[a]pyrene	370	260	280	83	79	6	3
Benzo[k]fluoranthene	370	260	240	130	118	10	3
Benzo[b]fluoranthene	330	220	340	87	108	6	10
Anthracene	180	150	160	46	63	5	2
Fluorene	120	250	230	51	73	4	1

in contaminated soils from Cape Evans. In addition, other compounds present in other Antarctic petroleum spills, such as acenaphthene and acenaphthylene, are not present. This may be attributed to the short time since spillage at Scott Base and McMurdo Station and because these lower molecular weight compounds are more susceptible to removal processes such as volatilization, leaching, or biodegradation. Several of the aromatic compounds found, including benzo[a]pyrene, benzo[a]anthracene and fluoranthene, are recognized carcinogens. Levels for most of the polyaromatic hydrocarbons detected in these samples were well above the acceptable levels established by the Dutch clean-up standards (Ministry for Housing, Spatial Planning and the Environment 1994), which range from 15 to 45 μg kg^{-1} dry weight. Although there are no guidelines established that indicate remediation is required for hydrocarbon-contaminated sites in the Antarctic, the levels of PAHs in the soils are above Dutch standards and should be of concern. The relevance of these standards in an Antarctic environment is not known but guidelines set for other parts of the world should be used as a standard in the polar regions until more precise guidelines are available.

Some of the wooden crates that contain petroleum cans at Cape Evans have painted labels indicating they contained 'motor spirits.' A previous analyses of the 'motor spirits' used by the *Terra Nova* expedition found approximately 22% n-alkanes, 37% iso-alkanes, 15% cyclo-alkanes, and 7% aromatics (Dougherty 1985). The petroleum contaminants within the soils reported in this paper indicate a much higher concentration of diverse aromatic compounds than are present in the sample of 'motor spirits' tested. This suggests that the fuel depot contains more varied materials such as lubricating engine oil and also possibly grease. The darkly stained surface soil in the depot area also suggests that other petroleum products were spilled at the site.

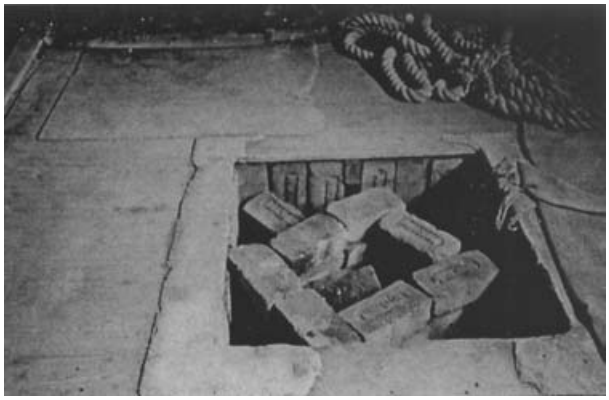

Fig. 3. Asbestos materials on floor around the remains of the pendulum apparatus used by Louis Bernacchi in the *Discovery* hut.

Asbestos

Materials that appeared to contain asbestos were sampled and analyzed microscopically to determine if asbestos was present. Materials containing 15–25% asbestos were found at the *Discovery* hut and the Cape Evans hut. At the *Discovery* hut, asbestos is present around the base of the pendulum apparatus used by Louis Bernacchi (Fig. 3) and on the interior west wall near the meat storage room, where slats of asbestos were used to hold a felt-like material on the walls. At Cape Evans, the entire magnetic observation hut, built on a hill southeast of the main hut, is lined with asbestos board. A large wooden containment building was erected over this structure many years ago and is only opened intermittently for inspection by conservators from the Antarctic Heritage Trust. A large amount of asbestos also litters the ground around the hut at Cape Evans. A survey of three areas near the hut showed that 54, 59, and 187 pieces of asbestos greater than 1 cm^2 were on the ground surface in snow-free areas adjacent to the hut (Fig. 4). No attempt was made in this survey to ascertain the amount of asbestos that was present below

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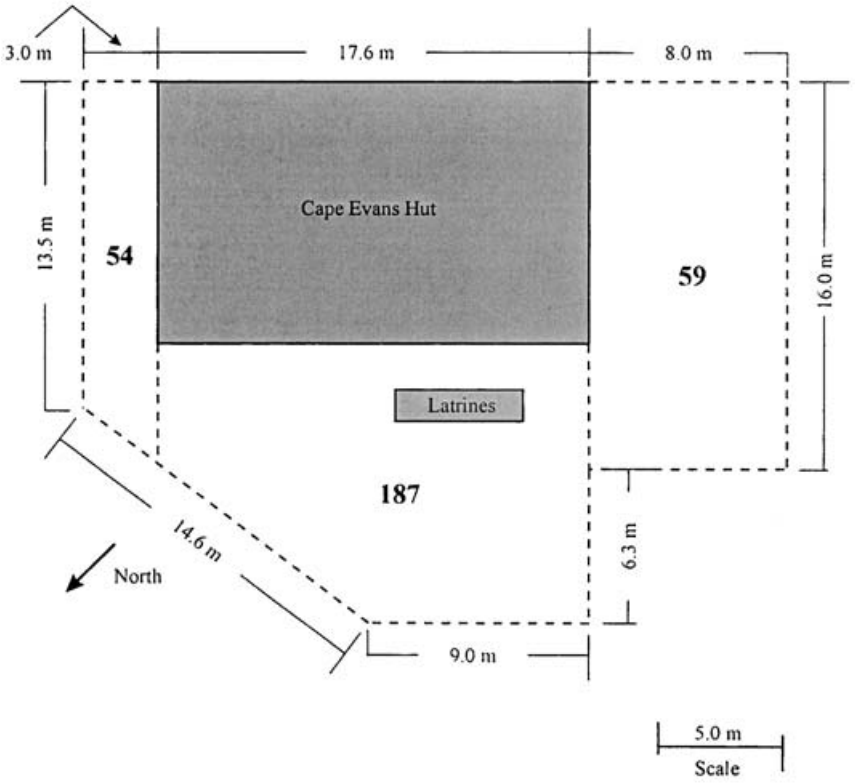

Fig. 4. Diagram of the area around Cape Evans hut with amounts of asbestos fragments greater than 1 cm^2 observed on the ground surface. Numbers in bold represent the mean number of asbestos fragments determined within three snow-free areas around the hut.

the soil surface or in areas covered by snow and ice. These fragments of asbestos appear to be continually fractured and broken into minute pieces as people visit the site and walk over the material. The coarse scoria at the site also grinds and abrades the asbestos materials as they are crushed and tramped upon. The asbestos can be found over a wide area around the hut (Fig. 5) and undoubtedly extends much farther under snow- and ice-covered areas not surveyed. The number of visitors to these historic sites has steadily increased in past years and a great deal of human activity takes place around the huts during the austral summer. The presence of large amounts of fragmenting asbestos where tourist activity takes place warrants action. In addition, as asbestos is abraded into minute particles it is distributed out into the Antarctic environment. At the Cape Evans hut, asbestos located at the shoreline is easily dispersed by winds into the sea and land around the hut. Although the effects of asbestos on Antarctic biota are not known, the continued release of this hazardous material into the environment should be of great concern.

Fig. 5. Snow-free area round Cape Evans hut that contains several hundred pieces of asbestos on the surface of the ground.

Heavy metals and other chemicals

Elemental analyses of selected wood and soil samples were completed to assess the presence of lead and other heavy metals at the sites (Tables 3 and 4). High concentrations of lead were found at specific locations at all three huts. At the *Discovery* hut, elevated lead concentrations were found in the soil immediately adjacent to the west wall and veranda post at the south side of the hut (Table 4). The exterior wallboards were painted with a terra cotta colored paint when erected and although little evidence of the paint is left on the wood the residual degraded paint appears to be present in the ground immediately next to the hut. Elevated concentrations of

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Table 3. Elemental analyses of historic woods from the expedition huts of the Ross Sea Region. Elements in ppm.

Sample	Cu	Cr	Fe	Pb	Zn
***Discovery* Hut**					
South exterior wallboard	8	3	4454	38	40
Paint on interior wall	15	2	2577	1060	3452
Base of veranda post	47	6	2590	1271	39
Cape Evans hut					
Buried wood	39	8	3316	148	300
South exterior wallboard	19	4	431	6	100
Interior chemical spill					
Deteriorated shelf	1042	2194	16,980	964	36
Deteriorated table top	405	1802	9596	1801	134
Cape Royds hut					
Exterior fascia board					
South side	2	1	150	419	612
West side	5	2	724	8572	6637
North side	11	5	1595	10,988	22,894
Interior porch ceiling board	16	10	649	115	160
Deteriorated wooden crate	13	10	18,460	1088	84
Wooden crate on ground	17	1	2126	891	74
Exterior wallboard near ground on west side	14	3	2356	56	59

lead are not found at all locations around the hut and also are not found in samples taken a short distance away from the structure (Table 4: soil samples taken from the south side of the *Discovery* hut and from 3 m away from the hut). A sample of terra cotta paint located on an interior wall of the hut was analyzed and results indicated that the paint currently contained 1060 ppm lead (Table 3). Salt deterioration and extensive defibration of the exterior woods has been reported causing the surface fibers to detach (Blanchette and others 2002). Wind blasting particles of ice and grit also contribute to the degradation of the exterior wood surfaces. These weathering processes have apparently removed the lead paint coating that was on the wood and in some areas deposited the residual material in the ground below the wallboards. Since some sampling sites did not contain elevated lead concentrations (Table 3: south exterior wallboard sample at *Discovery* hut), the degraded paint and surface wood fibers may have been dispersed by strong winds or surface soils disturbed during previous work at the hut. Extremely high concentrations of lead and zinc were found on the north fascia board of the Cape Royds hut and elevated concentrations in the wallboards near the roof from the west and south sides of the hut (Table 3). Apparently a lead/zinc flashing material was used on the roof when the hut was built (but is no longer visible on the roof) and these concentrations most likely originate from these materials. Strips of lead-containing material have been observed by the authors around the Cape Evans hut; these presumably were part of the original roofing materials. Samples of soils and wood from storage crates that held canned goods and other food supplies also have elevated lead. These can be found in the refuse area near the Cape Royds hut, in storage goods

Table 4. Elemental analyses of soil samples from areas adjacent to the historic huts on Ross Island. Elements in ppm.

Sample	Cu	Cr	Fe	Mg	Na	Pb	Zn
***Discovery* Hut**							
South side of hut	15	11	17,308	15,086	11,323	18	50
East side near veranda post	23	32	27,917	18,551	13,253	298	64
West side of hut	28	35	24,550	17,279	12,888	1222	65
3 meters west from hut	20	41	34,315	20,669	12,522	21	71
Cape Evans hut							
North corner of hut	14	110	15,408	2708	15,071	7	125
Northwest side of hut	150	16	79,273	2096	9582	476	1083
Cape Royds hut							
North side of hut	12	3	37,418	2920	13,180	196	220
Refuse area near hut	252	11	33,106	4490	20,846	1621	159
East side of hut	7	1	101,256	3141	11,051	224	68

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Fig. 6. Deteriorating cans and wooden crates of food stores left at the Cape Royds hut.

Fig. 7. Chemical spill inside the Cape Evans hut causing a deterioration of the wood. High concentrations of chromium and lead are associated with this caustic chemical spill.

Fig. 8. Bottles of chemicals on shelf in the Cape Evans hut. Most labels that identify the chemicals have deteriorated and cannot be read, but one labelled 'poison' remains.

Fig. 9. Many chemicals are still present in the Cape Evans hut, associated with the scientific apparatus left behind by the early explorers.

outside of the hut, and around the Cape Evans hut (Fig. 6). Many of the soils near these materials had concentrations of up to 1620 ppm lead (Table 4). In samples taken from soils without storage crates or deteriorated canned goods nearby (Table 4: sample taken from the north corner of Cape Evans hut), concentrations were only 7 ppm.

A very unusual type of wood deterioration was found within the Cape Evans hut affecting the shelves, wall, and table at the east end of the hut used by the expedition crew as a science laboratory (Fig. 7). Affected wood has been extensively defibrated, changing the normal structure of the wood to masses of brown fibrous material. Elemental analyses of this deteriorated wood showed high levels of copper, chromium, iron, and lead, suggesting that a caustic chemical spill had occurred. The chemicals were absorbed into the wood and have caused a destructive dissolution of the wood cell structure. This type of deterioration appears similar to advanced stages of attack observed by salts and other chemicals to wood (Blanchette and others 1991, 2002) where the lignified intercellular regions of the woody cell walls have been degraded. The deteriorated wood is also similar to degraded wood found in the historic laboratory of Thomas Edison, which apparently was affected by a similar type of chemical spill (Blanchette and others 1991). The chemicals caused a slow degradation of wood, and the process was allowed to continue unchecked because the laboratory is a protected historic building. In the Antarctic, the chemicals absorbed by the wood have had many decades to corrode and alter the cellular structure resulting in the current condition of the wood.

There are many chemicals in various unlabelled bottles, containers, and glass tubes or other scientific apparatus left within Cape Evans hut that should be evaluated to ascertain their identity (Figs 8 and 9). The high relative humidity found within the huts (authors, unpublished data) has promoted mold growth on paper, textiles, and even wood. These organisms have contributed to the poor condition of many of the labels on the chemical bottles and containers, and most have deteriorated. In the past, conservators from the Antarctic Heritage Trust have catalogued labelled chemical bottles in the historic huts, but many unknown substances remain. Chemical spills may occur by freeze–thawing of liquids and subsequent glass breakage, by inadvertent accidents

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from curious tourists visiting the hut, or even accidental spills during conservation and research activities within the hut.

Recommendations for remedial actions

The early explorers inadvertently left toxic and hazardous materials in Antarctica that contaminate the historic sites and can have an adverse effect on the environment, wildlife, and human health. Remediation is needed and action by the international community is warranted to remove these pollutants from Antarctica. The following recommendations are provided as a forum for discussion on appropriate ways to remove these historic but hazardous materials from further contact with the Antarctic environment.

1. Petroleum spills. Large concentrations of polyaromatic compounds, many of which are known carcinogens, have spilled into the soils at the historic fuel depot areas. At the lower depot, the contaminants are present immediately below and around the containers and the contamination extends up to 1 m away. In the upper fuel depot, the contaminants appear restricted to the area immediately under and adjacent to the containers. The Protocol for Environmental Protection to the Antarctic Treaty (1991), in Annex III, Article 1, indicates that past and present waste-disposal sites on land and abandoned work sites of Antarctic activities shall be cleaned up by the generator of such wastes and the user of such sites. However, this does not include removal of any structure designated as a historic site or monument or the removal of any waste material in circumstances where the removal would result in greater adverse environmental impact than leaving waste material in its existing location. It appears appropriate that all containers should be emptied of their petroleum materials so that continued release of polyaromatic compounds into the environment does not occur. Since the levels of contamination in the soil exceeds current standards used to determine if clean-up is required at sites where petroleum spills have taken place, one method of control would be to remove the contaminated soil under and around the fuel boxes and transport it out of Antarctica for remedial treatment. The historic site, however, contains numerous artifacts on the ground and in the top layers of the gravel, and excavation and removal of the contaminated soil would need to be done under the supervision and guidance of an archaeologist. Disturbance of the historic site with its rich cultural heritage is of great concern, and drastic measures, such as the removal of large quantities of soil, need careful consideration. Additional studies are needed to determine if the level of contamination within the historic boundaries is confined to the site and if it poses a threat to the surrounding Antarctic environment. Since this is the oldest known petroleum spill in Antarctica, the site also has potential scientific value to serve as an experimental area for studying and isolating native micro-organisms that grow in the contaminated soils and may be able to degrade and detoxify these substances. These organisms could have potential for bioremediation of petroleum spills not only at Cape Evans but for use throughout the polar regions. The historic petroleum spills at Cape Evans will need careful consideration to determine the best action to take.

Motor tractors and vehicles were used by both Shackleton and Scott, and petroleum products apparently were used at all of the hut locations. Although this investigation documents the spills at the Cape Evans hut, additional but limited sampling did not detect petroleum compounds in soils around the *Discovery* hut or the Cape Royds hut. More extensive sampling is needed at these locations as well as other areas around the Cape Evans hut to determine if there are any other areas where petroleum contamination exist.

2. Materials containing asbestos that litter the area around Cape Evans should be removed. Several hundred pieces larger than 1 cm^2 are on the surface of the ground in the snow-free areas around the hut. These materials continue to be fragmented and abraded as visitors to the site walk around the hut. It is not known how much additional asbestos exists under snow and ice, but as it melts the exposed asbestos should be removed. The larger pieces of asbestos can be easily collected, properly contained, and shipped out of the Antarctic for disposal. The smaller sized materials (less than 1 cm^2) and materials below ground, however, will require significant effort to collect. The structure that contains the hut used for magnetic observations appears to be functioning. This structure has significant historic value and should remain at the site. Although the current wooden structure covering the hut functions very well to contain the asbestos-lined hut, Antarctica's severe weather is taking its toll on the wood (Blanchette and others 2002). Wind and salt will continually erode the plywood used in the building causing it to delaminate and deteriorate. This structure must be maintained and upgraded in the near future. A more stable and permanent containment building will be needed to insure that the large amount of asbestos in this historic hut remains confined to the building. A structure that can withstand severe storms (and possibly allow visitors to view the magnetic hut through Plexiglass or other similar material) is needed to prevent the possibility of an extremely large amount of asbestos material being broadcast into the environment should the containment structure be destroyed by katabatic winds or other extreme weather conditions.

The asbestos in the *Discovery* hut that is holding insulation materials to the wall is not in an area that could easily be abraded or fragmented by visitors but could be removed to avoid potential future problems. The asbestos around the pendulum apparatus, however, is adhered to the floor and is subject to disruption and shredding as visitors walk around this area. Removal of the asbestos should be considered or a consolidant and protective covering used to prevent further erosion of the material. Limiting visitor

access to the area with asbestos would also prevent any further disruption of the material and release of asbestos particles in the hut.

3. The presence of heavy metals around the hut from lead-deteriorated paint is localized to a few areas immediately adjacent to the *Discovery* hut. A greater concern is the heavy metals that appear associated with the deteriorated canned goods around the Cape Royds and Cape Evans huts. As more of the canned goods stored at the huts continue to deteriorate, additional metal ions will be released into the soil. The movement and distribution of these heavy metals into the Antarctic environment should be studied to determine if any potential hazards could develop. The lead/zinc flashing materials that are at the site should be removed to avoid future weathering and release of additional metal ions into the soil. The historic woods that currently have increased levels of lead pose no problems, but locations should be noted when future restoration work is done. High concentrations of chromium and lead exist in woods affected by the chemical spill inside the Cape Evans hut. Access to this area should also be restricted to avoid the fragile defibrated wood being disturbed and possibly dispersed within the hut. Since the caustic substance is still in the wood and deterioration is likely to be continuing, these areas need special conservation efforts to remove the toxic substances from the wood and consolidate the affected woods.

4. A review of all scientific apparatus and chemicals in the hut should be completed and toxic or hazardous materials identified. In the event of a future accidental chemical spill, materials to contain and clean up the chemicals are needed within the huts. Test tubes, flasks, and other scientific apparatus containing battery acids, caustic alkaline materials, or any hazardous material should be removed or secured to avoid any possibility of spillage and damage to the historic hut and artifacts.

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