Management Plan

For Antarctic Specially Protected Area No. 175
HIGH ALTITUDE GEOTHERMAL SITES OF THE ROSS SEA REGION

(including parts of the summits of Mount Erebus, Ross Island and Mount Melbourne and Mount Rittmann, northern Victoria Land)

Introduction:

There exist a few isolated sites in Antarctica where the ground surface is warmed by geothermal activity above the ambient air temperature. Steam emissions from fumaroles (openings at the Earth's surface that emit steam and gases) condense forming a regular supply of water which, coupled with warm soil temperatures, provides an environment that selects for a unique and diverse assemblage of organisms. Geothermal sites are rare and small in extent covering no more than a few hectares on the Antarctic continent and circumpolar islands (or maritime sites). The biological communities that occur at continental geothermal sites are at high altitude and differ markedly to those communities that occur at maritime geothermal sites due to the differences in the abiotic environment.

There are three high altitude geothermal sites in the Ross Sea region, known to have unique biological communities. These are the summits of Mount Erebus, on Ross Island, and Mount Melbourne and Mount Rittmann, both in northern Victoria Land. The only other known high altitude site in Antarctica where evidence of fumarolic activity has been seen is at Mount Berlin in Marie Byrd Land, West Antarctica, although no biological research has been conducted at this site.

High altitude geothermal sites are vulnerable to the introduction of new species, particularly from human vectors, as they present an environment where organisms typical of more temperate regions can survive. These once isolated sites are now more frequently visited by humans for science and recreation, both of which require logistical support. Species from sites within Antarctica, and locally non-native to geothermal sites, or from regions away from Antarctica, may inadvertently be introduced to the Area through human activity.

High altitude geothermal sites are also vulnerable to physical damage to the substrate from trampling and over sampling because changes in the soil structure can affect the location and rate of steam emissions in which biological communities occur. The limited extent and fragility of these biological communities highlights the need for protection.

The primary reason for the designation of high altitude geothermal sites in the Ross Sea region as an Antarctic Specially Protected Area is to protect the outstanding ecological values, specifically the unique biological communities that occur in an environment where the selective factors are unique resulting in an assemblage of organisms not found anywhere else in the world. The biological communities are extremely vulnerable to the introduction of non-native species of plants, animals, microorganisms and non-sterile soils from biologically distinct regions within Antarctica and from regions outside Antarctica and to physical disturbance from trampling and oversampling through human activity. While high altitude geothermal sites are protected primarily for their outstanding ecological values (specifically the biological communities), they are also protected for their other scientific values such as microbiology, botany, terrestrial biology, geomorphology and geology.

The Area comprises three high altitude geothermal sites; Tramway Ridge on the summit of Mount Erebus (77° 31'S; 167° 06'E), three locations of geothermal activity on the summit of Mount Melbourne (74° 21'S; 164° 42'E), and the summit of Mount Rittmann (73° 28'S; 165° 37'E) (Map A).

Tramway Ridge, Mount Erebus was originally designated in Recommendation XIII-8 (1985) as a Site of Special Scientific Interest (SSSI) No. 11 after a proposal by New Zealand on the grounds that the Area supports an unusual ecosystem of exceptional scientific value to botanists and microbiologists. The Management Plan was revised and adopted in Measure 2 (1995) and Measure 3 (1997). The site was re- designated Antarctic Specially Protected Area (ASPA) No. 130 in Decision 1 (2002). The Management Plan was revised and adopted in Measure 1 (2002). It was reviewed and endorsed without changes at CEP X (2007).

The summit of Mount Melbourne was originally designated in Recommendation XVI-5 (1987) as SSSI No. 24, after proposals by New Zealand and Italy, on the grounds that the Area contains geothermal soils that support a unique and diverse biological community. An area enclosed in SSSI No. 24, Cryptogam Ridge, was designated as Special Protected Area (SPA) No. 22 in Recommendation XVI-8 (1991). SSSI No. 24 and SPA No. 22 were re-designated as ASPA No. 118a and 118b respectively in Decision 1 (2002). A merged Management Plan designating both Areas as ASPA 118 was adopted in Measure 2 (2003), with Prohibited and Restricted Zones providing for more stringent access conditions within the former SPA No.22. A Revised Management Plan was adopted in Measure 5 (2008).

Mount Rittmann was discovered during the 4th Italian Expedition in the 1988/89 field season. During the 6th Italian Expedition in the 1991/92 field season, fumaroles and ground heated by geothermal activity were discovered in a small volcanic crater. This site has not been designated previously for protection.

Both Mount Erebus and Mount Melbourne are visited annually by scientists from a wide range of disciplines and for management reasons (e.g. survey marks, radio repeaters and field huts). Mount Rittmann has had an increased number of visitors since its discovery.

Tramway Ridge, Mount Erebus is situated in Environment S – McMurdo – South Victoria Land Geologic based on the Environmental Domains Analysis for Antarctica (Resolution 3 (2008)) and in Region 9 – South Victoria Land based on the Antarctic Conservation Biogeographic Regions (Resolution 6 (2012)). Other protected areas within Environment S includes ASPAs 105, 116, 121, 122, 123, 124, 131, 137, 138, 154, 155, 156, 157, 158, 161 and 172 and ASMA 2.

Both Mount Melbourne and Mount Rittmann are situated in Environment U – North Victoria Land Geologic based on the Environmental Domains Analysis for Antarctica and in Region 8 – North Victoria Land based on the Antarctic Conservation Biogeographic Regions. Other protected areas within Environment U include ASPAs 106, 165 and 173.

This is the only ASPA or ASMA in the Ross Sea region designated to protect geothermal environments. There is only one other ASPA within the protected area system that protects a geothermal environment, ASPA 140 Parts of Deception Island, South Shetland Islands. However, ASPA 140 protects biological communities of maritime Antarctica which significantly differ from high altitude biological communities.

The designation of these sites as a protected area complements the Antarctic protected areas system because the Area: (i) contains the known locations of Antarctic high altitude geothermally heated ground, which, due to the Area's physical and chemical characteristics, supports biological communities that are both regionally and globally unique, and (ii) is vulnerable to human interference, particularly the potential for the introduction of non-native species from biologically distinct regions within Antarctica and from regions outside Antarctica but also between geothermal locations at a specific site, and damage from trampling and over sampling. The Area is considered to be of sufficient size at each site to provide adequate protection of the values identified.

1. Description of values to be protected

The Ross Sea region has considerable areas of late Neogene and Quaternary volcanism. However, only three sites, Mounts Erebus, Melbourne and Rittmann, have been confirmed to show signs of present day geothermal activity. Fumaroles (opening in the ground emitting steam) and steaming warm ground are the surface manifestation of geothermal activity at these sites. Hollow ice towers or ice pinnacles (chimneys) can form around fumaroles up to many metres in diameter and height, formed by the condensation and freezing of water vapour. Ice and snow hummocks are also present over geothermally heated ground. Other areas of heated ground are commonly ice free during summer and maintain surface temperatures greater than ambient air temperatures.

Most areas of fumaroles and warm ground are on or adjacent to the summit calderas of each volcano, however areas of surface activity do extend down slope on the northwest side of Mount Melbourne. Although these areas in the Ross Sea region are isolated to the high altitude summits of volcanoes, the environment provides resident biological communities with a regular supply of free water (from condensed steam and melting of snow), temperatures suitable for growth and physical protection or shelter from extreme weather (under ice and snow hummocks). Because of the considerable isolation and unusual set of evolutionary selection pressures, some researchers believe that these habitats may host some of the earliest forms of life on the planet, many of which have still not been described.

The vegetation communities at high altitude continental geothermal sites differ markedly from other maritime geothermal sites in Antarctica and the sub-Antarctic. The communities in the Ross Sea region are dominated by algae with a low diversity of species present compared with maritime Antarctic sites. The latter are dominated by bryophytes and have high species diversity across several groups. In the Ross Sea region geothermally heated sites, diatoms are absent and only one possible lichen has been found, this being an unidentified black crust reported from Mount Melbourne. Twelve species of bryophytes, algae and protozoa that occur at one or more of these sites have no other known Antarctic record (Annex 1, Table 1). Although these areas are located within the same geographic region, the vegetation communities at each of the three sites differ from one another, with five of the twelve species of bryophytes, algae and protozoa, which have no other Antarctic record, reported from only a single geothermal site in the Ross Sea region (Annex 1, Table 1).

The microorganisms in these communities have been poorly characterised, or in some cases remain uncharacterised. However recent studies are beginning to reveal the unique and diverse microbial communities present. Studies on extremophiles (organisms that thrive in physically or geochemically extreme environments) are recognised as useful for understanding the evolution of life as the first inhabitants of Earth possibly evolved in extreme habitats. Not all microorganisms identified from these sites are thermophiles (organisms that have their optimum growth rates at high temperatures typically between 45° and 122°C).

Some grow optimally at mesophilic temperatures (moderate temperatures typically between 20°C and 45°C) some distance away from the fumaroles (Annex 1, Table 2). This highlights the vulnerability of these biological communities to physical disturbance of the substrate from trampling or sampling.

While the environmental conditions (i.e. regular supply of free water, temperatures suitable for growth and physical protection or shelter from extreme weather) at the three isolated high altitude geothermal sites in the Ross Sea region superficially appear similar, the biological communities differ between the sites. A possible explanation is that the physico-chemical differences of the soils (e.g. pH, nutrient availability, substrate grain size, moisture content) select for a unique assemblage of species at each site. An alternative hypothesis suggests these environments may have been occasionally colonised by viable propagules carried by wind from other sites in Antarctica or from circumpolar islands or other continents. Dispersal may be rare events resulting in the colonization of the soil by viable propagules of the few species that are deposited at each site. For example, several of the isolated strains of *B. fumarioli* from Mount Rittmann showed remarkable similarity with strains identified from the Candlemas Islands, South Sandwich archipelago even though the two sites are over 5,600 km apart. Colonization from a common source and more likely aerial dispersal of free spores or potential human contamination has been proposed. More simply, the differences could be due to stochastic factors.

An increase in human activity at the Area's three sites emphasises the need for adequate protective measures in order to reduce the possibility of the introduction of new organisms by a human vector.

The highly unusual biological communities at all three sites are of outstanding scientific value. These sites provide insights into biogeography and dispersal as well as physiology of Antarctic organisms operating under unusual conditions. The limited geographical extent of the Area's ecosystems, the vulnerability of the sites to the introduction of non-native species from biologically distinct regions within Antarctica and from regions outside Antarctica but also between geothermal locations at a specific site and ground disturbance is such that appropriate management of these sites is necessary to ensure their long term protection.

2. Aims and objectives

The management of high altitude geothermal sites of the Ross Sea region aims to:

- avoid degradation of, or substantial risk to, the values of the Area by preventing unnecessary human disturbance to the Area;
- prevent or minimise the introduction to the Area of non-native plants, animals, microorganisms and non-sterile soils from biologically distinct regions within Antarctica and from regions outside of Antarctica and between geothermal locations at a specific site;
- preserve a part of the natural ecosystem of each of the Area's three sites, which are declared Prohibited Zones, as reference areas for future scientific studies;
- allow scientific research in the Area provided it is for compelling reasons which cannot be served elsewhere and which will not jeopardize the natural ecological system, specifically the biological communities and geology in the Area's three sites;
- ensure that the biological communities and geology are not adversely affected by excessive sampling or ground disturbance within the Area;
- allow visits for management purposes in support of the aims of the Management Plan.

3. Management Activities

The following management activities shall be undertaken to protect the values of the Area:

- Information on the location of the Area's three sites, stating special restrictions that apply, shall be displayed prominently, and a copy of this Management Plan shall be made available, at National Antarctic Programme stations, and research, management or field huts close to the Area's three sites.
- Signs and/or boundary markers illustrating the locations of the Area's three sites, with clear statements of entry restrictions, shall be placed at appropriate locations on the boundary of the individual sites [and Prohibited Zones] to help avoid inadvertent entry.
- Markers, signs or other structures erected within the Area for scientific, management or essential communication purposes shall be secured and maintained in good condition and removed when no longer required.
- The Area shall be visited as necessary, and no less than once every five years, to assess whether it continues to serve the purposes for which it was designated and to ensure that management activities are adequate.
- National Antarctic Programmes operating in the Area shall consult together with a view to ensuring the above management activities are implemented. In particular, National Antarctic Programmes are encouraged to consult with one another to prevent excessive sampling of soil and biological material within the Area. Also, National Antarctic Programmes are encouraged to consider joint implementation of guidelines intended to minimize the introduction and dispersal of non-native species within the Area and between the Area's three sites.

4. Period of designation

Designated for an indefinite period.

5. Maps

Map A: High altitude geothermal sites of the Ross Sea region location map. Horizontal Datum: WGS84, Antarctica Polar Stereographic Projection. Data Source: Base Vector Data, Antarctic Digital Database Version 6.

Map A1: ASPA 175 Tramway Ridge, Mount Erebus topographical map. Horizontal Datum: WGS72, Camp Area Projection. Vertical Datum: Mean Sea Level. Data Sources – Survey Data: Department of Survey and Land Information (DOSLI) Survey Plan 37/142 (Plan sourced from Land Information New Zealand (LINZ)); Contours and geothermally heated area: Data supplied by the University of Canterbury; Main map and inset overview diagram imagery: Digital Globe World View-2 Satellite (0.5 m resolution). Imagery date 23 January 2011. Imagery provided by the Polar Geospatial Centre, Department of Earth Sciences, University of Minnesota; Inset site photograph: Terrestrial photograph of Tramway Ridge geothermally heated ground looking north upslope. Image taken 26 November, 2010. Image provided by University of Waikato.

Map A2: ASPA 175 Cryptogam Ridge and Geothermal Slope, Mount Melbourne topographical map. Horizontal Datum: WGS84, UTM Zone 58S Projection. Vertical Datum: WGS84. Data Sources – Contours and protected areas derived from data collected during field survey undertaken 17 November, 2012 by LINZ; Main map and inset overview diagram imagery: DigitalGlobe GeoEye satellite imagery (0.5 m resolution).

Imagery date 14 November, 2011. Imagery provided by the Polar Geospatial Centre, Department of Earth Sciences, University of Minnesota; Inset site photograph: Terrestrial photograph taken looking northeast with Cryptogam Ridge in the foreground. Image taken 17 November, 2012. Image provided by Antarctica New Zealand.

Map A2/1: ASPA 175 Northwest slope, Mount Melbourne topographical map. Horizontal Datum: WGS84, UTM Zone 58 Projection. Vertical Datum: WGS84. Data Sources - Main map and inset overview diagram imagery: Digital Globe World View-2 Satellite (0.5 m resolution). Imagery date 14 November, 2011. Imagery provided by the Polar Geospatial Centre, Department of Earth Sciences, University of Minnesota; Inset site photograph: Terrestrial photograph of northwest slope geothermally heated ground looking east. Image taken in 2002. Image provided by R. Bargagli and the PNRA (the Italian National Programme for Antarctic Research).

Map A3: ASPA 175 Mount Rittmann topographical map. Horizontal Datum: WGS72, UTM Zone 58S Projection. Vertical Datum: WGS84 Vertical Datum. Data Sources – Contours and protected areas derived from data collected during field survey undertaken 16 November, 2012 by LINZ; Main map: DigitalGlobe World View-1 satellite imagery (0.5 m resolution). Imagery date 3 March, 2009. Imagery provided by the Polar Geospatial Centre, Department of Earth Sciences, University of Minnesota; Inset site photograph: Terrestrial photograph taken looking north toward Mount Rittmann remnant caldera. Image taken 16 November, 2012. Image provided by Antarctica New Zealand.

6. Description of the Area

6(i) Geographical co-ordinates, boundary markers and natural features

This ASPA consists of three sites including Tramway Ridge on the summit of Mount Erebus, three locations on the summit of Mount Melbourne and the summit of Mount Rittmann.

Tramway Ridge, Mount Erebus

Site Description:

Mount Erebus, (77° 31'S, 167° 06'E) is the largest and most active volcano in Antarctica and it is located on Ross Island (Map A). It rises to an altitude of 3,794 metres above sea level. It is a unique stratovolcano with a convecting anorthoclase phonolite lava lake in the main crater. The predominant rock type, and the only one which crops out near the summit, is anorthoclase phonolite.

The steep slopes of the main crater flatten out to an extensive plateau at an altitude of about 3,200 – 3,500 metres above sea level except on the south east slopes where the outer slope continues to drop steeply.

Tramway Ridge is a ridge that rises to approximately 3,450 metres above sea level on the northwest slope of the main crater (Map A1; Inset 1). The site is located along this ridge approximately 1.5 kilometres from the main crater. It is the most extensive area of geothermally heated ground on the summit of Mount Erebus, though locations of geothermally heated ground are widespread at the summit.

The site is, in general, on a gentle slope of about 5°, with much of the ice-free ground in the form of terraces which have a typical vertical height of about 0.5 metres and steeper sides of up to 30° in slope. The steep sides of the terraces are colonised by the majority of visible vegetation, and it is from these sides that visible steam emissions occur. Visible vegetation covers about 16% of the site. Low ice hummocks, up to approximately one metre in height and formed where steam has frozen, are distributed over the site. Ground temperatures of up to about 75°C have been recorded at 4 centimetres depth.

Boundaries: The boundary of the designated site is defined as a rectangle of 200 metres by 200.8 metres which encompasses most of the geothermally heated ground of lower Tramway Ridge. The western boundary of the site at the NW boundary corner extends from the coordinates 77° 31' 01.853" S; 167° 06' 21.251"E (Point A) south to the SW boundary corner at 77° 31' 08.327" S; 167° 06' 20.686"E (Point E). The boundary then extends east to the SE boundary corner at 77° 31' 08.448" S; 167° 06' 50.521"E (Point D). The boundary then extends north to the NE boundary corner at 77° 31' 01.976" S; 167° 06' 51.074"E (Point B) (Map A1).

The site is divided into two parts of almost equal size, the northern half being a Prohibited Zone (Map A1). The boundaries of the Prohibited Zone are described in Section 6(v).

The boundaries of the site (marked by boundary markers at each corner), the Prohibited Zone and prominent features are shown on Map A1. The boundary points of the Area and Prohibited Zone are marked by a boundary marker (Map A1; Point A-F) with a further boundary marker (Point H) located partway along the southern boundary of the Prohibited Zone. Two boundary markers (G and H) have been offset to better facilitate people working within the ASPA to identify the southern boundary of the Prohibited Zone and avoid entering the area (Map A1; ASPA Boundary Table of Coordinates).When bamboo flags are inserted in each boundary marker, the boundaries of the site and Prohibited Zone are visible when working in the ASPA.

Mount Melbourne

Site Description: Mount Melbourne (74° 21'S 164° 42'E) is a stratovolcano located in northern Victoria Land, between Wood Bay and Terra Nova Bay, on the western side of the Ross Sea, and about 10 kilometres east of Campbell Glacier (Map A). It rises to an altitude of 2,733 metres above sea level.

Mount Melbourne is part of the McMurdo Volcanic Group, which is a line of dormant and extinct volcanoes running along the coast of Victoria Land. The Mount Melbourne region is thought to be late Quaternary in age and the most recent eruption may have been as little as 150 years ago. The volcanic rocks have been described as trachyte to trachyandesite on the mountain itself, with basalt at its base.

Mount Melbourne is an almost perfect low-angle volcanic cone with locations of geothermally heated ground, fumaroles, and ice towers scattered around the summit crater and on some upper parts of the mountain. The summit caldera is about one kilometre in diameter and forms the névé for a westward flowing glacier. Several smaller basaltic cones and mounds occur near the base and on the flanks of the mountain. Geothermally heated ground is generally marked by snow-free, steaming ground or fumaroles and ice towers or pinnacles up to one metre in height. Surface soil temperatures have been recorded up to 50 °C at depths of a few centimetres.

Boundaries: The site consists of three separate locations, two on the main summit crater (Map A2) and a third on the northwest slope of the mountain (Map A2/1). On the south-eastern rim of the main summit crater of Mount Melbourne, there are two adjacent designated locations.

The first location, Cryptogam Ridge, is a distinct crescent shaped ridge and consists of areas of snow-covered unheated ground, snow-free geothermally-heated ground and ice-hummocks covering steam emissions that extends c. 40 metres in all directions from the ridge line.

The western boundary of the site from the NW boundary corner extends from the coordinates 74° 21′ 20.389″ S; 164° 41′ 31.652″ E (Point 1A) south approximately 50 metres to the SW boundary corner at 74° 21′ 22.096″ S; 164° 41′ 32.551″ E (Point 1N). The boundary then extends east following the crescent shape of Cryptogam Ridge to unmarked points at 74° 21′ 21.383″ S; 164° 41′ 38.254″ E (Point 1M); 74° 21′ 20.840″ S; 164° 41′ 45.230″ E (Point 1L); 74° 21′ 21.220″ S; 164° 41′ 49.934″ E (Point 1K); 74° 21′ 21.815″ S; 164° 41′ 54.574″ E (Point 1J); 74° 21′ 22.588″ S; 164° 41′ 58.044″ E (Point 1I) to the SE boundary corner at 74° 21′ 24.103″ S; 164° 42′ 00.579″ E (Point 1H). The boundary then extends north to the NE boundary corner at 74° 21′ 23.355″ S; 164° 42′ 07.010″ E (Point 1G). The northern boundary extends west following the crescent shape of Cryptogam Ridge to unmarked points at 74° 21′ 21.523″ S; 164° 42′ 03.989″ E (Point 1F); 74° 21′ 20.117″ S; 164° 41′ 57.869″ E (Point 1E); 74° 21′ 19.307″ S; 164° 41′ 51.137″ E (Point 1D); 74° 21′ 19.153″S; 164° 41′ 45.329″ E (Point 1C); 74° 21′ 19.650″ S; 164° 41′ 37.695″ E (Point 1B) to the NE boundary corner (Point 1A) (Map A2). Both the northern and southern boundaries are situated below the ice free ridge.

Cryptogam Ridge is divided into two parts with the western portion designated as a Prohibited Zone (Map A2). The boundaries of the Prohibited Zone are described in Section 6(v).

The second location (Geothermal Slope) on the south-eastern rim of the main summit crater of Mount Melbourne is adjacent to Cryptogam Ridge on a slope leading up the eastern rim of the summit crater (Map A2; Inset 2). Geothermal activity is evident on the hill slope as crevasses and ice towers extending up the steep caldera rim, approximately 50 metres wide (Map A2). The northern boundary of the site from the NW boundary corner extends from the coordinates 74° 21′ 13.740″ S; 164° 42′ 01.816″ E (Point 2A) south approximately 50 metres to the SW boundary corner at 74° 21′ 15.620″ S; 164° 42′ 03.474″ E (Point 2D). Theboundary then extends east up the slope to the SE boundary corner at 74° 21′ 14.567″ S; 164° 42′ 12.729″ E (Point 2C), then north to the NE boundary corner at 74° 21′ 12.865″ S; 164° 42′ 08.972″ E (Point 2B) (Map A2).

The third location (Northwest Slope) is on the northwest slopes of the volcano (Map A2/1) approximately 1.5 kilometres northwest of from Cryptogam Ridge. Geothermal activity is evident as a northwest to southeast trending line of ice towers and small patches of bare ground along the edge of a steep cliff. The boundaries for the location were not surveyed in the field but obtained via inference from satellite imagery. The northern boundary of the site from the NW boundary corner extends from the coordinates 74° 21′ 00″ S; 164° 39′ 02″ E(Point 3A) south downslope to the SW boundary corner at 74° 21′ 11″ S; 164° 39′ 02″ E (Point 3D). The boundary then extends east to the SE boundary corner at 74° 21′ 11″ S; 164° 42′ 05″ E (Point 3C), then north up slope to the NE boundary corner at 74° 21′ 00″ S; 164° 40′ 05″ E (Point 3B) (Map A2/1).

Mount Rittmann

Site Description: Mount Rittmann (73° 28′S, 165° 37′E) is located in the Mountaineer Range on the south side of the Aviator Glacier, between the Pilot Glacier and the head of the Icebreaker Glacier in northern Victoria Land (Map A3). It rises to an altitude of 2,600 metres above sea level and is approximately 103 kilometres north of Mount Melbourne and approximately 50 kilometres inland from the coast.

Fumaroles and geothermally heated ground occur within a single outcrop at the summit of Mount Rittmann in a minor caldera rim at approximately 2,000 metres above sea level. The entire site is surrounded by glacial ice (Map A3; Inset). The site consists of a rough and unstable steep slope approximately 300 metres wide and 80 metres high (Map A3). The ground consists of pyroclastic rocks and volcanic debris in a sandy matrix.

Two adjacent ice-free areas are situated at the centre of the site. Ice free geothermally heated ground and fumaroles dominate the areas with ice hummocks and ice towers generally situated around the edges of the ice-free areas and along the rim of the caldera structure. Around the fumaroles the ground is covered by a whitish efflorescence and patches of moss are visible on the surface of these areas. Surface soil temperatures of between 50 and 63°C have been recorded at 10 centimetres depth. The western side of the site is covered inice, but geothermal activity is visible along the caldera rim as ice towers or steaming ground.

Boundaries: The site encompasses the entire exposed caldera of Mount Rittmann. The western most boundary corner is located at the western edge of the caldera rim at 73° 28′ 18.797″S; 165° 36′ 43.851″E (Point A). The boundary follows the caldera rim east to unmarked points at 73° 28′ 16.818″ S; 165° 36′ 54.698″ E (Point B); 73° 28′ 16.290″ S; 165° 37′ 00.144″ E (Point C); 73° 28′ 16.405″ S; 165° 37′ 04.438″ E (Point D); 73° 28′ 17.655″ S; 165° 37′ 12.235″ E (Point E); 73° 28′ 18.024″ S; 165° 37′ 14.468″ E (Point F); 73° 28′ 19.823″ S; 165° 37′ 16.943″ E (Point G); 73° 28′ 20.628″ S; 165° 37′ 20.089″ E (Point H); 73° 28′ 21.530″ S; 165° 37′ 21.567″ E (Point I) to the easternmost boundary corner at 73° 28′ 22.015″ S; 165° 37′ 23.817″ E (Point J).

The boundary then extends south (downslope) to the SE boundary corner at 73° 28′ 23.436″ S; 165° 37′ 20.540″ E (Point K).The boundary then follows the bottom of the steep slope below the caldera rim and ice free areas to unmarked points at 73° 28′ 22.414″ S; 165° 37′ 17.302″ E (Point L); 73° 28′ 20.945″ S; 165° 37′ 13.936″ E (Point M); 73° 28′ 19.430″ S; 165° 37′ 08.865″ E (Point N); 73° 28′

18.558″ S; 165° 37′ 03.457″ E (Point O); 73° 28′ 18.722″ S; 165° 37′ 56.296″ E (Point P); 73° 28′ 19.778″ S; 165° 36′ 50.065″ E (Point Q), then upslope to the westernmost boundary corner (Point A).

The eastern ice free area is designated as a Prohibited Zone (Map A3). The boundaries of the Prohibited Zone are described in Section 6(v).

6(ii) Access to the Area

Access conditions applicable to all sites are listed in Section 7(ii). Site specific conditions for accessing each site are listed below.

Tramway Ridge, Mount Erebus

- Due to the high altitude of Tramway Ridge, helicopters should not be heavily loaded.
- There is a designated helicopter landing site approximately 250 metres northwest of the site at 77° 31' 00" S; 167° 05' 48" E or the helicopter may land near the United States Antarctic Programme (USAP) Upper (77° 30' 37.857"S; 167° 08' 48.5736"E) or Lower (77° 31' 32.6172"S; 167° 08' 12.8688"E) Erebus huts (Map A1; Inset 1).
- When travelling between Upper and Lower Erebus huts, it is strongly encouraged to keep to the preferred snowmobile route, and wherever practical, stay at least 200 metres away from the site boundary (Map A1; Inset 1).
- Access to the site should primarily be from Boundary Marker D (Map A1; Inset 2).

Mount Melbourne

- There is a designated helicopter landing site approximately 40 metres from Cryptogam Ridge at 74°21' 24.6" S; 164° 41' 56.0" E or at the alternative landing site at the summit of Mount Melbourne at 74° 20' 57.7"S; 164° 41' 28.9"E (Map A2 and A2/1; Inset 1).

Mount Rittmann

- The site is a steep unstable slope surrounded by glacial ice. Helicopters shall only land, where it is safe to do so, on glacial ice. When landing a helicopter in front of the slope, to the maximum extent practical (and that is safe), helicopters should not land within 100 metres of the sites boundary. When landing a helicopter above the slope, to the maximum extent practical (and that is safe), helicopters should not land within 25 metres of the site boundary (caldera rim) (Map A3).

6(iii) Location of structures within and adjacent to the Area

Tramway Ridge, Mount Erebus

- There are seven boundary markers indicating the boundary corner points and the southern boundary of the Prohibited Zone (Map A1; ASPA Boundary Table of Coordinates). A marker flag, attached to a pole, may be fixed to the boundary markers to define the Area and avoid inadvertent entry to the Area or the Prohibited Zone.
- There are three survey marks adjacent to the site (Map A1; Survey Mark Table of Coordinates).
- The Upper and Lower Erebus huts are located approximately 1 kilometre to the northeast (3,400 metres above sea level) and southeast (3,612 metres above sea level) of the site, respectively (Map A1; Inset).

Mount Melbourne

- There are two survey marks. MM01 is adjacent to Location 2 and is a metal mark set into a rock. MM02 is adjacent to Location 1 and consists of a metal tube set into a concrete base (Survey Mark Table of Coordinates; Map A2).
- National programmes operating in the area maintain a number of installations (weather stations, radio repeater and science experiments) on the highest summit of Mount Melbourne (Map A2; Inset 1).

Mount Rittmann

- There are two survey marks along the northeast boundary edge above the caldera rim (Map A3; Survey Mark Table of Coordinates). Both survey marks are a metal mark set into a rock.

6(iv) Location of other protected areas in the vicinity

Tramway Ridge, Mount Erebus

The nearest protected areas to Tramway Ridge, Mount Erebus are on Ross Island (Map A).

- ASPA 116: New College Valley, Caughley Beach, Cape Bird is 37 km to the north north-west.
- ASPA 156: Lewis Bay, Mount Erebus, Ross Island is 14 km to the north.
- ASPA 124: Cape Crozier, Ross Island is 54 km to the east.
- ASPA 122: Arrival Heights, Hut Point Peninsula, Ross Island and ASPA 158: Hut Point, Ross Island are 35 km and 38 km to the south, respectively.
- ASPA 155: Cape Evans, Ross Island is 21 km to the southwest.
- ASPA 121: Cape Royds, Ross Island and ASPA 157: Backdoor Bay, Cape Royds, Ross Island are 23 km to the west.

Mount Melbourne

The nearest protected areas to Mount Melbourne are in Terra Nova Bay (Map A).

- ASPA 161: Terra Nova Bay, Ross Sea is 45 km to the southeast.
- ASPA 165: Edmonson Point, Wood Bay, Ross Sea is 22 km to the east.
- ASPA 173: Cape Washington and Silverfish Bay, northern Terra Nova Bay, Ross Sea is 34 km to the south.

Mount Rittmann

Mount Rittmann is 103 km to the north of Mount Melbourne. There are no protected areas within a 100 km radius of Mount Rittmann (Map A).

6(v) Special zones within the Area

Access to the Prohibited Zone at each of the Area's three sites is strictly prohibited until such time that it is agreed, during a management plan review, that access should be allowed.

Tramway Ridge, Mount Erebus

The northern half of the site (Map A1) is designated a Prohibited Zone in order to preserve part of the site as a reference area for future scientific studies, while the southern half of the site (which is similar in biology, features and character) is available for scientific research.

The southern boundary of the Prohibited Zone is defined by a line from 77° 31' 05.103"S; 167° 06' 20.968"E (Point F) to 77° 31' 05.224"S; 167° 06' 50.792"E (Point C) that bisects the Area. The other three boundaries of the Prohibited Zone are defined by the boundaries of the Area with Point C (77° 31' 05.224"S; 167° 06' 50.792"E "E) to Point B (77° 31' 01.967"S; 167° 06' 51.074"E) making up the eastern boundary; Point B to Point A (77° 31' 01.853"S; 167° 06' 21.251"E) making up the northern boundary; and Point A to Point F making up the western boundary.

The southern boundary of the Prohibited Zone may be identified, approximately, on the ground as an extension westwards of the south ridge line of lower Tramway Ridge. When standing in the Area, the boundary markers (G, H and C) allow the bisecting line to be clearly visible.

Summit of Mount Melbourne

The westernmost 100 metres of Cryptogam Ridge (Location 1; Map A2) is designated a Prohibited Zone, in order to protect the most extensive stand of vegetation and preserve a part of the site as a reference area for future scientific studies, while the remainder of Cryptogam Ridge and Location 2 and 3 are available for scientific research.

The western boundary of the site from the NW boundary corner extends from the coordinates 74° 21' 20.389" S; 164° 41' 31.652" E (Point 1A) south approximately 50 metres to the SW boundary corner at 74° 21' 22.096" S; 164° 41' 32.551" E (Point 1N). The boundary then extends east following the crescent shape of Cryptogam ridge to unmarked points at 74° 21' 20.840" S; 164° 41' 45.230" E (Point 1L), then north to the NE boundary corner at 74° 21' 19.153" S; 164° 41' 45.329" E (Point 1C) (Map A2).

The Prohibited Zone is identified by the distinct change in slope of the ridge as it starts to decrease in elevation.

Mount Rittmann

Of the three geothermally heated areas identified at the site (Map A3), the eastern most area is designated a Prohibited Zone in order to preserve part of the site as a reference area for future scientific studies, while the remainder of the site (which is similar in biology, features and character) is available for scientific research.

The western boundary of the site from the NW boundary corner extends from the caldera rim at 73° 28' 17.655" S; 165° 37' 12.235" E (Point E) south down the steep slope approximately 80 metres to the SW boundary corner at 73° 28' 19.430" S; 165° 37' 08.865" E (Point N). The boundary then extends east following the bottom of the slope to the SE corner at 73° 28' 20.945" S; 165° 37' 13.936" E (Point M). The boundary then extends upslope north to the NE boundary corner at 73° 28' 19.823" S; 165° 37' 16.943" E (Point G) (Map A3).

7. Terms and conditions for entry permits

ALL PROVISIONS FOR ENTRY PERMITS APPLY TO THE AREA'S THREE SITES

7(i) General permit conditions

Entry into any of the Area's three sites is prohibited except in accordance with a Permit issued by an appropriate national authority. Conditions for issuing a Permit to enter the Area are that:

- it is issued for compelling scientific reasons which cannot be served elsewhere, or for reasons essential to the management of the Area;
- the actions permitted will not jeopardise the biological communities, ecological or scientific values of the Area;
- the actions permitted are in accordance with this Management Plan;
- access to the Prohibited Zones shall be prohibited;
- any management activities are in support of the objectives of the Management Plan;
- a Permit, or a copy, shall be carried within the Area, including a copy of all relevant maps from the Management Plan.

7(ii) Access to, and movement within or over, the Area

- Access to the summit of each volcano is generally by helicopter.
- Landing of helicopters within the Area's three sites is strictly prohibited.
- Helicopters should land at designated landing sites outside of the Area's three sites (refer to Section 6(ii) or Maps A1, A2 and A3).
- Helicopters should only land away from the designated landing sites in the event of an emergency.
- Helicopter overflights or hovering over any ice-free area of the Area's three sites should be avoided, except for essential scientific or management purposes when helicopters shall in no instance fly lower than 50 metres above the ground surface.
- The use of helicopter smoke grenades within the Area's three sites is prohibited.
- Vehicles (e.g. skidoos) are prohibited within the Area's three sites.
- Only those persons specifically authorised by Permit are allowed to enter the Area.
- All movement within the Area's three sites should be on foot.
- Permit holders should be aware that walking in the Area can compact soil, alter temperature gradients (which may change rates of steam release), and break thin ice crusts which may form over geothermally heated ground, with resulting damage to soil and biota below. The presence of snow or ice surfaces is not a guaranteed indication of a suitable pathway: therefore every reasonable effort should be made to minimise the effects of walking activity. Pedestrian traffic should be kept to the absolute minimum necessary consistent with the objectives of any permitted activities.

- Permit holders should also avoid walking on areas of visible vegetation or moist soil both on ice-free ground and among ice hummocks and, as far as practicable, areas of geothermally heated ground.
- Permit holders are strongly encouraged to collect GPS data for all movements within the Area and submit this data to the appropriate national authority with the visit report (see Section 7(x)).
- Permit holders shall not interfere (drill, sample, damage) with any ice structures unless specified in a Permit.

7(iii) Activities which may be conducted within the Area

Activities which may be conducted within the Area include:

- compelling scientific research which cannot be undertaken elsewhere and which will not jeopardise the biological communities, ecological or scientific values of the Area;
- essential management activities, including monitoring and inspection.

7(iv) Installation, modification, or removal of structures

- No new structures (i.e. signs or boundary markers) are to be erected within the Area, or scientific equipment installed, except for compelling scientific or management reasons and for pre-established periods, as specified in a Permit.
- All markers, structures or scientific equipment installed in the Area must be clearly identified by country, name of the principal investigator or agency, year of installation and date of expected removal.
- All such items should be sterilised prior to installation to ensure, that to the maximum extent possible, they are free of organisms, propagules and non-sterile soil, and be made of materials that can withstand the environmental conditions and pose minimal risk of contamination to the Area.
- Removal of specific structures or equipment for which the Permit has expired shall be the responsibility of the authority which granted the original Permit and shall be a condition of the Permit.

7(v) Location of field camps

- Camping is prohibited within the Area.
- Camping required for work at Tramway Ridge, Mount Erebus should be near the existing Upper (77° 30′ 37.857″S; 167° 08′ 48.5736″E) or Lower (77° 31′ 32.6172″S; 167° 08′ 12.8688″E) Erebus huts (Map A1; Inset 1).
- Camping is discouraged anywhere within 100 metres of the three locations on Mount Melbourne and Mount Rittmann.
- Camping should be on ice-covered ground only.

7(vi) Restrictions on materials and organisms which may be brought into the Area

To avoid compromising the ecological values, specifically the unique biological communities, for which the Area is protected, the following restrictions apply to all activities in the Area:

- The deliberate introduction of plants, animals, microorganisms and non-sterile soil into the Area shall not be permitted.
- To ensure that the ecological values of the Area are maintained, special precautions shall be taken against accidentally introducing plants, animals, microorganism or non-sterile soil from other Antarctic sites, including other sites or locations within the Area, stations, or from regions outside Antarctica, to any of the Area's three sites or between the Area's three sites by following the measures outlined in Section 7(x).
- All sampling equipment or markers brought into the Area shall be cleaned or sterilized.
- To the maximum extent practicable, footwear and other equipment used or brought into the Area (including bags or backpacks) shall be thoroughly cleaned before entering the Area.
- Visitors moving between the Area's three sites shall take extra care to ensure that all materials and equipment used at one site are cleaned or sterilized before moving to another site to avoid transferring species between these biologically distinct, but physically and climatically similar sites. In addition, because microbial diversity can differ over short distances, visitors moving between geothermal locations within a site shall take the same precautions.
- Neither fuel nor food is to be brought into the Area.
- Equipment or other materials are not to be stored in the Area.
- Chemicals, including radio-nuclides or stable isotopes, which may be brought into the Area for scientific or management purposes specified in the Permit, shall not be released into the environment and be removed from the Area at or before the conclusion of the activity for which the Permit was granted.
- Materials introduced into the Area shall be for a stated period only and shall be removed by the end of that stated period.
- Further guidance for reducing the risk of transfer of non-native species can be found in the CEP Non-native Species Manual (Edition 2011) and COMNAP/SCAR Checklists for supply chain managers of National Antarctic Programmes.

7(vii) Taking of, or harmful interference with, native flora and fauna

- Taking of, or harmful interference with, native flora and fauna and biological communities (specifically the microbiology) at these sites is prohibited, except in accordance with a permit issued in accordance with Annex II of the Protocol on Environmental Protection to the Antarctic Treaty.

7(viii) The collection or removal of materials not brought into the Area by the permit holder

- Material may be collected or removed from the Area only in accordance with a Permit and should be limited to the minimum necessary to meet scientific or management needs. Permits shall not be granted if there is reasonable concern that the sampling proposed would take, remove or damage such quantities of soil, sediment, microbiota, flora or fauna that their distribution or abundance within the Area would be significantly affected.
- Material of human origin likely to compromise the values of the Areas, which was not brought into the Area by the Permit Holder or otherwise authorised, may be removed from the Area, unless the impact of removal is likely to be greater than leaving the material *in situ*; if this is the case the appropriate authority should be notified.

7(ix) Disposal of waste

- All wastes, including all human wastes, shall be removed from the Area.

7(x) Measures that may be necessary to continue to meet the aims of the Management Plan

Permits may be granted to enter the Area to:

- carry out monitoring and Area inspection activities, which may involve the collection of samples or data for analysis or review;
- erect or maintain signposts, structures or scientific equipment; or
- carry out management activities.

To help maintain the ecological and scientific values derived from the isolation and relatively low level of human impact of the Area, visitors shall take special precautions against introductions, especially when visiting more than one of the Area's three sites in a season. Of particular concern are introductions sourced from:

- geothermal areas, both Antarctic and non-Antarctic;
- geothermal areas located at the same high altitude site which are not included within the Area;
- moving between any of the Area's three sites;
- soils from any other Antarctic site, including those near stations; and
- soils from regions outside Antarctica.

To this end, visitors shall take the following measures to minimise the risk of introductions:

- Any sampling equipment or markers brought into the Area shall be sterilised and maintained in a sterile condition before being used within the Area. To the maximum extent practicable, footwear and other equipment used or brought into the Area (including backpacks or carrybags) shall be thoroughly cleaned or sterilised and maintained in this condition before entering the Area;
- Sterilisation should be by an acceptable method, such as by UV light, autoclave, or by washing surfaces in 70% ethanol solution in water.
- Sterile protective over-clothing shall be worn. The over-clothing shall be suitable for working at temperatures of -20oC or below and comprise, at a minimum, sterile overalls to cover arms, legs and body and sterile gloves suitable for placing over the top of cold-weather gloves. Disposable sterile/protective foot coverings are not suitable for the scoria surface and should not be used. Instead, all footwear should be thoroughly brushed to remove soil particles and wiped with 70% ethanol solution.
- Both the interior and exterior of helicopters should be cleaned, as far as practicable, before moving to and from the Area, or between the Area's three sites.

7(xi) Requirements for reports

The principal permit holder for each visit to the Area shall submit a report to the appropriate national authority as soon as practicable, and no later than six months after the visit has been completed. Such visit reports should include, as applicable, the information identified in the recommended visit report form, contained in Appendix 2 of the Revised Guide to the Preparation of Management Plans for Antarctic Specially Protected Areas appended to Resolution 2 (2011), available from the website of the Secretariat of the Antarctic Treaty (www.ats.aq), and where possible, GPS data for all movements within the Area. The report shall take into account and identify which of the Area's three sites was visited.

If appropriate, the national authority should forward a copy of the visit report to the Party that proposed the Management Plan, to assist in managing the Area and reviewing the Management Plan.

8. Supporting documentation

Allan, R.N., Lebbe, L., Heyrman, J., De Vos, P., Buchanan, C.J. and Logan, N.A. 2005. *Brevibacillus levickii* sp. nov. and *Aneurinibacillus terranovensis* sp. nov., two new thermoacidophiles isolated from geothermal soils of northern Victoria Land, Antarctica. International Journal of Systematics and Evolutionary Microbiology 55: 1039-1050.

Armienti, P. And Tripodo, A. 1991. Petrography and chemistry of lavas and comagmatic xenoliths of Mount Rittmann, a volcano discovered during the IV Italian expedition in northern Victoria Land (Antarctica). Memorie della Societa Geologica Italiana 46: 427-451.

Bargagli, R., Broady, P.A. and Walton, D.W.H. 1996. Preliminary investigation of the thermal biosystem of Mount Rittmann fumaroles (northern Victoria Land, Antarctica). Antarctic Science 8(2): 121-126.

Bargagli, R., Skotnicki, M.L., Marri, L., Pepi, M., Mackenzie, A. and Agnorelli, C. 2004. New record of moss and thermophilic bacteria species and physicochemical properties of geothermal soils on the north-west slope of Mt. Melbourne (Antarctica). Polar Biology 27: 423-431.

Bonaccorso, A., Maione, M., Pertusati, P.C., Privitera, E. and Ricci, C.A. 1991. Fumarolic activity at Mount Rittmann volcano (northern Victoria Land, Antarctica). Memorie della Societa Geologica Italiana 46: 453- 456.

Broady, P.A. 1984. Taxonomic and ecological investigations of algae on steam-warmed soil on Mt. Erebus, Ross Island, Antarctica. Phycologia 23: 257-271.

Broady, P.A. 1993. Soils heated by volcanism. Pages 413-432 in E.I. Friedmann (ed.), Antarctic microbiology. New York, Wiley-Liss.

Broady, P.A., Given, D., Greenfield, L.G. and Thompson, K. 1987. The biota and environment of fumaroles on Mt. Melbourne, northern Victoria Land. Polar Biology 7: 97-113.

Greenfield, L.G. 1983. Thermophilic fungi and actinomycetes from Mt. Erebus and a fungus pathogenic to *Bryum antarcticum* at Cape Bird. New Zealand Antarctic Record 4(3): 10-11.

Hudson, J.A. and Daniel, R.M. 1988. Enumeration of thermophilic heterotrophs in geothermally heated soils from Mount Erebus, Ross Island, Antarctica. Applied and Environmental Microbiology 54: 622-624.

Hudson, J.A., Daniel, R.M. and Morgan, H.W. 1988. Isolation of a strain of *Bacillus schlegelii* from geothermally heated Antarctic soil. FEMS Microbiology 51(1): 57-60.

Hudson, J.A., Daniel, R.M. and Morgan, H.W. 1989. Acidophilic and thermophilic Bacillus strains from geothermally heated Antarctic soil. FEMS Microbiology Letters 60: 279-282.

Imperio, T., Viti, C. And Marri, L. 2008. *Alicyclobacillus pohliae* sp. Nov., a Thermophilic, endospore forming bacterium isolated from geothermal soil of the north west slope of Mount Melbourne (Antarctica). International Journal of Systematic and Evolutionary Microbiology 58: 221-225.

Janetschek, H. 1963. On the terrestrial fauna of the Ross Sea area, Antarctica. Pacific Insects 5: 305-311.

LeMasurier, W.E. and Wade, F.A. 1968. Fumarolic activity in Marie Byrd Land, Antarctica. Science 162: 352.

Lesser, M.O., Barry, T.M and Banaszak, A.T. 2002. Effects of UV radiation on a chlorophyte alga (*Scenedesmus* sp.) isolated from the fumarole fields of Mt. Erebus, Antarctica. Journal of Phycology 38: 473- 481.

Logan, N.A., Lebbe, L., Hoste, B., Goris, J., Forsyth, G., Heyndrickx, M., Murray, B.L., Syme, N., Wynn- Williams, D.D. and De Vos, P. 2000. Aerobic endospore-forming bacteria from geothermal environments in northern Victoria Land, Antarctica, and Candlemas Island, South Sandwich archipelago, with the proposal of *Bacillus fumarioli* sp. nov. International Journal of Systematic and Evolutionary Microbiology 50: 1741-1753.

Logan, N. and Allan, R.N. 2008. Aerobic endospore forming bacteria from Antarctic geothermal soils. Pages 155-175. In: Dion, P. And Nautiyal, C.S. (Eds.). Microbiology of Extreme Soils. Springer Verlang Berlin Heidelberg.

Lyon, G.L. and Giggenbach, W.F. 1974. Geothermal activity in Victoria Land, Antarctica. New Zealand Journal of Geology and Geophysics 17(3): 511-521.

Melick, D., Broady, P.A. and Rowan, K.S. 1991. Morphological and physiological characteristics of a non-heterocystous strain of *Mastigocladus laminosus* Cohn from fumarolic soils on Mount Erebus, Antarctica. Polar Biology 11:81-89.

Nathan, S. And Schulte, F.J., 1967. Recent thermal and volcanic activity on Mount Melbourne, northern Victoria Land, Antarctica. New Zealand Journal of Geology and Geophysics 10: 422-430.

Nicolaus, B., Marsiglia, F., Esposito, E., Tricone, A., Lama, L., Sharp, R., Di Prisco, G. and Gambacarta, A. 1991. Isolation of five strains of thermophilic eubacteria in Antarctica. Polar Biology 11: 425-429.

Nicolaus, B., Lama, L., Esposito, E., Manca, M.C., Di Prisco, G. And Gambacorta, A. 1996. *Bacillus thermoantarcticus* sp. nov. from Mount Melbourne, Antarctica: a novel thermophilic species. Polar Biology 16: 101-104.

Nicolaus, B., Improta, R., Manca, M.C., Lama, L., Esposito, E. And Gambacorta, A. 1998. Alicyclobacilli from an unexplored geothermal soil in Antarctica: Mount Rittmann. Polar Biology 19: 133-141.

Nicolaus, B., Lama, L., Esposito, E., Bellitti, M.R., Improta, R., Panico, A. And Gambacorta, A. 2000. Extremophiles in Antarctica. Italian Journal of Zoology 1: 169-174.

Nicolaus, B., Manca, M.C., Lama, L., Esposito, E. And Gambacorta, A. 2001. Lipid modulation by environmental stresses in two models of extremophiles isolated from Antarctica. Polar Biology 24: 1-8.

Nicolaus, B., Lama, L. And Gambacorta, A. 2002. Thermophilic Bacillus isolates from Antarctic environments. Pages 47-63 in Berkeley, R., Heyndrickx, M., Logan, N. And De Vos, P. (eds.), Applications and systematic of Bacillus and relatives. Balckwell Publishing.

Pepi, M., Agnorelli, C. And Bargagli, R. 2005. Iron demand by Thermophilic and mesophilic bacteria isolated from an Antarctic geothermal soil. Biometals 18(5): 529-536.

Poli, A., Esposito, E., Lama, L., Orlando, P., Nicolaus, G., deAppolonia, F., Gambacorta, A. And Nicolaus, B. 2006. *Anoxybacillus amylolyticus* sp. nov., a thermophilic amylase producing bacterium isolated from Mount Rittmann (Antarctica). Systematics and Applied Microbiology 29: 300-307.

Skotnicki, M.L., Selkirk, P.M., Broady, P., Adam, K.D. and Ninham, J.A. 2001. Dispersal of the moss *Campylopus pyriformis* on geothermal ground near the summits of Mount Erebus and Mount Melbourne, Victoria Land, Antarctica. Antarctic Science 13(3): 280-285.

Skotnicki, M.L., Bargagli, R. And Ninham, J.A. 2002. Genetic diversity in the moss *Pohlia nutans* on geothermal ground of Mount Rittmann, Victoria Land, Antarctica. Polar Biology 25: 771-777.

Soo, R.M., Wood, S.A., Grzymski, J.J., McDonald, I.R. and Cary, S.C. 2009. Microbial biodiversity of thermophilic communities in hot mineral soils of Tramway Ridge, Mount Erebus, Antarctica. Environmental Microbiology 11(3): 715-728.

Smith, G.H. 1992. Distribution and ecology of the testate rhizopod fauna of the continental Antarctic zone. Polar Biology 12: 629-634.

Ugolini, F.A. and Starkey, R.L. 1966. Soils and micro-organism from Mt. Erebus, Antarctica. Nature 211: 440-441.

Vickers, C.J. 2012. Investigating the physiological and metabolic requirements of the Tramway Ridge microbial community, Mount Erebus, Antarctica. MSc thesis, University of Waikato, New Zealand.

ANNEX 1: Site specific description of biological communities at each geothermal site. Tramway Ridge, Mount Erebus

Located 1.5 kilometres northwest of the main Mount Erebus crater is an ice-free, gently sloping geothermal area known as Tramway Ridge (Map A1). Soil temperatures have been recorded up to 75°C at 4 centimetres depth. The steam-warmed lithosols at the site provide an unusual habitat of limited extent. The geothermal heat, the acidic soils and the unusual regular supply of moisture by condensation of steam produce conditions that contrast markedly with most Antarctic soils.

The vegetation comprises a single bryophyte species and a diverse range of algae which differs from that found in other high altitude geothermal sites, as well as other Antarctic plant communities from low altitude areas (Table 1). A number of fungi have been identified but no detailed studies have taken place. The single moss species, *Campylopus pyriformis*, is unusual in that it has never been seen to produce leaves but persists in the protonematal stage (a thread like chain of cells). *C. pyriformis* is widely known from both northern and southern temperate regions of the world including Australia, New Zealand and South America. This species has not been recorded at any other continental location in Antarctica except at Mount Melbourne where it occurs as small cushions of mature leafy gametophytes up to about 4 cm^2 forming populations covering areas up to 200 cm^2 with up to 70% ground cover.

The vegetation occurs in zones related to surface temperature. The warmest ground, from about 35 to 60°C, is colonised by dark blue-green and reddish-brown mats of cyanobacteria, whereas cooler surfaces of about 10 to 30°C are dominated by green crusts of coccoid chlorophytes and moss protonema. Bare ground, lacking any macroscopic vegetation, has a temperature of between 0 and 20°C. The presence of a thermophilic cyanobacterium is especially noteworthy as it is an unusual variety of the hot spring cyanobacterium *Mastigocladus laminosus*, which is common elsewhere in the world. There is little evidence of the presence of micro-invertebrates in the soils. An early investigation reported the presence of a rhizopod protozoan and bdelloid rotifer although subsequent more detailed studies did not report these.

Early studies investigating bacterial communities on Tramway Ridge, using classical cultivation techniques, successfully cultured a limited number of novel thermophilic bacteria from the genera *Clostridia* and *Bacillus*. The three bacterial species found at Mount Erebus (*Bacillus schlegelii*, *Alicyclobacillus acidocaldarius* (previously *Bacillus acidocaldarius*) and *Thermoanaerobacter thermohydrosulfuricus* (previously *Clostridium thermohydrosulfuricum*)) have not been identified in samples collected from Mount Melbourne and Mount Rittmann (Table 2). Several halophilic (organisms that live in high salt concentrations) strains were also isolated from soil samples from Tramway Ridge and based on phenotypic characteristics assigned to *Micrococcus*.

New techniques (genetic based culture independent methods) have been employed at this site to characterize the microbial diversity. Analyses show a clear delineation in bacterial and cyanobacterial community structure between communities closest to fumaroles and communities away from the fumaroles. The soil temperature, pH, percentage carbon and moisture at the hottest temperature sites next to fumaroles were significantly different from sites away from the fumaroles, selecting for organisms with unique physiological traits.

Phylogenetic analysis identified the presence and exceptionally deep branching of bacterial sequences which varied to known microbial strains suggesting the soils at Tramway Ridge provide an atypical and unique habitat for microbial life and contain several yet to be described bacterial groups. Diversity of Archaea diversity was found to be low with a high sequence homology with known distant deep subsurface Archaea strains, indicating the Tramway Ridge species are from ancient lineages.

Mount Melbourne:

Geothermal activity on Mount Melbourne is concentrated in two main areas; at the rim of the main summit crater and on the northwest slope of the mountain. On the main summit crater, there are two locations within the Area. On the southern rim of the main summit crater of Mount Melbourne is a distinct deglaciated, crescent shaped ridge known at Cryptogam Ridge (Location 1; Map A2). Here warm ground extends along approximately 110 metres of the ridge. The areas of geothermally heated ground are marked by snow free areas, ice and snow hummocks up to a metre in height. Adjacent to Cryptogam Ridge is a slope (referred to as the geothermal slope) leading up to the eastern rim of the summit crater (Location 2; Map A2). The ground is marked by crevasses and ice towers extending up the steep caldera rim. On the northwest slopes of the volcano there is a northwest to southeast trending line of ice towers and small patches of bare ground that make up the third location at this site (Map A2/1).

Soil temperatures at these locations typically reach between 30 and 50°C at depths of a few centimetres. Survival of plant life is only possible through the occurrence of small water droplets, formed by the condensation of steam, which keep the soils moist and acts as a water source for the vegetation.

Mount Melbourne supports a unique biological assemblage with high biodiversity relative to the other two high altitude geothermal sites in the Ross Sea region (Table 1). Biota includes (i) algae (11 species) within crusts and mats that coat small substrata, (ii) bryophytes (two species of moss and one of liverwort), and (iii) a protozoan. Many of the species are not of a local provenance and are thought to have been dispersed to the site from outside Antarctica, probably by winds. A lichen association has been observed as a component of black crusts over small areas of warm soil. The warmest areas of ground on Cryptogam Ridge (Location 1) support yellowish-green patches of the moss *Campylopus pyriformis,* along with the liverwort *Cephaloziella varians* and brownish crusts of algae. The unusual occurrence of shallow peat is evidence of bryophyte growth over at least several decades. Sporophytes of *C. pyriformis* have not been observed at Mount Melbourne indicating it reproduces asexually by dispersal of vegetative propagules. Analysis of the population found genetic evidence that indicated a single colonisation event probably occurred followed by multiple mutations. A comparison with samples of *C. pyriformis* collected from Mount Erebus, 350 kilometres south of Mount Melbourne, found the two populations to be closely related providing evidence for dispersal between areas of heated ground.

Only sporadic patches of moss have been observed on the geothermal slope (Location 2). The amoeboid protozoan *Corythion dubium* was observed as empty shells in both mineral substrates and amongst bryophytes. The species is not common in continental Antarctica, and only found at one other site in Victoria Land. A number of fungi have been identified but no detailed studies have taken place.

The description of biota on Mount Melbourne is generally focused on Cryptogam Ridge (Location 1). More recent investigations of the biota on the northwest slope (Location 3) found no significant difference among the algal flora which is generally less well developed than that of Cryptogam Ridge. However, a third bryophyte species *Pohlia nutans* was identified from this location, a species closely related to populations found at Mount Rittmann and absent from Cryptogam Ridge. Furthermore, different populations of bacteria were identified from the two separate areas of geothermal activity on Mount Melbourne, even though they are only separated by a few kilometres.

Early microbial investigations carried out on samples collected from Crytpogram Ridge (Location 1) isolated new species of thermophilic bacteria such as *Bacillus thermoantarcticus* (now *thermantarcticus*), *Bacillus* (now *Alicyclobacillus*) *acidocaldarius* and *Bacillus fumarioli*. Later investigations were concerned with the soils on the northwest slope (Location 3) and identified the thermophilic strains *Alicyclobacillus* sp. and three mesophilic bacteria, *Micrococcus* sp., *Paenibacillus validus* and *Paenibacillus apiaries*. A further two novel species were identified more recently from the northwest slope, *Alicyclobacillus pohliae* sp. nov and *Brevibacillus levickii*, both of which have not been found on Cryptogam Ridge, but during the same investigation a new species of *Aneurinibacillus* genus was isolated from Cryptogam Ridge, and not the northwest slope. The name *Aneurinibacillus terranovensis* sp. nov. was proposed (Table 2).

Due to the restriction of certain species to certain locations on Mount Melbourne, investigations focussed on the metabolism of the different species and the soil characteristics and considered that the physico-chemical features of the geothermally heated ground may affect the colonisation history and dispersal of microorganisms and mosses at this site.

Mount Rittmann:

Although several expeditions into northern Victoria Land recognised the general distribution of volcanic centres in the region, Mount Rittmann was discovered only in the late 1980s. Located to the east of the head of the Aviator Glacier, a minor crater structure of Mount Rittmann is visible as a crescent shaped outcrop of a rough and unstable near vertical steep slope (approximately 300 metres wide and 80 metres high) surrounded by glacial ice (Map A3). Soil temperatures range from 50 to 63°C at 10 centimetres depth.

Like Tramway Ridge, Mount Erebus and the three locations on Mount Melbourne, the biota consists of bryophytes and a diverse range of algae and protozoa which differs from that found in other high altitude geothermal sites, as well as other Antarctic plant communities from low altitude areas (Table 1). A single bryophyte species, *Pohlia nutans* occurs as small loose colonies of short shoots only 1-2 mm in length with soil visible between the shoots. It is a cosmopolitan species known from Europe, Asia, Africa, Australasia and a number of locations around Antarctica including Mount Melbourne, although it is notably absent from Mount Erebus. Sporophytes have not been observed and it appears *P. nutans* reproduces asexually. Genetic analysis found the population at Mount Rittmann has low levels of genetic diversity and appears to be derived from a single immigration event followed by mutations, similar to the *C. pyriformis* on Mount Melbourne. A diverse range of algae has been cultured and identified, while direct microscopic examination of original samples only revealed occasional algae. While examining cultures for algae, two protozoa were found, one a small cyst forming naked rhizopod and the other a flagellate resembling *Bodo sp.*, neither of which were found on Mount Melbourne or Mount Erebus.

Microbial investigations carried out on samples collected from Mount Rittmann isolated thermophilic acidophilic (organisms that survive in acidic conditions) strains belonging to the genus *Alicyclobacillus* and the thermophilic genus *Anoxybacillus*. The genetic relatedness of the isolated strains of *Alicyclobacillus* suggested that the strains could be related to the species *A. acidocaldarius* or it could be distinct enough to be a new sub-species and the name *Alicyclobacillus acidocaldarius* subsp. *rittmannii* was proposed. The characteristics of the isolated strain of *Anoxybacillus* were found to represent a novel species and the name *Anoxybacillus amylolyticus* sp. nov. was proposed. Two species of bacteria, including *Aneurinibacillus terranovensis* and *Bacillus fumarioli*, were isolated from samples taken from Cryptogam Ridge on Mount Melbourne and Mount Rittmann but were unable to be isolated from the northwest slope on Mount Melbourne even though the two sites on Mount Melbourne are approximately 1.5 kilometres apart and Mount Melbourne and Mount Rittmann are approximately 103 kilometres apart (Table 2).

Table 1: Flora and fauna of fumarolic ground in high altitude geothermal areas of the Ross Sea region.

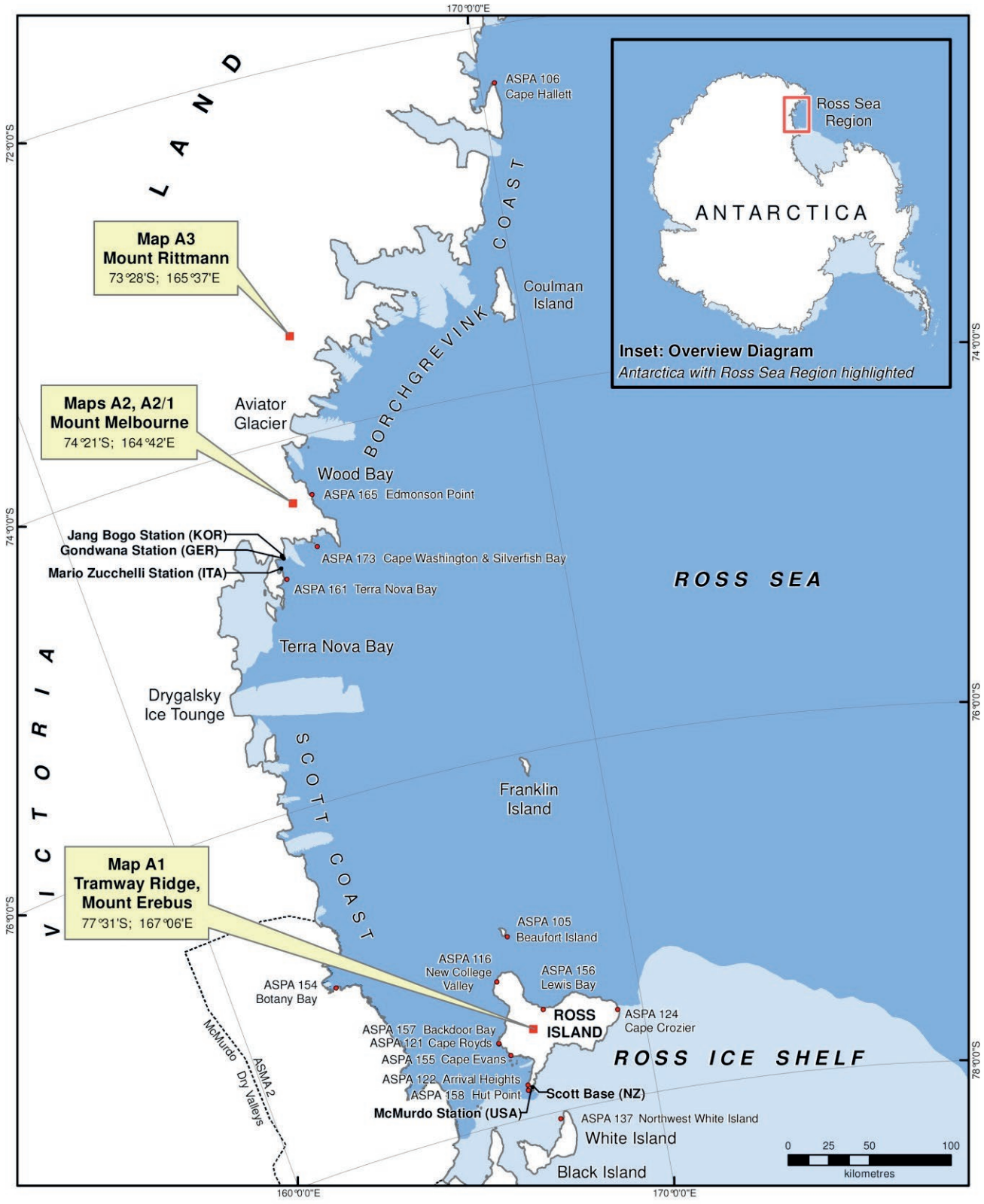
Taxon	Mount Erebus a	Mount Melbourne b	Mount Rittmann c
Bryophytes			
Campylopus pyriformis† (Moss)	+	+	
Pohlia nutans (Moss)		+	+
Cephaloziella exiliflora‡ (Liverwort)		+	
Algae - Cyanobacteria			
Aphanocapsa elachista†	+	+	
Gloeocapsa magma‡		+	
Phormidium fragile	+	+	
cf. Phormidium fragile			+
Tolypothrix bouteillei‡		+	
Mastigocladus laminosus†	+	+	+
Non-heterocystous *M. laminosus*	+		
Stigonema ocellatum†‡		+	
Nostoc sp.			+
Algae - Chlorophyta			
Bracteacoccus cf. minor	+		
Chlorella emersonii†	+	+	
Chlorella protothecoides†	+		
Chlorella cf. protothecoides			+
Chlorella reisiglii	+		
Chlorella cf. reisiglii			+
Chlorella cf. reniformis†		+	+
Chlorella saccharophila†‡	+		
Coccomyxa curvata‡	+		
Coccomyxa gloeobotrydiformis	+	+	
Coccomyxa cf. gloeobotrydiformis			+
Coenocystis oleifera	+	+	
Coenocystis cf. oleifera			+
Oocystis minuta	+		
cf. Oocystis minuta			+
Pseudococcomyxa simplex	+	+	
cf. Pseudococcomyxa simplex			+
Scotiellopsis terrestris†	+		
Scotiellopsis cf. terrestris			+
cf. Lyngbya sp. †‡			+
Scenedesmus sp. ‡	+		

Protozoa			
Corythion dubium‡		+	
Small cyst-forming naked rhizopod			+
Flagellate *cf. Bodo sp.*			+
Rhizopod protozoa	+		
Bdelloid rotifer	+		
Fungi			
Aspergillus sp.	+	+	
Chaetomium sp.		+	
Cryptococcus sp.		+	
Unidentified dematiacean sp.	+		
Malbranchea pulchella var. sulfurea		+	
Mucor sp.	+		
Myceliophthora thermophila		+	
Neurospora sp.	+		
Paecilomyces sp.		+	
Penicillium sp.	+		
Unidentified yeast	+		
Actinomycetes			
Streptomyces coelicolor†	+	+	
Thermoactinomyces vulgaris	+		
Thermomonospora sp.†	+	+	

a Broady, 1984; Ugolini and Starkey, 1966; Hudson and Daniel, 1988; Skotnicki et al., 2001; Janetschek, 1963
b Broady et al., 1987; Nicolaus et al., 1991; Lesser at al., 2002
c Skotnicki et al., 2002; Bargagli et al., 1996 (Species identification is tentative as isolates were not established for more detailed study).
†No other Antarctic record.
‡No other record from Victoria Land.

Table 2: Bacterial diversity of fumarolic ground in high altitude geothermal areas of the Ross Sea region.

Genus species	Mount Erebus	Mount Melbourne	Mount Rittman	Reference
Thermophilic Bacteria				
Bacillus				
- *Bacillus schlegelii*	+			Hudson and Daniel, 1988
- *Bacillus thermoantarcticus*		+		Hudson et al., 1988
- *Bacillus fumarioli*		+	+	Nicolaus et al., 1996 Logan et al., 2000
Alicyclobacillus				
- *Alicyclobacillus acidocaldarius* (previously *Bacillus acidocaldarius)*	+			Hudson and Daniel, 1988
- *Alicyclobacillus acidocaldarius subsp. rittmannii*			+	Nicolaus et al., 1998
- *Alicyclobacillus sp.*		+	+	Pepi et al., 2005 Bargagli et al., 2004 Nicolaus et al., 1998
- *Alicyclobacillus pohliae*		+		Imperio et al., 2008
Aneurinibacillus				
- *Aneurinibacillus terranovensis*		+	+	Allan et al., 2005
Anoxybacillus				
- *Anoxybacillus amylolyticus*			+	Poli et al., 2006
Brevibacillus				
- *Brevibacillus levickii*		+		Allan et al., 2005
Themoanaerobacter				
- *Thermoanaerobacter thermohydrosulfuricus* (previously *Clostridium thermohydrosulfuricum)*	+			Hudson and Daniel, 1988
Mesophilic Bacteria				
- *Micrococcus sp.*	+	+		Nicolaus et al., 2000; Nicolaus et al., 2001
- *Paenibacillus validus*		+		Pepi et al., 2005 Bargagli et al., 2004
- *Paenibacillus apiarius*		+		Pepi et al., 2005 Bargagli et al., 2004

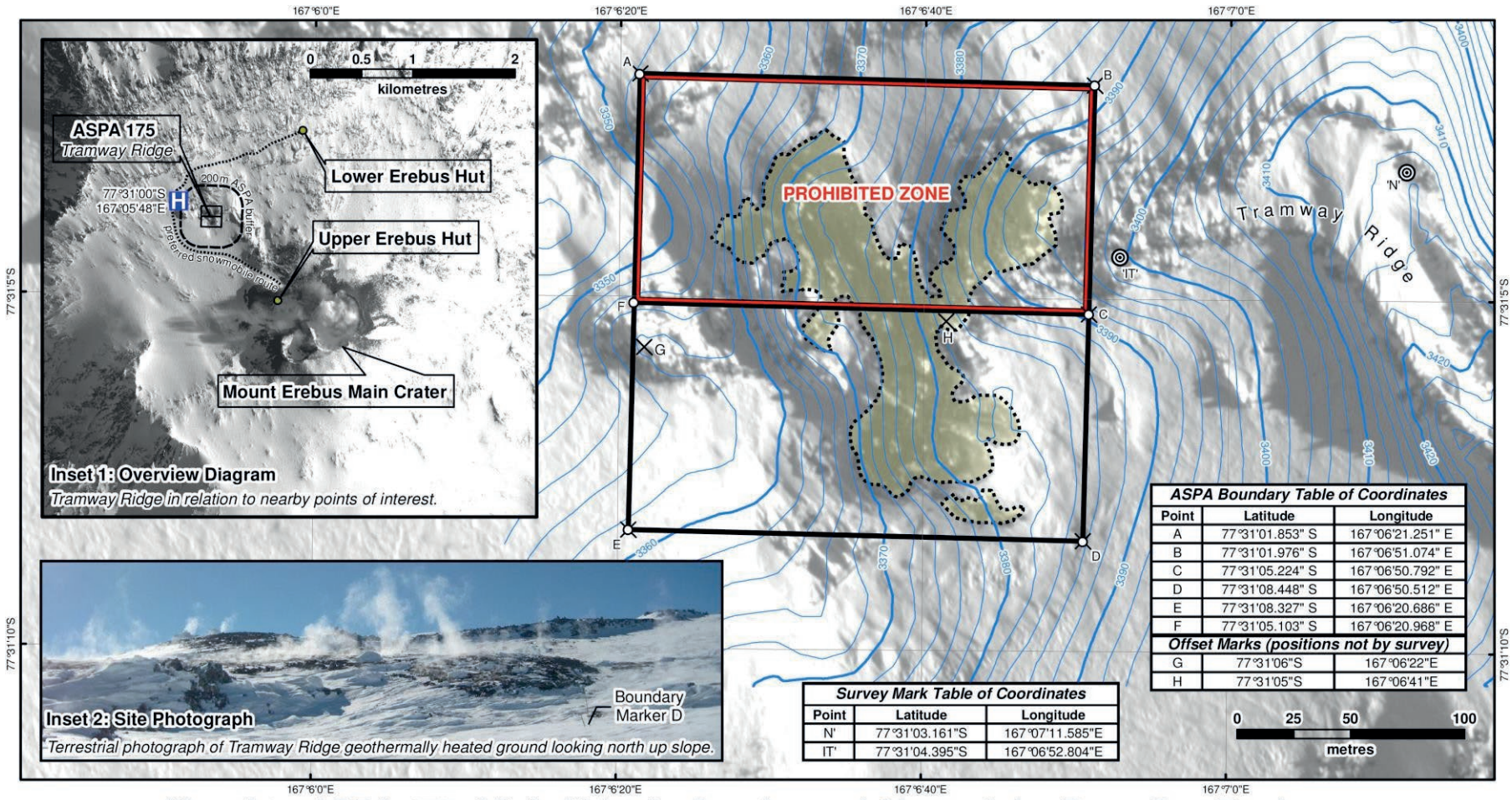


Map A - High Altitude Geothermal Sites of the Ross Sea Region

Location Diagram

Map Information:
Version 1.5 - 9 May 2014 (final).
Horizontal Datum: WGS84, Antarctica Polar Stereographic Projection.
True north is coincident with lines of longitude.

Data Sources:
Base Vector Data: Antarctic Digital Database Version 6.



ASPA Boundary Table of Coordinates

Point	Latitude	Longitude
A	77°31'01.853" S	167°06'21.251" E
B	77°31'01.976" S	167°06'51.074" E
C	77°31'05.224" S	167°06'50.792" E
D	77°31'08.448" S	167°06'50.512" E
E	77°31'08.327" S	167°06'20.686" E
F	77°31'05.103" S	167°06'20.968" E
Offset Marks (positions not by survey)		
G	77°31'06"S	167°06'22"E
H	77°31'05"S	167°06'41"E

Survey Mark Table of Coordinates

Point	Latitude	Longitude
N'	77°31'03.161"S	167°07'11.585"E
IT'	77°31'04.395"S	167°06'52.804"E

Map A1 - ASPA 175: High Altitude Geothermal Sites of the Ross Sea Region

Tramway Ridge, Mount Erebus Topographical Map

Map Information:

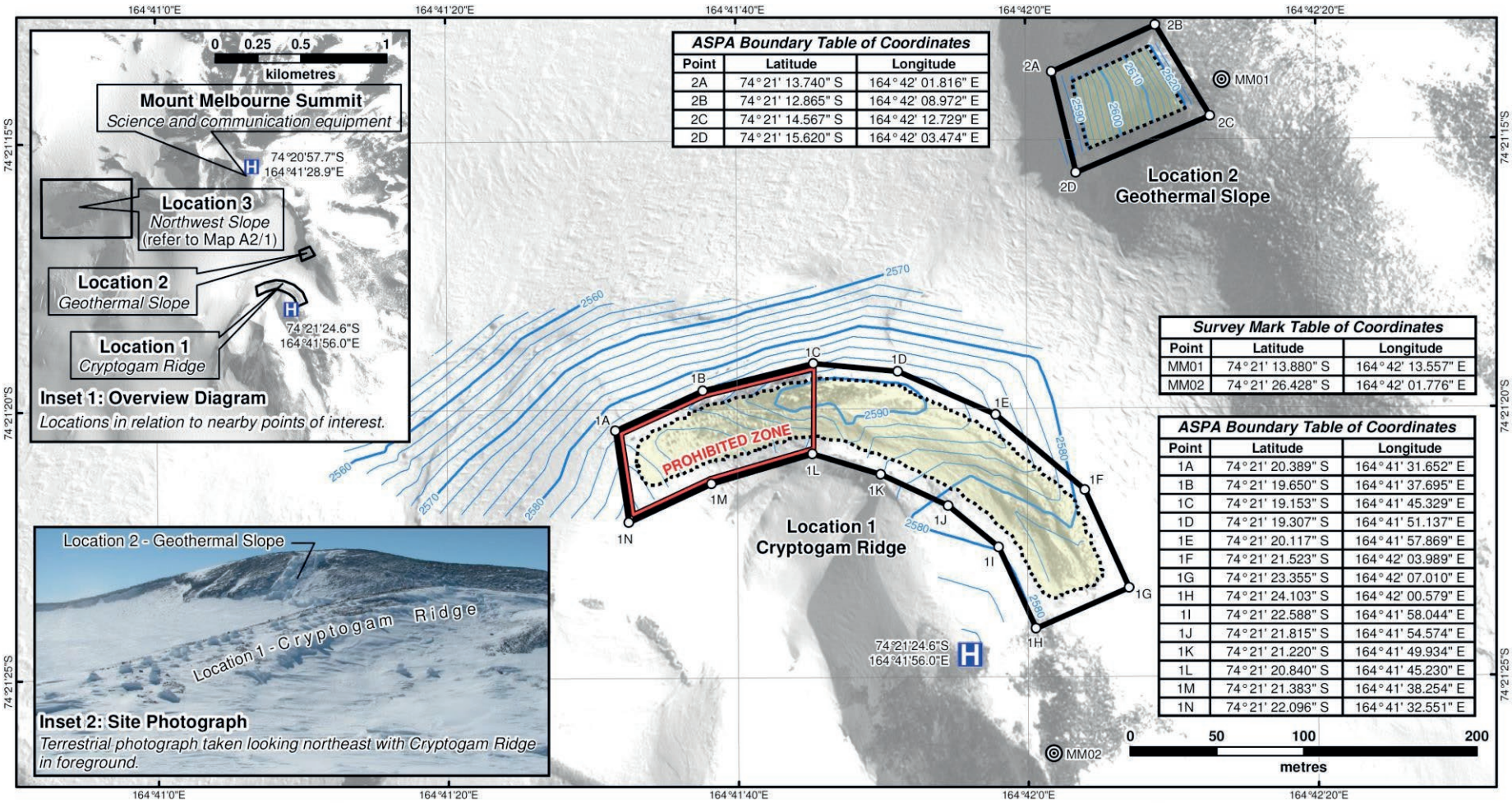
Version 1.7 - 9 May 2014 (final).
Horizontal Datum: WGS72, Camp Area Projection.
Vertical Datum: Mean Sea Level.
Satellite Imagery: orthorectified without ground-truthing.

Data Sources:

Survey Data: DOSLI Survey Plan 37/142.
Contours & Geothermally Heated Area: University of Canterbury.
Main Map & Overview Diagram Imagery: Digital Globe WorldView-2 Satellite (0.5 m resolution).
Site Photograph: University of Waikato.

Survey Mark
ASPA Boundary Point
Boundary Marker (approx.)
ASPA Boundary
Prohibited Zone Boundary
3420 Contour ~ 10-metre interval
Contour ~ 2-metre interval
Helicopter Landing Site
Geothermally Heated Ground (approx. & subject to change)

N



Map A2 - ASPA 175: High Altitude Geothermal Sites of the Ross Sea Region

Cryptogam Ridge and Geothermal Slope, Mount Melbourne Topographical Map

N

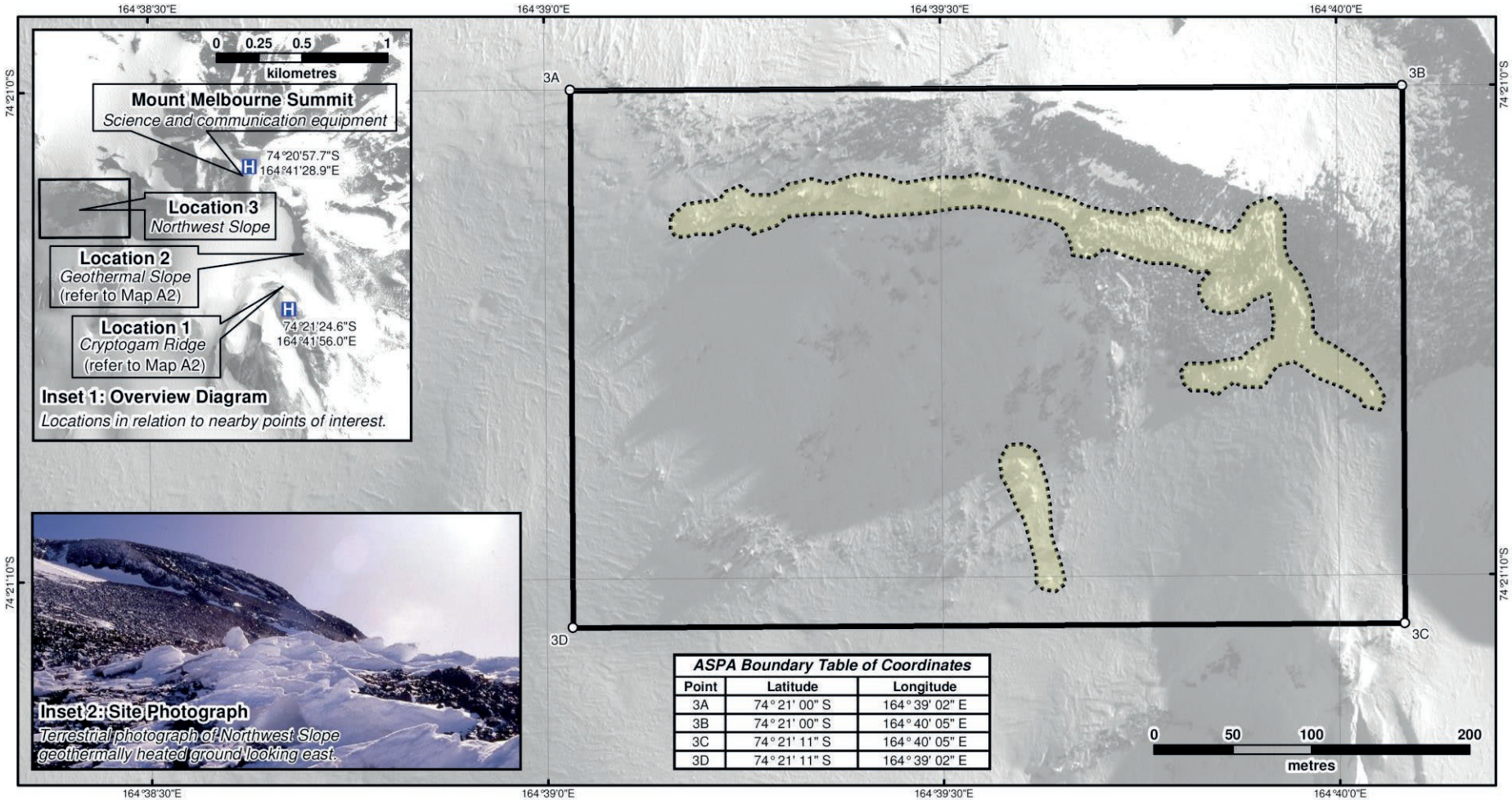
Map Information:

Version 1.6 - 9 May 2014 (final).
Horizontal Datum: WGS84, UTM Zone 58 Projection.
Vertical Datum: WGS84.
Satellite Imagery: orthorectified without ground-truthing.

Data Sources:

Survey Data: Obtained by field survey 17 November 2012.
Main Map & Overview Diagram Imagery: Digital Globe GeoEye Satellite (0.5 m resolution).
Site Photograph: Antarctica New Zealand.

- Survey Mark
- ASPA Boundary Point (unmarked)
- ASPA Boundary
- Prohibited Zone Boundary
- 2580 Contour ~ 10-metre interval
- Contour ~ 2-metre interval
- Helicopter Landing Site
- Geothermally Heated Ground (approx. & subject to change)



ASPA Boundary Table of Coordinates		
Point	Latitude	Longitude
3A	74° 21' 00" S	164° 39' 02" E
3B	74° 21' 00" S	164° 40' 05" E
3C	74° 21' 11" S	164° 40' 05" E
3D	74° 21' 11" S	164° 39' 02" E

Map A2/1 - ASPA 175: High Altitude Geothermal Sites of the Ross Sea Region

Northwest Slope, Mount Melbourne Topographical Map

N

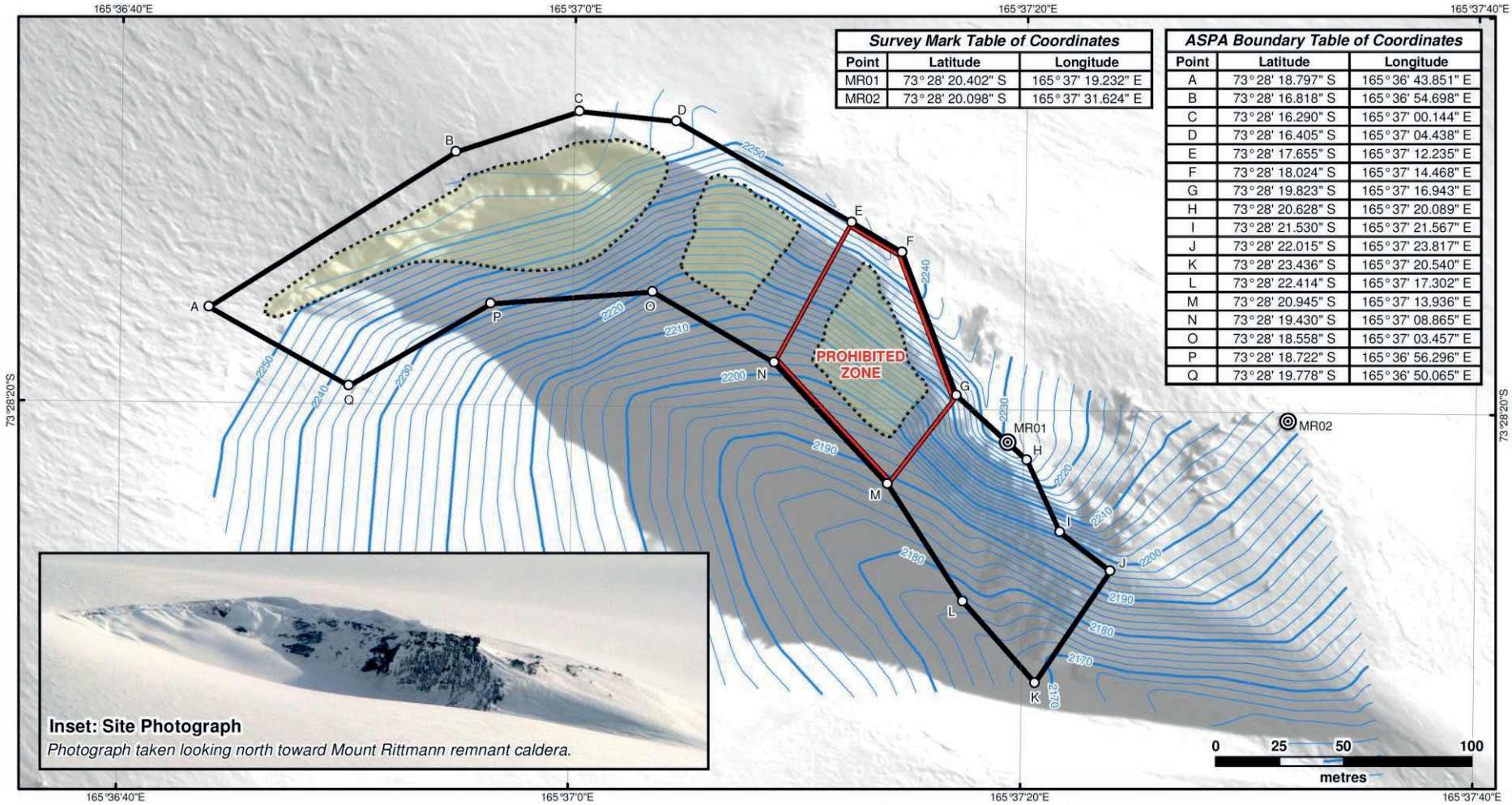
Map Information:

Version 1.4 - 9 May 2014 (final).
Horizontal Datum: WGS84, UTM Zone 58 Projection.
Vertical Datum: WGS84.
Satellite Imagery: orthorectified without ground-truthing.

Data Sources:

Survey Data: Data not by field survey. ASPA boundary obtained via inference from satellite imagery.
Main Map & Overview Diagram Imagery: Digital Globe GeoEye Satellite (0.5 m resolution).
Site Photograph: University of Siena.

- ASPA Boundary Point (unmarked)
- ASPA Boundary
- Helicopter Landing Site
- Geothermally Heated Ground (approx. & subject to change)



Survey Mark Table of Coordinates		
Point	Latitude	Longitude
MR01	73° 28' 20.402" S	165° 37' 19.232" E
MR02	73° 28' 20.098" S	165° 37' 31.624" E

ASPA Boundary Table of Coordinates		
Point	Latitude	Longitude
A	73° 28' 18.797" S	165° 36' 43.851" E
B	73° 28' 16.818" S	165° 36' 54.698" E
C	73° 28' 16.290" S	165° 37' 00.144" E
D	73° 28' 16.405" S	165° 37' 04.438" E
E	73° 28' 17.655" S	165° 37' 12.235" E
F	73° 28' 18.024" S	165° 37' 14.468" E
G	73° 28' 19.823" S	165° 37' 16.943" E
H	73° 28' 20.628" S	165° 37' 20.089" E
I	73° 28' 21.530" S	165° 37' 21.567" E
J	73° 28' 22.015" S	165° 37' 23.817" E
K	73° 28' 23.436" S	165° 37' 20.540" E
L	73° 28' 22.414" S	165° 37' 17.302" E
M	73° 28' 20.945" S	165° 37' 13.936" E
N	73° 28' 19.430" S	165° 37' 08.865" E
O	73° 28' 18.558" S	165° 37' 03.457" E
P	73° 28' 18.722" S	165° 36' 56.296" E
Q	73° 28' 19.778" S	165° 36' 50.065" E

Map A3 - ASPA 175: High Altitude Geothermal Sites of the Ross Sea Region

Mount Rittmann Topographical Map

N

Map Information:

Version 1.5 - 9 May 2014 (final).
Horizontal Datum: WGS84, UTM Zone 58 Projection.
Vertical Datum: WGS84.
Satellite Imagery: orthorectified with limited ground-truthing.

Data Sources:

Survey Data: Obtained by field survey 16 November 2012.
Main Map & Overview Diagram Imagery: Digital Globe WorldView-1 Satellite (0.5 m resolution).
Site Photograph: Antarctica New Zealand.

- Survey Mark
- ASPA Boundary Point (unmarked)
- ASPA Boundary
- Prohibited Zone Boundary
- Contour ~ 10-metre interval
- Contour ~ 2-metre interval
- Geothermally Heated Ground (approx. & subject to change)