CAFE

Concepts for Activities in the Field for Exploration

TN2: The Catalogue of Planetary Analogues

Written by

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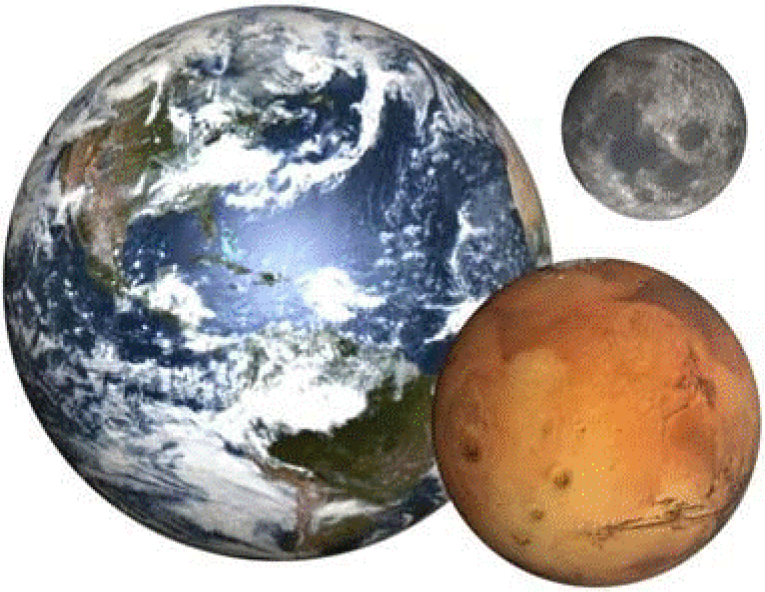
The Catalogue of Planetary Analogues



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Introduction

Planetary missions to the Moon and Mars have returned high-resolution images that show complex surface landforms in unprecedented detail. Spectral datasets from mission instruments reveal the presence of a wide array of mineral species on the surface. These discoveries are changing analogue site requirements for understanding the formation and processes occurring on our nearest neighbours, and for planning future exploratory missions. Analogue filed sites are now expected to include complementary examples of surface processes, rock types, mineral species, and microbial habitats as might be presently, or once were, present on the Moon and Mars. Over the last 60 years, the range and diversity of terrestrial analogues has expanded tenfold. The Catalogue of Planetary Analogues is a result of this growth and the need to collate these sites into a single space for use in scientific, engineering and mission planning activities.

The Catalogue of Planetary Analogues (The CPA) allows terrestrial analogue sites for important exploration targets on the Moon and Mars to be easily evaluated. For the Moon, impact craters and their associated features, volcanic constructs and terrains, granular flows and geological materials in the form of anorthosite and basaltic rocks have been assigned terrestrial field sites that mimic one or more of these features. For Mars, the list of geological features is extensive due to the range of processes having operated on the planets' surface, combined with the effects of liquid water. Impact features and volcanic landscapes, as well as fluvial features, aeolian processes, ice-related geomorphology, and subsurface water deposits are included. Many minerals and geological materials have been discovered on Mars and these have been investigated also. Planetary analogue sites have been assigned for each of these features. Astrobiological targets are of particular interest at present and an extensive list of analogue sites that can be used for astrobiological investigations is also included.

The CPA is a work in progress and will grow over time through user additions and future planetary mission results. The information included so far is a combination of literature research and contributions by academics, engineers and mission planners. As such some material may be currently missing or incomplete; however, as the information becomes available it will be included. The information provided is accurate at the time of writing and will be updated as necessary.

Directory

Planetary Body	Feature Class	Feature	Analogue Site Location (chapter)
Moon	Impact	Crater	3, 7, 10, 15, 16, 17, 22, 24
		Ejecta	7, 10, 17, 22, 24
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	Volcanic	Structure	12, 13, 14, 18, 25
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	Composition	Anorthosite	17
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		Impact Breccia	10, 15, 17, 22, 24
		Water/Ice	1, 4, 10, 12, 26
Mars	Impact Features	Crater	2, 7, 10, 15, 16, 22, 24
		Ejecta	3, 10, 22, 24
		Melt Sheets	10, 15, 24
		Hydrothermal Deposits	10, 15, 24
		Gullies	3, 15, 16,
		Crater Lakes	10, 15
	Volcanic	Structure	2, 12, 13, 14, 18, 25, 27
		Lava Flows	2, 6, 7, 8, 11, 12, 13, 14, 18, 25, 26, 27, 30
		Lava Tubes	12, 14, 27
		Pyroclastic Deposits	12, 13, 14, 27
		Collapse Pits	14
		Wrinkle Ridges	8, 12, 14, 27
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	Wind	Soils/regolith	1, 2, 6, 7, 11, 12, 13, 14, 19, 25, 26, 27, 29
		Dunes	2, 3, 11, 12, 19, 25, 28
		Yardangs	19
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	Ice	Polygon Terrain	1, 3, 4, 9, 10, 26
		Icy Flows/glacial features	1, 4, 10, 12, 13, 26
	Composition	Basalt	2, 6, 7, 8, 11, 12, 14, 15, 18, 25,

Planetary Body	Feature Class	Feature	Analogue Site Location (chapter)
			27
		Phyllosilicate	10, 11, 22, 29, 30
		Sulphate	2, 4, 9, 23, 26, 29
		Iron Oxide	2, 9, 12, 23, 30
		Silica	5, 12, 21, 30
		Carbonate	1, 4, 10, 11, 26,
		Water	All
	Astrobiology		1, 2, 4, 5, 8, 10, 11, 12, 13, 14, 16, 19, 20, 21, 22, 23, 26, 27, 9, 29, 30

List of Acronyms

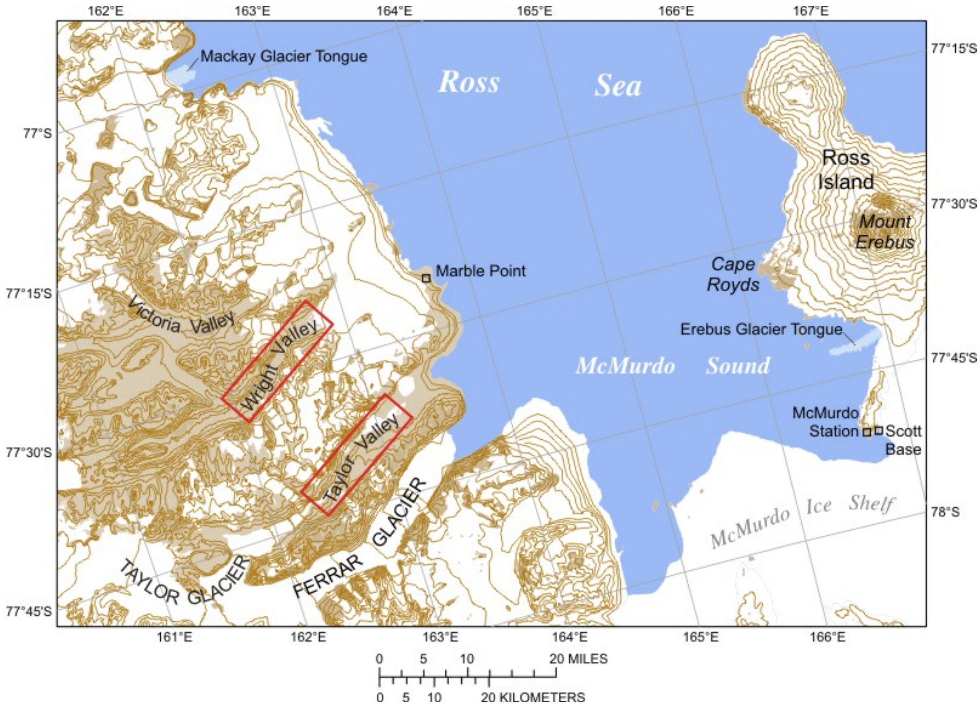
ADV	Antarctic Dry Valleys
AMASE	Arctic Mars Analogue Svalbard Expedition
ASL / asl	Above Sea Level
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATV	All-Terrain Vehicle
BPLF	Black Point Lava Flow
CRBG	Columbia River Basalt Group
CSA	Canadian Space Agency
EVA	Extra Vehicular Activity
FMARS	Flashline Mars Arctic Research Station
GD	Golden Deposit
GPS	Global Positioning System
HMPRS	Haughton-Mars Project Research Station
ILSR	Impacts Lunar Sample Return Analogue Mission
MAR	Mid-Atlantic Ridge
MARS	McGill Arctic Research Station
MI	Mars Institute
MSL	Mars Science Laboratory
NASA	National Aeronautics Space Administration
NWT	Northwest Territories
PK	Petropavlovsk-Kamchatsky
PLRP	Pavilion Lake Research Project
SFVF	San Francisco Volcanic Field
SPOT	Système Pour l'Observation de la Terre
USGS	United States Geological Survey
WNM	Wupatki National Monument

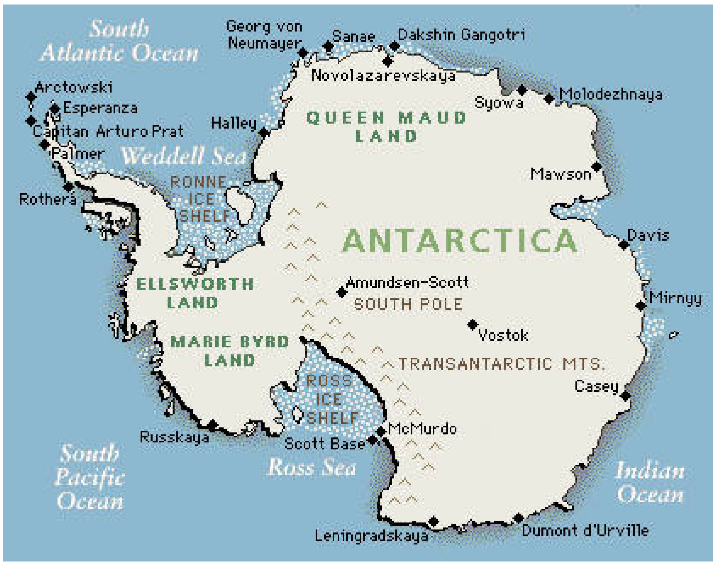
1 The Antarctic Dry Valleys

1.1 Location

Coordinates	77°30'S 163°00'E
Country/State/Province	Antarctica
Continent	Antarctica

1.1.1 Map



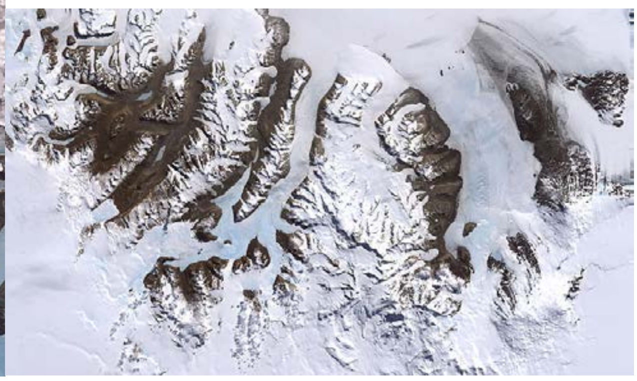
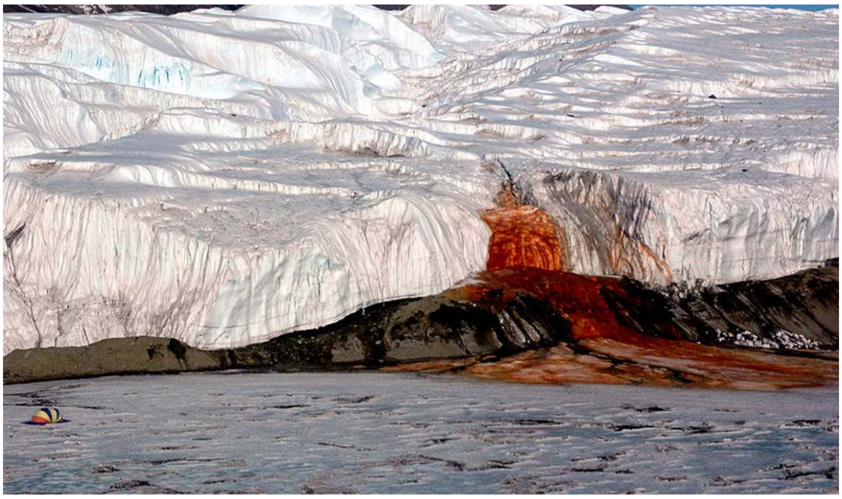


Top: USGS Map of the Dry Valleys/McMurdo Dry Valleys and below: Map of Antarctic bases.

1.1.2 Elevation

2800 metres

1.1.3 Image

ASTER image Credit: NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team. The Antarctic Dry Valleys, credit: image by Robert Simmon, based on data provided by the NASA GSFC Oceans and Ice Branch and the Landsat 7 Science Team. Blood Falls. Credit: US Antarctic Programme, National Science Foundation.

1.2 Context

1.2.1 Geological Setting

The Antarctic Peninsula was formed by uplift and metamorphism of sea-bed sediments during the late Palaeozoic and the early Mesozoic eras. This sediment uplift was accompanied by igneous intrusions and volcanism. The most common rocks in West Antarctica are andesite and rhyolite volcanics formed during the Jurassic Period. There is also evidence of volcanic activity, even after the ice sheet had formed, in Marie Byrd Land and Alexander Island. The West Antarctic Rift, a major active rift valley, lies between West and East Antarctica. The rift is still active with slow movement of West Antarctica away from East Antarctica.

East Antarctica is geologically very old, dating from the Precambrian era, with some rocks formed more than 3 billion years ago. It is composed of a metamorphic and igneous platform which is the basis of the continental shield. On top of this base are various more modern rocks, such as sandstones, limestones, coal and shales laid down during the Devonian and Jurassic periods to form the Transantarctic Mountains. In coastal areas such as Shackleton Range and Victoria Land some faulting has occurred.

The McMurdo Dry Valleys are a row of snow-free valleys in Antarctica located within Victoria Land west of McMurdo Sound. The Dry Valleys are so named because of their extremely low humidity and their lack of snow or ice cover. They are also dry because the mountains block seaward flowing ice from the East Antarctic ice sheet from reaching the Ross Sea. At 4800 km^2 the valleys constitute around 0.03% of the continent, and form the largest ice-free region in Antarctica. The unique conditions in the Dry Valleys are caused, in part, by katabatic winds; these occur when cold, dense air is pulled downhill by the force of gravity, heating as they descend, and evaporating all water, ice and snow.

1.2.2 Relevance

The Antarctic Dry Valleys are considered to be the most 'Mars-like' environment on Earth and contain a range of features found on Mars in the past and today. These include: a cold dry desert plus associated features; ice-wedge, sand-wedge and sublimation polygons; gullies; cold-based glaciers like those observed on Arsia Mons; cryptoendoliths and extremophiles; weathering pits and chemical weathering features; salts in soils; subsurface brines; saline lakes and iron-oxide rich hypersaline waters that contain a rare sub-glacial ecosystem of autotrophic bacteria that metabolizes sulphate and ferric ions.

Antarctica is also useful for human mission testing and mission scenarios as carried out at the Concordia Research Station. Here studies are also conducted into glaciology, astronomy, human biology and medicine. Habitat and LSS Simulation in extreme conditions; surface EVA in terrestrial gravity; and confinement tests. This site has been used by the NASA from January 2008 to February 2009 to test an inflatable habitat in an extreme environment.

1.3 Environmental

Climate/Weather	The ADV are hyper arid; a cold polar desert.
Temperature	Average annual temperatures here are around -18 °C.
Precipitation Type	Rainfall rare but can occur along coastal regions. No snow in valleys.
Annual Precipitation	Negligible.
Humidity	Low.
Wind	High; winds can reach speeds of 320 Km per hour.
Insolation	High solar radiation is recorded in the Dry Valleys. 24-hour sunshine during the southern hemisphere summer.

1.4 Infrastructure

1.4.1 Existing

There are 37 research stations in Antarctica; seven semi-permanent scientific field camps in the Dry Valleys with five in Taylor Valley alone.

1.4.2 Accessibility

Gaining access to Antarctica is difficult and achievable mainly by military aircraft or research vessels. Once there, to gain access to the Dry Valleys a helicopter from Ross Island, or travel over sea ice to the Southern Victoria Land coast is needed; then on foot to sites of interest.

1.4.3 Nearest Airport

The nearest airport is based at McMurdo. There are 28 airport landing facilities in Antarctica and all 37 Antarctic research stations have helipads.

1.4.4 Logistics

Contact British Antarctic Survey, United States Antarctic Programme, National Antarctic Research Programme PNRA of Italy or relevant country programme. All Antarctic fieldwork needs to be run through one of these agencies. Bring all supplies with you but can buy supplies in McMurdo; note that equipment can freeze, including laptops; connections from New Zealand or South America only. A permanent helicopter refuelling station is located at Marble Point, ADV. The nearest hospital is the McMurdo General Hospital.

1.4.5 Permissions

Things to be aware of: The Antarctic Treaty; the Madrid Protocol; 3 SSSI in ADV; ADV Code of Conduct.

1.4.6 Cost

Extremely high.

1.4.7 Scheduling

Access to the ADV is best through November to March for sea entry; and October to March for air entry.

1.5 Key References

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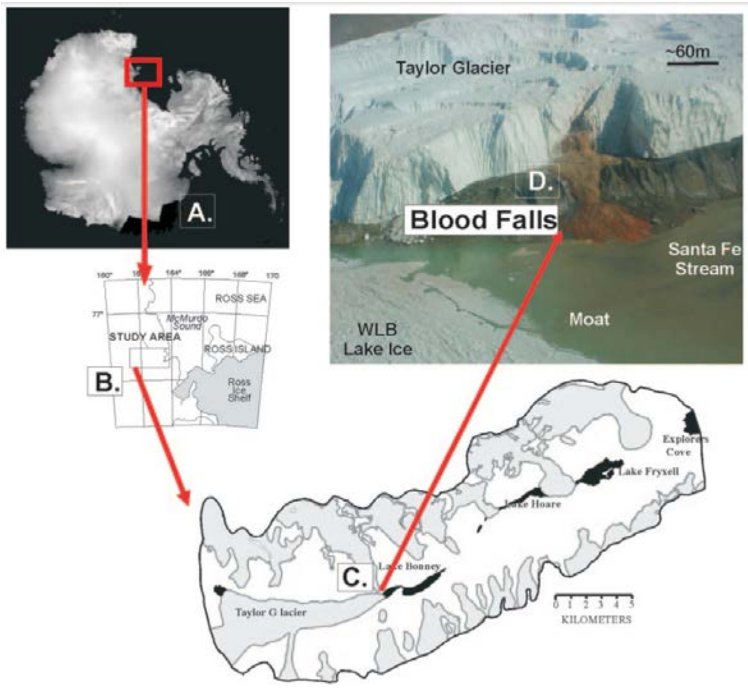
1.6 Site Specific Details

1.6.1 Blood Falls

1.6.1.1 Co-ordinates
77.722053°S, 162.271861°E

1.6.1.2 Physical Characteristics
Blood falls is an iron rich subglacial outflow, located at the snout of Taylor Glacier in Taylor Valley, part of the McMurdo Antarctic Dry Valleys. It provides a unique sampling location for a subglacial microbial community. The source of the outflow is a 80 m deep pool of brine or slush approximately 4 km towards the head of the glacier. Taylor Glacier is itself a outlet glacier form the East Antarctic Ice Shelf and is a cold-based glacier where temperatures at the base never rise above freezing, and as such is frozen to its base isolating the subglacial microbial community. The flow is not constant, but consists of periodic releases of pressurized brine (Mikucki et al., 2009).



Location of Blood Falls adapted from (Mikucki and Priscu, 2007).

1.6.1.3 Geochemical Characteristics

The underlying lithology of the dry valley region is a pre-Cambrain granite and gneiss basement extending up to ~800 m asl and exposed near the coast and the central portions of the dry valleys. This is overlain by relatively flat lying Devonian to Triassic age sedimentary rocks of the Beacon supergroup (Marchant and Head, 2007).

The Beacon group bedrocks of the upper part of Taylor valley are the Taylor subgroup (Webb, 1962) and consists principally of quartzose sandstone interbedded with cyclic siltstone, mudstone and pebbly sandstone (McKelvey et al., 1970).

The red precipitate at blood falls is a salt cone consisting of iron and sulphur oxide. The seep effluent is an anoxic alkaline hypersaline, iron and sulphur rich brine.

Table 1. Geochemical properties of the Blood Falls Seep (Mikucki et al., 2009).

Temp °C	pH	Total Fe (mM)	Total Cl (mM)	Total DIC (mM)	Total DIN (mM)	Sulphate (mM)	Oxygen (mM)
-5.2	6.2	3.45	1375	55	94	50	-

1.6.1.4 Astrobiological Characteristics

The subglacial brine beneath Taylor Glacier supports an active microbial community. This community exists in an anoxic, hypersaline, cold dark environment and has been well characterised in (Mikucki et al., 2009).

1.6.1.5 Prior Analogue Usage

Cryo-concentrated, hyper saline, sub glacial habitats would have been common during parts of Martian history. Although current conditions almost certainly preclude such a habitat on contemporary Mars, relic signatures may well be detectable. Blood Falls represents a unique opportunity to study a Terrestrial analogue ecosystem to enhance understanding of similar relic Martian sites.

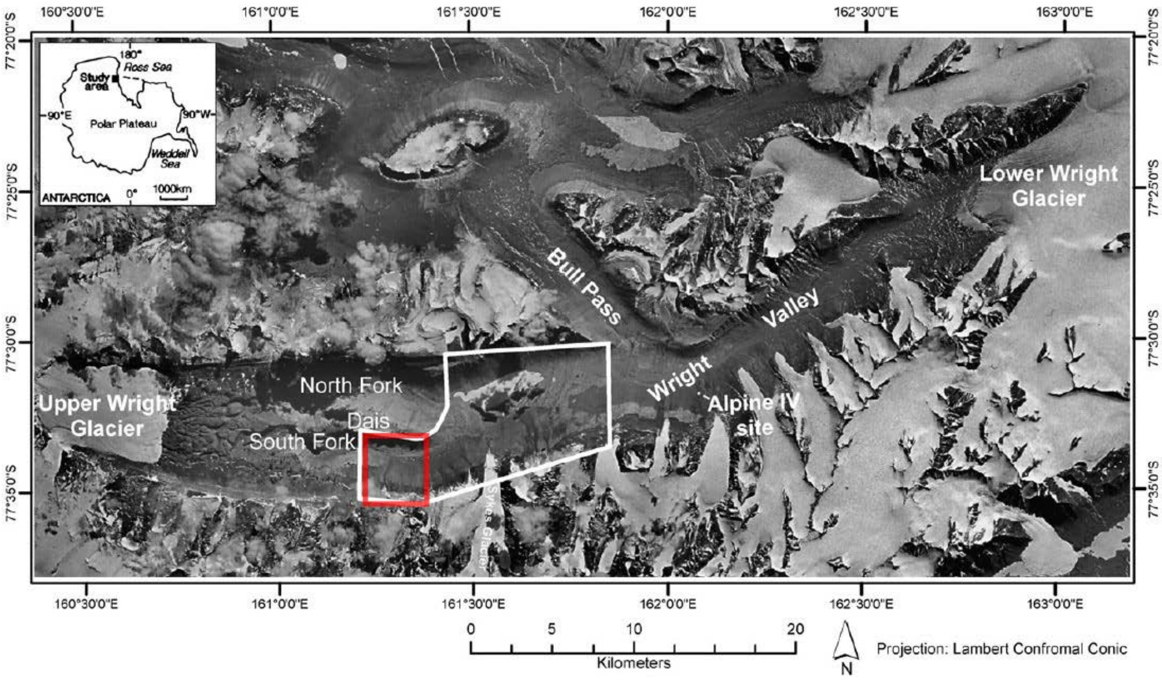
1.6.2 Wright Valley: South Fork Study Area

1.6.2.1 Co-ordinates

77.3336°S, 161.1724°E.

1.6.2.2 Physical Characteristics

Wright valley is one of the permanently ice free valleys in the dry valley group. The south fork study area is in the upper part of Wright valley, and comprises a valley floor bounded by an intervalley promontory (Dais) to the North and the valley slope rising approximately 1000 m above the floor to the south. The terrain is rock-strewn cryosol, and includes some areas of polygon landforms and a pair of gully networks descending from the ridge to the south. Climatically the south fork region straddles the coastal thaw zone and the inland mixed zone, as defined in (Marchant and Head, 2007).



Study Fork Study area is shown in red. Image adapted from McLeod et al. (2008).

1.6.2.3 Geochemical Characteristics

The bedrock of the study area comprises a pre-Cambrian basement complex including granite gneisses, lamprophyre, rhyolite, porphyry dikes and Jurassic dolerite sills. This is overlain with Devonian to Triassic age sedimentary rocks of the Beacon supergroup principally comprising quartzose sandstone. The bedrock of the valley floor and slope is well hidden by cryosol, comprising a dry layer, a thin wet layer and permafrost beginning 25-30 cm below the surface (Levy et al., 2008). The cryosol is a mix of colluvial and glacial deposits incorporating examples of all Taylor group lithologies. Due to the sublimation and evaporation dominated hydrology of the soil is saline, with a salt rich region up to 15 cm thick (Wentworth et al., 2005). The exposed ridgeline of the valley in the study area is made of dolerite and dolerite boulders and rocks can be found on the slope below.

1.6.2.4 Astrobiological Characteristics

Life in the study region is sparse and heterogeneous. Granite and marble stones host communities of photosynthesising hypoliths (Cowan et al., 2010). Sandstones host cryptoendolithic fungi and lichens in addition to bacteria (De la Torre et al., 2003). In addition to these surface communities the cryosol, both active and permafrost hosts viable microbial cells (Gilichinsky et al., 2007). Conditions in the study zone are representative of Martin conditions during glacial epochs, where melting and sublimation are widespread processes rather then the current sublimation dominated climate.

1.6.2.5 Prior Analogue Usage

Salt crystals present in soil samples taken from permanently dry soils in Wright valley have been shown to be analogous to crystals taken from Martian meteorites and samples taken of the Martian soil by robotic landers (Wentworth et al., 2005). This study area exhibits the interaction of gullies with polygonal terrain. This an interaction frequently observed on Mars and the physical structure and chronology determined by field studies of the terrestrial area have proved important in analysis of Martian data (Levy et al., 2008; Levy et al., 2009).

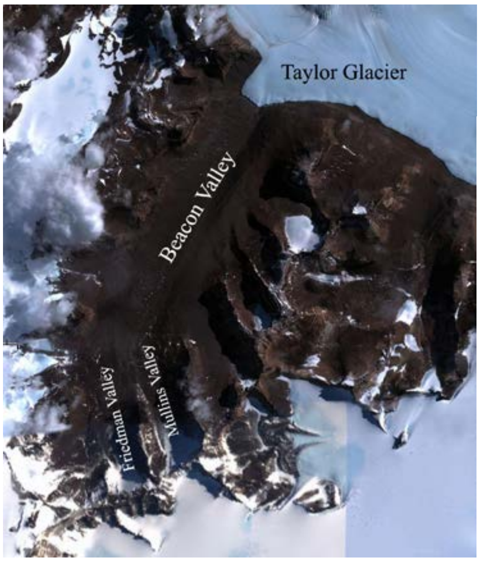
1.6.3 Beacon Valley

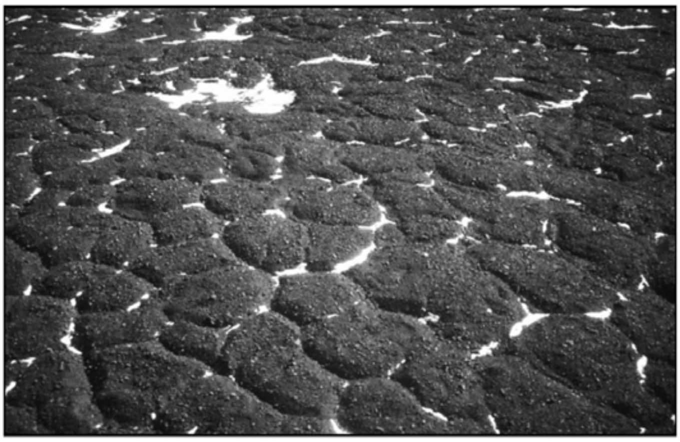
1.6.3.1 Co-ordinates

77.842°S 160.844°E.

1.6.3.2 Physical Characteristics

Beacon valley is situated away from the coast at the centre of the sandstone and dolerite Quartermain Mountains. The valley lies at an average elevation of 1350 m and is predominantly free of surface ice. The southern entrance is filled with a peripheral lobe of the Taylor glacier extending 1.5 km into the valley and terminating in a 25 m ice cliff. Alpine rock glaciers flow into the valley from the Mullins and Friedman adjunct valleys (Rignot et al., 2002) while the floor is a relatively flat, stable, till surface, heavily patterned with 15 m diameter sand wedge polygons (Marchant et al., 2002). The till consists of a thin layer of loose rocks atop ~0.6m of gravel in a sand and mud matrix. Below this permafrost and massive ice deposits extend to a maximum depth of 15 m.





Aerial view of the Beacon Valley taken from Google Maps and annotated by the authors. An oblique image of polygons in the central region (Marchant et al., 2002). The average diameter of the polygons is 18 m.

1.6.3.3 Geochemical Characteristics

The bedrock of Beacon Valley consists of sandstones, siltstones and conglomerates of the Beacon Supergroup, and sills and dikes of Ferrar Dolerite. The valley floor till is a diamict made up of local sandstones and dolerite and glacially transported granite, all released by sublimation of the underlying stagnant ice deposits. (Ng et al., 2005). The mean annual temperature is approximately – 34°C.

1.6.3.4 Astrobiological Characteristics

Beacon valley is extremely dry and cold but still hosts microbe populations in the permafrost (Gilichinsky et al., 2007), crypotendoliths in sandstone rocks and boulders and endoliths in translucent granite surface rocks (Cowan et al., 2010). The soil of the central region is a dry permafrost sublimation dominated ecosystem. Snowdrift and limited melting increase soil moisture and microbial activity on the periphery, and occasionally in the central region. However in general the only available moisture is found as saline thin films around permafrost structures. The soil is salt rich and slightly alkaline.

1.6.3.5 Prior Analogue Usage

The centre of Beacon valley is part of the stable upland zone and represents the best terrestrial analogue for current Martian conditions (McKay, 2009), particularly around polar regions where yearly snow fall or drift adds a modicum of soil moisture. The sublimation polygons are excellent models for similar structures in the Martian polar regions (Levy et al., 2010) as are the rock glaciers (Levy et al., 2011). As a test of the similarity of environments and the panspermia hypothesis microbes harvested form Beacon valley were exposed to space and then grown in Martian simulator (Scalzi et al., 2012).

2 The Atacama Desert

2.1 Location

Coordinates	20 °S to 30 °S
Country/State/Province	Northern Chile and Southern Peru
Continent	South America

2.1.1 Map

© 2003 National Geographic Society

2.1.2 Elevation

Up to 6885m.

2.1.3 Images


Left: Atacama Desert (courtesy of J. DiRuggiero). Right: A huge sand dune in the Valley of the Moon, Atacama Desert, Chile. Credit: Richard Alleman. Bottom left: Valley of the Moon photo: Servicio Nacional de Turismo, Chile. Bottom right: Mars-like landscape of the Atacama.

2.2 Context

2.2.1 Geological Setting

The Atacama Desert stretches 600 miles (1000 Kilometres) from Peru's southern border into northern Chile, from a thin coastal shelf to the pampas—virtually lifeless plains that dip down to river gorges layered with mineral sediments from the Andes. The pampas bevel up to the altiplano, the foothills of the Andes, where alluvial salt pans give way to snow-capped volcanoes reaching up to 6 000 metres. The plateau is composed of salt basins (salars), sand and lava flows that are bounded by the Pacific Coastal Range and the Andes; the result of the confluence between the subtropical high-pressure zone, the cold Humbolt current along the coast, and offshore winds. In a region about 100 Kilometres south of Antofagasta, which averages 3000 metres height, the soil has been compared to that of Mars.

2.2.2 Relevance

The Atacama Desert provides a range of analogues for both Mars and the Moon, such as hyper-arid deserts; Mars-like soils; desert pavement; volcanic deposits; hydrothermal deposits; playas; channels; alluvial fans; Aeolian features; impact deposits; oxidation; and perchlorates.

2.3 Environmental

Climate/Weather	Arid, temperate desert.
Temperature	Extremes are 0 -/+ 23 °C.
Precipitation Type	Rain.
Annual Precipitation	< 10mm/yr
Humidity	Very low.
Wind	
Insolation	20.9 $MJ/m^2/day$. High solar irradiance.

2.4 Infrastructure

2.4.1 Existing

There is no infrastructure so field teams typically camp in the desert for a few days at a time and either return to Antofagasta or San Pedro de Atacama, depending on where they are sampling.

2.4.2 Accessibility

Paved roads exist from Antofagasta, then dirt roads, and finally off road. You absolutely need a 4-wheel drive, a GPS, and to plan your routes ahead of time using satellite imagery.

2.4.3 Nearest Airport

Antofagasta.

2.4.4 Logistics

You need to carry everything with you for sampling and camping for several days at a time and will need to use a 4-wheel drive pick-up truck. Everything that goes into the field must come out. There are no bathrooms except for a few cantinas along the main north-south road. Base camp is the city of Antofagasta where you can find pretty much everything you need. Shipping of samples is typically done via the local UPS office in town. Having personal contacts with scientists at one of the two Universities in Antofagasta can greatly facilitate logistics. One important point to note is that the desert is not empty - there are many active mining operations and there are people traveling throughout; so do not leave any material or equipment unattended - it will disappear. We typically pack up our camp, even when we return to the same location in the evening.

2.4.5 Permissions

Establish contacts with scientists at the local universities but no actual permits are needed to enter the desert.

2.4.6 Cost

Airfares to Antofagasta from East Coast ($1400/per person), food and board ($150/day/per person according to the latest government per diem rates), car rental for 2 weeks, 4 persons ($5000), petrol and equipment for 2 weeks ($3000), and samples shipping to the U.S. ($1000; ~ 100 Lbs).

2.4.7 Scheduling

Year round access but best to go in the Autumn or spring in the U.S.

2.5 Key References

Previous analogue campaigns: Carnegie Mellon and NASA – ZOE; Life Marker Chip.

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2.6 Site Specific Details

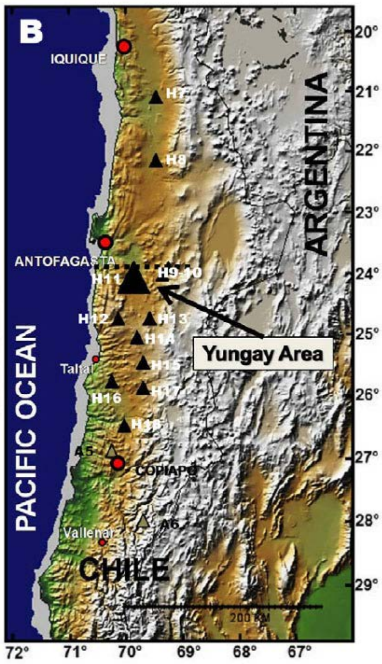
2.6.1 Yungay Area

2.6.1.1 Co-ordinates

24.062 S, 69.923 W.

2.6.1.2 Physical Characteristics

The Yungay region is situated in the Chilean Central Depression, between the Andean and coastal mountains. The soil comprises gravelly fluvial sediment surrounding low hills and mountains generally dubbed the Atacama gravels. Subsequent fluvial incision into the gravels has resulted in extensive fans and terraces. The soil is comprised of fine particles, 68% of which are between 250 um and 2 mm in diameter, and is rich in water-soluble salts. [Valdivia-Silva et al., 2012; Sutter et al., 2007).



The large black triangle marks the Yungay Area.

2.6.1.3 Geochemical Characteristics

The top 1 cm of alluvial soil of the Yungay area is composed of the following minerals.

Table 1. Yungay area soil mineralogy (Stalport et al., 2012).

Quartz	Albite	Anorthite	Hematite	Kaolinite	Calcite
37.0%	27.2%	24.5%	4.7%	2.5%	4.1%

Due to the long-term hyperaridity the soil is also rich in salts and nitrates that would typically be broken down by biological and aqueous activity. A sample of the surface in the Yungay region yielded the following analysis.

Table 2. Yungay soil salts (Sutter et al., 2007).

SO4	CO3	NO3	Cl
20%	1%	0.01%	0.5%

Soil pH varied from 5.5 to 8.6, with an abiotic oxidative potential of 365 – 635 mV (Navarro-Gonzalez et al., 2003).

2.6.1.4 Astrobiological Characteristics

Very little active biological material can be recovered from the soils of the hyperarid zone. Plant activity is zero and only limited bacterial species are recovered (of questionable activity) Endolithic cyanobacteria colonise halite rocks, but not quartz and the varnish present on some rocks has been recently shown to be microbial in origin. The prime astrobiological characteristic is the extreme aridity and the long-term climatic stability that has allowed the build-up of unique compounds. Terrestrial biological processes do not operate in the soil and so this site is a prime analogue of the microbial environment present on the Martian surface. [Wierzchos et al., 2006; Drees et al., 2006; Kuhlman, et al., 2008).

2.6.1.5 Prior Analogue Usage

The infrared spectra of soils in the Yungay region have been shown to be similar to the spectra of bright soil regions on Mars. Many soil analysis instruments are tested at the Yungay region or using Yungay soil samples. These include the Mars Organic Analyzer designed for the European ExoMars project, which has been successfully tested at Yungay and the Sample Analysis at Mars instruments for NASA's Mars Science Laboratory mission. In addition to providing soil samples for analogous analysis the region has been used as a model for remote Martian exploration in order to test a rover performing a biological survey [Sutter et al., 2007; Stalport et al., 2012; Chiesl et al., 2009; Cabrol et al., 2007).

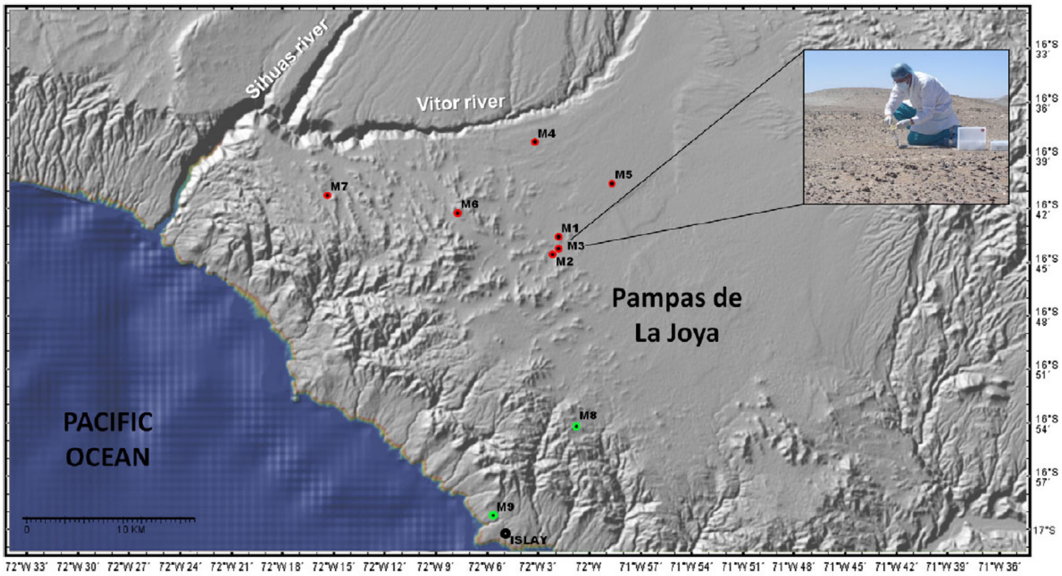
2.6.2 Pampas de La Joya

2.6.2.1 Co-ordinates

16.699 S, 71.806 W

2.6.2.2 Physical Characteristics

Pampas de La Joya is an uplift plain bordered on the northeast by the Andean foothills and to the southwest by the Cordillera de La Costa. The plain is an average of 1200 m asl and divided into several sectors by the gorges if the Sihuas and Vitor rivers. The entire region is covered with a semi continuous blanket of white volcanic sand, overlying alluvial fan, fluvial, duricrusts, aeolian and lacustrine beds. The soils of this region vary from point to point and contain a mix of sand, clay and silt.



A topographic view of the Pampas de La Joya. The red circles mark hyperarid sample sites (Valdivia-Silva et al., 2012).

2.6.2.3 Geochemical Characteristics

The soils of the Pampa are a complex mix of weathered bedrock, eolian volcanic ash and alluvial deposits. Granitic pegmatites provide large fragments of white quartz that litter the surface. The soil is predominantly formed of sand sized clasts comprising weathered Mollendo Gneiss bedrock mixed with granitic and volcanic debris and cemented with clayed minerals, hydrous iron oxides and gypsum. Soil acidity varied from 6.2-7.8 over a range of a few meters. Absolute values for soil salts have not yet been determined, and can be expected to vary from point to point due to the heterogeneity of the soil, but includes the same range of chlorides, sulphates and nitrates as found at the Yungay region. The soils are abiotically oxidative with a redox potential of between 4.15-660 mV (Valdivia-Silva et al., 2011).

2.6.2.4 Astrobiological Characteristics

Parts of La Joya have been found to contain lower cell counts than Yungay. As with Yungay the soil is oxidising, high in salts and almost entirely anhydrous. This is a very good model for Martian soils and results from Martian instruments can be replicated using La Joya soil samples (Valdivia-Silva et al., 2011).

2.6.2.5 Prior Analogue Usage

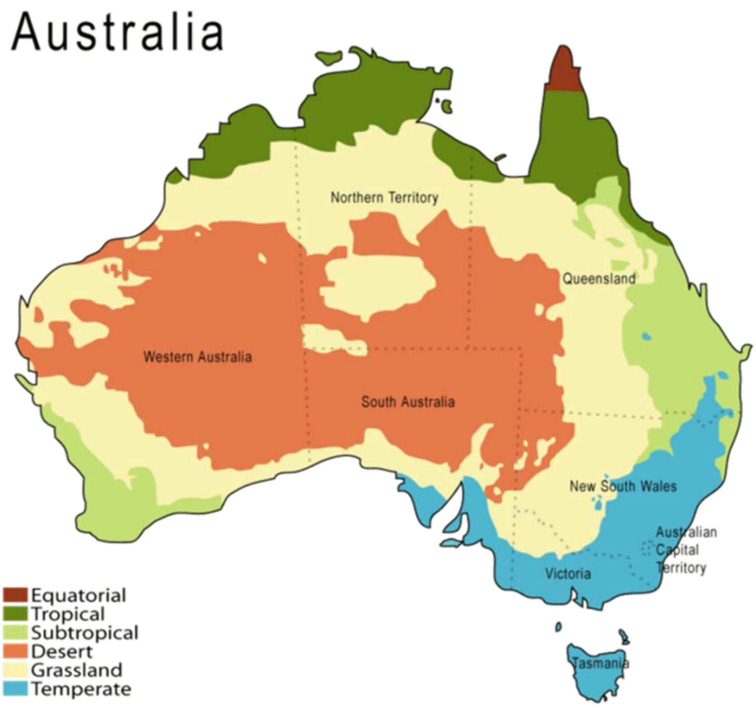
Soil samples from La Joya have been tested using experiments analogous to the Viking thermal volitisation experiment and the TEGA instrument from the Phoenix lander (Valdivia-Silva et al., 2011; Valdivia-Silva et al., 2012; Valdivia-Silva et al., 2009).

3 Central Australia

3.1 Location

Coordinates	Alice Springs is located at 23.7°S, 133.87°E
Country/State/Province	Australia
Continent	Australia

3.1.1 Map



Climatic zones of Australia. Central Australia analogue sites are located within the desert zones.

3.1.2 Elevation

Alice Springs is located at 576 metres above sea level.

3.1.3 Images

Left: The gibber plains of the Sturt Stony Desert in South Australia which Thomas et al.(2005) has proposed as an analogue of deflation surfaces imaged at Chryse Planitia by the Viking 1 lander. Right: The mesas of the Painted Desert near Arkaringa (West et al., 2010).

3.2 Context

3.2.1 Geological Setting

The ancient terrains and arid regions of central Australia have preserved many landforms that are unique to Australia. Low relief deserts with extensive duri-crust plains; and stony deserts and continental-scale dune fields are found along with numerous well preserved impact structures. Examples of drainage aligned playas, clay pans, acid lakes, hyper saline embayments and moundspring complexes can also be found.

3.2.2 Relevance

Fluvial and Aeolian features, plus moundsprings on Mars. Desert landforms, barchan dunes and dry fluvial deposits; martian regolith and soils; and major martian channels. Impact craters, ejecta rays, and impact crater wall gullies are analogous to those on the Moon and Mars. Hydrothermal deposits and hot springs are observed with extremophiles, microfossils and stromatolites. Additionally, relief inversion analogues; acid waters and mineral deposits; and weathering crusts are studied as planetary analogues. Australia also contains examples of polygonal landforms, debris taluses and aprons, gully forms and a variety of volcanic fields.

3.3 Environmental

Climate/Weather	Arid desert.
Temperature	For most of the year the temperature is > 26 °C; October to March > 30 °C.
Precipitation Type	Rain and frost.
Annual Precipitation	Average rainfall to the North of Alice Springs is 305 mm; south this decreases to 127 mm.
Humidity	Low.

Wind	Variable.
Insolation	Average of 9 hours sunshine per day.

3.4 Infrastructure

3.4.1 Existing

In most areas infrastructure is lacking so whilst conducting fieldwork camping is the only option. Helpful Government agencies that have a research focus:

CSIRO: http://www.csiro.au/Organisation-Structure/Divisions/Ecosystem-Sciences/AliceSprings.aspx.

National Parks: http://www.nretas.nt.gov.au/national-parks-and-reserves.

NRETA: http://www.nretas.nt.gov.au/home.

3.4.2 Accessibility

To get anywhere in the desert areas a 4WD is a necessity.

3.4.3 Nearest Airport

Alice Springs.

3.4.4 Logistics

Alice Springs (40 000 population) has modern facilities, once you leave the town you have to be fully equipped. Furthermore, the country is well imaged by various orbiting instruments and results from sophisticated airborne remote sensing instruments are available locally.

3.4.5 Permissions

To work here you need a Government work permit and also permission for any government, traditional lands or private property access. Contact local government agencies for details. http://www.dlp.nt.gov.au/strategic-planning/alice-springs-region Need traditional owners permission. Contact Aboriginal Areas Protection Authority http://www.alicesprings.nt.gov.au/directory/display/id/4. and/or Alice Springs town Council http://www.alicesprings.nt.gov.au/alice-springs-community/indigenous.

3.4.6 Cost

Variable depending on the sites chosen for study.

3.4.7 Scheduling

Southern hemisphere winter is the best time to visit. 75% of rain falls during the spring/summer months and is influenced by the monsoonal activities to the north-west Kimberly region and the Northern region.

3.5 Key References

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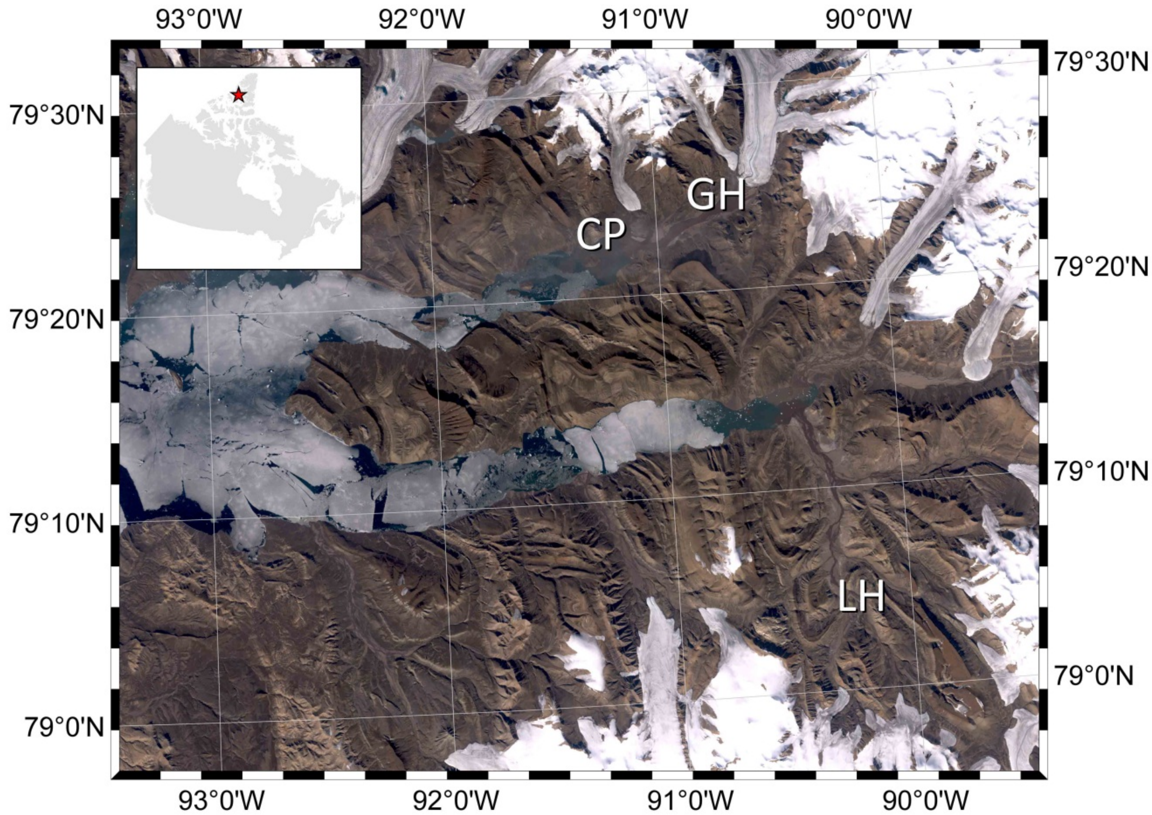
4 Axel Heiberg Island

4.1 Location

Coordinates	79°26' N, 90°46' W.
Country/State/Province	Canada / Nunavut
Continent	North America

4.1.1 Map



Axel Heiberg Island location in Canada (inset) and the location of spring sites within the MARS area (courtesy of T. Haltigin, CSA).

4.1.2 Elevation

The highest point is at 2210 metres.

4.1.3 Images

Axel Heiberg vista and the MARS (courtesy of A.Singleton).

4.2 Context

4.2.1 Geological Setting

Axel Heiberg Island is situated within the Sverdrup Basin, a north easterly striking sedimentary trough covering an area of approximately 313 000km^2 (Pollard et al.,1999). The McGill Arctic Research Station (M.A.R.S) is located in a mountainous area where peaks rise to a maximum of approximately 2000m ASL, and is dominated by ice caps, outlet and valley glaciers, polar desert, arctic tundra and permafrost. It is found near the termini of the White and Thompson Glaciers at the head of Expedition Fiord on the west side of Axel Heiberg Island. The ‘serrated’ profiles of the area are the result of gypsum weathering and anhydrite outcrops along with resistant volcanic sills and dikes. The island is characterized by a series of evaporite diapirs that have been revealed by erosion over the past tens of thousands of years (Pollard et al., 2009).

A permafrost thickness of >400 metres was documented in an exploration well on the east side of Axel Heiberg, roughly 60 kilometres from Expedition Fiord. It is reasonable to assume that similarly deep continuous permafrost also exists in study areas. Seven perennial spring sites have been identified on Axel Heiberg Island (Pollard et al., 1999; Andersen et al., 2008). The discharge temperatures are between -4 and +12 °C and flow rates vary from <1 to 30–40 l/s. Discharge is typically mineralized with varying amounts of dissolved salts that depress their freezing temperature. The springs derive their dissolved salts from the underlying evaporates. The current research emphasis is in the fields of glaciology, geology, hydrology, geocryology, exobiology and astrobiology.

4.2.2 Relevance

Axel predominantly provides analogue sites for Mars such as polygons; perennial spring mineral deposits; salt deposits; valleys; and areas for extremophile studies. Particular areas include: periglacial landforms; ground ice; volcanic and evaporite geology; ice-covered lakes; fjord sedimentation; hydrology; perennial and mineral springs; biology of low pH environments; life in ice and permafrost; endoliths and hypoliths.

4.3 Environmental

Climate/Weather	Polar desert.
Temperature	Eureka (comparable) annual temperature of -19.7 °C.
Precipitation Type	Snow, rain in summer.
Annual Precipitation	64 mm, 60% which falls as snow.
Humidity	NA
Wind	Variable.
Insolation	Eureka: low of 15.27 MJ/(m^2d) in 1973 to a high of 22.75 in 1988.

4.4 Infrastructure

4.4.1 Existing

McGill Arctic Research Station (M.A.R.S.) http://www.geog.mcgill.ca/mag2/fieldstations.htm.

4.4.2 Accessibility

Nearest town is Resolute Bay, Cornwallis Island, Nunavut.

4.4.3 Nearest Airport

Resolute Bay, then transport to the field site by Twin Otter aircraft.

4.4.4 Logistics

To use this site and research station you must first contact Dr. Wayne Pollard at McGill University, Department of Geography, 805 Sherbrooke Street West, Montreal, PQ, Canada H3A 2K6. Tel: +1 (514) 398-4454. Fax +1 (514) 398-7437. E-mail: pollard@felix.geog.mcgill.ca. Support staff available at research station. Accommodation and meals at research station included.

4.4.5 Permissions

Researchers working in the Arctic are required to have a territorial scientific research licence. It is the responsibility of the individual researchers to ensure that they have all the necessary licences and permits. The Nunavut Research Institute (P.O. Box 1720 - C.P. 1720, Iqaluit, NU X0A 0H0; Tel: +1 (867) 979-4108; Fax: +1 (867) 979-4681; Website: http://www.nunanet.com/~research) is responsible for issuing scientific research licences; they can advise you as to what documentation is required and can assist you in obtaining it. Note that the licensing process can be lengthy and you should apply at least three months before you plan to go into the field.

4.4.6 Cost

Basic cost to access and use research station per person per day CAD $210; see attached document for breakdown costs for conducting fieldwork.

4.4.7 Scheduling

Approximately 31 March to 30 August (dates are subject to change).

4.5 Key References

McGill Arctic Research Station (M.A.R.S.):

http://www.geog.mcgill.ca/mag2/fieldstations.htm

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Pollard, W., Haltigin, H., Whyte, L., Niederberger, T., Anderson, D., Omelon, C., Nadeau, J., Ecclestone, M. and Lebeuf, M. (2009) Overview of analogue science activities at the McGill Arctic Research Station, Axel Heiberg Island, Canadian High Arctic. *Planetary and Space Science* 57:646-659. (and references therein).

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4.6 Site Specific Details

4.6.1 Saline Perennial Springs

4.6.1.1 Co-ordinates

Gypsum Hill: 79.409175N, 90.732765W

Colour Peak: 79.388711N, 91.267662W

4.6.1.2 Physical Characteristics

Gypsum Hill and Colour Peak contain cold perennial, anoxic, saline springs. These springs are mineral rich and surrounded by a wide variety of mineral deposits. In addition they host year round communities of distinctive microbial extremophiles (Niederberger et al., 2009). They occur in topographically and geologically similar settings on Expedition Fjord where the surrounding hills drop to the Fjord level forming floodplains and water channels.

The Gypsum Hill spring systems comprises more than forty seeps and springs situated at the base of the steep southeast facing slope (Gypsum Hill) that was formed by the Expedition Diapir. The springs are in a band 300 metres long and 30 metres wide and are 10-20 metres asl. The terrain around the springs is formed from boulder-sized alluvial material overlapped by sandy outwash. As such, it is littered with large boulders from both the exposed anhydrite and till, while the immediate area is characterised by small mounds separated by shallow gullies. A large annual icing forms, of 0.3-21 metres thickness, extending from the spring site up to 700 metres downstream and 300 metres onto the floodplain.

The springs at Gypsum hill are split into three distinct groups, each of which is characterised by a warmer central portion bracketed by colder flows. The average temperature of the outflow varies between –3.5 °C on the cold edges to 6.6 °C at the centre of each group. The total measured flow rate is 10-15 L/s with an average of 0.9-1.0 L/s per seep or spring.

Colour Peak is a 560 metres pyramid shaped mountain formed by the anhydrite Colour Diapir. The spring system comprises over 20 springs approximately 15 metres or greater asl on the south-facing slope, split into three groups by the topography. The outflow has created heavily eroded gullies down which it flows into the fjord. The slope above the springs is covered with a lateral moraine while sandy beach and alluvial-fan deposits lie at the base. The spring sites are situated in weathered bedrock and grey silty mud, all covered with grey and black precipitates. The total measured flow rate is between 20-25 L/s with a maximum of 1.8-1.8 L/s for individual vents. The average temperature varies between –4.0 to 5.6°C, with higher temperatures associated with higher flow rate vents.

There are three types of outflow, pools seeps and springs. Pools are only found at Gypsum Hill and consist of circular pools 1-2 metres in diameter and 0.2-0.4 metres deep. Water and gas bubble up through loose black sand on the pool floor. Seeps are similar to pools vents but lack the flow or topography to form the pool. The most common outflow is from springs, the outflow of which forms hard precipitate channels (Pollard et al., 1999).

4.6.1.3 Geochemical Characteristics

Both sites are situated in anhydrite piercement structures, and are therefore dominated by anhydrite colluvial material ranging in size from boulders to fine silt and sand. Glacial till can also be found incorporating material from the surrounding complex sedimentary lithologies of the Sverdrup basin (Pollard et al., 2009). The geochemical make-up of the spring waters can be found in detail in Pollard et al (1999).

These dissolved minerals give rise to a number of precipitates at both sites; however, structures at Colour Peak are far more developed due to their relative protection from spring flooding of the fjord. Spring vents at both sites have produced hard black runoff channels, primarily composed of calcite with some gypsum at the edge of the flow. The gypsum is often coated with a thin layer of halite. The gypsum layers are soft, porous, and composed of widely packed crystals 100-500 µm across (Pollard et al., 1999; Omelon et al., 2006).

At Gypsum Hill the seasonal icing is coated with a thin paste-like yellowish gypsum coating which dehydrates to a fine powder and is mostly removed year on year preventing accumulation. White crystalline efflorescent salt deposits form in the splash zone of most springs vents and flow areas at both sites. At Colour Peak crystals of the unusual, thermally unstable mineral ikaite ($CaCO_3$ z $6H_2O$) can be found in some of the pools formed by the spring outflow (Omelon et al. 2001).

4.6.1.4 Astrobiological Characteristics

Both Colour Peak and Gypsum Hill show clear evidence of microbial activity. This includes H_2S gas, microbial mats and filaments on sediment surfaces in some spring pools and channels. At Gypsum Hill there are iron oxide deposits with a microbial sheen. Overall the microbial communities are primarily anoxic, cold and hyper salinity resistant sulphur metabolisers though this only characterises the greater part of a diverse community.

Analysis of the Gypsum Hill communities indicates that 40% of the microbes are heterotrophic and autotrophic sulphur-oxidising bacteria that were classified into four phyla, Actinobacteria, Bacteroidetes, Firmicutes, and Proteobacteria (Perreault et al., 2008).

During winter months the outflow channels at Gypsum Hill are snow covered, and microbial streamer mats develop of chemolithoautotrophic sulphur-oxidizing Thiomicrospira. These are transitory and dissipate during summer months (Niederberger et al., 2009).

4.6.1.5 Prior Analogue Usage

There is some mineralogical evidence for spring activity on Mars, well away from any thermal source. Therefore the data and models of the Gypsum Hill and Colour Peak have been used to analyse the Mars data and propose the existence of cold Martian springs (Andersen et al., 2002). In addition, some of the extremophiles catalogued at the spring sites are considered capable of surviving in a hypothetical Martian cold saline spring and so have been cultured in a simulated Martian environment (Pollard et al., 2009). Therefore, these sites represent a close terrestrial analogue to a Martian environment with promising astrobiological properties.

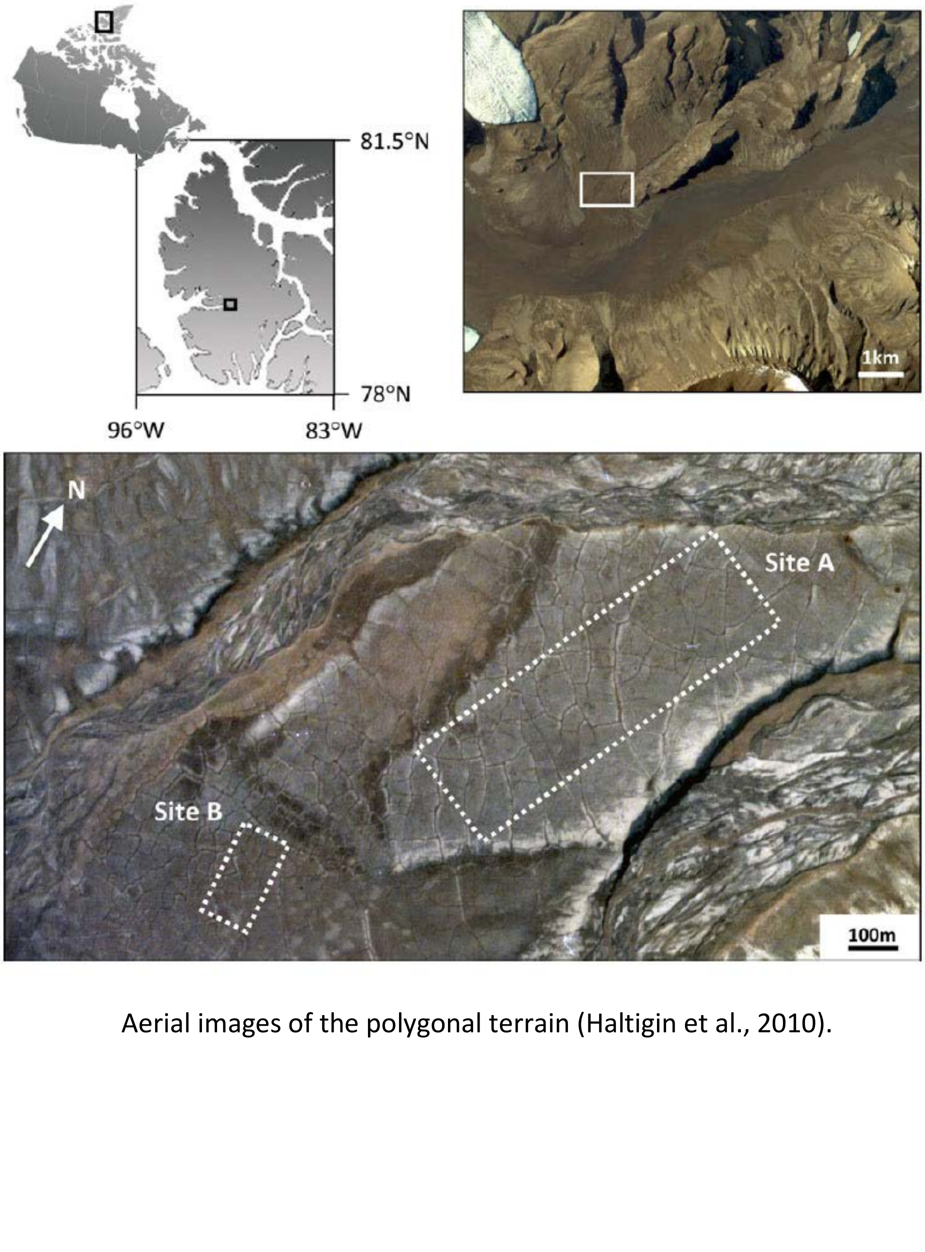
4.6.2 Polygonal Terrain

4.6.2.1 Co-ordinates

79.2314N, 90.505907W.

4.6.2.2 Physical Characteristics

The polygonal features at Strand Fjord are located on the Expedition river floodplains. The site is thinly vegetated and comprises centimetre-sized alluvial-fan materials overlain by fine grained floodplain deposits. The features themselves are large and irregular and defined by a network of interconnected troughs (Singleton et al., 2010).



Aerial images of the polygonal terrain (Haltigin et al., 2010).

4.6.2.3 Geochemical Characteristics

The silt and sand deposits are primarily alluvial, originating from the nearby Expedition River. The regional lithology is primarily anhydrite cements with limestone interbeds and a rock salt base, so these make up the majority of the deposits. (Pollard et al., 2009).

4.6.2.4 Astrobiological Characteristics

This site is not well known for its astrobiological potential. Deep subsurface ice deposits, however, are representative of potential martian habitats.

4.6.2.5 Prior Analogue Usage

Significant areas of polygonal terrain have been detected on Mars. This site is one of several in the high Canadian arctic that have been used as analogues for those Martian features. This site is notable for demonstrating the limits of electromagnetic field sensors. It illustrates that polygonal terrain can be an indicator of deep as well as shallow ground ice deposits (Singleton et al., 2010).

4.6.3 Colour Lake Fen

4.6.3.1 Co-ordinates

79.24918N, 90.45424W.

4.6.3.2 Physical Characteristics

The area is a small high arctic fen, fed by snowmelt and runoff from the adjacent Colour Lake. During the summer months, the surface of the fen is moderately vegetated. The topsoil consists of ~ 5 cm of peat overlying black mineral cryosol. Permafrost begins approximately 60 centimetres below the surface and extends to a depth of 600 metres (Buttle and Fraser, 1992).

Colour lake. The fen is to the left of the lake. (Image taken from http://www.aslo.org/photopost/showphoto.php/photo/967/title/colour-lakeaxel-heiberg-islandnunavutcanada/cat/502).

4.6.3.3 Geochemical Characteristics
The fen is an acidic environment with a pH of 5 dominated by H^+, Na^+, K^+ and Cl^-. These ions were concentrated by runoff from surrounding alkaline soils. The origin of the soils in the fen is most likely glacial sedimentation deriving from the surrounding lithologies and is situated within a basin made up of two underlying lithologies. The western bedrock is consists of sandstone, siltstone, shale, while the eastern bedrock is an anhydrite/gypsum diapir. These are separated by a gabbro dyke.

4.6.3.4 Astrobiological Characteristics
The cryosol and permafrost is host to diverse anoxic, acid, saline and cold tolerant microbial communities. Almost 1000 taxa were catalogued by Wilhelm et al (2011), 2/3 of which were found in the active layer and the permafrost. The permafrost microbes were found to be predominantly in survival mode rather than colony forming mode.

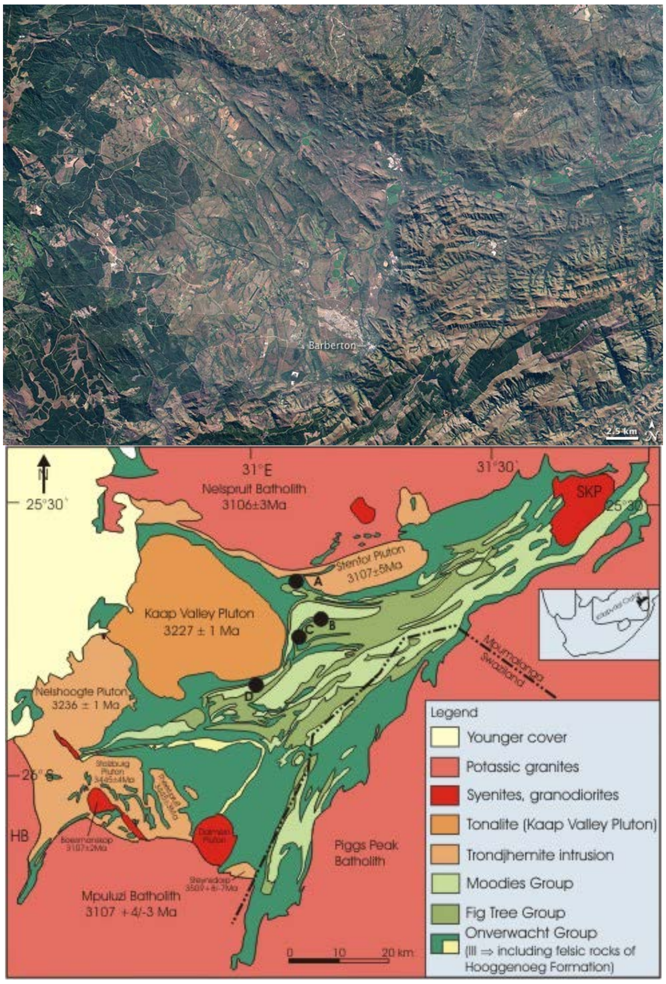
4.6.3.5 Prior Analogue Usage
A martian soil survey in the Meridiani Planum region found minerals indicative of saline acidic brines. Therefore acidic cryosol/permafrost habitats may have once existed and are perhaps still extant on the martian surface. This site comprises a terrestrial analogue for these environments and hosts microbes capable of survival under these Mars-like conditions (Fairén et al., 2009).

5 The Barberton Greenstone Belt

5.1 Location

Coordinates	25°47’10”S 31°3’11”E
Country/State/Province	South Africa / Mpumalanga province / Barberton
Continent	Africa

5.1.1 Map



Top: A NASA Landsat 7 natural colour image of the Barberton Mountains. Bottom: A geological map of the Barberton greenstone belt and surroundings.

5.1.2 Elevation

Variable.

5.1.3 Images

These microspheres (putative cellular remains) are from the Barberton Greenstone Belt and have an age of 3.4 Ga.

5.2 Context

5.2.1 Geological Setting

The Barberton Greenstone Belt is located on the Kaapvaal craton, which covers much of the southeastern part of Africa, and was formed by the emplacement of granitoid batholiths. The Kaapvaal craton was once part of a supercontinent, Vaalbara that also included the Pilbara craton of Western Australia. Vaalbara existed approximately 3.6 to 2.2 Ga ago, and then split into two different continents. The Barberton greenstone belt itself consists of a sequence of mafic to ultramafic lavas and metasedimentary rocks emplaced and deposited between 3.5 and 3.2 Ga. The volcano-sedimentary Onverwacht Group, at the base of the succession, has a thickness of approximately 15 kilometres and is subdivided into six formations. The lower three formations (Tjakastad Subgroup) consist mainly of mafic and ultramafic volcanic rocks (komatiites, komatiitic basalts, high-magnesium basalts and tholeiitic basalts) that were erupted approximately 3500 million years ago into an ancient oceanic environment (similar to present-day ocean-floor domains)

The Barberton Greenstone Belt of eastern South Africa is well known for its gold mineralisation and for komatiites, a type of ultramafic volcanic rock named after the Komati River that flows through the belt. Some of the oldest exposed rocks on Earth (greater than 3.6 Ga) are located in the Barberton greenstone belt of the Swaziland–Barberton areas and these contain some of the most widely accepted fossil evidences for Achaean life. Cell-sized prokaryote fossils are seen in the Barberton fossil record in rocks as old as 3.5 billion years. There are excellent exposed sedimentary and metasedimentary rocks. The oldest microfossils are found in the Onverwacht Group in both the Kromberg and Hooggenoeg Formations. Both of these formations are predominantly igneous rock; the sedimentary rock has been metamorphosed. It is also possible to find microfossils in chert. From the evidence in these rocks, it is likely that early life existed in the form of microbial mats and stromatolites.

5.2.2 Relevance

The Barberton Greenstone belt allows the occurrence, and preservation potential, of microbial life on Mars to be evaluated. Barberton allows the study of fossilised microbial mats and stromatolites; volcanic sediments; aqueous alteration; and hydrothermal activity.

5.3 Environmental

Climate/Weather	Grassland savannah of the Highveld escarpment and subtropical Lowveld plains. The west is drier, hotter and colder than the rest of the province.
Temperature	Averages from 20.2 °C in June to 26.8 °C in January.
Precipitation Type	Rain.
Annual Precipitation	672 mm.
Humidity	
Wind	
Insolation	

5.4 Infrastructure

5.4.1 Existing

Lots of local farms and villages dotted around.

5.4.2 Accessibility

Sites can be reached by car, not necessarily 4x4 but could be helpful if the area has experienced heavy rain to get to the Buck Reef section. Any vehicle must have a high clearance. Outcrops at Komati River can only be reached by foot. Josefsdal Chert Formation accessible from road.

5.4.3 Nearest Airport

Nelspruit is 50 - 100 kilometres to the north of the Buck reef field site or the main International airport at Johannesburg is 450 - 500 kilometres to field area.

5.4.4 Logistics

The Barberton area is very large so there are a number of options depending upon where you choose to work. In the south there are hotels at Badplass and self-catering cottages, but this leaves ~1-2 hours' drive to outcrops. Internet is available here. The Komdraii Camp has self-catering cottages in a village called Ekulendeni. Town of Elukwatini is 40 minutes from the camp and has a local hospital. In Northern Barberton there are numerous hotels in Barberton town, plus a modern hospital. Expeditions are recommended to have 2 or more people and at least one male is essential (groups of lone women are not safe). Wildlife is not a problem, however, there are poisonous snakes and ticks are present that carry lime disease. It is best to avoid stagnant pools of water.

5.4.5 Permissions

Komati River site is in Songrimvelo National Park, park fees and need to hire a ranger. Buck Reef section is in the SAPI forest, so you need permission to enter the property. But there is no cost to do so.

5.4.6 Cost

For 4 people, 1 week including airfare from Europe around 6000 euros.

5.4.7 Scheduling

It is best to visit in the southern winter as it gets very hot and rainy in the summer. Sunblock is needed as there is a hole in the ozone over South Africa.

5.5 Key References

Cheney, E.S. (1996) Sequence stratigraphy and plate tectonic significance of the Transvaal succession of southern Africa and its equivalent in Western Australia. Precambrian Research 79:3–24.

Mojzsis, S.J.; Arrhenius, G., Keegan, K.D., Harrison, T.H., Nutman, A.P., and Friend, C.L.R. (2007) Evidence for life on Earth 3,800 million years ago. Nature 384:55–58.

Walsh, M. (1991) Microfossils and possible microfossils from the early Archean Onverwacht Group, Barberton mountain land, South Africa. *Precambrian Research* 54: 271–293.

Westall, F., de Ronde, C.E., Southam, G., Grassineau, N., Colas, M., Cockell, C. and Lammer, H. (2006) Implications of a 3.472-3.333? Gyr-old subaerial microbial mar from the Barberton greenstone belt, South Africa for the UV environmental conditions on the early Earth. *Philosophical Transactions of the Royal Society B* 361:1857-1876.

Schidlowski, M (1988). A 3,800-million-year isotope record of life from carbon in sedimentary rocks. *Nature* 333:313–318.

Schopf, J.W. (2006). "Fossil evidence of Archaean life". Philosophical transactions of the Royal Society, series B: Biological sciences 361:869–885.

5.6 Site Specific Details

5.6.1 Buck Reef

5.6.1.1 Co-ordinates

5.6.1.2 Physical Characteristics

5.6.1.3 Geochemical Characteristics

5.6.1.4 Astrobiological Characteristics

5.6.1.5 Prior Analogue Usage

5.6.2 The Josefsdal Chert

5.6.2.1 Co-ordinates

5.6.2.2 Physical Characteristics

5.6.2.3 Geochemical Characteristics

5.6.2.4 Astrobiological Characteristics

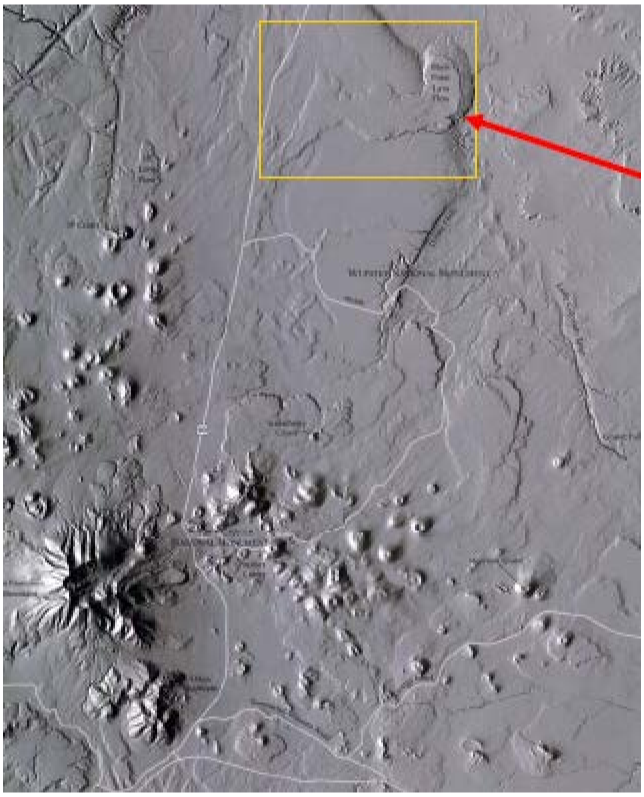
5.6.2.5 Prior Analogue Usage

6 Black Point Lava Flow

6.1 Location

Coordinates	35° 42′ 0.0″ N, 111° 18′ 0.0″ W
Country/State/Province	USA / Arizona
Continent	North America

6.1.1 Map



USGS Digital Elevation Model of the San Francisco Volcanic Field with Black Point Lava Flow highlighted.

6.1.2 Elevation

1580 metres.

6.1.3 Images

Black Point Lava Flow in northern Arizona, seen in this photograph taken from the International Space Station. The eastern edge of the flow slumps down to the surrounding plain, and it ends along the Little Colorado River (lower right),(NASA Earth Observatory).

6.2 Context

6.2.1 Geological Setting

Black Point Lava Flow and associated volcanic features are located within Wupatki National Monument (WNM), located in a high desert in northern Arizona between Flagstaff and the Grand Canyon, which contains excellent exposures of the Permian Kaibab and Triassic Moenkopi Formations. The volcanics are part of the San Francisco Volcanic Field (SFVF), which covers about 1800 square miles and is one of several late Cenozoic volcanic fields located along the southern margin of the Colorado Plateau. Volcanic activity in the SFVF began approximately 6 million years ago in the western portion of the field and continued intermittently, culminating with the eruption of Sunset Crater Volcano in the eastern extent approximately 900 years ago. Throughout this time, activity progressed eastward producing over 600 volcanoes, mostly basaltic cinder cones. Some geologists suggest that this occurred due to a hot spot within the Earth's mantle beneath northern Arizona that caused eruptions as the North American Plate moved slowly westward over it.

Black Point Lava Flow in particular is located in western Wupatki and flowed to the northeast but cannot be traced back to a source vent as younger lava flows cover the southwestern portion of the flows. Either one or several cinder cones to the southwest of Wupatki produced the Black Point Approximately 865 000 to 870 000 years ago. Petrographic analysis reveals that all of the flows in the SFVF are composed predominantly of olivine, augite, plagioclase and an opaque mineral. The individual flows vary in modal abundance of these minerals in the groundmass, the number and size of phenocrysts, and phenocryst assemblages. In the western portion of the monument, the flows are trachybasalt and alkali olivine basalt in composition (Hanson, 2006). Five flows are exposed in the eastern portion of the monument identified as basinite and alkaline olivine basalts.

6.2.2 Relevance

Black Point has predominantly been used as an analogue for the lunar surface; however, basaltic lavas are also of relevance to Mars. Analogues include: Lava flow compositions and morphologies; cinder cones; impact crater morphologies; and palaeoregolith (due to sediments underlying the lava flows). The site is also excellent for analogue mission simulations of technologies and human EVAs, plus astronaut geological training.

6.3 Environmental

Climate/Weather	Tundra and Desert areas, high altitudes. Thunderstorms common.
Temperature	Ranges from -9 °C (January) to 28 °C (July).
Precipitation Type	Rain and snow.
Annual Precipitation	Av.ann rain: 583.19 mm; Av.ann snow: 2763.52 mm.
Humidity	Low.
Wind	Constant and often high.
Insolation	Av.annual days of sunshine: 288.

6.4 Infrastructure

6.4.1 Existing

No facilities on site on the lava flow, however there are National Park services in the area including a visitor's centre and archaeological monuments.

6.4.2 Accessibility

Wupatki NM is located along the northeastern edge of the SFVF and a loop road connects Wupatki with Sunset Crater Volcano National Monument. Wupatki Pueblo Trail, located at the Visitor Centre, open from 9-5, less than an 8 kilometre round trip. Wupatki Pueblo is closed to public use when the Visitor Centre is closed. Access exceptions include ranger-led activities, official functions or by special use permit. A road runs past the lava flow itself, and then hikes to individual sites.

6.4.3 Nearest Airport

Flagstaff, Arizona.

6.4.4 Logistics

Nearest hospital is in Flagstaff 72 kilometres (45 miles) away. Hotel accommodation is based in Flagstaff. No water in the area so must bring supplies.

6.4.5 Permissions

Black Point is located within Wupatki National Monument with protected archaeological sites of spectacular puebloan ruins. National parks Service research permits may be required to do work in the park see (https://science.nature.nps.gov/research/ac/ResearchIndex). In general the park is publically accessible. $5.00 - 7 Days Fee is per person, good for 7 days at both Sunset Crater Volcano and Wupatki National Monuments. Vehicle Capacity 1-6 (Sedan) $28 - Day. Vehicle Capacity 7-25 (Van) $40 - Day . Vehicle Capacity 26 or more (Bus) $100 – Day.

6.4.6 Cost

Flights, hotel, accommodations, cars and research permits.

6.4.7 Scheduling

Summer months are best to visit.

6.5 Key References

Analogue Study History:

The area was originally identified as a candidate lunar analogue site during the Apollo era. At that time, the east end of the lava flow and the valley of the Little Colorado River were examined for training and simulations of lunar missions. Several explosion craters were blasted out of the top of the lava flow to simulate an impact crater field on the lunar surface. It became a major lunar analogue test site during the early phases of the Constellation Programme. Several 1- and 3-day simulations of lunar missions were conducted in October 2008 along the western and southwestern portions of the flow. The site was used again to simulate a 14-day lunar mission in September 2009. In 2010, the site was greatly expanded to the west so that it includes the SP cinder cone and lava flow. Mission simulations in 2010 utilised two Space Exploration Vehicles and other assets to simulate the operational requirements of a 28-day mission to the Malapert Massif region of the Moon.

Garry, W.B., Hörz, F., Lofgren, G.E., Kring, D.A., Chapman, M.G., and Eppler, D.B. (2009) Science operations for the 2008 NASA Lunar Analog Field Tests at Black Point Lava Flow, Arizona. *40th LPSC* Abstract #1649.

Gruener, J.E. et al., (2012) NASA Desert RATS 2010: Preliminary results for science operations conducted in the San Francisco Volcanic Field, Arizona. *Acta Astronautica* doi:10.1016/j.actaastro.2011.12.006

Hanson, S.L. (2006a) Characterization and Correlation of Lava Flows in Wupatki National Monument, Northern Arizona, Western National Parks Assn. Research Report no. 06-11, pp. 12.

Young, K. E.; Hodges, K.; Eppler, D.; Horz, F.; Lofgren, G. E.; Hurtado, J. M.; Desert Rats Science Team (2010) San Francisco Volcanic Field, Arizona, as An Analog for Lunar and Martian Surface Exploration. *American Geophysical Union, Fall Meeting*. Abstract #P13B-1378.

6.6 Site Specific Details

6.6.1 Edge of BPLF and SP Lava Flow

6.6.1.1 Co-ordinates

35° 42′ 0.0″ N, 111° 18′ 0.0″ W.

6.6.1.2 Physical Characteristics

Lava flows as described above. Soil and basaltic gravel materials found around and on the edges of the lava flow. Sometimes pebbles and cobbles also observed. The surficial units due to colluvium or alluvium, with particles mostly sand-size to cobble-size, derived from adjacent volcanic or basement units. Depending on where a particular sample was collected, it could contain basaltic cinders or lithic fragments, or rounded chert-like pebbles. Most rock samples need to be collected using a geological hammer, however, the surficial samples only need a small shovel.

6.6.1.3 Geochemical Characteristics

The lava flows produce massive and vesiculated rocks, and a variety of clastic, scoriaceous, agglutinitic, and spatter samples are found at the numerous volcanic cones. Most of the rock samples from the lava flows have a porphyritic fabric, with plagioclase being the dominant phenocryst (~20%), followed by olivine and pyroxene (~5%). Most volcanic rock samples were collected in the field are moderately to heavily weathered with surface crusts or rinds present, and some volcanic samples also contain carbonate weathering products (Gruener et al., 2012).

6.6.1.4 Astrobiological Characteristics

Several types of lichen are found on the basaltic lava flows so not optimal for astrobiological investigations due to contamination.

6.6.1.5 Prior Analogue Usage

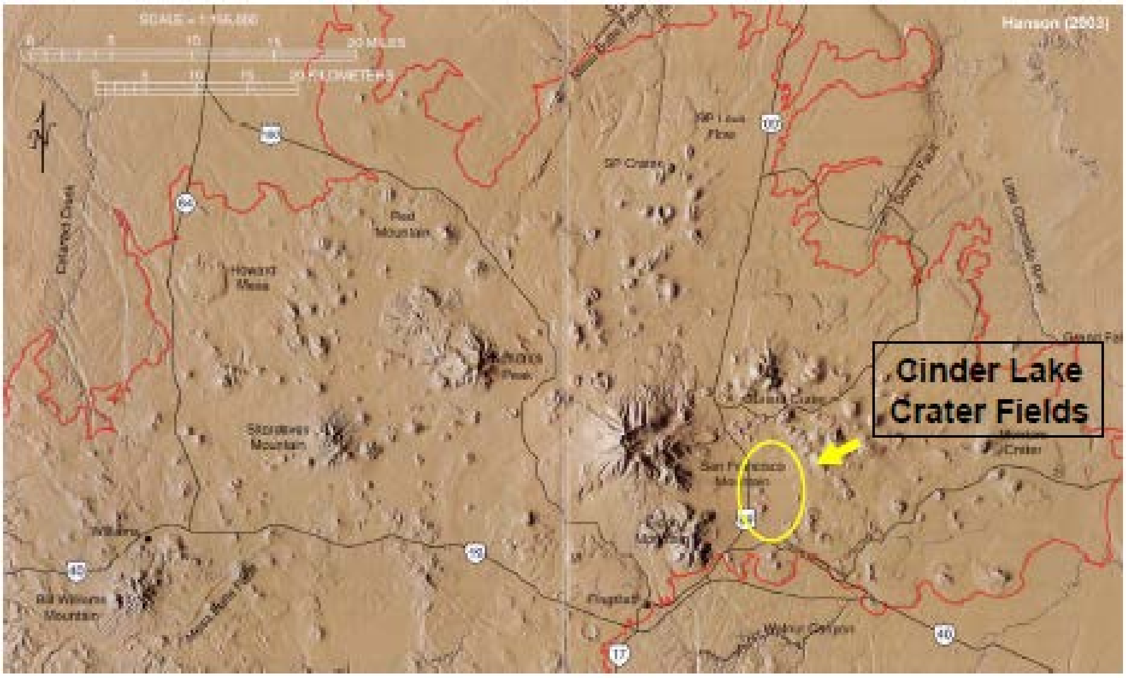
NASA Desert RATS 2010.

7 Cinder Lake

7.1 Location

Coordinates	35.3225°, -111.51806°
Country/State/Province	USA / Arizona
Continent	North America

7.1.1 Map



7.1.2 Elevation

2030 metres.

7.1.3 Images

Top: USGS Photo P448, F106763 of the crater field. Left: Jim Irwin and Dave Scott of Apollo 15 practice driving the LRV with the Grover training vehicle. Right: Pete Conrad and Al Bean of Apollo 12 training at the Cinder Lake crater field.

7.2 Context

7.2.1 Geological Setting

In the 1960s, the Astrogeology branch of the United States Geological Survey (USGS) in Flagstaff created an artificial crater field at Cinder Lake in order to train astronauts as well as test equipment and techniques for lunar exploration. They used a Lunar Orbiter image to re-create an actual lunar landscape by setting off charges of the right size to make craters of the right size, as well as setting them off in the proper sequence to get the overlaying ejecta laid out in the same order as seen in the lunar image.

Cinder field in Arizona is covered by Sunset Crater debris that erupted c. 1064 AD, where basaltic cinders cover clay beds. Construction of the first phase of the field (47 craters) occurred between the 28^{th} and 31^{st} July 1967 to create a field 500 ft wide. It was designed to duplicate (at 1:1 scale) an area within Mare Tranquillitatis that was visible in a Lunar Orbiter II image. Craters range in diameter from 5 to 40 ft. The field was expanded 8-12 October 1967, which added 96 craters (or 143 in total) in an area of 800 ft. A second field contains 354 craters. During the blasts to create the craters, the light-coloured clay material was excavated producing distinctive ejecta deposits, including rays as observed on the Moon and Mars.

7.2.2 Relevance

Impact craters on Earth can be an analogue for either the Moon or Mars; however, Cinder Lake was designed as a lunar analogue. Variations in basaltic cinder types and thicknesses were considered a direct analogue for hypothesized cinder fields on the Moon. The layered cinder terrain also served as a proxy for tapering impact ejecta horizons and the lunar regolith. Craters; crater rays; ejecta; impact glasses, shock effects and layered deposits are all studied.

Ultimately, Cinder Lake is an analogue training area for astronauts in a realistic lunar-like landscape. It is highly suitable for testing rovers (prototypes of the A15-17 LRV) and procedures for determining location within a cratered lunar landscape. It was used to test the crews' ability to describe crater morphologies and stratigraphic relationships in unconsolidated materials. It has been used to test hand tools, and deployment methods for scientific experiment packages (prototypes of ALSEP).

7.3 Environmental

Climate/Weather	High altitude tundra and desert areas.
Temperature	Ranges from -9 °C (January) to 28 °C (July).
Precipitation Type	Rain and snow.
Annual Precipitation	Av.ann rain: 583.19 mm; Av.ann snow: 2763.52 mm.
Humidity	Low.
Wind	Variable.
Insolation	Average annual days of sunshine: 288.

7.4 Infrastructure

7.4.1 Existing

Roads to site. USGS Astrogeology Science Centre in Flagstaff. No on site facilities.

7.4.2 Accessibility

Access from several directions, but the best seems to be forest road 776 which is marked as the "Cinder Hills ORV area" on a sign along highway 89 just south of the turnoff into the Sunset Crater National Park. Can drive right up to the craters.

7.4.3 Nearest Airport

Flagstaff, Arizona is 10 miles away.

7.4.4 Logistics

Hotel accommodation and hospital in Flagstaff, 10 miles away; can camp at Cinder Hills right next to Sunset Crater northeast of Flagstaff. Lots of sport ATV drivers use Cinder Lake as a race track due to the rough area and craters.

7.4.5 Permissions

National parks Service research permits may be required to do work in the park see (https://science.nature.nps.gov/research/ac/ResearchIndex). In general the park is publically accessible. $5.00 - 7 Days Fee is per person, good for 7 days at both Sunset Crater Volcano and Wupatki National Monuments. Vehicle Capacity 1-6 (Sedan) $28 - Day. Vehicle Capacity 7-25 (Van) $40 - Day . Vehicle Capacity 26 or more (Bus) $100 – Day.

7.4.6 Cost

Costs to cover flights to Flagstaff, car hire and accommodation are required so fieldwork is relatively cheap.

7.4.7 Scheduling

Summer months best to visit the area but can get very hot at midday.

7.5 Key References

Beattie, D.A., (2001) Taking Science to the Moon. Johns Hopkins University Press, Baltimore, MD, 301p.

Léveillé, R. (2010) A half-century of terrestrial analog studies: From craters on the Moon to searching for life on Mars. *Planetary and Space Science* 58:631-638.

Margolin, P., (2000) The making of lunar explorers. *Geotimes,* August (web feature).

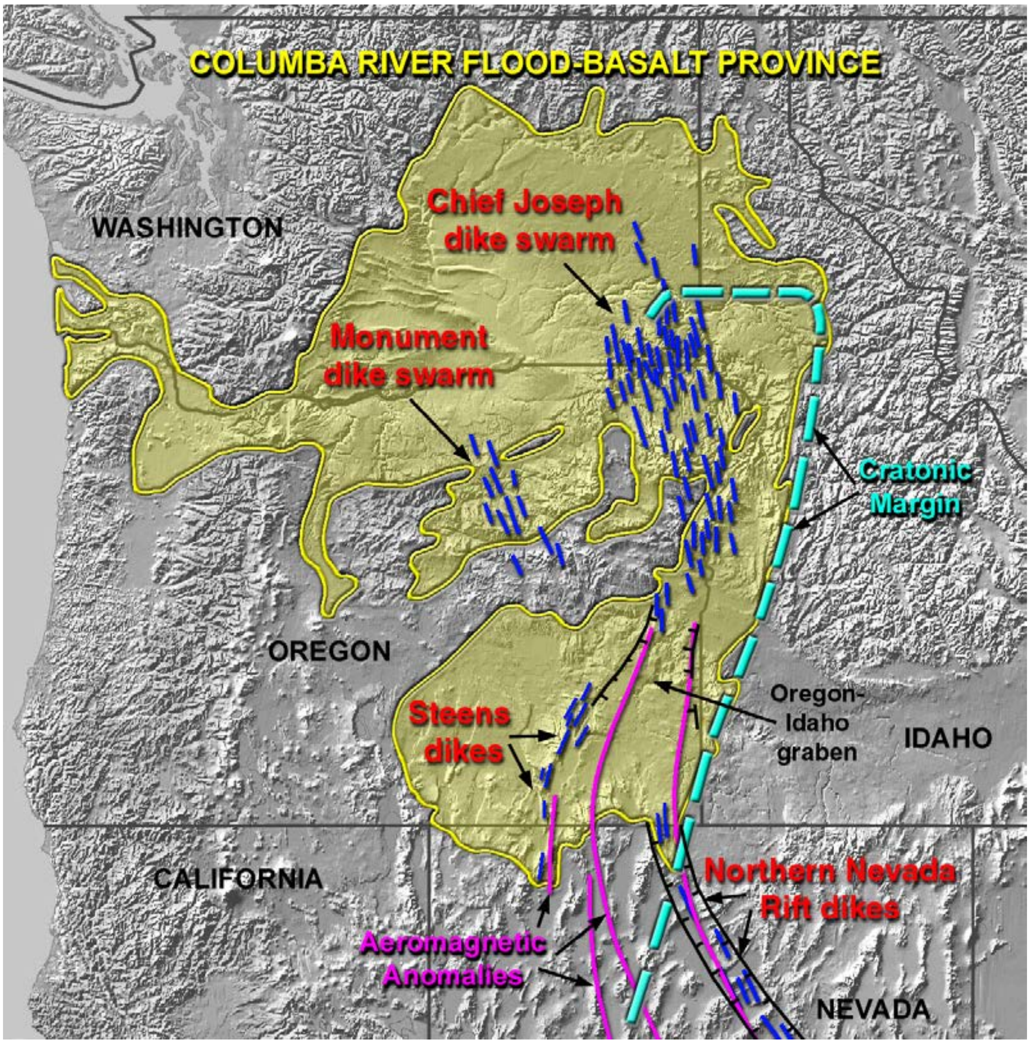
Schaber, (2005) The U.S. Geological Survey, Branch of Astrogeology: a chronology of activities from conception through the end of Project Apollo (1960–1973). *USGS Open-File Report 2005*-1190. Reston, VA. 341p.

8 Columbia River Basalt Group

8.1 Location

Coordinates	Various
Country/State/Province	USA / Washington, Oregon, Idaho, Nevada, and California.
Continent	North America

8.1.1 Map



Camp and Ross, 2004 http://www.MantlePlumes.org/RadVolcMigrations.html.

8.1.2 Elevation

Various elevations observed.

8.1.3 Images

Left: Steens Mountain. Right: Gorge cutting through the CRBG lava flows with layers exposed.

8.2 Context

8.2.1 Geological Setting

The CRBG is one of the largest flood basalts to ever flood the Earth's surface covering, 163 700 km² of the Pacific Northwest, during the late Miocene and early Pliocene epochs. This formed a large igneous province with an estimated volume of 174 300 km³. Subsequent erosion during the Missoula Floods exposed these lava flows, revealing many layers of the basalt flows at Wallula Gap, the lower Palouse River, and the Columbia River Gorge and throughout the Channelled Scablands. The cause of this volcanism is attributed to a major hot-spot, the Yellowstone hot spot, whose initial flood-basalt event occurred near Steens Mountain. As the North American Plate moved several centimetres per year westward, the eruptions progressed through the Snake River Plain across Idaho and into Wyoming. Consistent with the hot spot hypothesis, the lava flows are progressively younger as they travel east. The Columbia River Basalt Group exhibits essentially uniform chemical properties throughout the bulk of individual flows.

These basalts are well-known due to their astrobiological potential. They are host to a deep subsurface microbial community that thrives completely independent of photosynthesis (Stevens and McKinley, 1995). In the deep subsurface of this several kilometre thick volcanic succession, confined aquifers of low-sulphate, low-chloride bicarbonate groundwater have been observed with a pH of 7.5 to 8.5. At depth, sodium and chloride predominate, and pH varies from 8 to 10.5. The community found here is sustained by methanogens (Stevens and McKinley, 1995) who act as the primary producers and consume the H_2 produced by the serpentinization of olivine within the basalt i.e. autotrophic metabolism coupled to mineral weathering.

8.2.2 Relevance

The CRBG rocks provide analogues for both the Moon and Mars, and astrobiological analogues for Mars. Flood basalt volcanism both process and chemistry is important for both planetary bodies, as well as basalts interbedded with sediments; subsurface basaltic aquifers; pillow lavas; dykes; volcanic weathering and clays and palagonite. The Yakima folds on the central Columbia Plateau are a succession of thrusted anticlines thought to be analogues of planetary wrinkle ridges. Extremophilic life living within the basalt and in the absence of light and oxygen is important for the search for life on Mars.

8.3 Environmental

Climate/Weather	Temperate deserts.
Temperature	Warm summers and cool winters; varies between states and elevations.
Precipitation Type	Rain; snow in the winter and at high elevations.
Annual Precipitation	Washington: 15cm as east of Cascades in rain shadow; Oregon high deserts < 250mm rain per year.
Humidity	Low.
Wind	Variable.
Insolation	

8.4 Infrastructure

8.4.1 Existing

Roads and hiking trails are found throughout the area.

8.4.2 Accessibility

Good accessibility; many outcrops and sites are seen by road cuttings or found just off the main roads. Excellent exposures are to be found. Public access to most areas unless on private land where permissions should be sought to enter and work in.

8.4.3 Nearest Airport

The nearest airport is dependent upon which part of flow you will be travelling to. Major airports are found in Washington, Oregon and Idaho.

8.4.4 Logistics

Cheaper to travel in off seasons spring and autumn, and fewer tourists are present. Need car to get to sites; nearest hospitals and hotels will be in the local towns and cities.

8.4.5 Permissions

Local landowners and private land may provide access restrictions but otherwise most areas provide free public access.

8.4.6 Cost

Travel, car hire and accommodation.

8.4.7 Scheduling

Summer is mostly dry and sunny.

8.5 Key References

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Mège, D. and Reidel, S.P. (2001) A method for estimating 2D wrinkle ridge strain from application of fault displacement scaling to the Yakima folds, Washington. *Geophysical Research Letters* 28:3545-3548.

Michalski, J.R., Kraft, M.D., Sharp, T.G., and Christensen, P.R. (2006) Effects of chemical weathering on infrared spectra of Columbia River Basalt and spectral interpretations of martian alteration. *Earth and Planetary Science Letters* 248:822-829.

Sprenke, K.F., Baker, L.L., Clevy, J.R., and Rember, W.C. (2012) Sediments interbedded with Columbia River Basalts: A Mars Analog for weathering, mass wasting, and preservation of biomolecules. *Third Conference on Early Mars*. Abstract # 7013.

Stevens, T.O. and McKinley, J.P. (1995) Lithoautotrophic microbial ecosystems in deep basalt aquifers. *Science* 270:450–454.

8.6 Site Specific Details

8.6.1 The Yakima Folds

8.6.1.1 Co-ordinates

8.6.1.2 Physical Characteristics

8.6.1.3 Geochemical Characteristics

8.6.1.4 Astrobiological Characteristics

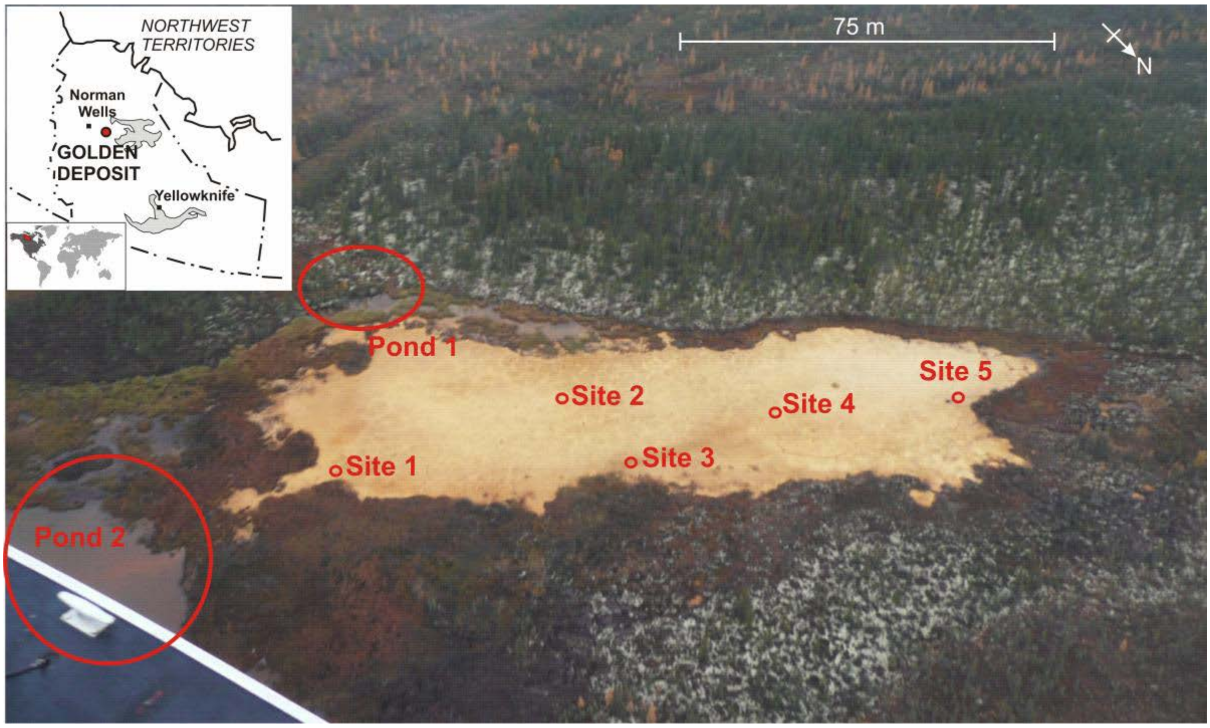
8.6.1.5 Prior Analogue Usage

9 The Golden Deposit

9.1 Location

Coordinates	65° 11'58"N, 124° 38'15"W
Country/State/Province	Canada / North West Territories
Continent	North America

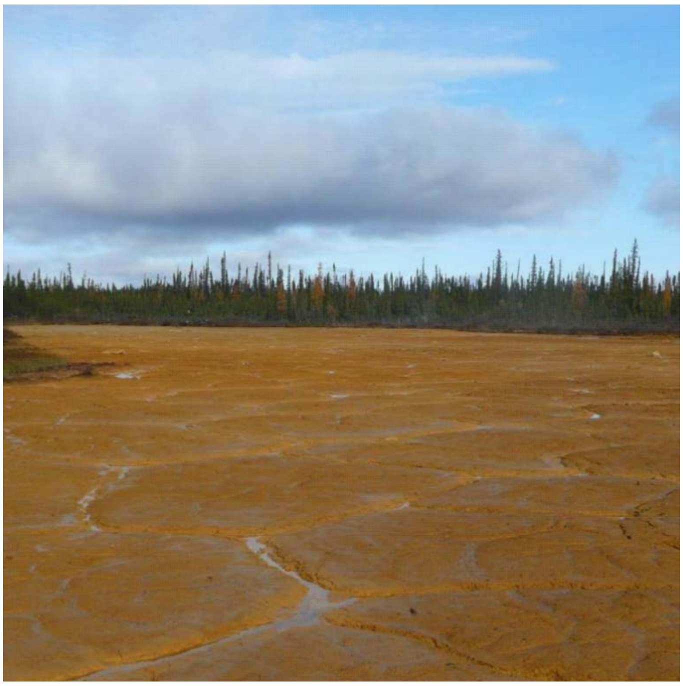
9.1.1 Map



Aerial photograph of the Golden Deposit, taken during September 2009 by Battler, M. Inset map of Northwest Territories, Canada showing approximate location of the Golden Deposit, south east of Norman Wells, and world map showing location of Northwest Territories, Canada. (Battler et al., 2012).

9.1.2 Elevation

9.1.3 Images



The Golden Deposit, where water flows through troughs surrounding 1-3 metres polygonal “islands”. Areas within polygonal islands are dry and sufficiently hard to stand on (Battler et al., 2012).

9.2 Context

9.2.1 Geological Setting

The Golden Deposit is located 100 kilometres east of Norman Wells, Northwest Territories, Canada in a cold semi-arid desert. It is visible from the air as a brilliant golden-yellow patch of unvegetated soil, approximately 140 metres x 50 metres. The GD is underlain by permafrost and consists of yellow sediment, which is precipitating from seeps of acidic, iron-bearing groundwater. On the surface, it appears as a patchwork of raised polygons, with acidic waters flowing from seeps in troughs between polygonal islands. The mineralogy is predominantly natrojarosite and jarosite, with hydronium jarosite, goethite, quartz, clays, and small amounts of hematite. Water pH varies significantly over short distances depending on proximity to acid seeps, from 2.3 directly above seeps, to 5.7 several metres downstream, and up to 6.5 in ponds proximal to the deposit. Visual observations of microbial filament communities and phospholipid fatty acid analyses confirm that the GD is capable of supporting life for at least part of the year. Jarositic-bearing sediments extend beneath vegetation up to 70 metres out from the deposit and are mixed with plant debris and minerals presumably weathered from bedrock and glacial till.

9.2.2 Relevance

The Golden Deposit is predominantly relevant to Mars. This site is of particular interest because mineralogy (natrojarosite, jarosite, hematite, and goethite) and environmental conditions (permafrost and arid conditions) at the time of deposition are conceivably analogous to jarosite deposits on Mars. Most terrestrial analogues for Mars jarosite have been identified in temperate environments, where evaporation rates are very high and jarosite form along with other sulphates due to rapid evaporation (e.g. Rio Tinto, Spain; Western Australian acidic saline lake deposits). The GD is a rare example of an analogue site where jarosite precipitates under dominant freezing processes similar to those which could have prevailed on early Mars. Thus, the GD offers a new perspective on jarosite deposition by the upwelling of acidic waters through permafrost at Meridiani Planum and Mawrth Vallis, Mars.

9.3 Environmental

Climate/Weather	Polar desert.
Temperature	Average in January -27 °C, June 17 °C.
Precipitation Type	Rain and snow.
Annual Precipitation	< 300 mm per year.
Humidity	Low.
Wind	
Insolation	5 hours in winter, 20 in summer.

9.4 Infrastructure

9.4.1 Existing

None at the site.

9.4.2 Accessibility

No roads or paths. Need to fly in by float plane, land on lake about 1-2 kilometres from the site. Trek on foot through marshy, swampy terrain. It is possible to also land on site by helicopter.

9.4.3 Nearest Airport

International: Yellowknife, NWT. Small local airport with float planes: Norman Wells, NWT.

9.4.4 Logistics

Whilst conducting fieldwork, researchers must either fly to the site every day or camp in the area. A dry area of ground is located on the hill top and is surrounded by marshy terrain; 75 x 40m which is good for camping. Accommodation is available offsite in Norman Wells. Drinking water must be bought here as the water around the field site is acidic. Bear protection is needed.

9.4.5 Permissions

Researchers need to apply to the appropriate region within NWT for a research permit. Research permits need to be translated into the appropriate language for the local tribe to read and approve.

9.4.6 Cost

It is expensive to fly in everyday on a float plane, but even more for a helicopter.

9.4.7 Scheduling

Site can be visited all year. The winter is good for science as it is cold but the summer is better for sampling and logistics.

9.5 Key References

Melissa M. Battler, Gordon R. Osinski, Darlene S. S. Lim, Alfonso F. Davila, Frederick A. Michel, Michael A. Craig, Matthew R. M. Izawa, Lisa Leoni, Gregory F. Slater, Alberto G. Fairén, Neil R. Banerjee, and Louisa J. Preston. (2012) Characterization of the acidic cold seep emplaced jarositic Golden Deposit, NWT, Canada, as an analogue for jarosite deposition on Mars. Icarus. DOI: http://dx.doi.org/10.1016/j.icarus.2012.05.015.

Michel, F.A., van Everdingen, R.O. (1987) Formation of a jarosite deposit on Cretaceous shales in the Fort Norman area, Northwest Territories. Canadian Mineralogist 25:221-226.

10 The Haughton Impact Structure

10.1 Location

Coordinates	75° 22' N, 89° 41' W.
Country/State/Province	Canada / Nunavut / Devon Island
Continent	North America

10.1.1 Map

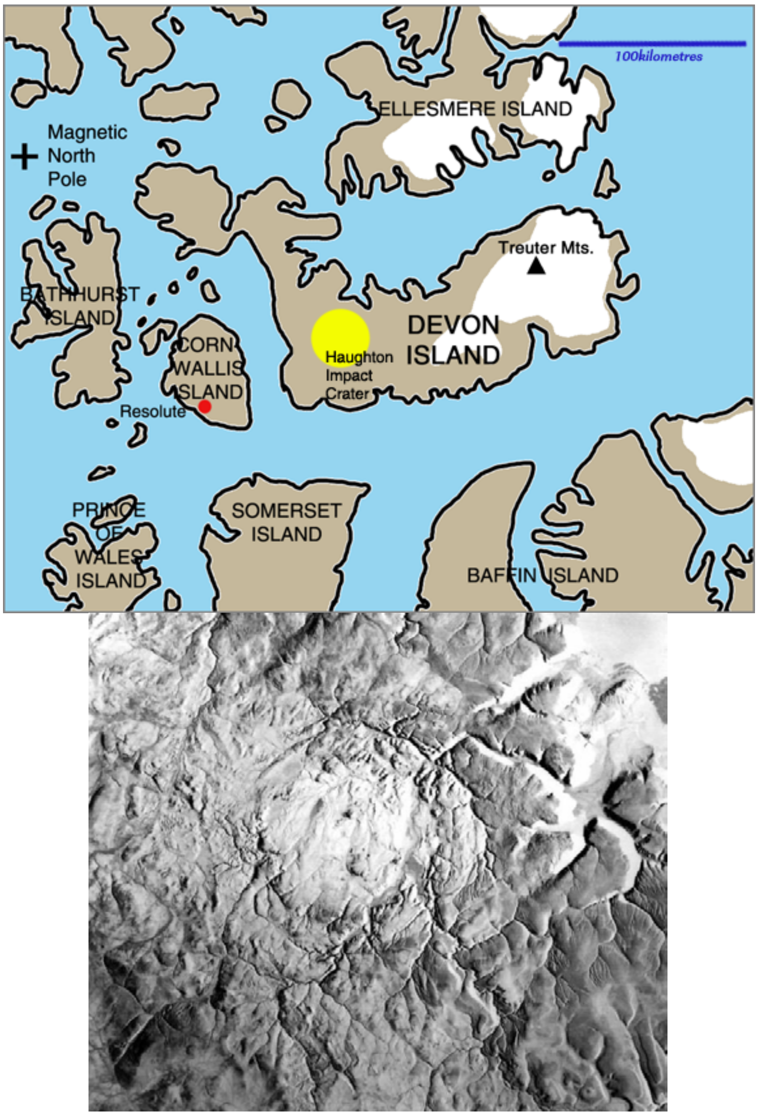


Diagram of the Devon Island region, source: http://en.wikipedia.org/wiki/Image:DevonIsl.png accessed August 2012. A synthetic aperture radar image of the Haughton impact structure.

10.1.2 Elevation

Highest point on Devon Island is 1920 metres.

10.1.3 Images

Field images of the Haughton impact structure and surrounding terrains reproduced from Osinski et al (2010) with permission. (a) A long traverse stopped beside a large ejecta block thrown out of the initial transient crater by the force of the impact; (b) aerial photograph of hills of impact melt breccia (regolith). Note the well-formed gully networks; (c) typical polar desert terrain around the rim of the Haughton impact structure; (d) large canyon systems pose considerable obstacles for navigation and surface mobility; (e) as is typical for the Arctic, outcrops are often at the top of steep rubble slopes; and (f) steep-sided canyon system.

10.2 Context

10.2.1 Geological Setting

The Haughton impact structure is a well-exposed and well preserved 23 kilometres diameter 39 million year old impact structure located on the western side of Devon Island, in the Canadian High Arctic (Osinski et al., 2005a).It was created by an impactor estimated to be 2 kilometres in diameter. Studies show that Haughton is a complex impact structure, with a well-developed central uplift and faulted crater rim that possesses a series of impactites (impact-modified and generated rocks), including a 4100-metres-thick series of crater-fill impact melt rocks and ejecta blanket remnants (Osinski et al., 2005a; Osinski and Spray, 2005). The Haughton structure formed in a ~1.9-kilometres-thick series of sedimentary rocks, predominantly carbonates, overlaying Precambrian crystalline basement rocks of the Canadian Shield (Osinski et al., 2005a).

10.2.2 Relevance

Haughton is a good analogue for both the Moon and Mars due to its rocky, dusty and un-vegetated terrains. Although the target rocks do not provide a good geological analogue for either the Moon or Mars, the site has been instrumental for understanding the cratering process in general (see overview by Osinski et al., 2005a). The Haughton structure and surrounding region also offers a wide variety of geological features and microbiological case studies of strong planetary analogue value and potential (Lee and Osinski, 2005), including a variety of impact terrains and associated features such as a crater lake and hydrothermal system, gullies, dendritic valley networks, and ice–wedge polygons and other landforms indicative of ground-ice. Astrobiological studies can be conducted here on life in extreme environments (Haughton is set in a polar desert); life in impact-induced hydrothermal systems and colonisation of impact environments.

Haughton is also a good analogue to conduct human planetary exploration activities.

- Exploration can be conducted from the basecamp (i.e., outpost) of the Haughton–Mars Project Research Station (HMPRS): applicable for lunar surface operations;
- Traverses can be conducted on foot within 1–2 kilometres of the basecamp; all-terrain vehicles (ATV) can simulate unpressurized rover traverses at distances up to 10–20 kilometres, and a Mars Humvee (simulating a pressurized rover) can enable multi-day traverses;
- The geographic location and isolation necessitate strict safety protocols (e.g., regular communications with the base camp, and submission of detailed route plans) and similar mission constraints (i.e., months between subsequent expeditions; mass constraints for sample return, etc.) as may be expected for the Moon;
- The short-field seasons (typically 6 weeks), mean that traverses have to be prioritized;
- The HMPRS represents a long-term, human exploration analogue facility with advanced analogue mission operations support infrastructure (Braham and Pires, 2007).

10.3 Environmental

Climate/Weather	Polar Desert.
Temperature	Average annual temperature -16 °C.
Precipitation Type	Snow
Annual Precipitation	Average < 13mm.
Humidity	NA
Wind	Variable.

Insolation	During the field season there is 24 hr daylight.

10.4 Infrastructure

10.4.1 Existing

Haughton-Mars project Research Station (HMPRS) and the Flashline Mars Arctic Research Station (FMARS) run by the Mars Society.

10.4.2 Accessibility

Nearest town: Resolute Bay, Cornwallis Island, Nunavut

10.4.3 Nearest Airport

Resolute Bay, transport to the field site is by Twin Otter aircraft.

10.4.4 Logistics

Mars Institute (MI), 980 Seymour Street, Suite 1306, Vancouver, BC V6B 1B5, Canada. Point of Contact: Dr. Pascal Lee. Tel: +1-408-687-7103. E-mail: pascal.lee@Marsinstitute.info.

10.4.5 Permissions

Researchers working in the Arctic are required to have a territorial scientific research licence. It is the responsibility of the individual researchers to ensure that they have all the necessary licences and permits. The Nunavut Research Institute (P.O. Box 1720 - C.P. 1720, Iqaluit, NU X0A 0H0; Tel: +1 (867) 979-4108; Fax: +1 (867) 979-4681; Website: http://www.nunanet.com/~research) is responsible for issuing scientific research licences; they can advise you as to what documentation is required and can assist you in obtaining it. Note that the licensing process can be lengthy and you should apply at least three months before you plan to go into the field.

10.4.6Cost

Basic cost to access and use research station per person per day $165; see attached document for breakdown costs.

10.4.7Scheduling

Approximately 01 July to 10 August (dates are subject to change).

10.5 Key References

The Haughton Mars Project: http://www.marsonEarth.org/.

Flashline Mars Arctic Research Station: http://fmars.marssociety.org/.

Cockell, C.S. and Lee, P. (2002) The biology of Impact craters – a review. *Biological Reviews* 77:279-310.

Cockell, C.S., et al., (2002) Impact-induced microbial endolithic habitats. *Meteoritics and Planetary Science* 37:1287-1298.

Haltigin, T.W., et al., (2012) Geometric Evolution of Polygonal Terrain Networks in the Canadian High Arctic: Evidence of Increasing Regularity over Time. *Permafrost and Periglacial Processes*. 23:178-186.

Lee, P., and Osinski, G.R. (2005) The Haughton-Mars project: Overview of science investigations at the Haughton impact structure and surrounding terrains, and relevance to planetary studies. *Meteoritics & Planetary Science* 40:1755–1758.

Osinski, G.R., Spray, J.G., Lee, P. (2001) Impact-induced hydrothermal activity within the Haughton impact structure, arctic Canada: Generation of a transient, warm, wet oasis. *Meteoritics & Planetary Science* 36:731–745.

Osinski, G.R., Lee, P., Parnell, J., Spray, J.G., Baron, M. (2005a) A case study of impact-induced hydrothermal activity: the Haughton impact structure, Devon Island, Canadian High Arctic. *Meteoritics & Planetary Science* 40:1859–1878.

Osinski, G.R., Lee, P., Spray, J.G., Parnell, J., Lim, D.S.S., Bunch, T.E., Cockell, C.S., Glass, B.J. (2005b) Geological overview and cratering model for the Haughton impact structure, Devon Island, Canadian High Arctic. *Meteoritics & Planetary Science* 40:1759–1776.

Osinski, G.R., Lee, P., Cockell, C.S., Snook, K., Lim, D.S.S., and Braham, S. (2010) Field Geology on the Moon: Some lessons learned from the exploration of the Haughton Impact Structure, Devon island, Canadian High Arctic. *Planetary and Space Science* 58:646-657.

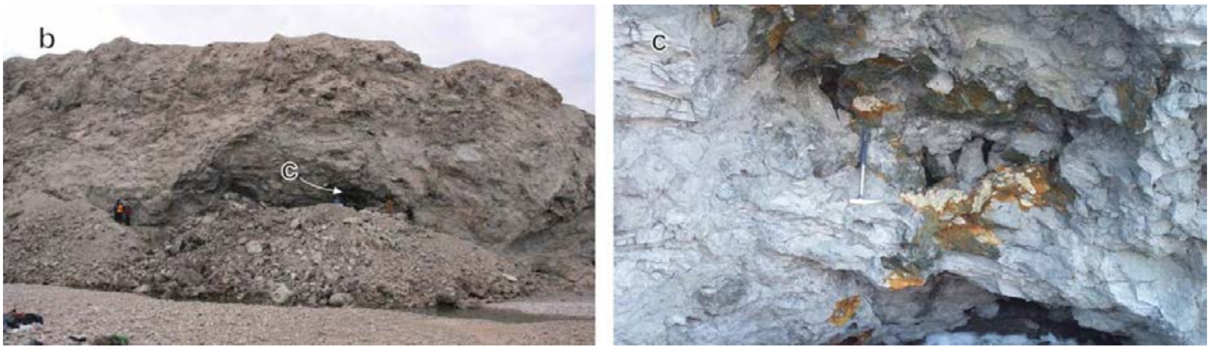
Singleton, A.C., et al., (2010) Electromagnetic characterization of polar ice-wedge polygons: Implications for periglacial studies on Mars and Earth. *Planetary and Space Science*, 58:472-481.

10.6 Site Specific Details

10.6.1 Hydrothermal Supersite

10.6.1.1 Co-ordinates
75.21.5N 89.32.40W.

10.6.1.2 Physical Characteristics
The hydrothermal supersite is situated to the south east of the Haughton crater, and consists of two closely spaced vugs set into a polymict impact breccia cliff approximately 5-10 metres above the underlying pre-impact rocks that have been exposed by the Haughton river. The vugs are irregularly shaped, with an internal volume of 5-10 m^3 and are lined with a variety of hydrothermal minerals (Osinski et al., 2001). The polymict impact breccia is made up of a microscopic matrix incorporating mineral and lithic clasts, and is of the grey type, which has been interpreted as forming from the ejecta blanket and does not incorporate material from the crystalline basement (Osinski et al., 2005b). Clasts increase in size with depth reaching metre size on the lowest levels. A thin blanket of erosion generated silt and sand covers much of the formation.



The two hydrothermal supersites discovered in 1999 of impact breccia altered by impact-induced hydrothermal activity (Osinski et al., 2010).

10.6.1.3 Geochemical Characteristics

The hydrothermal minerals that coat the vug surfaces exist in a series of phases related to the temperature of the hydrothermal system. In order of decreasing abundance these are calcite, marcasite, fibroferrite, celestite, barite, fluorite and quartz (Osinski et al., 2005a).

10.6.1.4 Astrobiological Characteristics

All hydrothermal activity has long since ceased and so the current ecology is that of a modern terrestrial polar desert. Various photosynthesising microorganisms have colonised many of the rocks. The unique astrobiological character of the site is in the potential for preserved biosignatures in the mineral deposits around the hydrothermal vugs, within impact shocked rocks and potentially the ancient crater lake deposits (Cockell et al., 2002).

10.6.1.5 Prior Analogue Usage

The hydrothermal systems at Haughton are not precise chemical analogues for Martian hot springs as no evidence has been found for a neutral chloride hydrothermal system as is required for the Na, Cl and K enrichment detected in soils around Martian springs. However they represent one of the best preserved impact-generated hydrothermal systems on Earth in a climate that is relatively Mars like. As is well known the warm wet conditions of hydrothermal vents are microbial thermophile oasis, and in this case represent re-colonisation of a sterile environment. Therefore analysis of the deposits in search of microfossils and other bio signatures will potentially inform the interpretation of Martian data.

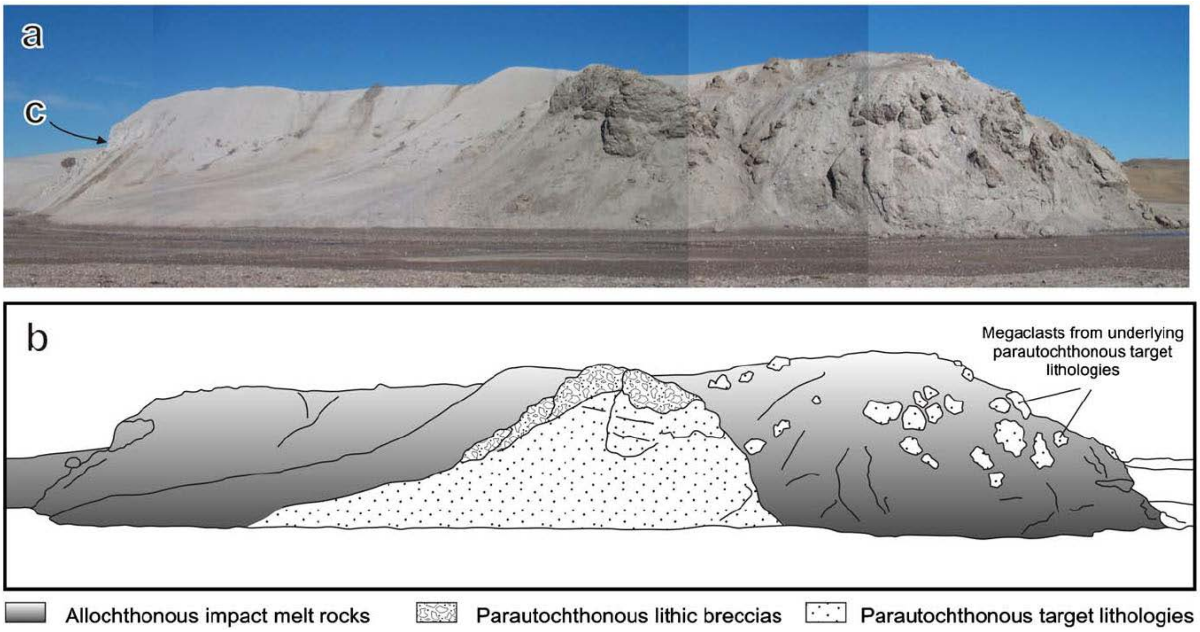
10.6.2 Impact Breccia Supersite

10.6.2.1 Co-ordinates

75.11.53N, 81.51.4W.

10.6.2.2 Physical Characteristics

The impact breccia supersite is situated towards the centre of the Haughton structure and is the only site where the displaced rocks of the central uplift can be observed transitioning to impact melt breccia. Physically, it is an isolated ~40 metres high outcrop left by erosion of the surrounding terrain. The lithologies present are exposed target rocks; Bay Fiord formation evaporates and limestone, and lithic melt breccia. The outcrop includes clasts ranging from metre-sized megaclasts near the transition from target rocks to breccia; to cm scale clasts in the allochthonous lithic melt breccia. As with all sites the outcrop is covered with a thin layer of erosion generated silt and sand.



An outcrop of impact melt breccias draping the central uplift near the centre of the Haughton impact structure (a) Panoramic field photograph of the site; (b) digitized field sketch showing the units exposed in (a) (Adapted from Osinski et al (2010)).

10.6.2.3 Geochemical Characteristics

Six samples of the impact melt breccia were taken from the breccia supersite at two locations over two seasons. The first two samples were taken from breccia close to the underlying target lithology while the other four were taken from initially higher breccia levels.

Groundmass				Clasts						
Cal	Gls	An	Tot	Dol	Lst	Evp	Sst	Xst	Gls	Tot
11.5	10.9	36.3	58.7	21.1	1.9	8.3	0.6	-	10.4	42.3
9.8	0.3	60.5	70.6	20.0	0.5	7.6	0.5	0.8	-	29.4
19.5	28.9	-	48.4	41.3	3.2	-	1.1	0.4	5.6	51.6
23.1	31.7	-	54.8	43.1	0.1	-	0.3	0.2	1.5	45.2
26.7	26.6	-	53.3	39.9	0.2	-	0.2	1.1	5.3	46.7
28.8	26.4	-	55.2	39.0	0.8	-	0.4	0.9	3.7	44.8

Abbreviations: Cal = calcite; Gls = silicate impact melt glass; An = anhydrite; Tot = total; Dol = dolomite; Lst = limestone; Evp = evaporite (gypsum and/or anhydrite); Sst = sandstone; Xst = crystalline

10.6.2.4 Astrobiological Characteristics

The fractures and chasms of heavily shocked clasts host colonies of photosynthesising bacteria. These endolithic communities are far more thermally stable than those on the exterior of rocks and are provided protection from damaging UV (Cockell et al., 2002). Shocked clasts are expected to exist around Martian impact sites and the protected nature of endolithic sites is of far greater importance to potential biology given the extremes of temperature and high incident UV found on the Martian surface.

10.6.2.5 Prior Analogue Usage

Analysis of the breccia supersite, in conjunction with many other locations around Haughton have allowed for the refinement of an impact cratering model that is directly applicable to craters of similar size on both Mars and the Moon (Osinski et al., 2005b). The Breccia supersite in particular represents an example of a geological site of interest as may well be discovered during Martian or Lunar traverses and presents a model of an adaptive and iterative approach to EVA planning.

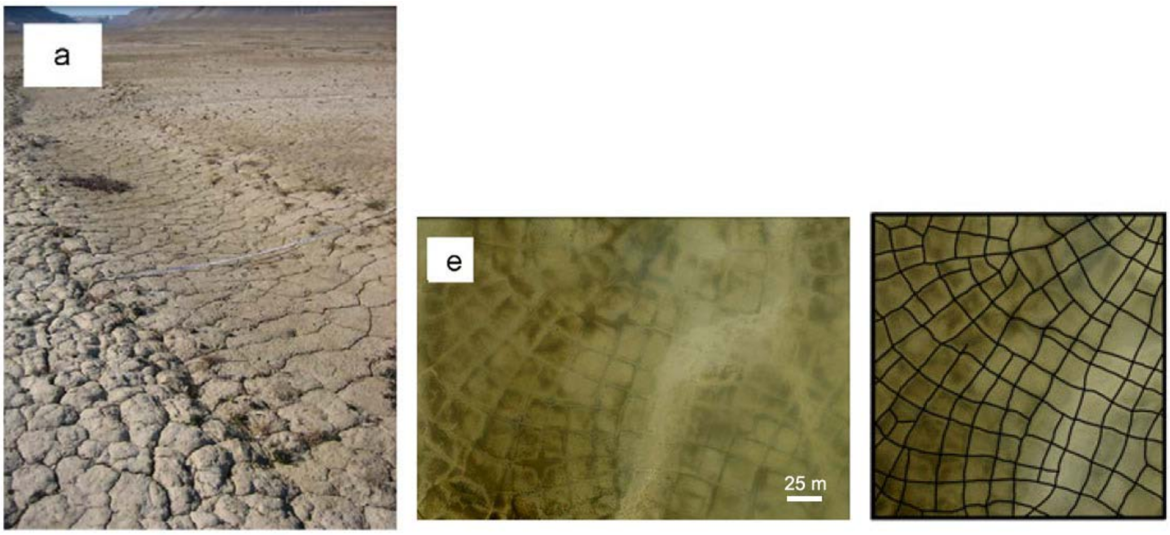
10.6.3 Ice Wedge Polygons

10.6.3.1 Co-ordinates

75.21.26.8 N 88.40.47.2 W

10.6.3.2 Physical Characteristics

Polygonal terrain is a distinctive landscape found in permafrost terrain on both the Earth and Mars. Polygonal features are outlined by interconnected furrows that originate as rheological responses to ground ice. The ice wedge polygons are found in the Thomas Lee inlet site, a wide flat bay. The soils are fine-grained clays and silts deposited as deepwater proglacial silt blankets, generally free of macroscopic organic material. All of the investigated features were delineated by troughs, most of which were bordered by two symmetrical ridges. Foliated wedge ice was detected at a depth of approximately 75 cm.



Left: Fine-grained marine or glacio-fluvial sediments at Thomas Lee Inlet, Devon Island (Adapted from Singletone et al., 2010). Right: Image (e) of Polygons at Thomas Lee Inlet on Devon Island and an outline of their patterns.

10.6.3.3 Geochemical Characteristics

The sample site is located in Allen Bay and Cornwallis Group formations. Therefore the soil and silt will be primarily sourced from these lithic stocks. The Allen Bay formation consists of dolomite with some limestone and dolomitic limestone. The Cornwallis Group consists of limestone, anhydrite, and silt and shale.

10.6.3.4 Astrobiological Characteristics
The ice wedge polygons indicate the presence of subsurface ice. Permafrost is not conducive to life, however many organisms are capable of long-term preservation in permafrost and revive when conditions become more hospitable. Therefore, permafrost locations on Mars are both potential biological repositories and indicators of regions that may have once been hospitable under more clement climatological conditions.

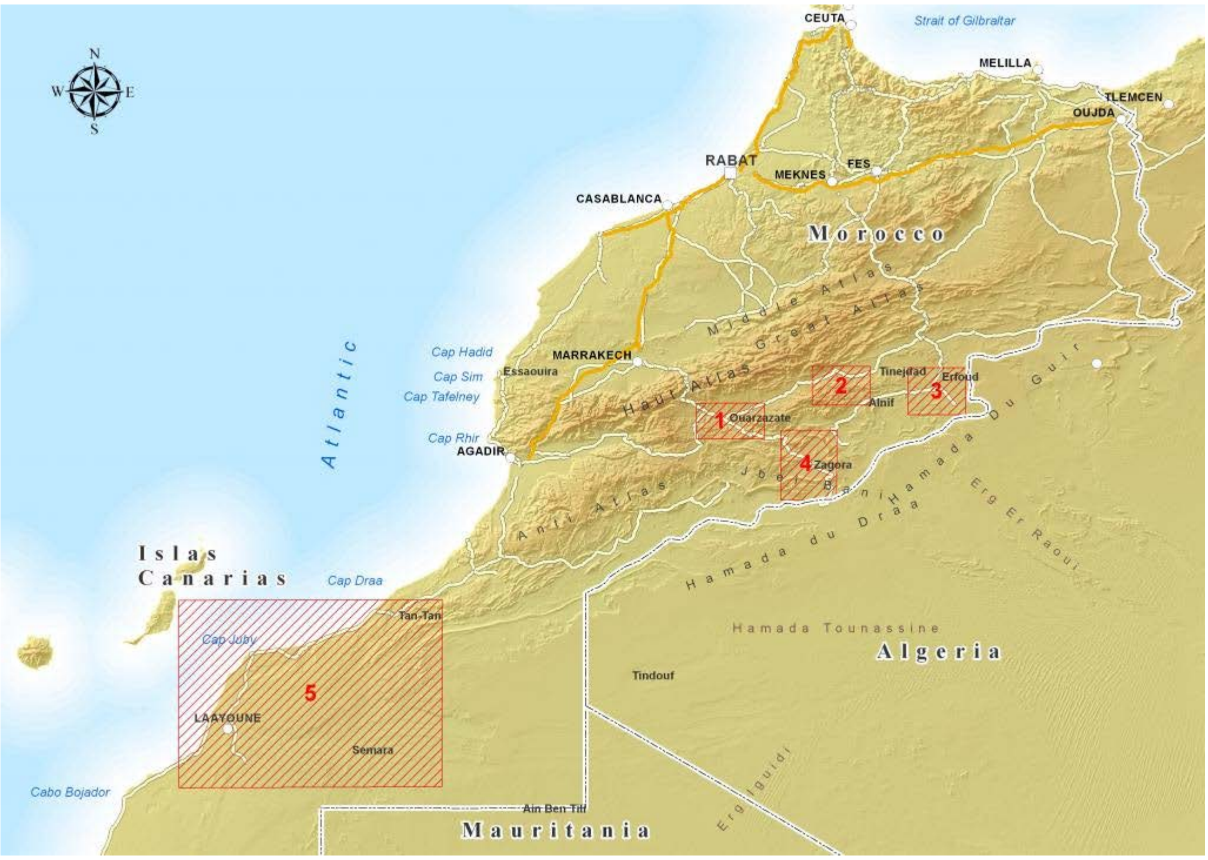
10.6.3.5 Prior Analogue Usage
Ice wedge polygons have been extensively documented on the surface of Mars. Therefore the Thomas Lee Inlet site has been part of a number of studies aiming to understand the formation of these structures. One tested an electromagnetic induction sensor, calibrating the readings with field work (Singleton et al., 2010). Another used statistical analysis of high-resolution aerial images to delineate between primary and secondary troughs and hence map the geometric evolution of the polygon network (Haltigin et al., 2012).

11 Ibn Battuta

11.1 Location

Coordinates	30.5°, -6.75°
Country/State/Province	Morocco
Continent	Africa

11.1.1 Map



Map of Moroccan analogue sites. Copyright IbnBattutaCentre/IRSPS.

11.1.2 Elevation

2500 metres.

11.1.3 Images

Top: Erfoud, Morocco (http://www.oewf.org/cms/index.php?mars2013); Bottom: Kess Kess mounds (Rueggeberg, Andres).

11.2 Context

11.2.1 Geological Setting

550 million years ago several large continental blocks collided to form Africa and the southern continents of the Earth (including Africa) were interconnected. Life was still little developed and the sea that covered Morocco was full of algal mats that consisted of cyanobacteria. Large parts of the Anti-Atlas today are formed by their fossilized remains. 440 million years ago Morocco was born, which was located at the time near the South Pole. Within a few thousand years a gigantic ice cap formed over North Africa and the Sahara. The glacial scratches are preserved today and can be seen in the mountains in the Tazzarine - Zagora area. 200 000 years later the ice began to melt and huge amounts of fresh meltwater poured into the sea. Not far from Erfoud a group of rounded limestone hummocks can be found, The Hamar Lakhdad mud mounds, formed in the sea above volcanic hot springs that provided ample nutrients and energy for the microbial builders of the mounds. Eventually the sea retreated, triggered by the continental collision of Morocco and North America. Morocco was uplifted and folded. The newly formed mountains, however, quickly were attacked by wind, temperature changes and water. At the time large river systems transported the sand and gravel away from the mountains towards the sea and carved gorges and canyons. The end product of all this weathering is quartz sand and the grains accumulated in huge sand dunes near the town of Erfoud.

11.2.2 Relevance

The areas around the Ibn Battuta Centre are fantastic Mars analogues and also provide excellent terrain and landscapes for planetary exploration activities. A number of features are located in this area such as ancient stromatolites and modern bacteria; mud volcanoes; travertine; evaporates; fossil geothermal vents; Aeolian landforms and deflation surfaces; clays and basalts.

11.3 Environmental

Climate/Weather	Arid desert.
Temperature	10 - 37 °C, above 40 °C in July and August.
Precipitation Type	Rain.
Annual Precipitation	180 to 260 mm per year.
Humidity	Very Dry.
Wind	Averages 2.6 m/s.
Insolation	High.

11.4 Infrastructure

11.4.1 Existing

The Ibn Battuta Centre for exploration and field activities is the main centre through which fieldwork in the area should be conducted. Most sites will require hotel accommodation. Remote sites are supported by comfortable camping in Berber tents if done through the centre. There is an office in Marrakech and mobile field camp for field activities.

11.4.2 Accessibility

Many sites are close to tourist facilities. Air shipping to Marrakech. Local transport by 4WD or truck can be provided by Ibn Battuta Centre.

11.4.3 Nearest Airport

Marrakech, Ouarzazate and Errachidia.

11.4.4 Logistics

The Ibn Battuta Centre provides logistical support for any field activity in the area. Hotels based in cities will be up to 60 minutes from sites. Hospitals in cities, emergency centres in towns, evacuation from the field is possible if needed.

11.4.5 Permissions

Organisation that owns the site is the International Research School of Planetary Sciences (IRSPS). Contact person is Gian Gabriele Ori. Permissions and other formalities carried out by Ibn Battuta Centre.

11.4.6 Cost

The cost is variable depending upon the number in the party and field sites to be visited.

11.4.7 Scheduling

Accessible all year, however the summer months of July and August are incredibly hot.

11.5 Key References

The Ibn Battuta Centre website: http://www.ibnbattutacentre.org/

Angel de Pablo, M., Blanco, J.J., Moya, M.E., Garcia, M., Acaso, E., Rubial, M.J., Blanco, J.J. (2008) Chebbi region, Morocco: a testing site for future rover missions to Mars. *37th COSPAR Scientific Assembly.* P.666

Cavalazzi, B. (2006) Kess Kess carbonate mounds, Hamar Laghdad, Anti-Atlas, SE Morocco – A Field Guide.

Franchi, F., Cavalazzi, B., Rossi, A.P., Pondrelli, M., Barbieri, R. (2012) Kess Kess hydrothermal mounds in Morocco: A unique analog for exploring possible fossil or extant life on Mars. *43rd LPSC*. Abstract #2245.

Sauermann, G., Rognon, P., Poliakov, A., Herrmann, H.J., 2000. The shape of the barchan dunes of Southern Morocco. *Geomorphology* 36:47–62.

11.6 Site Specific Details

11.6.1 Ouarzazate

Southern margin of the basin contains Neogene sediments which are over a northerly dipping Precambrian basement. In central and southern parts of the basin, the Mesozoic sequence pinched out against the Paleozoic beds below the Neogene sediments.

11.6.1.1 Ben Haddou 1

11.6.1.1.1 Co-ordinates

7°4'21,7"W; 30°59'37"N

11.6.1.1.2 Physical Characteristics

Site consists of a flat deflation surface, a large open plain with limited to no elevated areas. There are large amounts of rocky terrain with medium to small sized rocks and boulders.

11.6.1.1.3 Geochemical Characteristics

11.6.1.1.4 Astrobiological Characteristics

11.6.1.1.5 Prior Analogue Usage

This area has been used to test and calibrate high resolution images and DEMs from robots and drones.

11.6.1.2 Ben Haddou 2

11.6.1.2.1 Co-ordinates
7°7’15,8”W; 31°2’24”N.

11.6.1.2.2 Physical Characteristics
Areas of variable elevation exist here, with concentrated sites of rocky ground.

11.6.1.2.3 Geochemical Characteristics

11.6.1.2.4 Astrobiological Characteristics

11.6.1.2.5 Prior Analogue Usage

11.6.1.3 Stromatolites

11.6.1.3.1 Co-ordinates
6°43’18,3”W; 30°47’30”N.

11.6.1.3.2 Physical Characteristics
This site contains large cross sections of rock walls that display well preserved stromatolites including stratification patterns; facies and lithologies. The stromatolites are Precambrian in age.

11.6.1.3.3 Geochemical Characteristics

11.6.1.3.4 Astrobiological Characteristics
This site allows the preservation of the evidence of early life in the rock record on the early Earth and Mars to be studied and tools able to identify such life to be tested in situ.

11.6.1.3.5 Prior Analogue Usage

11.6.1.4 Travertine

11.6.1.4.1 Co-ordinates
6°42’0,4”W; 30°59’20,4”N.

11.6.1.4.2 Physical Characteristics
A body of Travertine occurs along the shoreline of a Quaternary lake. The deposits themselves rest by a marginal fault in the basin. The Travertine forms a prograding mass running from the marginal fault and moving towards the basin. Strata are clearly exposed.

11.6.1.4.3 Geochemical Characteristics

11.6.1.4.4 Astrobiological Characteristics

11.6.1.4.5 Prior Analogue Usage

11.6.1.5 Adad

11.6.1.5.1 Co-ordinates
6°40’19,7”W; 30°47’60”N.

11.6.1.5.2 Physical Characteristics

11.6.1.5.3 Geochemical Characteristics

11.6.1.5.4 Astrobiological Characteristics

11.6.1.5.5 Prior Analogue Usage

High-resolution DEM's have been constructed in this area.

11.6.1.6 Saoun

11.6.1.6.1 Co-ordinates

6°43'19"W; 30°42'0,1"N.

11.6.1.6.2 Physical Characteristics

This area is large, open and flat with high relief hills. This site is very good for testing landing scenarios.

11.6.1.6.3 Geochemical Characteristics

11.6.1.6.4 Astrobiological Characteristics

11.6.1.6.5 Prior Analogue Usage

11.6.2 Alnif

11.6.2.1 Tinerhir

11.6.2.1.1 Co-ordinates

5°14'18"W; 31°13'43"N.

11.6.2.1.2 Physical Characteristics

Flood basalt units are observable here within a large valley. The source of the basalt is along the fault in the Northern slope of the valley, and occurs at the top of a dissected plateau.

11.6.2.1.3 Geochemical Characteristics

Basalts; white Mesozoic carbonates and Quaternary black lava flows.

11.6.2.1.4 Astrobiological Characteristics

11.6.2.1.5 Prior Analogue Usage

11.6.2.2 Alnif

11.6.2.2.1 Co-ordinates

5°39'6"W; 31°26'1,4"N.

11.6.2.2.2 Physical Characteristics

This site is located on a hill composed of oolitic limestone next to a paved road connecting Alnif and Tinerhir.

11.6.2.2.3 Geochemical Characteristics
The oolitic limestone is grey in colour resembling the lunar surface, and is a fine grained deposit.

11.6.2.2.4 Astrobiological Characteristics
Carbonates on Mars which indicate a source of water, and therefore potentially an environment that is suitable for life.

11.6.2.2.5 Prior Analogue Usage

11.6.3 Erfoud

11.6.3.1 Rissani 1

11.6.3.1.1 Co-ordinates
4°24’11”W; 31°17’39”N.

11.6.3.1.2 Physical Characteristics
A large canyon feature exists here with variable elevation and views that look out onto wide plains of soft fine grained sands and rocky outcrops. The large amount of variable terrains and elevations means this site is useful for testing exploration activities.

11.6.3.1.3 Geochemical Characteristics

11.6.3.1.4 Astrobiological Characteristics

11.6.3.1.5 Prior Analogue Usage

11.6.3.2 Rissani 2

11.6.3.2.1 Co-ordinates
4°24’23”W; 31°15’36”N.

11.6.3.2.2 Physical Characteristics
Rissani 2 is a wide deflation area with exposed sand patches.

11.6.3.2.3 Geochemical Characteristics

11.6.3.2.4 Astrobiological Characteristics

11.6.3.2.5 Prior Analogue Usage

11.6.3.3 Rissani 3

11.6.3.3.1 Co-ordinates
4°21’35”W; 31°14’10”N.

11.6.3.3.2 Physical Characteristics
This is a wide space with small variations in elevation; exposed facies deposits can be found and studied here. A thick layer of thin dust material covers the area creating resemblances to the lunar and martian surfaces.

11.6.3.3.3 Geochemical Characteristics

11.6.3.3.4 Astrobiological Characteristics

11.6.3.3.5 Prior Analogue Usage

11.6.3.4 Kess Kess

11.6.3.4.1 Co-ordinates

4°3’9”W; 31°22’4”N.

11.6.3.4.2 Physical Characteristics

The area contains a large collection of well-preserved Sedimentary volcanoes made from carbonate, internal geometries can be observed along exposed fault cuts. The volcanoes provide a strong resemblance to mounds with similar morphologies on the martian surface making it a good testing site.

11.6.3.4.3 Geochemical Characteristics

11.6.3.4.4 Astrobiological Characteristics

Features ‘Hollard Mound’ (Middle Devonian Mud Mound) – Worm Tube Fossils found, facies in the core of the mound differ from that around and show signs of ancient hydrocarbon venting. Preserved microbial biosignatures are found here.

11.6.3.4.5 Prior Analogue Usage

11.6.3.5 Chebbi

11.6.3.5.1 Co-ordinates

3°59’42”W; 31°12’50”N.

11.6.3.5.2 Physical Characteristics

This area is located at the south of the Atlas range, forming the northern edge of the Sahara desert. It is a plain landscape with smooth hills and a southern dune field composed of different types of dunes. Wind-streaks are common with sizes ranging between centimetres to tens of metres. Aeolian processes like dust storms and dust devils are observed in the spring and summer. The region is also characterized by the desert pavement formed by different size particles from sand to blocks that are decimetres to metres in diameter. Salts deposits and crusts are visible in different areas related to evaporation processes plus aeolian and fluvial deposits cover the surface, highlighting bedrock outcrops and sedimentary layers in the same way as observed on Mars.

11.6.3.5.3 Geochemical Characteristics

11.6.3.5.4 Astrobiological Characteristics

11.6.3.5.5 Prior Analogue Usage

All these characteristics and the communications and accommodations facilities available make this area an interesting site for exploration rover missions testing and training of future astronauts that will work on the surface of Mars.

11.6.3.6 Lake Maider

11.6.3.6.1 Co-ordinates
4°42’52”W; 30°39’18”N.

11.6.3.6.2 Physical Characteristics

11.6.3.6.3 Geochemical Characteristics

11.6.3.6.4 Astrobiological Characteristics

11.6.3.6.5 Prior Analogue Usage

11.6.3.7 Maider

11.6.3.7.1 Co-ordinates
4°33’40”W; 30°46’28”N.

11.6.3.7.2 Physical Characteristics
This is a large flat open site, with little to no grain deposits. Barchan Dunes run across part of the site. Three of the Kess Kess bodies occur at the top of the site.

11.6.3.7.3 Geochemical Characteristics

11.6.3.7.4 Astrobiological Characteristics

11.6.3.7.5 Prior Analogue Usage

11.6.4 Zagora

11.6.4.1 Zaouia

11.6.4.1.1 Co-ordinates
6°2’18,2”W; 30°43’15”N.

11.6.4.1.2 Physical Characteristics
Ephemeral streams running through a large open plain.

11.6.4.1.3 Geochemical Characteristics

11.6.4.1.4 Astrobiological Characteristics

11.6.4.1.5 Prior Analogue Usage

11.6.4.2 Zagora

11.6.4.2.1 Co-ordinates
5°42’16”W; 30°19’23”N.

11.6.4.2.2 Physical Characteristics
A mixture of features are observed here such as deflation surfaces, hills, valleys, and ephemeral streams providing sites for a variety of testing scenarios. A variety of rock sizes exist here from small to large, mostly polished due to the wind and sand.

11.6.4.2.3 Geochemical Characteristics

11.6.4.2.4 Astrobiological Characteristics

11.6.4.2.5 Prior Analogue Usage

11.6.4.3 Mhamid

11.6.4.3.1 Co-ordinates
5°41’14”W; 29°54’25”N.

11.6.4.3.2 Physical Characteristics
The site consists of a few small ergs and a variety of dunes ranging from dome-shaped, barchan and star shapes. There is also a ridge which surrounds and interlaces the ergs.

11.6.4.3.3 Geochemical Characteristics

11.6.4.3.4 Astrobiological Characteristics

11.6.4.3.5 Prior Analogue Usage

11.6.5 Tan Tan

11.6.5.1 Sebkha Tazra

11.6.5.1.1 Co-ordinates
12°19’19”W; 27°55’36”N.

11.6.5.1.2 Physical Characteristics

11.6.5.1.3 Geochemical Characteristics

11.6.5.1.4 Astrobiological Characteristics

11.6.5.1.5 Prior Analogue Usage

11.6.5.2 Sebkha Tah

11.6.5.2.1 Co-ordinates
12°47’52”W; 27°42’7”N.

11.6.5.2.2 Physical Characteristics

11.6.5.2.3 Geochemical Characteristics

11.6.5.2.4 Astrobiological Characteristics

11.6.5.2.5 Prior Analogue Usage

11.6.5.3 Sebkha Oum Dba

11.6.5.3.1 Co-ordinates
13°0’23”W; 27°32’31”N.

11.6.5.3.2 Physical Characteristics

11.6.5.3.3 Geochemical Characteristics

11.6.5.3.4 Astrobiological Characteristics

11.6.5.3.5 Prior Analogue Usage

11.6.5.4 Sebkha Aridal

11.6.5.4.1 Co-ordinates
14°0’9”W; 26°9’51”N.

11.6.5.4.2 Physical Characteristics

11.6.5.4.3 Geochemical Characteristics

11.6.5.4.4 Astrobiological Characteristics

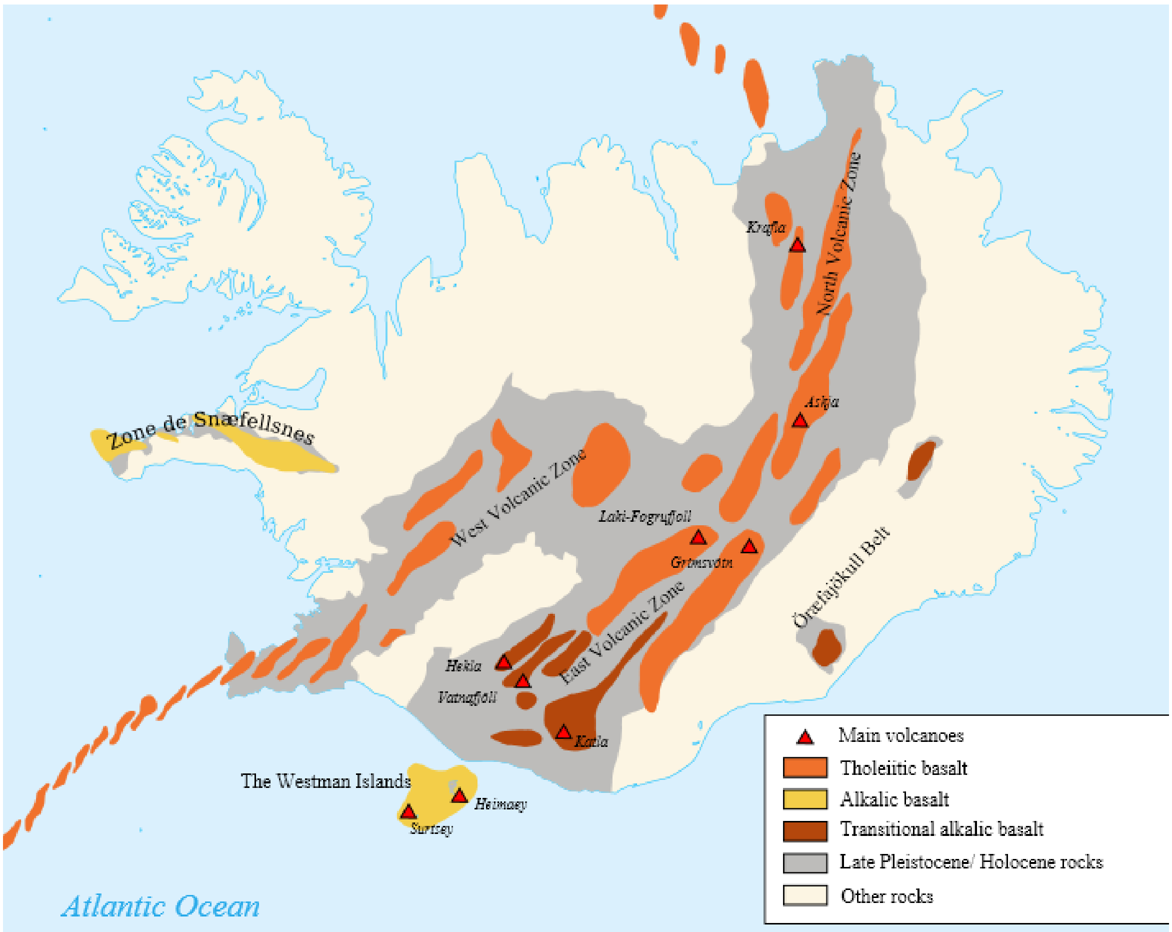
11.6.5.4.5 Prior Analogue Usage

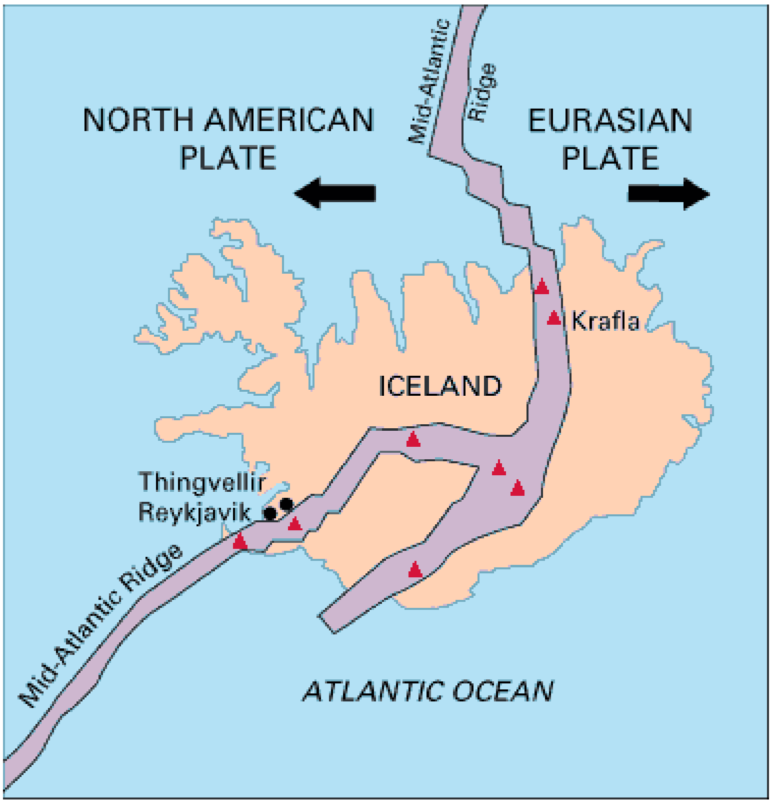
12 Iceland

12.1 Location

Coordinates	65° 0′ 0″ N, 18° 0′ 0″ W
Country/State/Province	Iceland / various
Continent	Europe

12.1.1 Map





Top: Volcanic zones of Iceland. Bottom: The MAR and how Iceland formed.

12.1.2 Elevation

The Lowest point is at Jökulsárlón Lagoon at -146 metres beneath the Atlantic Ocean at 0 metres. the highest point is Hvannadalshnúkur at 2110 metres.

12.1.3 Images

Top: Geyser, Bottom: A vent of Eyjafallajokull (Preston, L.J.).

12.2 Context

12.2.1 Geological Setting

Iceland lies over a hot, upwelling mantle plume and the Mid-Atlantic Ridge (MAR). The North American and Eurasian plates are moving apart at 1–2 cm/yr creating extensive basaltic volcanism, fissure eruptions and Earthquakes (Thordarson and Hoskuldsson, 2002).

Iceland has 30 active volcanic systems with associated geothermal activity, which has been categorised into high and low temperature fields based on deep well temperatures and silicic geothermometry (Geptner et al., 2005). There are 250 low-temperature fields (~150 °C), 20 high-temperature fields (340–380 °C), and 600–700 hot springs in the region. Due to the near-Arctic latitude at which Iceland lies, much of the volcanism is in direct contact with glacial activity. Indeed, the elevated topography of the currently dormant volcanoes leads to increased glaciation of volcanic centres, despite their relatively high heat flow. An example is Europe's largest glacier Vatnajökull, which overlies seven volcanic centres.

12.2.2 Relevance

Iceland is a natural laboratory for analogue studies of Mars and the Moon, and additionally provides a fantastic playground for planetary surface activities. Analogue sites in Iceland include; basaltic lavas and volcanism; glaciovolcanism; periglacial features; volcanic features such as lava tubes, caves, ridges, cones, hydrothermal deposits; Mars-like soils and pyroclastics; pillow lavas; hot springs and geysers and volcanic Aeolian features such as dunes. Aqueous alteration effects on all these volcanic features can be studied, as are observed on Mars. Astrobiological features include the aforementioned hot springs and their associated microbial populations, as well as life within ices and volcanic materials aka extremophiles.

12.3 Environmental

Climate/Weather	Temperate as moderated by the North Atlantic Current.
Temperature	Av. July 10-13 °C; Av. In south: winter lowlands O °C, highlands -10 °C down to -25 °C in the northern part of the country.
Precipitation Type	Rain and snow.
Annual Precipitation	Wettest month is October with 88 mm; driest is May with 42 mm.
Humidity	59 to 92%; rarely drops below 40%.
Wind	Prevailing wind direction is easterly, typically reaching 18 m/s.
Insolation	Ranges from 0.03 kWh/m²/day (December) to 4.71 kWh/m²/day (June).

12.4 Infrastructure

12.4.1 Existing

Iceland enjoys an extensive infrastructure. The current national road system connects most of the cities and is largely in the coastal areas. It consists of about 12 691 kilometres of roads, with 3262 kilometres paved. There are no railways in Iceland.

Airplanes and ships conduct travel between Reykjavík and Iceland's smaller cities. Additionally, there are daily international flights from Iceland (both Reykjavik and Keflavik) to Europe and North America. There are 12 airports with paved runways and 74 with unpaved runways.

12.4.2 Accessibility

Iceland is easily reached via air and the main international airport is Keflavík (IATA: KEF; ICAO: BIKF), located in the southwest of the country about 40 kilometres from Reykjavík. For city drives and to the most popular geological tourist features, a car is needed. If going during the winter months or on unpaved roads (of which there are many) a 4WD is needed. Off-roading is not particularly safe in Iceland due to hidden holes and crevices under rocks and ice; however, it is still done in select areas. Many sites can be driven to with a short hike at the end. Any sites in the higher volcanic areas will require extensive hiking.

12.4.3 Nearest Airport

Keflavík International Airport (Icelandic: Keflavíkurflugvöllur) (IATA: KEF, ICAO: BIKF), also known as Reykjavík-Keflavík Airport, is the largest airport in Iceland and the country’s main hub for international transportation.

12.4.4 Logistics

There are many hotels, hostels and camp grounds that can be used when staying in Iceland. Medical care is of high quality, but limited services are available outside of large urban areas. Over the counter medicines cannot be purchase in Iceland without a doctor’s note, unlike pharmacies in Europe and the States. Once in the field, minimal services are available and petrol stations are few and far between, take enough provisions for your trip and take your rubbish out with you. Up on the volcanoes there are many marked hiking trails and huts leading to the summits, plus rangers out on skiddoes. The weather can change here without warning so be prepared and if possible have a GPS and/or sat phone.

12.4.5 Permissions

The Icelandic Nature Conservation Act regulates outdoor activities and standards of conduct. It stipulates that everyone has the right to travel around the country and enjoy its nature as long as the traveller is tidy and careful not to damage or otherwise spoil natural resources.

It is permissible to cross uncultivated private property without seeking any special permission, but landowners may limit routes with signs and other marks. State-owned land such as conservation areas and forestry areas are open to everyone with few exceptions. These exceptions include – but are not limited to – access during breeding seasons or during sensitive growth periods.

For research and fieldwork purposed it is advisable to make contact with local scientists. No regulations exist on taking samples and equipment in or out of the country.

12.4.6 Cost

Getting to Iceland can be done fairly cheaply: Icelandair and Iceland Express both offer many excellent fares and promotions. However, once there prices in Iceland can be vastly higher than in other parts of Europe due to the high import duties and the 25.5% VAT rate, particularly for alcohol, foreign foods, clothing, etc.

12.4.7 Scheduling

Mid-June to August is high season, but accessibility can be limited until as late as July because of snow. Many facilities outside Reykjavík are closed from September to May.

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12.6 Site Specific Details

12.6.1 Askja

12.6.1.1 Co-ordinates
65° 1′ 48″ N, 16° 45′ 0″ W.

12.6.1.2 Physical Characteristics
Askja is a 50 km^2 caldera in the Dyngjufjoll volcanic complex, which is composed of moberg subglacial eruptive products, basaltic lava flows and minor rhyolites. The complex is part of the neovolcanic zone within the MAR spreading centre. Askja itself was formed, for the most part, at the end of the Ice Age in a major ash eruption which caused the roof of the magma chamber at the heart of the central volcano to subside. The Odadahraun plains are located here which consist of lava flows, basaltic sands and ash deposits (Greeley et al., 2002).

12.6.1.3 Geochemical Characteristics
Askja is dominated by basaltic volcanism and has been modified by strong winds, periglacial processes, and fluvial activity. The region is relatively vegetation free with most windblown particles derived from volcaniclastic materials and the weathering of lavas.

12.6.1.4 Astrobiological Characteristics

12.6.1.5 Prior Analogue Usage
Apollo Training Site.

12.6.2 Eyjafjallajokull

12.6.2.1 Co-ordinates
63° 38′ 0″ N, 19° 36′ 0″ W.

12.6.2.2 Physical Characteristics
Eyjafjallajökull is a stratovolcano completely covered by an ice cap. The ice cap covers an area of about 100 square kilometres, feeding many outlet glaciers. It has an elevation of 1651 metres at its highest point, and has a crater 3 – 4 kilometres in diameter, open to the north. The crater rim has three main peaks, being Guðnasteinn, 1500 metres, Hámundur, 1651 metres and Goðasteinn, 1497 metres. In the spring of 2010, the eruption of Eyjafjallajökull created an analogue of volcanic activity that could have emplaced the ash deposits on Mars. The eruption prior to 2010 began in December 1821 and lasted for over a year, with intermittent explosive activity spreading a thin layer of tephra (ash and larger ejected clasts) over the surrounding region.

12.6.2.3 Geochemical Characteristics
Olivine and pyroxene-rich basalts and volcanic ash are found here.

12.6.2.4 Astrobiological Characteristics
The new basaltic lavas are being studied here to understand the colonisation of volcanic environments by micro-organisms and their preservation. This analogue will enable understanding of potential volcanic habitats for life on Mars.

12.6.2.5 Prior Analogue Usage

12.6.3 Krysuvik

12.6.3.1 Co-ordinates
63° 53′ 45.02″ N, 22° 3′ 8.96″ W.

12.6.3.2 Physical Characteristics
The geothermal area Krýsuvík is situated on the Reykjanes peninsula in Iceland. It is in the south of Reykjanes in the middle of the fissure zone on the Mid-Atlantic Ridge which traverses Iceland. The landscape at Krýsuvík was formed by volcanic activity and upheaval. The Grænavatn, Gestsstaðavatn and Augun lakes are explosion craters created by volcanic eruptions at various times. Of those, Grænavatn lake is the largest, some 46 metres deep. Its water is green due to thermal algae and crystals which absorb the sun.

Hot springs, fumaroles and mud pots are found at this site.

12.6.3.3 Geochemical Characteristics
Fe-rich soils are found here due to iron-rich waters flowing through basaltic rocks and the alterations and weathering of basaltic rocks. Sinters are found through the area rich in silica and opal; plus numerous deposits of sulphur.

12.6.3.4 Astrobiological Characteristics
Extremophiles which live in extreme temperatures and acidic pH are found here within the spring waters and surrounding rocks and sediments.

12.6.3.5 Prior Analogue Usage

12.6.4 1783-1784 Laki Flow Field

12.6.4.1 Co-ordinates

12.6.4.2 Physical Characteristics

12.6.4.3 Geochemical Characteristics

12.6.4.4 Astrobiological Characteristics

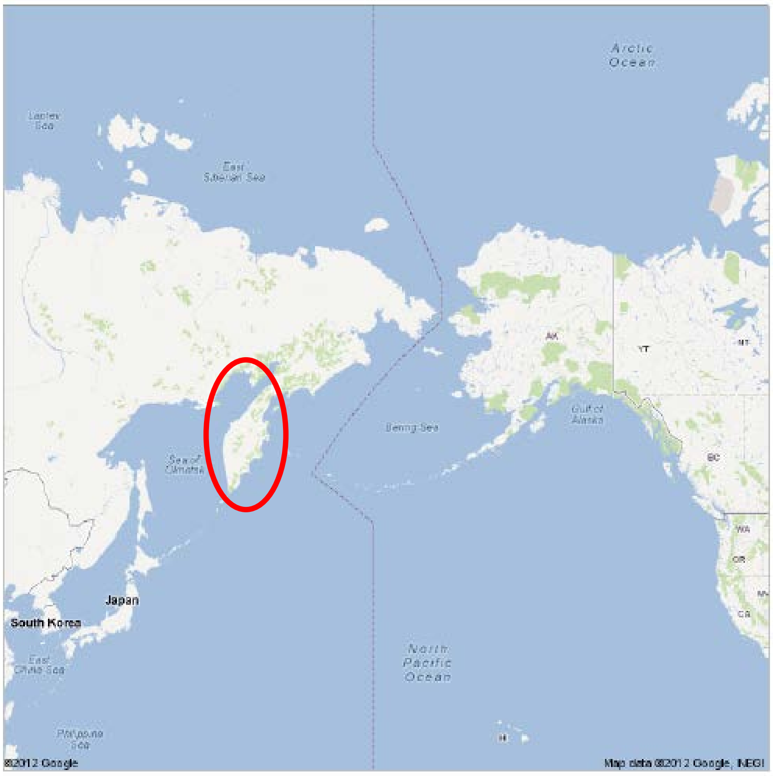
12.6.4.5 Prior Analogue Usage

13 Kamchatka

13.1 Location

Coordinates	Extending from lat. 51°N to lat. 61°N
Country/State/Province	The Russian Federation
Continent	Europa and Asia

13.1.1 Map

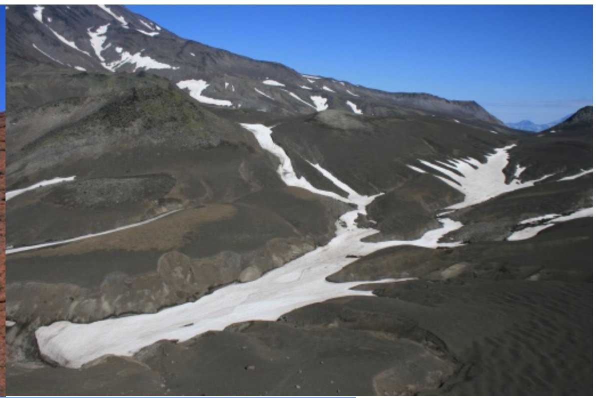


Googlemaps image, accessed August 2012.

13.1.2 Elevation

Highest volcano is Klyuchevskaya Sopka at 4750 metres.

13.1.3 Images

Images used with permission from C. Souness. Left to right: Mars-like volcanic surfaces; Scoria formations at the foot of Avachinsky; Koriaksky from the flanks of Avachinsky; Periglacial landscapes on Tolbachik scoria.

13.2 Context

13.2.1 Geological Setting

The Kamchatka River and the surrounding central side valley are flanked by large volcanic belts containing around 160 volcanoes, 29 of them still active. The peninsula has a high density of volcanoes and associated volcanic phenomena, with 19 active volcanoes being included in the six UNESCO World Heritage List sites in the Volcanoes of Kamchatka group, most of them on the Kamchatka Peninsula. In the centre of Kamchatka is Eurasia's world famous Geyser Valley which was partly destroyed by a massive mudslide in June 2007. These volcanic features are the sites of occurrences of certain extremophile micro-organisms that are capable of surviving in extremely hot environments. Glaciers as well as glacial and periglacial landforms are found in the active volcanic areas. South of 57˚N there is no permafrost due to the relatively mild winters and heavy snow cover, whilst northward discontinuous permafrost prevails. The unique geology, climate and morphology of various locales in Kamchatka have created environments that may be of utility as Mars analogue sites.

13.2.2 Relevance

The volcanoes and volcanic landforms of Kamchatka can be used as both martian and lunar analogues i.e. lava flows, scoria, ash. Additionally, the cold climate and frozen ground provides an additional suite of analogues for Mars, namely volcanic debris-covered glaciers; patterned ground and landscapes of periglacial activity; and dry gullies in scoria deposits. Extremophile studies into life that survives in volcanic environments and cold temperatures as exists on Mars are also important.

13.3 Environmental

Climate/Weather	Generally sub-arctic, however, in higher and northerly areas it has a polar climate. Covered in snow from October to late May.
Temperature	Summer maxima <15 °C and winter lows around −8 °C.
Precipitation Type	Rain in the summer, snow in winter. There is considerable variation between the rain-drenched and heavily glaciated east coast and the drier and more continental interior valley.
Annual Precipitation	2,700 mm.
Humidity	Up to 97% in summer months.
Wind	Variable depending on elevation.
Insolation	

13.4 Infrastructure

13.4.1 Existing

The Klyuchevskaya Sopka massif has no huts or infrastructure of any kind adjacent to the peaks and glacier. However, there is a bothy-style hut (which is new and in good condition) to the west and on the route in from Kozyrevsk. This hut lies at the edge of the forest and is approximately 25 kilometres from the volcano massif. This makes it impractical as a fieldwork base, although it is a convenient rest stop on the trip in and out of the area. To the north, on the route in from Klyuchi, there is another hut, known as the 'volcanologist's hut'. It is rumoured that it is in a poor state of repair however.

Tolbachik volcano has a small settlement for the use of scientists and tourists. It is expected that any interested parties would be able to secure use of these premises for a price. The buildings are located on the southern slopes of Tolbachik, but are still a long way from the summit.

There are very few facilities in most areas. Any field parties will need to be fully self-sufficient and carry everything they need, including a means of defence against bears, and a satellite phone. As non-Russians it is impossible to get access to a firearm unless you have a Russian guide. Therefore, flares and bear-spray (mace) are a possible alternative. Flares can be secured in Petropavlovsk-

Kamchatsky, mace may have to be imported in hold luggage (not that we recommend or endorse this).

13.4.2 Accessibility

There are almost no roads in Kamchatka. Only the main highway which runs north from Petropavlovsk-Kamchatsky (PK) is of any significance. Therefore access to sites off this highway is difficult. This is easily overcome by hiring a helicopter, and private charters are available from the airport in PK, although these are extremely expensive.

In some places, such as Klyuchevskaya Sopka and Tolbachik areas, 6x6 trucks are available (with a driver) for travel through the dense and bear-infested forests which lie between the highway and the raised, volcanic tundra areas. These are expensive (approx £600 each way), however if the ride can be shared with another party then the fare can be split.

Tracks could be negotiated by most capable 4x4 vehicles and capable drivers, and also by dirt bike, however, this is not recommended. Without support there is a risk of being bogged in and getting stuck out in bear country. 6x6 trucks are VERY capable, and although expensive, they are reliable.

Beyond the forests, the tundra can be (and, given it is a sensitive ecosystem, should be) crossed on foot.

13.4.3 Nearest Airport

The main airport in Kamchatka is at Yelizovo, which is about 10 miles outside of PK. It is fully equipped despite being a bit 'Old West' in its approach. All flights into and out of Kamchatka go through here, as do internal helicopter flights. There is an airport at Kozyrevsk, but this is no longer in use. There is also an airfield at Klyuchi, however, this is military only.

13.4.4 Logistics

The water is very fresh in Kamchatka and can be drunk from the tap. In the field water is, however, often very silty due to the fine volcanic deposits, therefore it is advisable to carry some with you and allow it to settle during rest stops before drinking. Furthermore, when working on the volcanic scoria areas, it is often impossible to find water as many areas are desert-like due to exceptionally efficient drainage through scoria deposits. There are several streams running down the flanks of Klyuchevskaya.

When working in the Klyuchevskaya Park area you must take all rubbish with you out of the field. This is a rule, but should also be done out of respect for the sensitive and unique landscape.

Primus stoves are recommended, as petrol is freely available at petrol stations. Meths can be hard to source, as can canned petrol so Primus stoves are best.

There are relatively few options for accommodation outside PK and Yelizovo. However, most people will offer a room in their house for a modest fee. You can virtually rely on this, as the locals in Kamchatka's small communities have very low incomes and will jump at the chance to supplement it. People are very friendly and very genuine. There is a large Hospital in PK. However, access to this can be difficult when you are in the field.

There is a mountain rescue service in PK that field teams should visit prior to heading out. Make sure you leave a log of your destination, the route, departure date and return date, as well as your satellite phone number. The headquarters is located very close to the 'Bezimiany' (literally, 'no name') bus station in the southeast of PK.

13.4.5 Permissions

At the time of writing no permit was needed to work in the Klyuchevskaya Sopka park. However, this seems likely to change, so be sure to check before booking fieldwork here.

It is mandatory to register your visa in Russia upon arrival and this usually comes with a fee of about 25 - 35 Dollars U.S. No permission is 'officially' needed to remove samples, however, expect complications if you are taking large quantities, and expect delays explaining them at the airport. It may be wise to check with the Russian embassy, although this may become expensive when taking the official route.

No pre-training is needed, although functional Russian language is almost an essential in a place where English speakers are scarce.

13.4.6 Cost

For 2 people, the trip might cost up to £4000 (all in) for a 3 week campaign. This estimate is still low, with only a few nights' accommodation and no guides. Expensive components are flights (about £800 each) and the 6x6 ATV (£1200 in total).

13.4.7 Scheduling

Kamchatka is very cold in the winter, and very hot in summer. It is recommend visiting in September-October when there are fewer Mosquitoes. The weather becomes less reliable in autumn, but the absence of bugs makes up for it. This however could prevent fieldwork, so the choice is very much up to each team. Do not underestimate the mosquito problem however.

Flights are considerably cheaper in winter. This is a factor to bear in mind if resources are low. However, it is likely that transport and survival will be a challenge in the winter conditions.

13.5 Key References

Demidov, N.E. and Gilichinsky, D.A. (2009) Terrestrial Permafrost models and Analogues of Martian habitats and inhabitants. *Soil Biology* 16:323-341.

Souness, C.J., Abramov, A. (2012) The Volcanic terrains of Kamchatka, Eastern Russia: A Glacial and periglacial environment with potential for Mars analog-based research. 42nd LPSC, Abstract # 1071.

13.6 Site Specific Details

13.6.1 Avachinsky Area

13.6.1.1 Co-ordinates

13.6.1.2 Physical Characteristics

13.6.1.3 Geochemical Characteristics

13.6.1.4 Astrobiological Characteristics

13.6.1.5 Prior Analogue Usage

13.6.2 Klyuchevskaya Volcano Group

13.6.2.1 Co-ordinates

13.6.2.2 Physical Characteristics

Located 56 °N, and includes the active volcanoes Klyuchevskya (4800 metres), Bezymianni (2900 metres), Ushkovsky (3900 metres) and Tolbachik (3100 metres).

13.6.2.3 Geochemical Characteristics

13.6.2.4 Astrobiological Characteristics

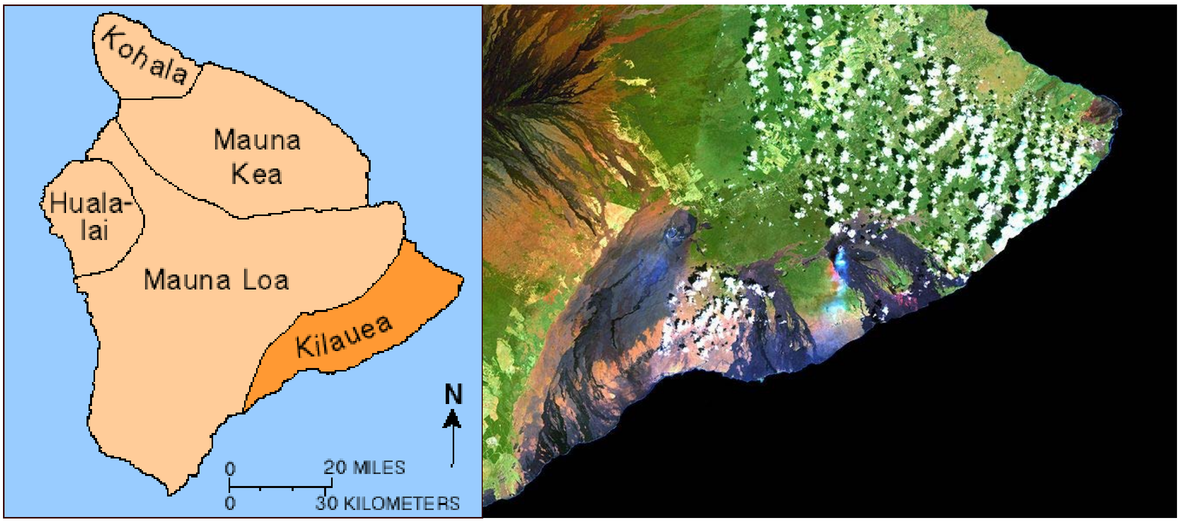
13.6.2.5 Prior Analogue Usage

14 Kilauea

14.1 Location

Coordinates	19°25’30”N 155°17’31”W
Country/State/Province	USA / Hawai’i
Continent	North America

14.1.1 Map



Left: The five volcanoes of the Big Island, Hawai’i. Right: This simulated true-color image of Kilauea was derived from data gathered by the Enhanced Thematic Mapper plus (ETM+) on the Landsat 7 satellite between 1999 and 2001.

14.1.2 Elevation

1277m.

14.1.3 Images


Photos from Kilauea (courtesy of L.J.Preston). Top left: The summit caldera of Kilauea; Top right: lava fields; Bottom left: Pahoehoe lava; Bottom right: Lava erupting from a tube system down Pulama pali into the sea.

14.2 Context

14.2.1 Geological Setting

Kīlauea is a volcano part of the Hawaiian-Emperor seamount chain, and one of five shield volcanoes that together form the island of Hawaiʻi. It is the youngest and most active volcano on the Big Island of Hawai`i. Kīlauea was created as the Pacific tectonic plate moved over the Hawaiian hotspot in the Earth's underlying mantle. Topographically, Kīlauea appears as only a bulge on the southeastern flank of Mauna Loa, and so for many years Kīlauea was thought to be a satellite of its giant neighbour, not a separate volcano. However, research shows it has its own magma-plumbing system, extending to the surface from more than 60 kilometres deep in the Earth. Kilauea first erupted underwater between 300,000 and 600,000 years ago, with the first sub aerial eruptions occurring 50-100,000 years ago. The eruption that began in 1983 continues today at a cinder-and-spatter cone with the lava erupting from the cone flowing through a tube system that runs 11 kilometres to the sea.

14.2.2 Relevance

Shield volcanoes of Hawai'i, in particular Kilauea, are excellent analogues for both Mars and The Moon. They allow studies of shield volcanoes; basaltic lavas; caves; lava tubes; collapse pits; skylights; palaeoregolith; life in the subsurface; life in basalt; and extremophiles. Additional features observed at Kilauea include volcanic deserts; gullies; alluvial plains and Mars-like outwash channels.

14.3 Environmental

Climate/Weather	The park has distinct climate zones that vary according to elevation
Temperature	Av. July high 28.3 °C, av Jan low 19.4 °C.
Precipitation Type	Rain.
Annual Precipitation	1752.6 mm
Humidity	High.

Wind	
Insolation	244 days of sun per year.

14.4 Infrastructure

14.4.1 Existing

A Visitors centre is located at the main vent of Kilauea; but there are no huts or stations on the lava fields.

14.4.2 Accessibility

If driving, follow the Hawaii Belt Road, Route 11 from Hilo, towards the caldera and then hike to sites. Crater Rim Drive is an 11-mile loop road that encircles the summit caldera.

14.4.3 Nearest Airport

Hilo International Airport.

14.4.4 Logistics

Many hotels are located in Hilo and there are bed and breakfast-type places in Volcano. There is also a hotel, cabins and camping in Hawaii Volcanoes National Park. No food or fuel is available along the Chain of Craters Road. No streams or water sources in the coastal part of the park so need to bring water with you. There is also no shade in the park so bring adequate protection.

14.4.5 Permissions

Kilauea resides in a National Park so fieldwork requires a research permit, including safety and operations plans (see https://science.nature.nps.gov/research/ac/ResearchIndex). If working on State land you need to contact the state Department of Land and Natural Resources (http://hawaii.gov/dlnr) to figure out which division(s) manages the land you want to cross or work in, and then apply for research permits from the appropriate division(s). If on Hawaii County land, contact them for permissions (http://www.hawaiicounty.gov/parks-and-recreation/). Of course if you're on private land, you'll have to contact the land owner.

All work/access will require a permit or permission of some kind, often from multiple entities. Regarding sample collection: approval from the appropriate agency/landowner must be sought. Some work may require hiring an archaeologist in case there's culturally-significant rock work (walls, foundations, etc.) at the site you're working at, but the agency/landowner will know if this is an issue.

14.4.6 Cost

Entrance Fee per car: $10 for 7 days; pedestrian: $5 for 7 days.

14.4.7 Scheduling

Can travel to Kilauea at any time of year, however, it is rainiest in Nov-March.

14.5 Key References

The International Lunar Surface Operations-In-Situ Resource Utilization (ISRU) analogue field test. http://www.nasa.gov/exploration/multimedia/isru-hawaii.html.

HI-SEAS (Hawaii Space Exploration Analog and Simulation) http://manoa.hawaii.edu/hi-seas/.

Bishop, J.L., Schiffman, P., Lane, M.D. and Dyar, M.D. (2005) Solfataric alteration in Hawaii as a mechanism for formation of the sulfates observed on Mars by OMEGA and the MER Instruments. *LPSC XXXVI*. Abstract #1456.

Seelos, K. D., R. E. Arvidson, B. L. Jolliff, S. M. Chemtob, R. V. Morris, D. W. Ming, and G. A. Swayze (2010), Silica in a Mars analog environment: Ka'u Desert, Kilauea Volcano, Hawaii*, J. Geophys. Res.,* 115:E00D15, doi:10.1029/2009JE003347.

Cushing, G.E., and Titus, T.N. (2009) Kilauea pit craters as Mars analogs: A New Direction for Cave-detection Techniques. *40th LPSC* Abstract # 1203.

Morris, R. V., et al. (2000) Mineralogy, composition, and alteration of Mars Pathfinder rocks and soils: Evidence from multispectral, elemental, and magnetic data on terrestrial analogue, SNC meteorite, and Pathfinder samples, J. Geophys. Res., 105(E1), 1757–1817, doi:10.1029/1999JE001059.

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Craddock, R. A.; Irwin, R. P.; Williams, R.; Swanson, D.; Howard, A. D.; Quantin, C.; Kuzmin, R.; Zimbelman, J. R. (2005) The Geology of the Ka'u Desert, Hawaii as a Mars Analog. *AGU Fall Meeting*. Abstract #H33C-1402.

14.6 Site Specific Details

14.6.1 Ka’u Desert

14.6.1.1 Co-ordinates

19°24’31”N 155°17’48”W.

14.6.1.2 Physical Characteristics

The Ka'u Desert is located on the western flank of Kilauea. It is a desert because it receives little annual rainfall (about 150 mm/yr) and is subjected to constant outgassing from Kilauea, which creates a harsh, acidic environment. Near the summit of Kilauea the Ka'u Desert is characterized by the Keanakako'i tephra deposit, which is several metres deep thinning out to a discontinuous deposit 1.5 kilometres towards the centre of the desert. The deposit has been carved by a number of gullies that are flat-floored and terminate in a series of amphitheatre-shaped plunge pools. Most of the interior desert contains weathered lava flows, extensive deposits of sand, and several more recent lava flows and volcanic edifices. The southern portion of the desert is bounded by the Hilina Pali fault scarp, which is 500 metres above the Pacific Ocean and contains a complex series of outwash plains, alluvial fans, and debris flows.

14.6.1.3 Geochemical Characteristics

Rain here combines with sulphur dioxide released by the volcanic vents to create acid rain with a pH as low as 3.4. This inhibits plant growth.

14.6.1.4 Astrobiological Characteristics

14.6.1.5 Prior Analogue Usage

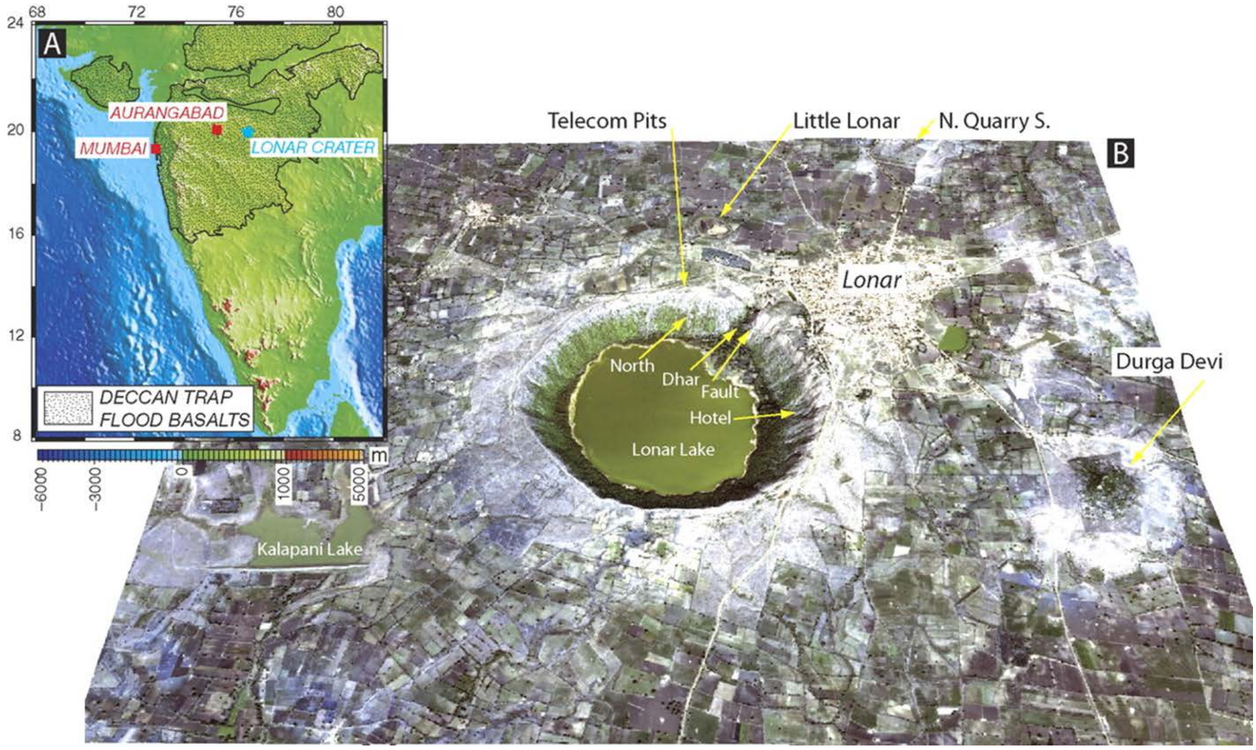
The Ka'u Desert represents a good Mars analog because (1) similar to valley networks, the development of channels and gullies in the Ka'u Desert has been interrupted by resurfacing events, (2) associated fluvial deposits have been heavily modified by aeolian processes, and (3) the alluvial fans on the Hilina Pali have unusually large source areas.

15 Lonar Crater

15.1 Location

Coordinates	19° 58'36"N 76° 30'30"E
Country/State/Province	India / Buldana district, Maharashtra.
Continent	Asia

15.1.1 Map



EToPo2 (http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html) topography of India (colour scale is in metres, coordinates in latitude and longitude), showing the extent of the Deccan Plateau (Deshmukh, 1988; Bondre et al., 2004) and the location of Lonar Crater; (B) Four-band, pan-sharpened, true-colour Quickbird satellite image of Lonar Crater, draped on the digital elevation model of Figure 2. The locations of measured stratigraphic sections from Figure 3 are marked with yellow arrows. The crater rim diameter is 1.88 kilometres (Maloof et al., 2009).

15.1.2 Elevation

583 metres.

15.1.3 Images

Lonar Crater Lake.

15.2 Context

15.2.1 Geological Setting

The impact crater is believed to have formed about 55 000 years ago due to the impact of a projectile that came from a northerly direction at a velocity of 19.6 Kilometres per hour. The meteorite is estimated to have been 60 metres in diameter weighing a million tons. The crater is 1.8 Kilometres in diameter and 150 metres deep; situated in a plateau (the Deccan Plateau) of basaltic rock; one of only two terrestrial impact craters known to be emplaced in basaltic target rock. Samples from drill cores into the crater floor identified basaltic impact breccias that have been altered by post-impact hydrothermal processes producing an assemblage of secondary alteration minerals such as saponite and carbonate (Hagerty and Newsom, 2003). Lonar crater is also filled with water to create Lonar Lake, a saline soda lake. Amber lake, also called little Lonar is a small crater lake nearby that must have been created by the impact of a sub particle from the Lonar meteorite.

15.2.2 Relevance

Lonar crater is a good analogue for the Moon and Mars for impact processes on these bodies and its geology i.e. impact cratering in basaltic rocks. The composition of the Lonar basalts is similar to martian basaltic meteorites so it is a good analogue for similarly sized impact craters on Mars and the effects impacts have on basalts. Impact-induced hydrothermal systems on Mars and impact melt breccias can also be studied at Lonar as well as impact crater lakes. There are hot water springs inside the lakes and biological nitrogen fixation is occurring here providing astrobiological analogues for Mars.

15.3 Environmental

Climate/Weather	Semi-arid.
Temperature	Summer, 38 °C; winter 28 to 12 °C.
Precipitation Type	Rain
Annual Precipitation	Moderate especially during monsoon season.
Humidity	Low
Wind	
Insolation	

15.4 Infrastructure

15.4.1 Existing

You can trek to the crater lake from town. There is a narrow road lined with houses and shops that after ~1 Kilometres leads to the entrance gate to Dhara temples. There are concrete steps built onto a narrow track into the crater and to the lake plus a narrow track runs around the lake.

15.4.2 Accessibility

Lonar is easily accessible from Mumbai via Aurangabad (a convenient railway station 5 hours away) whilst Jalna is the nearest railway station 3 hours away. The crater itself is ~1kilometres from Lonar town.

15.4.3 Nearest Airport

Mumbai.

15.4.4 Logistics

Rail route usually gets blocked during monsoon season. There are several lodges at Lonar town near the Bus Station. Street food and fresh juice is available in the market. There are plenty of Dhabas and tea stalls in the town. There is also an ATM near the bus stand and there are a few Internet Cafes in town.

15.4.5 Permissions

The crater is publically accessible. 15 temples exist within the crater, respect for them and the pilgrims visiting them is required.

15.4.6 Cost

Variable.

15.4.7 Scheduling

Best time to visit: winter months. Summer hottest: March - May. Monsoon season: June – October.

15.5 Key References

Fredriksson, K., Dube, A., Milton, D.J., and Balasundaram, M.S. (1973) Lonar Lake, India: An Impact Crater in Basalt. *Science* 180:862-864.

Fudali, R.F., Milton, D.J., Fredriksson, K., and Dube, A. (1980) Morphology of Lonar Crater, India: Comparisons and implications. *Earth, Moon and Planets* 23:493-515.

Hagerty, J.J., and Newsom, H.E. (2003) Hydrothermal alteration at the Lonar Lake impact structure, India: Implications for impact cratering on Mars. *Meteoritics &Planetary Science* 38:365-381.

Maloof, A.C., Stewart, S.T., Weiss, B.P., Soule, S.A., Swanson-Hysell, N.L., Louzada, K.L., Garrik-Bethell, I. and Poussart, P.M. (2009) Geology of Lonar Crater, India. *Bulletin of The Geological Society of America* 122:109-126.

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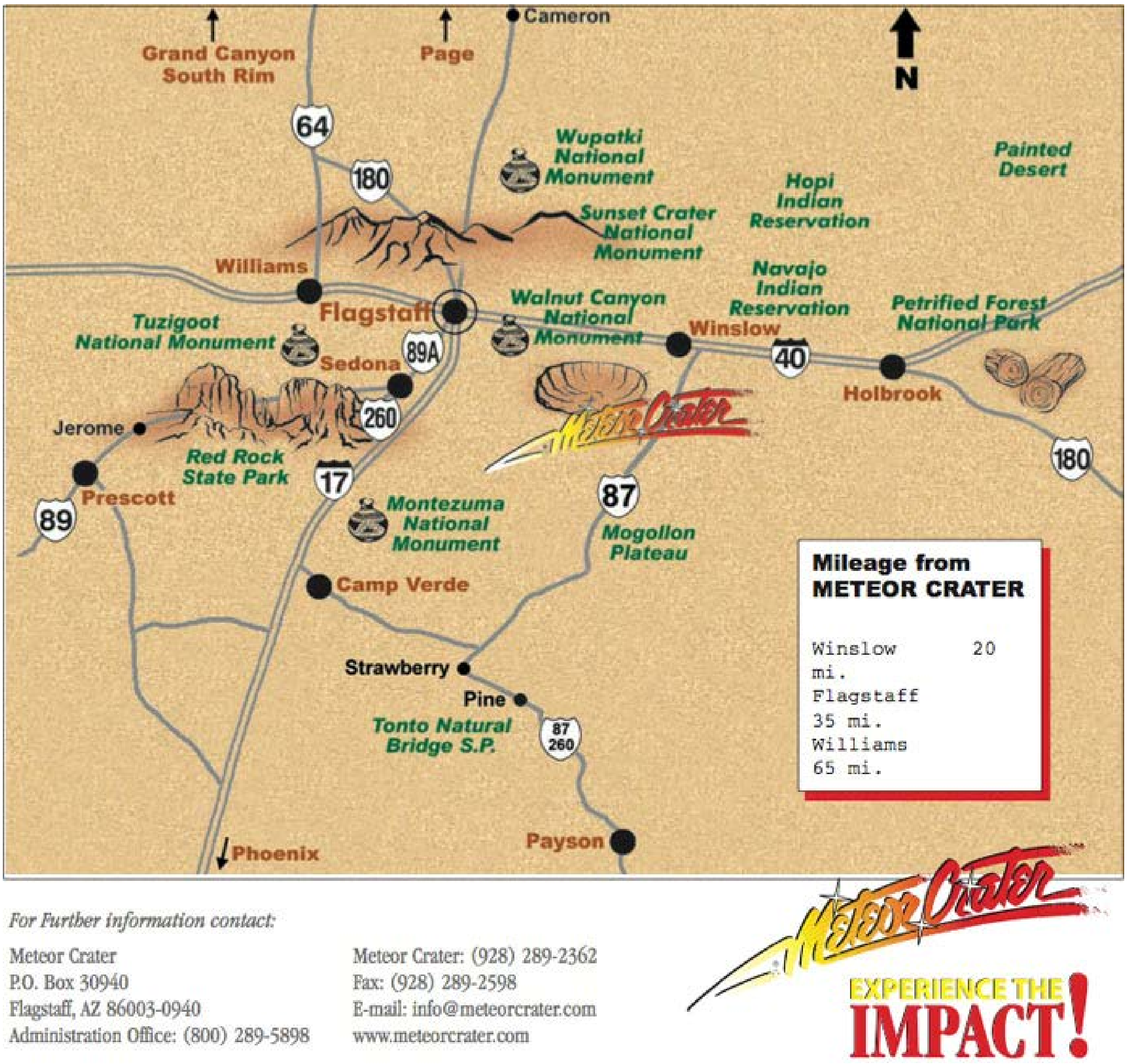
16 Meteor Crater

16.1 Location

Coordinates	35°1'38"N 111°1'21"W
Country/State/Province	USA / Arizona
Continent	North America

16.1.1 Map



16.1.2 Elevation

1700 metres.

16.1.3 Images

This image has a resolution of 2 metres per pixel, and illumination is from the right. Layers of exposed limestone and sandstone are visible just beneath the crater rim, as are large stone blocks excavated by the impact (NASA Earth Observatory).

16.2 Context

16.2.1 Geological Setting

Meteor Crater/ Barringer Crater is a mid-late Quaternary simple impact crater formed when an iron-nickel bolide impacted into Mesozoic sediments, primarily the Moenkopi Shale, Kaibab Limestone and Coconino Sandstone. It is about 1200 metres in diameter, 170 metres deep, and is surrounded by a rim that rises 45 metres above the surrounding plains. At this site there is an ejecta blanket, with flat to hummocky terrain created by emplacement of impact fragmented and shocked Kaibab limestone. Boulders here are up to 2-3 metres in size to <0.25 metres cobbles of primarily Kaibab Limestone in a matrix of shocked limestone and sandstone.

16.2.2 Relevance

Meteor crater and the processes relating to its formation are analogues for both the Moon and Mars. Simple bowl-shaped craters on both planetary bodies can be modelled as well as the ejecta deposits, glass and shocked materials. Potential astrobiological interests exist due to preservation of carbon species within the impact glasses.

16.3 Environmental

Climate/Weather	Arid Desert
Temperature	Ranges from -9 °C (January) to 28 °C (July).
Precipitation Type	Rain and snow.
Annual Precipitation	
Humidity	Low.
Wind	Variable.
Insolation	Average Annual days of sunshine: 288.

16.4 Infrastructure

16.4.1 Existing

The Visitor Centre is on the north side of the crater rim and is open to the public; there is an entrance fee. There is access to a lookout on the north rim. A petrol station and RV Park are located right off the meteor crater road exit which is the best option for a bathroom break.

16.4.2 Accessibility

Meteor Crater is located off I-40 at exit 233, then 6 miles south on the paved road. It is 35 miles east of Flagstaff, and 20 miles west of Winslow. With permissions, you can access dirt roads leading around and up to the south rim of the crater. A 4WD vehicle with good clearance is recommended. All other movement would be by foot.

16.4.3 Nearest Airport

Flagstaff, AZ, is the nearest airport, about 1 hour from the crater.

16.4.4 Logistics

All food and water must be brought into the crater with you, and all forms of waste must be taken out. Accommodations are best in hotels in Flagstaff but you can arrange to camp at the RV park. No one is permitted to stay on site overnight. The nearest hospital is the little Colorado medical centre in Winslow about 25 min driving time or the Flagstaff Medical Centre is 55 minutes away. Bring some source of shade, the climate is quite dry and the sun will beat down on you all day. Bring LOTS of water. Beware of wildlife and stay out of the way of the cattle drive. Meteor crater has a security vehicle monitoring the area at all times and they will stop unknown vehicles.

16.4.5 Permissions

Sponsoring organisation: Meteor Crater Enterprises Inc. Meteor Crater and the visitor centre are on private property owned by the Barringer Family - the surrounding area is still used by the family for cattle farming. If you are not connected with this family, the first step would be to call the visitor centre manager or director and discuss your project. A clear, well- laid out plan is ideal. The visitor centre has two local consulting geologists that advise them on the validity and risk of your project. They rarely permit people to enter the crater itself, often work is completed on the crater rim. Sampling should be discussed with the visitor centre representative and would be on a case-by-case basis.

16.4.6 Cost

Field work here is relatively cheap. A five day trip for four people travelling within North America should cost under $5000.

16.4.7 Scheduling

The ideal time of year to visit would be in late Autumn, October - November when the desert climate will be manageable and the tourist population at a minimum.

16.5 Key References

Bjork, R.L. (1961) Analysis of the Formation of Meteor Crater, Arizona: A Preliminary Report. *Journal of Geophysical Research* 66:3379-3387.

Melosh, H.J. and Collins, G.S. (2005) Planetary Science: Meteor Crater formed by low-velocity impact. *Nature* 434:157.

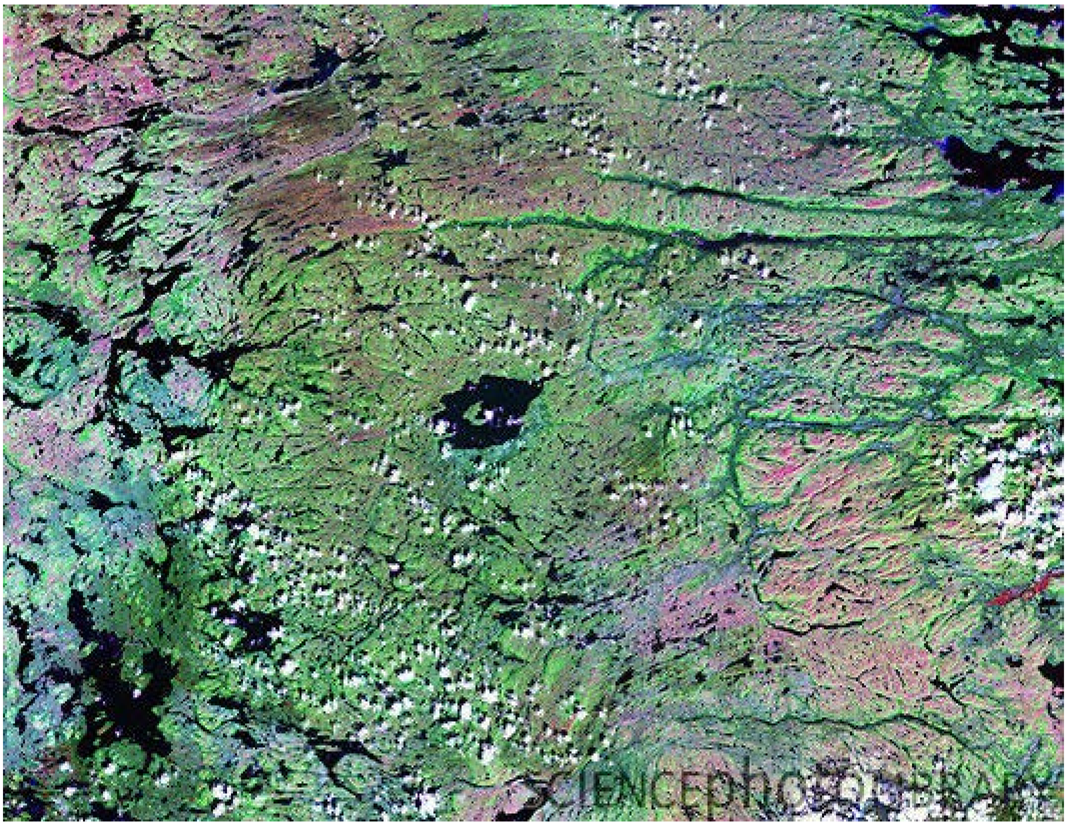
Shoemaker, E.M. (1963) Impact Mechanics at Meteor Crater, Arizona. *In: The Moon Meteorites and Comets*. Edited by: Kuiper, G.P. and Middlehurts, B. The University of Chicago press, Chicago, pp 301.

17 Mistastin Lake Crater

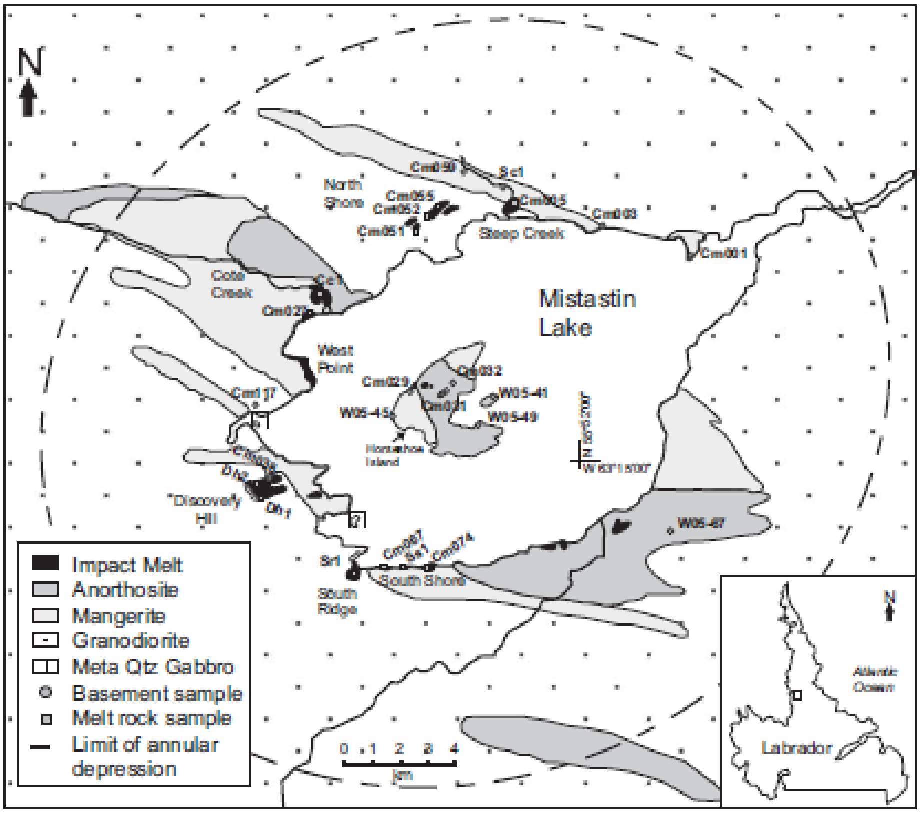
17.1 Location

Coordinates	N 55° 53' W 63° 18'
Country/State/Province	Canada / Labrador
Continent	North America

17.1.1 Map



Mistastin Lake Crater Landsat 7 satellite image in infrared and visible light. Credit: NASA/SCIENCE PHOTO LIBRARY.



Generalized geology map of Mistastin impact structure, modified from Currie(1971), Grieve(1975) and Marion and Sylvestor (2010).

17.1.2 Elevation

338 metres.

17.1.3 Images


Photos from the ILSR analogue mission during the summer of 2011, courtesy of A. Pickergill and C. Marion. Top left: View towards Mistastin Lake; Top right: Aerial view of the camp; Bottom left: The Rover; Bottom right: Anorthosite target rock.

17.2 Context

17.2.1 Geological Setting

The Mistastin Lake impact crater is a 28 Kilometres diameter crater, 36 +/- 4Ma in age. A nearly circular lake occupies the inner 16 kilometres diameter portion of the crater, with two islands named Horseshoe and Bullseye Islands which are the remnants of the central uplift of the crater. A distinct crater rim is also preserved here. The target rocks at Mistastin consist of anorthosite, mangerite and granodiorite. A suite of impactites include: shocked and/or fractured target rocks, monomict breccia, polymict lithic breccia, impact melt-bearing breccia (“suevite”) and impact melt rocks. The crater is located in the northeast end of the Mesoproterozoic Mistastin Batholith, which consists of a series of intrusive bodies, including anorthositic and granitic rocks together with lesser gabbroic rocks (see reviews by Grieve, 1975; and Marion and Sylvester, 2010).

17.2.2 Relevance

Mistastin represents an exceptional lunar analogue site which includes both an anorthositic target and newly-discovered ejecta deposits. It is comparable to many of the larger impact craters on the Moon (150 - 200 kilometres in diameter) when scaled for gravity differences. Examples of geological lunar analogues include: anorthosite at variable shock levels; 80 metres thick units of impact melt rock within the crater rim; suevite composed of a fine grained light grey matrix with abundant plagioclase clasts and melt fragments; and double layer eject deposits i.e. impact ejecta overlain by impact melt rock which is analogous to craters on the Moon where impact melt ponds lie over blocky ejecta blankets (Mader et al., 2010). The crater can also be used to further understand impact processes in general.

17.3 Environmental

Climate/Weather	Transition zone between arctic and sub-arctic climates.
Temperature	-39 to +32 °C. Av winter -17 °C, av summer +10 °C.
Precipitation Type	Rain / freezing rain and snow.
Annual Precipitation	

Humidity	
Wind	
Insolation	Newfoundland has less than 1600 hours per year.

17.4 Infrastructure

17.4.1 Existing

There are cabins around the lake, but they are the Innu's cabins and require special permission to use. The best way to get around the lake is by zodiak, but it is not for beginners - the water is cold and the waves are intimidating. There are a lot of sensitive archaeological sites around the crater, so ATVing is a sensitive issue. Stick to the ATV paths already made.

17.4.2 Accessibility

Mistastin has two official airstrips, East (on a banana shaped esker) and West (on a sandy delta). There is a third on the south shore that might be used. A float plane can also land in a few of the protected bays, primarily on the East end of the lake near the mouth of East Mistastin River.

17.4.3 Nearest Airport

Goose Bay is built around the airport and military base, 340 kilometres from Mistastin. Nain, Voisey's Bay and Natuashish have airports or permanent landing strips less than 200 kilometres distance from Mistastin.

17.4.4 Logistics

A chartered plane or helo or RCMP helo is the only option for evacuation. Nearest hospital is in Goose Bay 340 kilometres away. All food and supplies brought in by helo. The locals call Mistastin - Kamestastin and prefer this term as it is in their native language. Newfoundland has a unique time zone in N.America. 30 minutes ahead of EST and 1.5 hours ahead of central Canada. Labrador itself operates on EST.

17.4.5 Permissions

Mistastin is on Innu lands and permission is required from the Innu Nations, their 'head office' is in Sheshashit, 30 minutes from Goose Bay. Wildlife permit in case of bears is required. Include the Innu in fieldwork, and it is advisable to offer to have representatives to accompany you.

17.4.6 Cost

Costs can range immensely based on your group size and how you plan on getting around. A bare minimum of CAD$15K is required. With two helicopter moves, costs was CAD$27K (for a camp of 2 people). A field campaign of 20 people costs over CAD$100K (mostly chartered flights and helos).

17.4.7 Scheduling

Best time of year to go for weather and bugs is early September - usually.

17.5 Key References

ILSR analogue missions: http://cpsx.uwo.ca/research/analogue-missions.

Grieve, R.A.F. (1975) Petrology and chemistry of impact melt at Mistastin Lake crater, Labrador. Geological Society of America Bulletin 86:1617–1629.

Grieve, R.A.F. (2006) Mistastin. In: Impact Structures in Canada, Earth Sciences Sector Natural Resources Canada, Geological Association of Canada, pp.115–120(Chapter16).

Mader, M.M., Osinski, G.R., Marion, C., Dammeier, R., Shankar, B. and Sylvester, P. (2010) Mistastin impact structure, Labrador: A geological analogue for lunar highland craters. *Nördlingen Ries Crater Workshop.* Abstract #7018.

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17.6 Site Specific Details

17.6.1 Discovery Hill

17.6.1.1 Co-ordinates

17.6.1.2 Physical Characteristics

17.6.1.3 Geochemical Characteristics

17.6.1.4 Astrobiological Characteristics

17.6.1.5 Prior Analogue Usage

17.6.2 Cote Creek

17.6.2.1 Co-ordinates

17.6.2.2 Physical Characteristics

17.6.2.3 Geochemical Characteristics

17.6.2.4 Astrobiological Characteristics

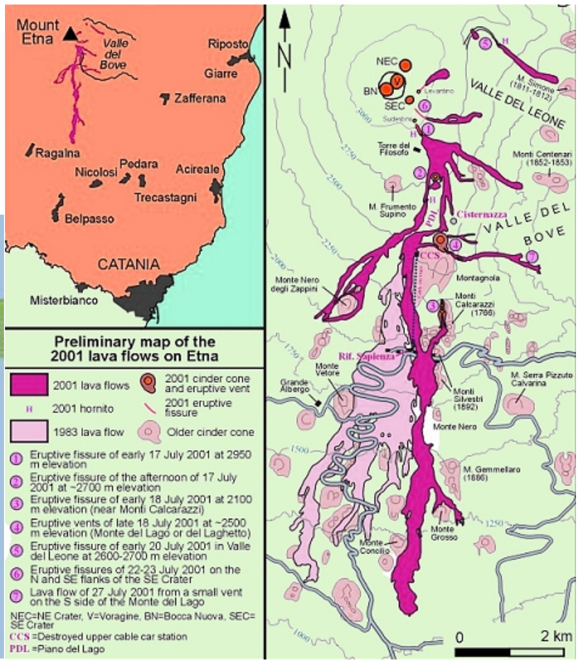
17.6.2.5 Prior Analogue Usage

18 Mt. Etna

18.1 Location

Coordinates	37° 45′ 18″ N, 14° 59′ 42″ E
Country/State/Province	Sicily
Continent	Europe

18.1.1 Map



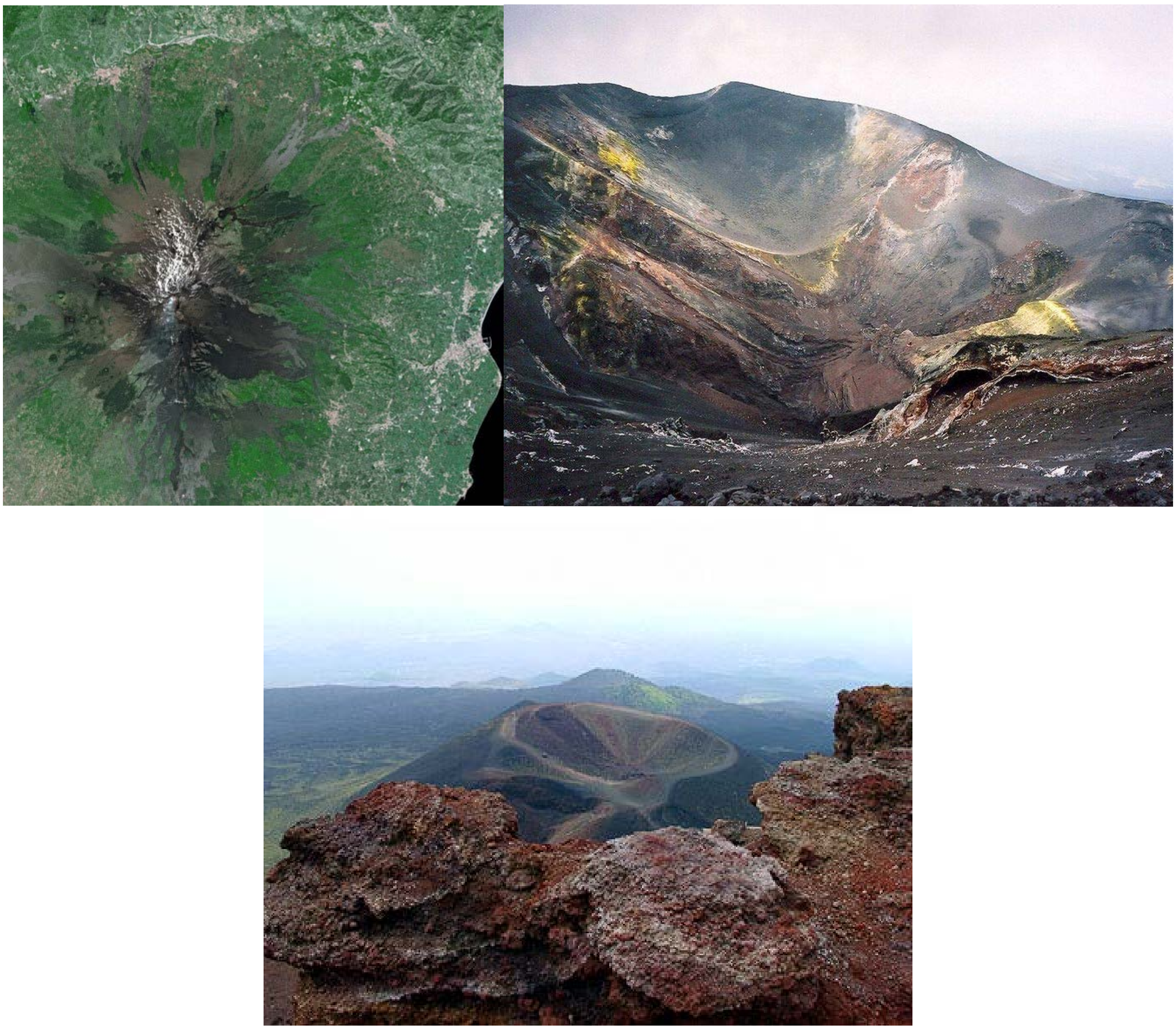
Freeworldmaps.net 2006.Source: http://boris.vulcanoetna.com/gifs

/image/Etna_eruption2001/2001.jpg

18.1.2 Elevation

3350 metres.

18.1.3 Images



Top left: Etna by SPOT satellite (CNES – Spot Image). Top right: Valle del Bove, Mount Etna. A lateral crater of the 2002-2003 eruption near the Torre del Filosofo, about 450 metres below Etna's summit.

18.2 Context

18.2.1 Geological Setting

Mt Etna is an active stratovolcano on the east coast of Sicily that first erupted 500,000 years ago. It lies above the convergent plate margin of the African and Eurasian Plates. Mt. Etna is the tallest active volcano in Europe. The high frequency of eruptions, and the ease of access, has allowed numerous studies of flow-field formation.

18.2.2 Relevance

Mt. Etna acts as an analogue for features on the Moon and Mars for both scientific and robotic studies. Etna also provides examples of volcanic processes that scientists think may occur on Venus.

Individual features of interest include basaltic lavas; volcanoes and the Tharsis Rise on Mars; pyroclastic deposits; and open lava channels on Mars and sinuous rilles on the Moon.

18.3 Environmental

Climate/Weather	A Mediterranean climate; very hot summers and short, mild winters
Temperature	Average annual High of 23.12°C (August), Average annual Low 11.47°C (Jan/Feb).
Precipitation Type	Rain; snow in winter months, snow can be observed year round at the summit of Mt. Etna.
Annual Precipitation	Mean annual precipitation of 547.2mm.
Humidity	Relative humidity is highest in Dec/Jan at 77% with a low of 66% in July.
Wind	The wind averages between 6 - 7 knots each month. July and August can be very hot and dusty if the Sirocco wind is blowing from the Sahara.
Insolation	Sunshine occurs here for most of the year.

18.4 Infrastructure

18.4.1 Existing

18.4.2 Accessibility

Access to the mountain is good with a cable car; 4WD and trekking available. Mt. Etna, is a place where ordinary travellers can visit.

18.4.3 Nearest Airport

Catania-Vincenzo Bellini Airport (IATA: CTA, ICAO: LICC) is located 2.3 NM (4.3 kilometres; 2.6 mi) southwest of Catania, the second largest city on the Italian island of Sicily.

18.4.4 Logistics

Accommodation and restaurants can be found in Rifugio Sapienza and the surrounding Parco dell'Etna.

18.4.5 Permissions

Permits should be sought from the Parco dell'Etna.

18.4.6 Cost

Flights to Catania-Vincenzo Bellini Airport, car hire and accommodation are relatively cheap.

18.4.7 Scheduling

Summer months best due to the favourable weather conditions.

18.5 Key References

Bailey, J.E., Harris, A.J.L., Dehn, J., Calvari, S., Rowland, S.K. (2006) The changing morphology of an open lava channel on Mt. Etna. *Bull Volcanol* 68:497-515.

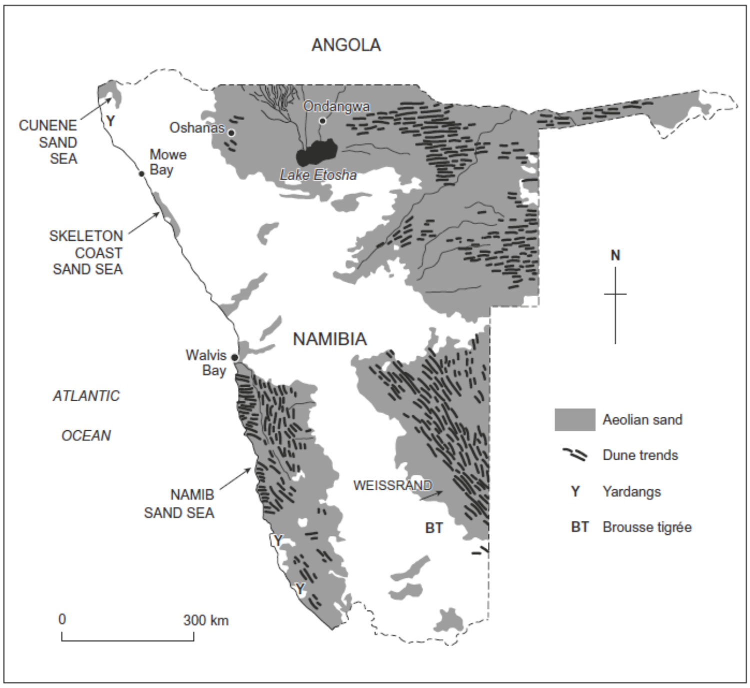
Valerie Ciarletti, Stephen Clifford, Andre-Jean Vieau, Benjamin Lustrement, Rafik Hassen-Kodja, Philippe Cais, and Dirk Plettemeier. (2011) The 2018 ExoMars WISDOM GPR on Mt. Etna: First Field test Results in a Mars Analogue Volcanic Environment. *Geophysical Research Abstracts* 13:EGU2011-12723-1.

19 The Namib Desert

19.1 Location

Coordinates	Extends from the Olifants River in South Africa 32 °S to the Carunjamba River in Angola 14° S. Gobabeb is located at 23°34'S, 15°03'E.
Country/State/Province	Namibia
Continent	Africa

19.1.1 Map



Location of the Namib Sand Seas (Bourke and Goudie, 2009)

19.1.2 Elevation

From the Atlantic coast eastward, the Namib gradually ascends in elevation, reaching up to 200 kilometres inland.

19.1.3 Images

Top: Slim and normal barchan dunes from southern Namibia. Average a/c at this location is 0.5.
Bottom: A proto-megabarchan composed of individual barchans in the southern Namib. Images reproduced with permission from Google Earth and DigitalGlobe (Bourke and Goudie, 2009).

19.2 Context

19.2.1 Geological Setting

The Namib Desert stretches for more than 2000 kilometres (1200 mi) along the Atlantic coasts of Angola, Namibia, and South Africa. It is the oldest desert in the world. The Gobabeb research station lies at the intersection of three key Namib ecosystems: the dune sea, the rocky gravel plains, and the dry Kuiseb River, a linear oasis which cuts through the others. These ecosystems support a striking abundance of life, including many endemic species. The site is on the boundary between the western fog-belt and the inland rainfall areas, and lies approximately where the winter and summer rainfall areas merge.

19.2.2 Relevance

The desert provides analogues for both the Moon and Martian features such as deserts; sand and gravel; Individual dunes on Mars that have been classified as barchan, barchanoid, transverse, or complex dunes. Transverse dunes are the most common dune form with examples of star and linear dunes. Sand seas found near the coast contain gravel plains and scattered mountain outcrops are found further inland. The sand dunes, some of which are 300 metres high and span 32 kilometres long, are the second largest in the world and are closest in size to those on Mars. Southern Namib (between Lüderitz and the Kuiseb River) comprises a vast dune sea, ranging in colour from pink to vivid orange. In the Sossusvlei area, several dunes exceed 300 metres in height. The barchans tend to occur in the proximity of the coast. Chemically, the Namib Desert is almost completely lacking water bodies on the surface as most rivers flow underground and/or are dry for most of the year mimicking conditions proposed for Mars today and in the past. Finally, life can be studied in these conditions of low water availability and high temperatures.

19.3 Environmental

Climate/Weather	Coastal desert, hyper-arid.
Temperature	Coast: 9-20 °C; inland: variable sometimes > 45 °C with freezing temperatures overnight.
Precipitation Type	Rain and fog.
Annual Precipitation	2 mm in the most arid regions to 200 mm at the escarpment.
Humidity	High in coastal regions creating fog, less inland.
Wind	Sand moving winds from south to south west.
Insolation	High.

19.4 Infrastructure

19.4.1 Existing

The Gobabeb Research Station. All information on the facilities and costs can be found at http://www.gobabebtrc.org/.

19.4.2 Accessibility

There are good roads between Windhoek and the coastal towns (Walvis Bay and Swakopmund). Then it’s dirt roads to sites (i.e. you will need a 4WD). There are several reputable hire companies online.

19.4.3 Nearest Airport

Windhoek is the nearest airport but there is a private airstrip available for chartered flights. Permission to land is required, contact Gobabeb.

19.4.4 Logistics

There is limited fuel away from the main cities and roads, so bring your own fuel and supplies. Bring your own drinking water. The nearest town, Walvis Bay, is 120 kilometres away. Fog is common and coastal regions can experience 180 days of fog per year.

19.4.5 Permissions

Apply well ahead of travel date (3-6 months) because there is always a delay in processing the paperwork. Good agency to use is: Marietha Bouwer Agencies, 8th Floor, Capital Centre Building, Windhoek, Namibia, Tel : + 264 61 255710/1, Fax : + 264 61 255712

19.4.6 Cost

Depends upon the work. Standard costs of flights, accommodation and transport.

19.4.7 Scheduling

The best time to travel is in the southern hemisphere winter. However, it's also high tourist season so accommodation and vehicles may have limited availability. Book well ahead of time.

19.5 Key References

Bourke, M.C. (2010) Barchan dune asymmetry: Observations from Mars and Earth. *Icarus* 205:183-197.

Bourke, M.C. and Goudie, A.S. (2009) Varieties of barchan form in the Namib Desert and on Mars. *Aeolian Research* 1:45-54.

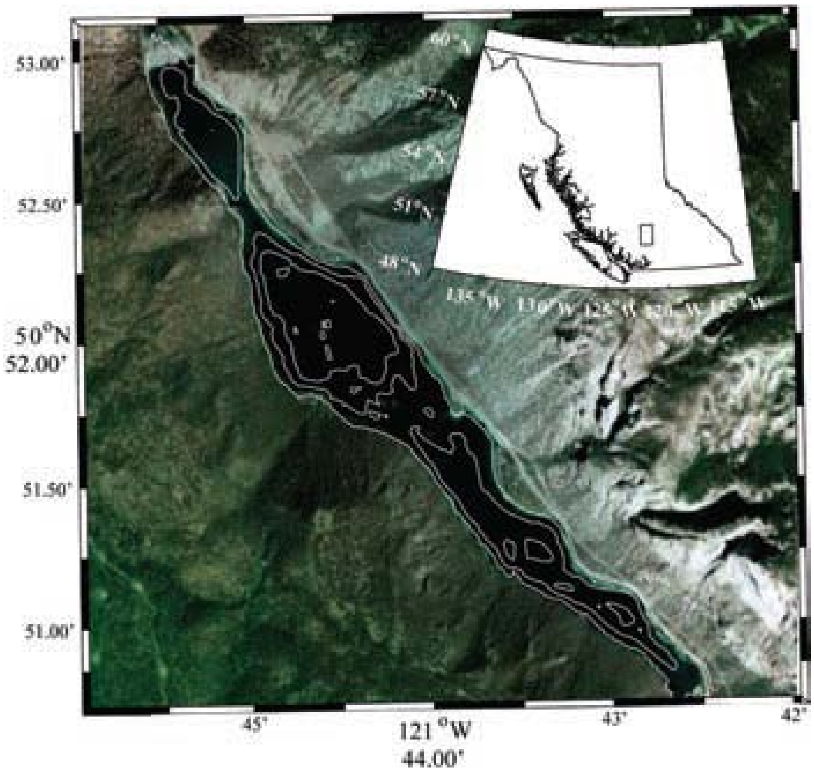
Bourke, M.C., Bullard, J.E. and Barnouin-Jha, O.S. (2004) Aeolian sediment transport pathways and aerodynamics at troughs on Mars. *Journal of Geophysical Research* 109: E07005, doi:10.1029/2003JE002155.

20 Pavilion Lake

20.1 Location

Coordinates	50°51’N, 121°44’W
Country/State/Province	Canada / British Columbia
Continent	North America

20.1.1 Map



A Google Earth image of Pavilion Lake with 20 metres depth contours is shown in white. Inset shows location of Pavilion Lake within the province of British Columbia, Canada (Lim et al., 2011).

20.1.2 Elevation

820 metres.

20.1.3 Images

Top: Pavilion lake from above and from the lake shore; Bottom: Microbialites and a DeepWorker single-person submersible used to analyse and sample them (Credit: Donnie Reid).

20.2 Context

20.2.1 Setting

Pavilion Lake is a 5.7 kilometres-long slightly alkaline, groundwater-fed, freshwater lake located in Marble Canyon in the interior of British Columbia, Canada, with incredible rock structures. Rocks identified underwater here are similar to ancient stromatolites, namely microbialites, which are organosedimentary structures. Microbialites are commonly formed through the trapping and binding of sediment and/or mineralization of microbes. Pavilion and Kelly Lakes contain microbialites, whilst Cariboo Plateau has carbonate-rich lakes with microbial mats.

The Pavilion Lake Research Project is part of the Canadian Space Agency's (CSA) Analogue Research Network because of its connections to the understanding of life in the universe and human space exploration. Understanding how modern microbialites grow and the signatures that they leave behind in the rock record provide a window into the earliest life forms on Earth. If life did evolve on other planets, the structures at Pavilion Lake might also be similar to those preserved within the planet's rock record.

In terms of exploration analogies for human space exploration, submersible pilots and divers are exposed to harsh conditions that require life support systems to study the microbialites. This is analogous to astronauts in space who require space suits and rovers to explore the surface of the

Moon, and in the future, Mars. Exploration methods are closely monitored to learn how to efficiently explore new planets and conduct science in extreme environments.

20.2.2 Relevance

Pavilion Lake provides an analogue environment for both the Moon and Mars.

(1) Science - the structures at Pavilion Lake are similar to those found on the early Earth, and are among the most structurally diverse of microbialites in the modern world. There are microbial mats here, as well as biosignatures, bio mineralisation and magnetotactic bacteria, which allows for life detection strategies to be tested. Alkaline and hypersaline lakes can be studied.

(2) Exploration – the operational manner in which the PLRP team conducts science at Pavilion Lake presents an analogue for human lunar and martian missions.

20.3 Environmental

Climate/Weather	Cold semi-arid climate.
Temperature	Over the course of a year, the temperature typically varies from -5°C to 30°C and is rarely below -15°C or above 36°C.
Precipitation Type	Rain and light snow.
Annual Precipitation	Wettest month is December with 34mm of precipitation. The driest month is August with 11mm of precipitation.
Humidity	The relative humidity typically ranges from 28% (dry) to 93% (very humid) over the course of the year.
Wind	Typical wind speeds vary from 0 m/s to 11 m/s rarely > 15 m/s.
Insolation	Ranges from 0.82 kWh/m²/day (December) to 5.64 kWh/m²/day (June).

20.4 Infrastructure

20.4.1 Existing

There are roads into the Provincial Park, a Visitors centre, park rangers, and camp sites.

20.4.2 Accessibility

Marble Canyon Provincial Park is located on Hwy 99, 22 miles (35 kilometres) northeast of Lillooet and 25 miles (40 kilometres) west of Cache Creek, British Columbia.

20.4.3 Nearest Airport

Kamloops Airport (YKA) is 133 Kilometres or you could fly to Vancouver International Airport which is 300 Kilometres away.

20.4.4 Logistics

Marble Canyon Provincial Park campground has capacity for 30 vehicle/tent sites. The campground is open year round, with fees collected April to October. Only basic facilities are provided – picnic tables, pit toilets, fire pits, firewood and water. There is no boat launch provided. Note, the nearest public telephone is at the Pavilion Store, 10kilometres west of Highway 99.

20.4.5 Permissions

Permissions not needed to enter the park, however, to conduct research there permits may be needed depending upon the research to be conducted. A strong relationship should be built between field teams and the Ts'Kw'aylaxw First Nation and local Pavilion Lake residents in Clinton.

20.4.6 Cost

Vehicle Accessible Camping Fee: $16.00 per party / night in Marble Canyon Provincial Park campground. Flights to Kamloops or Vancouver are reasonably priced.

20.4.7 Scheduling

Summer provides the best access but increased tourist traffic on highways, early Autumn is the most comfortable time to go as fewer bugs; early Spring good but can be wet. Winter is snow covered and cold.

20.5 Key References

http://www.pavilionlake.com/history-of-plrp.php

Léveillé, R. (2009) Validation of astrobiology technologies and instrument operations in terrestrial analogue environments. Comptes Rendus Palevol. 8:637-648.

Lim, D. S.; Laval, B.; Slater, G.; Andersen, D.; Airo, A.; Mullins, G.; Schulze-Makuch, D.; Cady, S.; McKay, C. (2005) Pavilion Lake, British Columbia, Canada - An investigation of potentially unique freshwater microbialites, and their application to Mars exploration. *AGU Fall Meeting* Abstract #P42B-06.

Darlene Lim, Allyson Brady, Andrew Abercromby, Dale Andersen, M Andersen, Richard Arnold, John Bird, Harry Bohm, L Booth, Sherry Cady, Zena Cardman, Amy Chan, Olivia Chan, Caroline Chanard, Ben Cowie, Alfonso Davila, Matthew Deans, William Dearing, Mike Delaney, Michael Downs, Terrence W. Fong, and et al. (2011) A historical overview of the Pavilion Lake Research Project - Analog science and exploration in an underwater environment ," Analogs for Planetary Exploration, Special Paper 483., W. B. Garry and J. Bleacher , ed., Geologic Society of America.

Osinski, G.R., Léveillé, R., Berinstain, A., Lebeauf, M., Bamsey, M. (2006) terrestrial Analogues to Mars and the Moon: Canada’s Role. *Geoscience Canada* 33:175-188.

20.6 Site Specific Details

20.6.1 Kelly Lake

20.6.1.1 Co-ordinates

20.6.1.2 Physical Characteristics

20.6.1.3 Geochemical Characteristics

20.6.1.4 Astrobiological Characteristics

20.6.1.5 Prior Analogue Usage

20.6.2 Cariboo Plateau

20.6.2.1 Co-ordinates

20.6.2.2 Physical Characteristics

20.6.2.3 Geochemical Characteristics

20.6.2.4 Astrobiological Characteristics

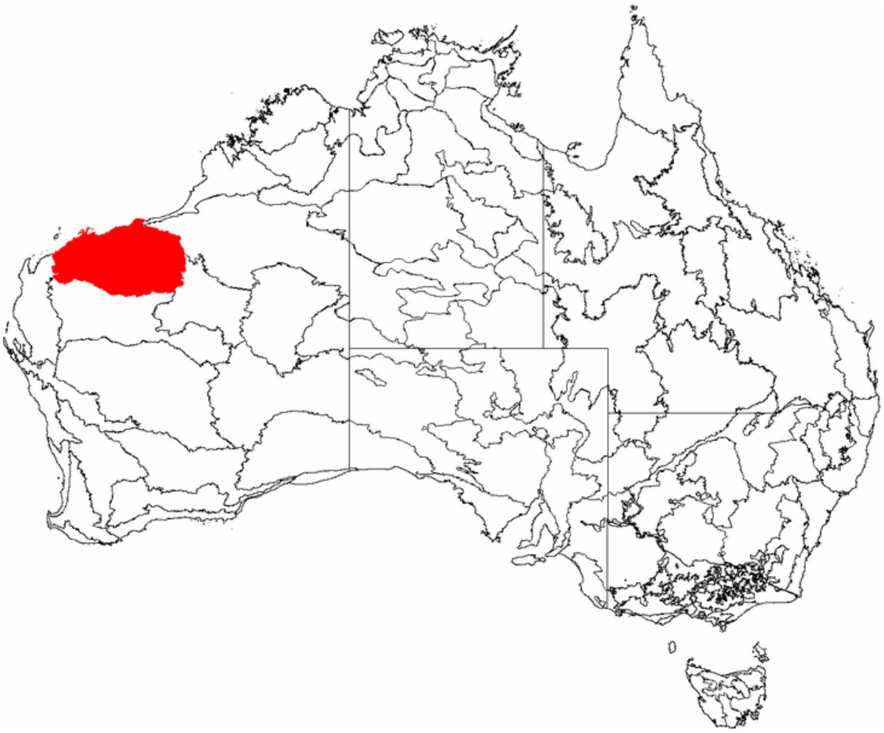
20.6.2.5 Prior Analogue Usage

21 Pilbara

21.1 Location

Coordinates	21°S 119°E
Country/State/Province	Australia
Continent	Australia

21.1.1 Map



The Pilbara region in red, Western Australia.

21.1.2 Elevation

Variable.

21.1.3 Images

Stromatolites at Pilbara (courtesy of F.Westall).

21.2 Context

21.2.1 Geological Setting

The 3.5 Ga Dresser Formation in the North Pole Dome of the Pilbara Craton, Western Australia is the geological setting of Earth's oldest stromatolites (Walter et al., 1980) and microfossils (Ueno et al., 2001a,b, 2004). The Dresser Formation is a package of interbedded chert ± barite units and pillow basalts within the lower part of the ca. 3.52–3.42 Ga Warrawoona Group of the Pilbara Supergroup. Exposed in the North Pole Dome, the Dresser Formation is preserved as a ring of hills, up to 14 kilometres in diameter (Van Kranendonk, 2000; Van Kranendonk et al., 2002, 2007; Blewett et al., 2004). The fossiliferous, bedded chert–barite unit at the base of the Dresser Formation varies between 4 and 60m thick. It is composed of predominantly bedded grey, white, black and locally red chert, thick units of coarsely crystalline barite in layers sometimes metres thick and oriented parallel, or discordant, to bedding, conglomerate, sandstone, carbonate, and stromatolitic laminates (Lambert et al., 1978; Walter et al., 1980; Groves et al., 1981; Hickman, 1983; Buick and Dunlop, 1990; Nijman et al., 1998; Van Kranendonk, 2000, 2006). It is overlain by pillowed komatiitic basalt affected by greenschist-facies metamorphism, and underlain by spinifex-textured metabasalt that is pervasively affected by intense hydrothermal alteration.

Fossil stromatolites in the Dresser Formation include domical and stratiform varieties with wrinkly laminations, and coniform stromatolites in chert with well-defined bedding, including ripples. Evidence of diverse stromatolites has been described from the Strelley Pool Chert within the North Pole Dome (Hofmann et al., 1999; Van Kranendonk et al., 2001; Allwood et al., 2006; Van Kranendonk, 2006, 2007). Filamentous microfossils were described by Awramik et al. (1983, 1988), Schopf (1993) and Schopf et al. (2002, 2007) at other sites within the East Pilbara, plus carbonaceous filaments have been described from silica veins that underlie the bedded chert–barite units and have been interpreted as microfossils of chemoautotrophs (Ueno et al., 2001a,b, 2004, 2006). However, the biogenicity of such structures has been challenged.

21.2.2 Relevance

Pilbara is an analogue for Mars and can provide insights into the origins of life on Earth and Mars and the preservation potential for life in general. Volcanic sediments; metamorphism of volcanics and fossils; aqueous alteration and hydrothermal mineralisation within volcanics can be studied;

combined with astrobiological studies into the preservation of carbon over billions of years; and the identification of fossils leading to the development of life detection strategies.

21.3 Environmental

Climate/Weather	Desert.
Temperature	Typically varies from 13°C to 36°C
Precipitation Type	Light rain and thunderstorms.
Annual Precipitation	309.1 mm.
Humidity	Highly variable:16% to 91%
Wind	Low: 1 m/s to 10 m/s.
Insolation	Between 11 and 13 hours sunshine per day on average.

21.4 Infrastructure

21.4.1 Existing

Small town of Marble Bar is in the middle of the field area. No research stations or camps outside of this town.

21.4.2 Accessibility

Tarred and untarred roads are found in the area. Field areas are pretty remote, but many outcrops are accessible by untarred roads depending on the rains.

21.4.3 Nearest Airport

The nearest airport is Port Hedland or Caruthers.

21.4.4 Logistics

There is a hospital at Port Hedland. Marble Bar has a store, hotel, motel, camp ground, nursing post. Can camp in the field area but no infrastructure for this, must bring own drinking water. Satellite radio recommended to make daily contact calls. Dangerous snakes and spiders are found in the area but are not overly active during the winter. Minimum of 2 people is recommended for safety per expedition.

21.4.5 Permissions

No permissions are needed to work here that we have been made aware of. Obviously if crossing private land or property on the way to sites, get permission from the landowners.

21.4.6 Cost

4 people, 1 week, including airfare from Europe 18000 - 20000 Euros.

21.4.7 Scheduling

Best time to visit is in the southern winter as summers can get very hot. During the dry season bush fires are common.

21.5 Key References

Allwood, A.C., Walter, M.R., Burch, I.W. and Kamber, B.S. (2007) 3.43 billion-year-old stromatolites reef from the Pilbara Craton of Western Australia: Ecosystem-scale insights to early life on Earth. *Precambrian Research* 158:198-227.

Van Kranendonk, M.J., Philippot, P., Lepot, K., Bodorkos, S., Pirajno, F. (2008) Geological setting of Earth's oldest fossils in the ca. 3.5 Ga Dresser Formation, Pilbara Craton, Western Australia. *Precambrian Research* 167:93-124.

21.6 Site Specific Details

21.6.1 Dresser Formation

21.6.1.1 Co-ordinates

21.6.1.2 Physical Characteristics

21.6.1.3 Geochemical Characteristics

21.6.1.4 Astrobiological Characteristics

21.6.1.5 Prior Analogue Usage

21.6.2 Strelley Pool Chert

21.6.2.1 Co-ordinates

21.6.2.2 Physical Characteristics

21.6.2.3 Geochemical Characteristics

21.6.2.4 Astrobiological Characteristics

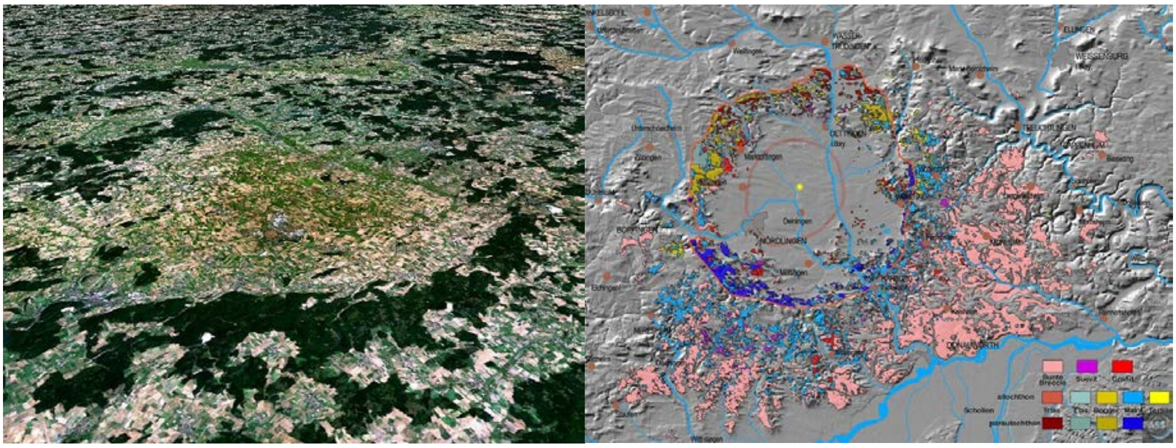
21.6.2.5 Prior Analogue Usage

22 The Ries Impact Crater

22.1 Location

Coordinates	N 48° 53' E 10° 37'
Country/State/Province	Germany / Western Bavaria / Nördlinger
Continent	Europe

22.1.1 Map



Nördlinger Ries, viewed from the southwest, created with NASA WorldWind using Landsat 7 satellite image. Within the Ries crater, the city of Nördlingen stands out. Digital Elevation Model with selected overlain geology.

22.1.2 Elevation

Nördlingen lies at 441 metres.

22.1.3 Images

A) Suevite overlying Bunte Breccia at Aumühle quarry. Photo: G. Osinski, Location: 3 kilometres inside the northeast crater rim. Scale: Distance from left to right is 100 metres. B) Bunte (= multicoloured) breccia ejecta on top of Malmian limestones. Gundelsheim quarry

22.2 Context

22.2.1 Geological Setting

The mid-Miocene (14.6 + 0.2 Ma) Ries impact structure located in southern Germany is arguably one of the best-characterized and best-preserved terrestrial impact structures. Ries is a complex crater with a diameter of ~24 kilometres. The two-layer target is comprised of dominantly Mesozoic flat lying sediments that unconformably overlie crystalline Hercynian basement. Impactite units are well preserved; the glass-bearing impact breccia or surficial "suevite" comprises one of four main proximal ejecta deposits. Glass clasts are typically vesiculated, schlieren-rich mixtures containing abundant mineral and lithic fragments. Detailed geochemical and petrological study of the Ries glasses is presented elsewhere (Osinski, 2003). Post-impact hydrothermal alteration has been well documented at the Ries impact structure.

22.2.2 Relevance

The Ries impact crater is relevant for both the Moon and Mars through the study of impact crater morphology and processes i.e. mid-size complex impact craters; impact ejecta and glasses and phyllosilicates. Astrobiologically, it has recently become the subject of studies into the ability of life to inhabit impact glasses.

22.3 Environmental

Climate/Weather	Temperate.
Temperature	July and August hottest with max daily temperatures > 37°C.
Precipitation Type	Rain and snow.
Annual Precipitation	June and July wettest months with a monthly average >50 mm.
Humidity	High in the summer months.
Wind	Variable
Insolation	

22.4 Infrastructure

22.4.1 Existing

Field locations around the impact crater are near small towns for daily supplies. There is a post office in Nördlingen for shipping samples.

22.4.2 Accessibility

Sites are easily accessible by car followed by a short hike along moderate terrain. Good hiking shoes and long pants and long sleeved shirts are recommended as protection against sun, bugs, and stinging nettles. Car rental is available in Stuttgart, be sure to specify an automatic in advance if a manual transmission is unsuitable. It is a 3 hour drive into Nördlingen from the airport.

22.4.3 Nearest Airport

Stuttgart International Airport is ~150 kilometres to the east, this is an easy drive and is the recommended route. Frankfurt International Airport is ~300 kilometres to the north.

22.4.4 Logistics

The nearest hospital is in Nördlingen, Stoffelsberg 4, D-86720, Nördlingen, phone number: ++49-9081-2990. Pharmacies are for prescription medication only. Two species of poisonous snakes exist here. For active quarries a hard hat, steel toed shoes, safety glasses, vest, ear protection recommended. Sun protection and rain gear are highly recommended for summer months. Many quarries do not offer shade. There are often problems with using credit cards (even visa) carry enough cash. Not much English is spoken in the area.

22.4.5 Permissions

The area is a registered Geopark, run and maintained by the nearby ‘Rieskrater Museum’. Special permission is required to sample and visit most sites. Many sites are active or abandoned cement quarries. Permission is required for access to the quarries. Contact the museum to arrange samples and access to an extensive drill core library. Gisela Poesges (Poesges@noerdlingen.de) is extremely helpful in gaining access and arranging field excursions.

22.4.6 Cost

Budget ~$1000 CND (£750)/ week for a field party of 4. Costs include car rental, hotel, meals.

22.4.7 Scheduling

Travel in the summer months (May – September). Possible snow cover from October – April. In the summer, June and July are the wettest months and July and August are the hottest. Travel in the spring, late April – early June, to avoid heat and heavy rain.

22.5 Key References

Osinski, G. R. Impact glasses in fallout suevites from the Ries impact structure, Germany: An analytical SEM study. Meteoritics & Planetary Science 38, 1641-1667 (2003).

Pohl, J., Stöffler, D., Gall, H. & Ernstson, K. in Lunar Science Institute topical conference ; Symposium on planetary cratering mechanics, Flagstaff, Ariz.United States edn (eds D. J. Roddy, R. O. Pepin, & R. B. Merrill) (Pergamon Press New York N.Y. United States (USA)).

Von Engelhardt, W. Distribution, petrography and shock metamorphism of the ejecta of the Ries Crater in Germany; a review; Cryptoexplosions and catastrophes in the geological record, with a special focus on the Vredefort Structure. Tectonophysics\ 171\, 259\ (1990).

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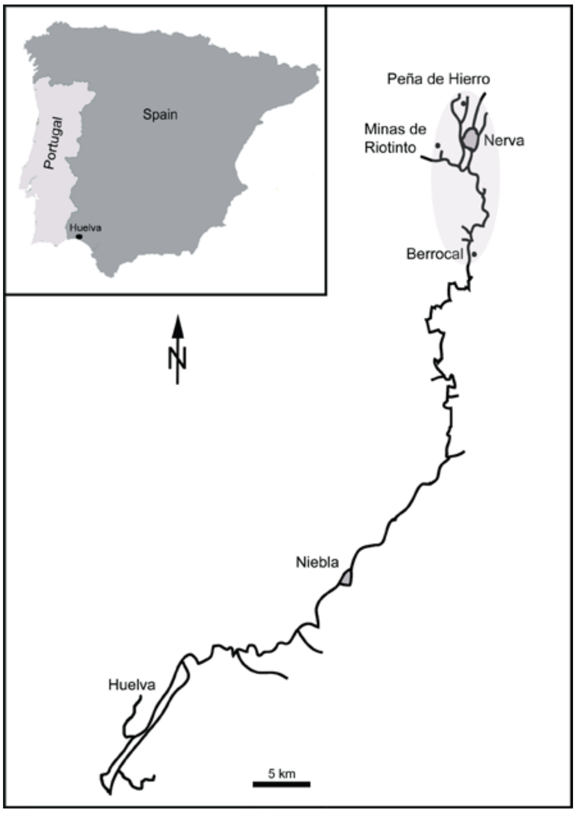
23 Rio Tinto

23.1 Location

Coordinates	Huelva is located at 37°15’N 6°57’W
Country/State/Province	SW Spain / Nerva to Huelva
Continent	Europe

23.1.1 Map

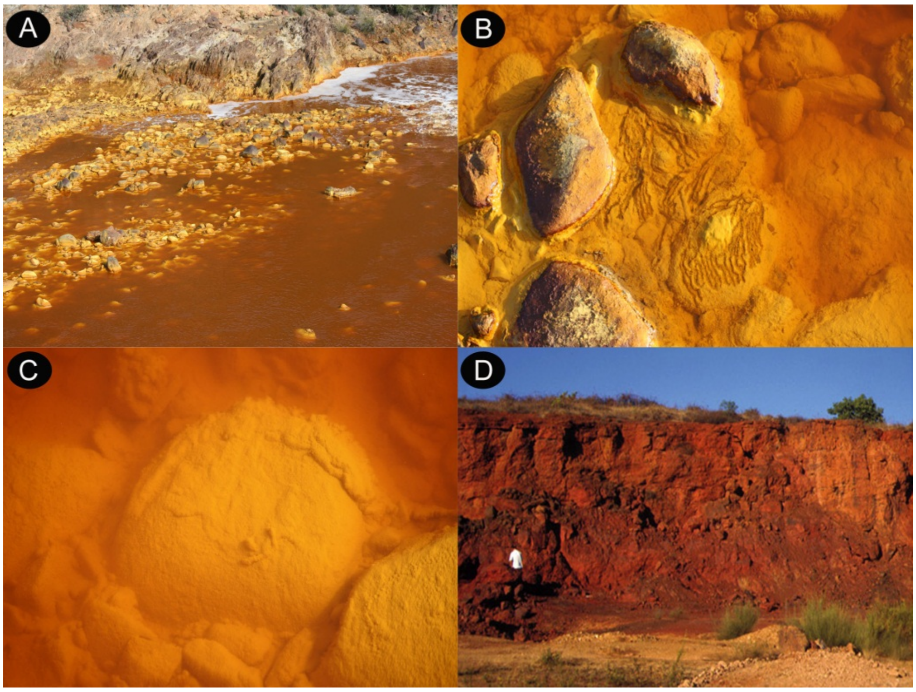


The Rio Tinto River and its location within Spain (Preston et al 2011).

23.1.2 Elevation

Huelva is located at 54m above sea level.

23.1.3 Images



Field photographs of the different deposits sampled in this study. (A) The modern river channel composed of dramatic concretions of cobbles, cemented together with iron precipitates at Berrocal. (B) Hydrated iron oxides coating cobbles on the river bed. Tracks visible indicating the locations of samples taken. (C) Close-up view of the hydrated iron oxides and cobble coatings on the river floor. These layers were peeled off for preservation and analysis. (D) The old river terrace outcrops formed 2.1 Ma (Fernández-Remolar & Knoll, 2008). Adapted from Preston et al (2011).

23.2 Context

23.2.1 Geological Setting

The Tinto River system originates at Peña de Hierro in the middle of the Iberian Pyrite Belt, one of the world's richest regions of polymetallic sulphide deposits (van Geen et al., 1997), and flows into the Atlantic Ocean at Huelva. The basin of the Tinto River covers an area of 1676 Km^2 with the 100-kilometres long acidic river containing a high concentration of heavy metals in solution. The river flows downhill at a shallow gradient (0.6%), which facilitates the development of active microbial communities on the riverbed. The river is subject to a Mediterranean type regime, with the highest flows occurring during the winter (8.1 m^3 s^{-1}) and the lowest in the summer (0.07 m^3 s^{-1}) (M.O.P.U. 1988). The pH remains at a mean of 2.3 year-round produced by the buffer effect of high ferric iron concentrations (López-Archilla et al., 2001; Fernández-Remolar et al., 2008). Rio Tinto is a natural acid rock drainage system, which refers to the creation of highly acidic conditions via the weathering of rocks containing base metal sulphide minerals. The abundance of sulphide minerals, mainly pyrite and chalcopyrite, provides the necessary substrate for the development of chemolithotrophic bacteria whose active metabolism is responsible for the extreme conditions of the habitat (Singer & Stumm, 1970).

23.2.2 Relevance

Rio Tinto is an excellent analogue site for Mars. It includes an acidic system; ancient river channels and deposits; iron-oxide and sulphate deposits; extremophile environments and excellent examples of the preservation of fossils and biosignatures.

23.3 Environmental

Climate/Weather	A temperate or Mediterranean climate.
Temperature	Average annual temperature is 18.1 °C.
Precipitation Type	Rain.
Annual Precipitation	Average annual precipitation of 490 mm.
Humidity	Average annual humidity ~ 64%.
Wind	Variable
Insolation	Average of 8 hours sunshine per day.

23.4 Infrastructure

23.4.1 Existing

Laboratory close to the headwaters of the Tinto River contains a glove box. Basic shops and supermarkets are found in the area and most hardware stores stock tools that can be used for fieldwork.

23.4.2 Accessibility

Excellent access to the field sites by car. Some specific sites are away from the roads but can be reached by an easy hike.

23.4.3 Nearest Airport

Seville. Buses leave Seville and Huelva daily to Rio Tinto.

23.4.4 Logistics

There is a hospital in Rio Tinto; two hotels Hotel Vazquez Díaz (Nerva) and Hotel Atalaya (Rio Tinto) and the hotel water is drinkable.

23.4.5 Permissions

Contact Fundación Rio Tinto, which owns the lands where Rio Tinto headwaters and springs are located. Downstream lands are fully open for visiting and sampling.

23.4.6 Cost

1000 euros per team member each for 10 days at field site and staying in hotels should be expected.

23.4.7 Scheduling

Accessible all year, however May and October are the best months.

23.5 Key References

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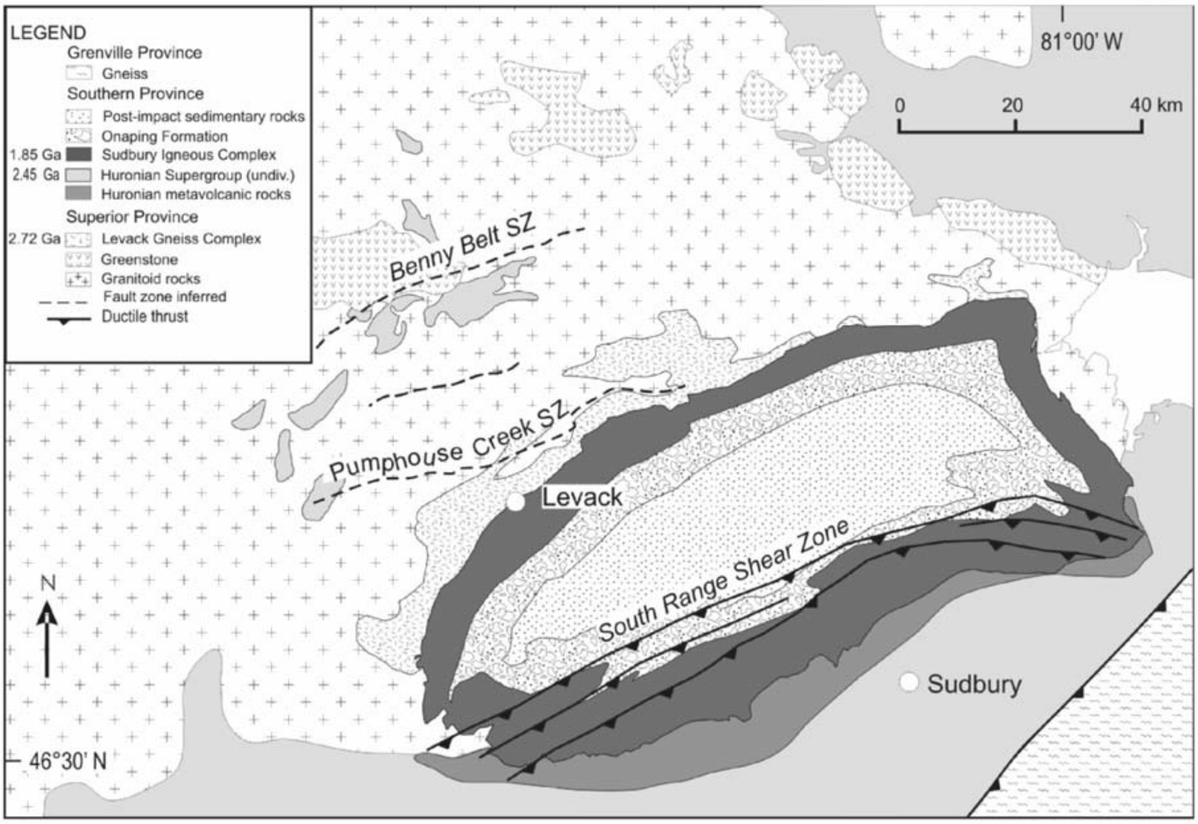
Preston, L.J., Shuster, J., Fernández-Remolar, D., Banerjee, N.R., Osinski, G.R., and Southam, G. (2011) The preservation and degredation of filamentous bacteria and biomolecules within iron oxide deposits at Rio Tinto, Spain. *Geobiology* 9:233-249.

24 Sudbury Impact Crater

24.1 Location

Coordinates	46°36'N 81°11'W
Country/State/Province	Canada / Sudbury / Ontario
Continent	North America

24.1.1 Map

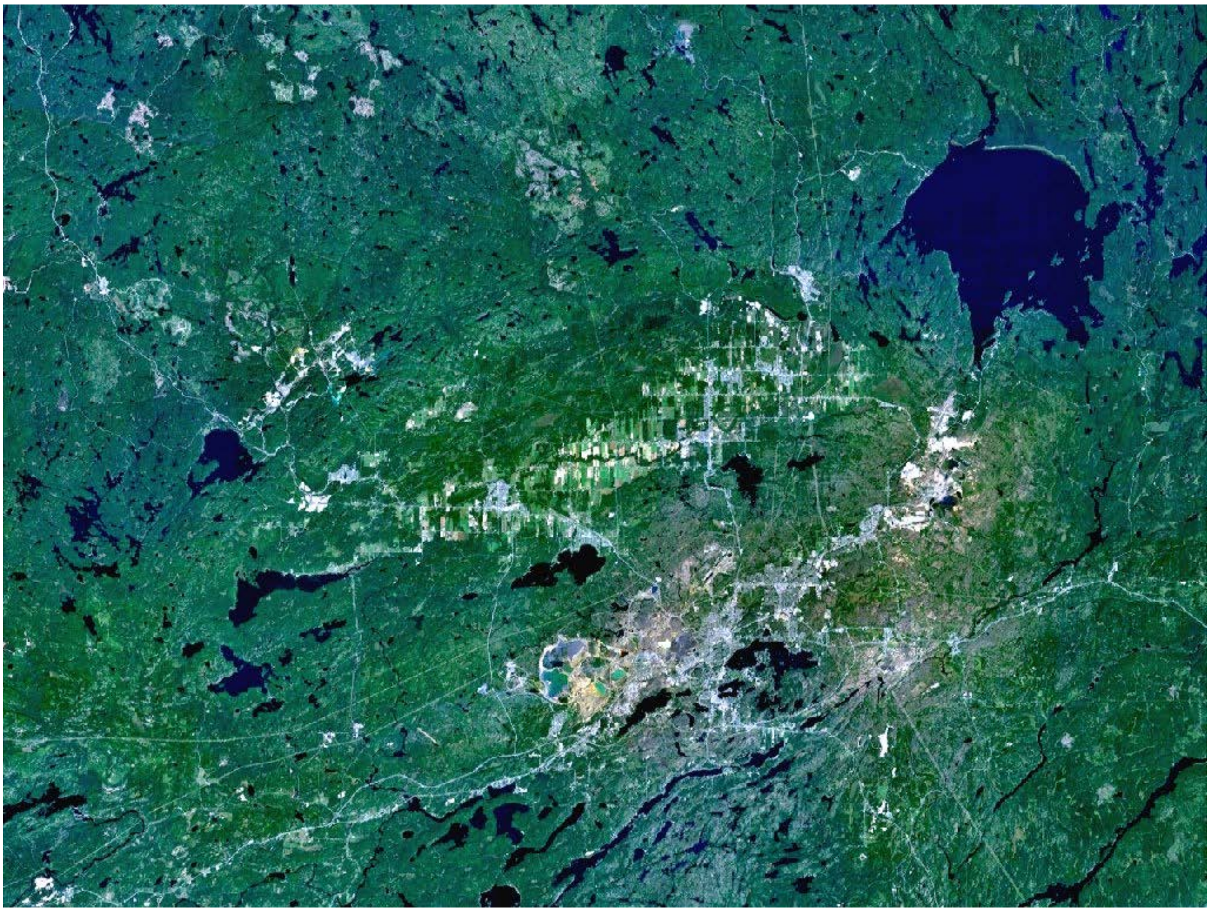


Schematic geologic map of the Sudbury area (from Grieve et al., 2008).

24.1.2 Elevation

347.5 metres.

24.1.3 Images



The Sudbury and Wanapitei impact craters in Ontario, Canada. Sudbury is the large, elliptical structure (60 x 30 kilometres), Wanapitei is the lake filled crater at upper right. Created with NASA WorldWind using Landsat 7 (Visible Colour) satellite image.

24.2 Context

24.2.1 Geological Setting

The Sudbury impact structure comprises the so-called Sudbury Basin, the enclosing Sudbury Igneous Complex (SIC), and the surrounding brecciated and fractured Archean and Proterozoic rocks of the Superior and Southern provinces of the Canadian Precambrian Shield (Giblin 1984). It is estimated that the impact event that created Sudbury occurred ~1.85 Ga ago (Krogh et al. 1984) and created a differentiated impact-melt sheet (the SIC) within the impact structure (Grieve et al. 1991; Dickin et al. 1999; Therriault et al. 2002). Estimates of the apparent crater diameter are mostly in the ~150–200 kilometres range (Stöffler et al. 1994; Grieve et al. 1991), but some recent estimates range up to 260 kilometres (Tuchscherer and Spray 2002; Spray et al. 2004). The impact event at Sudbury occurred in an active orogenic belt and the impact structure was folded and then faulted by northwest-southeast shortening during the Penokean orogeny (Rousell 1984; Riller 2005). The result is the elliptical ~30 × 60 kilometres shape of the Sudbury Basin.

24.2.2 Relevance

The Sudbury impact crater can be an analogue for impact craters and processes on the Moon and Mars. In particular: large impact structures; melt rocks; impact melt breccias; melt sheets; hydrothermal systems; shatter cones; and metals and mineral deposits. The Sudbury area is also a good site for planetary exploration activities to be conducted. In July 1971, the Apollo 16 astronauts visited Greater Sudbury, Ontario, Canada for geology training exercises, the first time U.S. astronauts ever did so.

24.3 Environmental

Climate/Weather	Temperate.
Temperature	Typically varies from -18°C to 25°C.
Precipitation Type	Rain and snow.
Annual Precipitation	Rainfall: 656 mm; snowfall: 274 cm.
Humidity	High from 38% to 96% .
Wind	Wind speeds vary from 1 m/s to 7 m/s.
Insolation	Max of 16 hours in July, min of 8.35 hours in December.

24.4 Infrastructure

24.4.1 Existing

The Impact basin has extensive infrastructure as it is surrounded by towns, mines, open pits, and a city.

24.4.2 Accessibility

Easy to get to the Sudbury area, highway 69 north from Toronto takes about 4-5 hours to drive. Many sites located by roads or highways; some more remote with helicopter needed. Good to use a 4x4 to get around the area but is up to the team.

24.4.3 Nearest Airport

Sudbury has its own airport with flights from Canada and the U.S. The nearest international airport is Toronto.

24.4.4 Logistics

There are two hospitals in Sudbury, and after hours clinics. Outdoor stores exist for equipment; motels, hotels, and camping grounds are available. Can camp at field site with permissions of owners/or on Crown land. If working on a mining company site, you will most likely be required to fill out a lot of paperwork on safety, plus any results from the work may have to go through the company before publication.

24.4.5 Permissions

Dependent on who owns the land you want to work on. Key mining companies Vale, Xstrada, Wallbridge, FNX plus smaller junior companies. Some areas are privately owned and native land exists here. Sampling is allowed but the extent and usage of samples will depend upon the owners of the site.

24.4.6 Cost

Flights, hotel and equipment purchase/rental in Sudbury. Potential costs other than financial might be incurred when working on native land.

24.4.7 Scheduling

Summer provides the best access but increased tourist traffic on highways, early Autumn is the most comfortable time to go as fewer bugs but still warm; early Spring is good but can be wet. Winter is snow covered and cold!

24.5 Key References

Ames, D.E., Watkinson, D.H. and Parrish, R.R. (1998) Dating of a regional hydrothermal system induced by the 1850 Ma Sudbury impact event. *Geology* 26:447-450.

Grieve, R.A.F., Reimold, W.U., Morgan, J., Riller, U. and Pilkington, M. (2008) Observations and interpretations at Vredefort, Sudbury, and Chicxulub: Towards an empirical model of terrestrial impact basin formation. *Meteoritics & Planetary Science* 43:855-882.

Moores, J.E., Francis, R., Mader, M., Osinski, G.R., Barfoot, T., Barry, N., Basic, G., Battler, M., Beauchamp, M., Blain, S., Bondy, M., Capitan, R-D., Chanou, A., Clayton, J., Cloutis, E., Daly, M., Dickinson, C., Dong, H., Flemming, R., Furgale, P., Gammel, J., Gharfoor, N., Hussein, M., Grieve, R., Henrys, H., Jaziobedski, P., Lambert, A., Leung, K., Marion, C., McCullough, E., McManus, C., Neish, C.D., Ng, H.K., Ozaruk, A., Pickersgill, A., Preston, L.J., Redman, D., Sapers, H., Shankar, B., Singleton, A., Souders, K., Stenning, B., Stooke, P., Sylvester, P., and Tornabene, L. (2012) A Mission Control Architecture for Lunar Sample Return as Field Tested in an Analogue Deployment to the Sudbury Impact Structure. *Adv. Space Res. – Lunar Exploration Special Issue*. DOI: http://dx.doi.org/10.1016/j.asr.2012.05.008.

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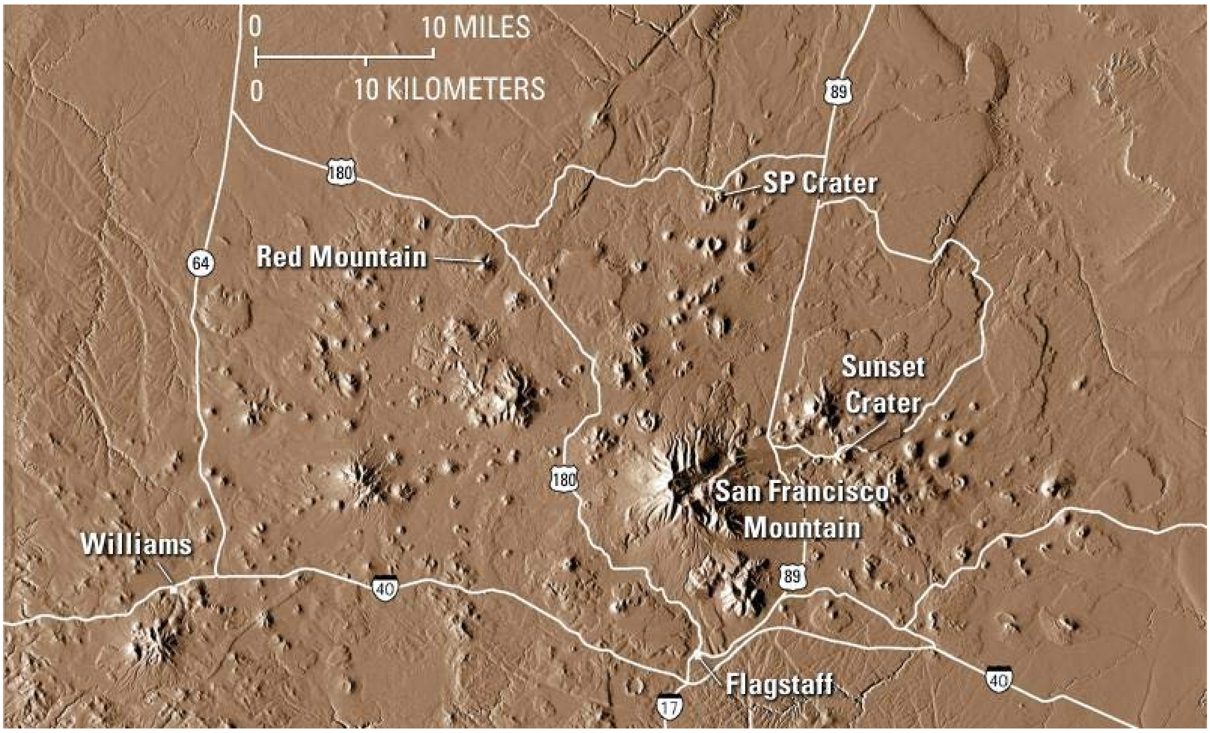
Spray, J.G., Butler, H.R. and Thompson, L.M. (2010) Tectonic influences on the morphometry of the Sudbury impact structure: Implications for terrestrial cratering and modelling. *Meteoritics & Planetary Science* 39:287-301.

25 Sunset Crater

25.1 Location

Coordinates	35°21’51”N 111°30’11”W
Country/State/Province	USA / North-central Arizona.
Continent	North America

25.1.1 Map



This digital elevation model (DEM) of the San Francisco Volcanic Field shows many of the more than 600 vents which have erupted in the area during the past 6 million years

25.1.2 Elevation

Plateau encompassing the San Francisco volcanic field is at 2150m a.s.l. The landscape of the eastern margin of the San Francisco volcanic field decreases in elevation in the direction of the prevailing wind – from 2130m at the base of the Sunset scoria cone to 1400m at the Little Colorado River.

25.1.3 Images

Sunset Crater summit

25.2 Context

25.2.1 Geological Setting

The San Francisco Volcanic Field lies on the southern margin of the Colorado Plateau near its boundary with the Basin and Range Province. The field, covering an area of ~5000 km^2, extends eastward in an irregular belt from near Williams, Arizona, to the Little Colorado River just east of Flagstaff. Volcanism began approximately 6 million years ago in the western part of the field and has since migrated eastward producing over 600 volcanic vents. Activity culminated with the eruption of Sunset Crater Volcano just over 900 years ago. This 300 metres (1000 ft) tall alkali olivine basalt cinder cone is now preserved by the National Park Service, one of three monuments administered by the Flagstaff Area National Monuments.

25.2.2 Relevance

Wind action has redistributed the widespread tephra deposit into a variety of aeolian dune forms that serve as a terrestrial analogue for similar landforms and Aeolian processes on Mars. Specific sites include volcanoes; lava flows; basalt; tephra (ash and lapilli); basaltic dune fields i.e. volcaniclastic aeolian deposits (Coppice dunes may be analogous to Martian wind-shadow or lee dunes in which sand accumulates in the lee of non-vegetation obstacles).

25.3 Environmental

Climate/Weather	Semi-arid to arid climatic conditions are found here.
Temperature	Average daily maximum July ~ 28 °C; January ~ 6 °C.
Precipitation Type	Rain, with snow in winter months at higher elevations.
Annual Precipitation	Mean annual precipitation is 430 mm.
Humidity	
Wind	The prevailing wind is SW; strong winds < 20 ms^{-1} in spring months.
Insolation	

25.4 Infrastructure

25.4.1 Existing

There are roads that lead up to sites, commonly followed by a short hike. The USGS Astrogeology Science Centre in Flagstaff can help with infrastructure and logistical considerations. No on site facilities exist.

25.4.2 Accessibility

Access to the National park can be achieved from several directions, such as highway 89 with a turnoff into the Sunset Crater National Park. Hiking has to be done up the volcano itself but the summit is closed to hiking. Many trails exist to aid in this.

25.4.3 Nearest Airport

Flagstaff, Arizona is the nearest airport located about 10 miles away.

25.4.4 Logistics

Hotel accommodation and hospital in Flagstaff which is 10 miles away; or camping can be done at Cinder Hills right next to Sunset Crater northeast of Flagstaff.

25.4.5 Permissions

National parks Service research permits may be required to do work in the park see (https://science.nature.nps.gov/research/ac/ResearchIndex). In general the park is publically accessible: $5.00 - 7 Days Fee is per person which is good for 7 days at both Sunset Crater Volcano and Wupatki National Monuments. Vehicle charges to bring cars into the park are as follows: Capacity 1-6 (Sedan) $28 – Day; capacity 7-25 (Van) $40 – Day; capacity 26 or more (Bus) $100 – Day.

25.4.6 Cost

Permits, flights, car hire and accommodation.

25.4.7 Scheduling

Summer months are best but from early July until early September afternoon thunderstorms develop almost daily over the higher terrains. Spring and Autumn normally good for fieldwork.

25.5 Key References

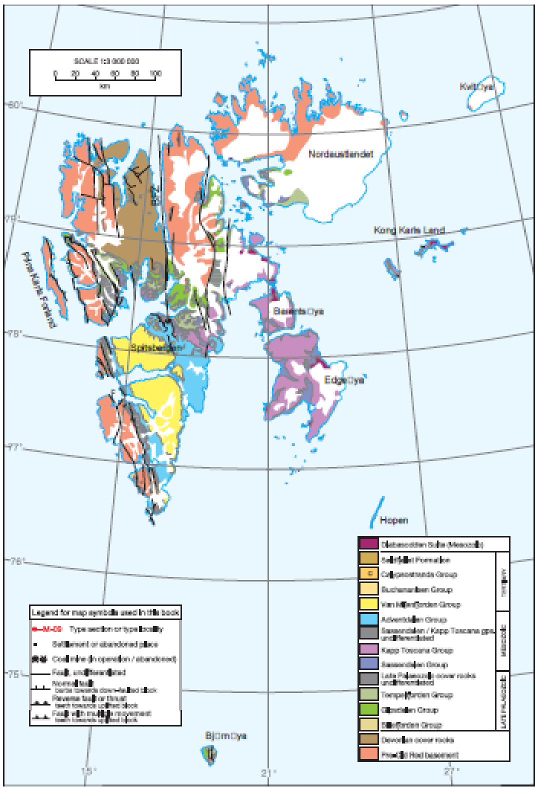
Hooper, D.M., McGinnis, R.N., and Necsoiu, M. (2012) Volcaniclastic Aeolian deposits at Sunset Crater, Arizona: terrestrial analogs for Martian dune forms. Earth Surface Processes and Landforms 37:1090-1105.

26 Svalbard

26.1 Location

Coordinates	78°N 16°E
Country/State/Province	Norway
Continent	Europe

26.1.1 Map



Simplified geological map of Svalbard (from Dallmann 1999)

26.1.2 Elevation

Much of the Svalbard landscape, particularly the island of Spitsbergen, is mountainous. A highest elevation of 1713 metres above sea level is reached at Newtontoppen on northeastern Spitsbergen. Other significant peaks include: Perriertoppen (1712 metres), Ceresfjellet (1675 metres), Chadwickryggen (1640 metres), and Galileotoppen (1637 metres), all of which are located upon Spitsbergen.

26.1.3 Images

A) The Lab-On-a-Chip Applications Development Portable Test System (LOCAD-PTS) being used in the Arctic (Bockfjord, Svalbard) to analyse hot spring pools for microbial life during the NASA-sponsored Arctic Mars Analogue Svalbard Expedition (AMASE) in 2004. B) Patterned ground on Svalbard. Credit Cousins, C. and the AMASE2010.

26.2 Context

26.2.1 Geological Setting

Svalbard is located in the northwestern corner of the Barents Shelf. The archipelago represents an uplifted part of this otherwise submerged shelf. The uplift was most extensive in the north and west, leaving progressively older rocks in these directions. Svalbard’s' geological records can be subdivided into three main units: the metamorphic basement complex, the unaltered sedimentary cover rocks, and unconsolidated deposits. Mountains composed of igneous and metamorphic rocks have been glacially eroded; masses of sand, gravel, mud plus limestone and sandstone-shale successions are observed; and unconsolidated deposits formed during the last ice age include moraines, fluvial deposits, beach deposits, talus, gullies and scree. Volcanoes were active during the Quaternary with related thermal springs still active. During most of its geological history, Svalbard was submerged, allowing the deposition of sand, gravel, mud, lime, etc., which progressively altered into bedrock. There is little soil in Svalbard and no forests or agricultural areas.

26.2.2 Relevance

Svalbard presents a similar terrain composed of red sand, gravel and mud sized grains; and a similar cold climate to Mars. It is a Mars analogue research site due to the presence of carbonate terraces and carbonate rosettes (like those found within Martian meteorite ALH84001); polar habitats; fluvial features; gullies; volcanoes; hot springs; and the ability to test prototype instruments that allow tests for life detection in the field. Many characteristics of Martian gullies and fans are very similar to gullies and alluvial fans in Svalbard. These include the overall morphology and dimensions, slopes in alcoves, channels, and fans, and the spatial association with periglacial landforms such as polygons and patterned ground. There is little vegetation cover here so an unprecedented number of geological outcrops are visible.

26.3 Environmental

Climate/Weather	A cold arctic desert.
Temperature	Annual mean temperature at sea level is about -5 °C, but this decreases fast with altitude.
Precipitation Type	Rain, snow in winter months.
Annual Precipitation	Mean of 271 mm
Humidity	The specific humidity on Svalbard is very low, but the relative humidity is high i.e. there is not much water vapour in the air, but the air is close to saturation.
Wind	The windiest month is January where on average the wind blows faster than 10m/s. The wind direction is generally East or South East
Insolation	Ranges from 0 kWh/m²/day (January/December) to 5.69 kWh/m²/day (June).

26.4 Infrastructure

26.4.1 Existing

The only "highway" links the Longyearbyen airport to the Mine 7 via Longyearbyen. There are paved streets in the settlement of Longyearbyen itself and many of the local residents tend to have cars. Snowmobiles are common transportation in wintertime. Travel between islands and settlements can be done by plane or helicopter any time of year. Boats can be used in summer.

26.4.2 Accessibility

Svalbard can either be accessed by plane (see nearest airport information) or by boat. These are the only practical means of visiting the more far-flung bits of the archipelago like Ny-Ålesund. AMASE utilises the R/V Lance ship sponsored by the Norwegian Polar Institute. Research sites are accessed by personnel and equipment using zodiacs. An unusual amount of rock is exposed on Svalbard, with little soil or vegetation cover, and can therefore be studied uninterrupted over long sections.

26.4.3 Nearest Airport

Longyearbyen has the largest airport on the islands SAS (Scandinavian Airline Systems) has scheduled flights from Oslo and Tromsø. There are also occasional charters from Murmansk or Moscow.

26.4.4 Logistics

A range of accommodation is available only on Longyearbyen, which offers camping, guesthouses and luxury hotels. Barentsburg and Ny-Ålesund also have a single hotel each. When participating through AMASE, accommodations etc are ship-based. It is recommended to take protection against bears whilst in the field. Equipment and instruments taken to Svalbard need to be adapted to function in the low temperatures and have to be carried or helicopter transported to research sites.

26.4.5 Permissions

As a general rule, most field activities require a permit from the Governor. Details of information to be submitted in research applications can be found here: http://www.sysselmannen.no/en/Scientists/Fieldwork-researchers/. Working through the AMASE programme is always an option, led by Dr Andrew Steele of the Carnegie Institution for Science and Dr Hans Amundsen of PGP, University of Oslo, Norway. Strict regulations exist regarding the environmental protection of Svalbard, no vehicle usage is allowed on land.

26.4.6 Cost

Flights from mainland Norway cost U.S.$150-350 each way, whereas a typical 3-day cruise starting from Longyearbyen may cost you from 7900 kr (c. U.S.$1500, cheapest cabin, twin sharing). Accommodation in cheap guesthouses costs on the order of 500 kr/night and sit-down meals nudge up closer to 100 kr each - both figures you can very easily double if you want to stay in a full-service hotel. Guided activities start at about 500kr per day (e.g. trekking and kayaking) but can go to 1000kr and above for tours requiring specialist equipment.

26.4.7 Scheduling

Summer months best due to the favourable weather conditions.

26.5 Key References

Steele, A., Amundsen, H.E.F., Botta, O., and the AMASE 2006 Team (2006) The Arctic Mars Analogue Svalbard Expedition 2006. *Proceedings of the Mars 2030 Workshop* 55-60.

E. Hauber, Mathias Ulrich, F. Preusker, F. Trauthan, D. Reiss, A.E. Carlsson, H. Hiesinger, R. Jaumann, H.A.B. Johansson, L. Johansson, A. Johnsson, S. McDaniel, M. Olvmo, M. Zanetti (2009) Svalbard (Norway) as a terrestrial analogue for Martian landforms: Results on alluvial fans. European Planetary Science Congress Abstracts, vol. 4 EPSC2009-772.

A. Steele, H.E.F. Amundsen, P.G. Conrad, L. Benning and M. Fogel, on Behalf of the AMASE 07 team (2008) Arctic Mars Analogue Svalbard Expedition (AMASE) 2007. LPSC XXXIX, abstract #2368.

26.6 Site Specific Details

26.6.1 Bockfjord Volcanic Complex (BVC)

26.6.1.1 Co-ordinates
79°29’5 3” N, 13°12 ’20” E

26.6.1.2 Physical Characteristics
The complex consists of three separate eruptive centres (Sverrefjellet, Halvdanpiggen and Sigurdfjellet) within a distance of 20 kilometres. The centres show varying volcanic and subvolcanic features and are preserved at different erosional levels, all from the eroded remains of stratovolcano to subvolcanic vents. Volcanic soils and remnants of flood basalt eruptions are preserved. A wide variety of upper mantle and lower crustal xenoliths comprise about 15-20 vol% of the volcanic centres (Amundsen 1987; Amundsen et al. 1987, 1988). Carbonate rosettes are also found within the xenoliths at Sverrefjell volcano.

26.6.1.3 Geochemical Characteristics
The petrographic composition of the basalts is alkaline, with phenocrysts of olivine, titanaugite and rare plagioclase together with xenocrysts, embedded in a fine-grained matrix of euhedral olivine,

titanaugite, plagioclase laths, titanomagnetite and basaltic glass. Carbonate rosettes are found here within peridotite xenoliths. Gases at the Troll and Jotun hot springs are studied.

26.6.1.4 Astrobiological Characteristics

Presence of methanogens in weathered olivine xenoliths, and microbial activity has been detected in buried blue ice vents near the summit of the Sverrefjell volcano. Coring of glacial ice and sampling of snow algae at the adjacent glaciers carried out to (a) quantify the adaptive strategies of psychrophiles to nutrient and light limitations (b) determine the presence and preservation potential of organic signatures in ice cores and (c) develop and test planetary protection strategies related to decontamination of flight and experimental hardware.

26.6.1.5 Prior Analogue Usage

AMASE: Deployment of CliffBot and the space suit in the Devonian redbeds on the opposite site of Bockfjorden; Comprehensive imaging and Raman spectroscopy of carbonate globules; Raman and CheMin studies on xenoliths on the Sigurdfjell volcano; field testing of prototype instruments that are part of the science payload of the NASA MSL rover.

26.6.2 Ebbadalen Formation

26.6.2.1 Co-ordinates

78°42’35” N, 16°43’04” E.

26.6.2.2 Physical Characteristics

26.6.2.3 Geochemical Characteristics

The sediments at the Ebbadalen Formation in Billefjorden, central Spitsbergen, comprise Carboniferous (ca. 320 Ma) Ca-Sulphate bearing evaporites deposited in a shallow marine setting. Outcrops show mixed sulphate/clastic lithologies that might be analogous to evaporite sediments studied by the Mars Exploration Rover (MER) Opportunity at Meridiani Planum on Mars (Klingelhöfer et al., 2004).

26.6.2.4 Astrobiological Characteristics

Spheroidal concretions, morphologically similar to the “Blueberries” on Mars, are covered with lichens, and show a high level of biological activity.

26.6.2.5 Prior Analogue Usage

AMASE: Cliffbot Rover

26.6.3 Murchison Fjord

26.6.3.1 Co-ordinates

79°52’43” N, 18°29’17” E.

26.6.3.2 Physical Characteristics

26.6.3.3 Geochemical Characteristics

26.6.3.4 Astrobiological Characteristics

This site bears outcrops of ~800 Ma old stromatolites and lagoonal carbonates, which were collected for laboratory investigations to find biosignatures.

26.6.3.5 Prior Analogue Usage
AMASE.

26.6.4 Adventtoppen and Hiorthfjellet

26.6.4.1 Co-ordinates
78° 16′ 22.8″ N, 15° 44′ 42″ E and ?

26.6.4.2 Physical Characteristics
Small alluvial fan-like landforms characterized by straight and/or sinuous channels, flow lobes (debris tongues) Boulder sized (>1 metres) rocks are present, but rare. The length of fans ranges between 80 metres and ~800 metres, with heights between 9 and ~140 metres (from apex to toe). Overall gradients vary between 0.11 and 0.43, with a peak at 0.18-0.2.

26.6.4.3 Geochemical Characteristics

26.6.4.4 Astrobiological Characteristics

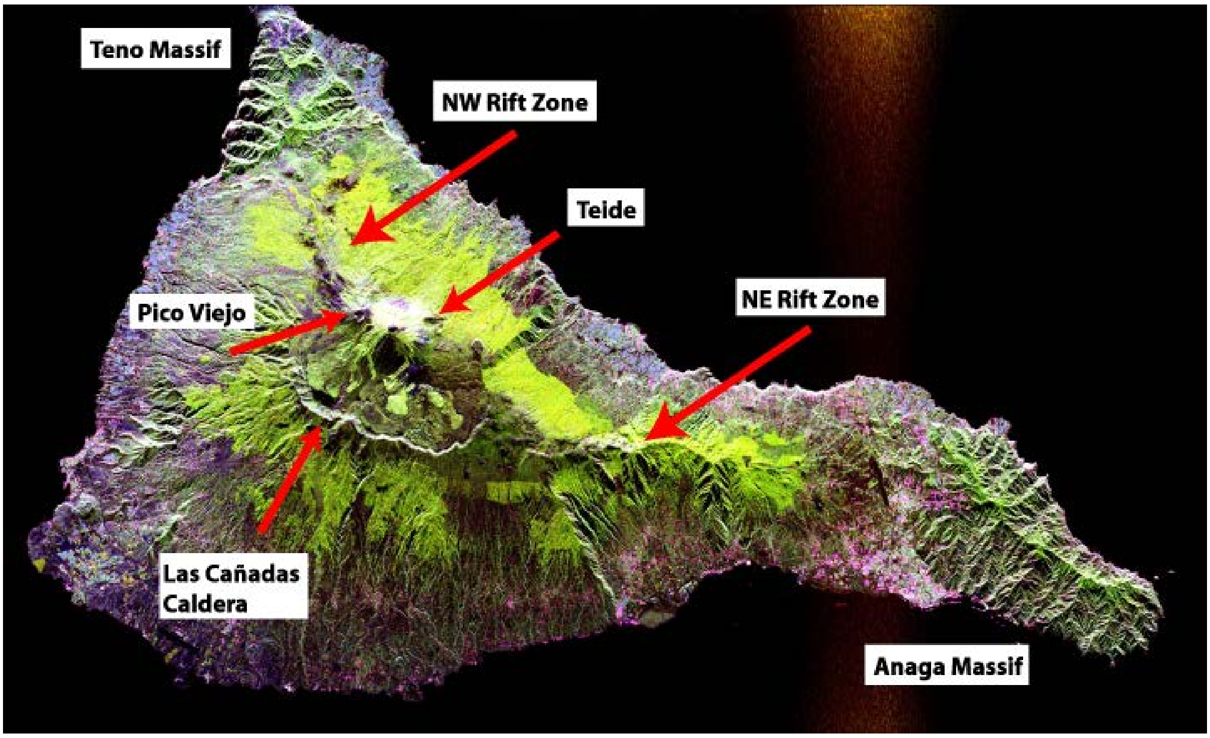
26.6.4.5 Prior Analogue Usage

27 Tenerife

27.1 Location

Coordinates	28°13'27.97"N, 16°37'36.60"W
Country/State/Province	Spain / Canary Islands / Tenerife
Continent	Europe

27.1.1 Map



The image was acquired by the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavour on October 11, 1994

27.1.2 Elevation

The summit of Mount Teide is at 3718 metres; many analogue sites at 2,200 metres.

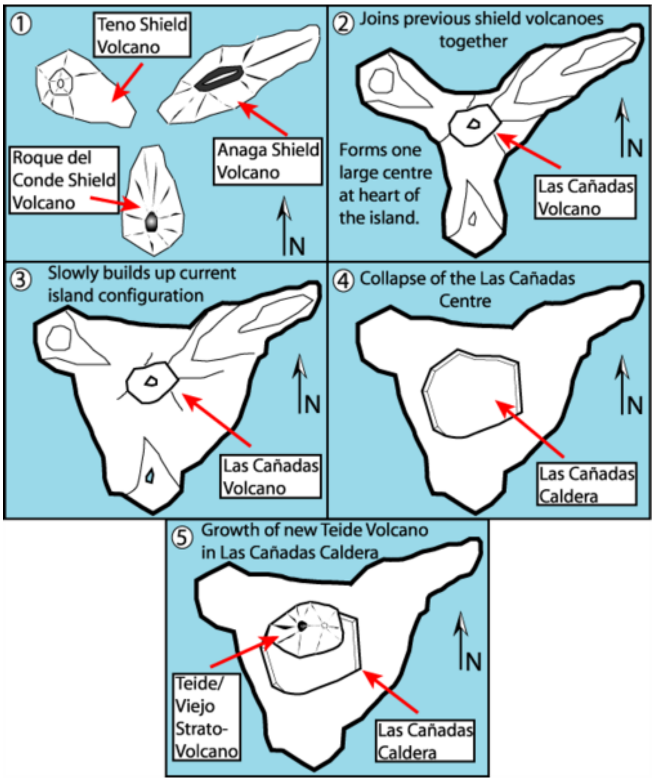
27.1.3 Images

Top: Teide Panorama. Below: Geology and landscapes and Teide National Park (D.Houcke).

27.2 Context

27.2.1 Geological Setting

Tenerife, located off the African passive margin in the North Atlantic Ocean, is the world's largest intra-plate volcanic island after Hawai'i. The twin, asymmetrical stratovolcanos of Teide and Pico Viejo are the most recent centres of activity on the volcanic island. Similar to the other Canary Islands and volcanic ocean islands in general, the island of Tenerife was built by accretion of three large shield volcanoes, which developed in a relatively short period of time. This early basaltic shield stage volcanism formed the bulk of the emerged part of Tenerife. The shield volcanoes date back to the Miocene and early Pliocene.



Schematic diagram of the formation of the island of Tenerife and evolution of the current Teide volcano: 1) the island began as three separate shield volcanoes. 2) After a period of erosion of the older massifs a new period of volcanic activity saw the creation of the large Las Canadas volcano. 3) The islands current shape begins to become apparent as Las Canadas grows. 4) The Las Canadas edifice collapses to form the Las Canadas Caldera. 5) The current Teide/Vierjo Central complex grows within this collapsed calera.

Rocks exposed on the surface of the Teide–Pico Viejo complex are mainly mafic to intermediate, with an increasing volume of felsic material during more recent eruptions. Borehole investigations down to 1750 metres a.s.l. beneath the Las Cañadas Caldera floor (which do not reach pre-Teide–Pico Viejo materials) show that the erupted magmas have evolved from the oldest basanitic lavas through to the more recent plagioclase basanite, phono-tephrite and tephri-phonolite lavas (Ablay and Martí, 2000). The upper surfaces of the lava flows are scoured and denuded and the lavas on the southern flank are cut by deep drainage gullies. Hydrothermal alteration in the summit region of Teide is mainly concealed within the outer scarps and is mostly pervasive to selective but also occurs as local surface precipitates and fracture fillings. Minor pyroclastic deposits are found which have been hydrothermally altered. Glacial and periglacial landforms are also observed on Teide (see del Potro et al, 2009 and references therein for further geological descriptions).

27.2.2 Relevance

Teide visually and geologically provides a good analogue for Mars and the Moon. Volcanoes and volcanic landforms and processes can be studied such as vents; lava flows (both basaltic and differentiated); unconsolidated pyroclastic deposits; hydrothermal alteration; lava tubes and caves; dykes; channels and valleys; basaltic rift system and ridges; and astrobiology of volcanic environments. The red, oxidised, basaltic, tephra from Tenerife has optical properties that resemble the established simulant JSC-1 (Allen et al., 1998) and Mars bright regions (Mustard and Bell, 1994).

For astrobiological studies, lava tubes and volcanic caves are a potential habitat for Martian life. Evidence for the existence of Martian caves such as long lava channels and lines of pits have been identified from orbiting space craft and epithermal neutron maps indicate the presence of water a few metres below the surface which would be accessible to cave life. Inside, life would be sheltered from the harsh surface conditions of UV radiation and low humidity as well as from extreme weather conditions. The caves in Teide national park are an ideal terrestrial analogue of Martian caves. They are situated at an altitude of 2500 metres in an area of low humidity with low levels of contamination as access to the area is limited for conservation reasons (Morse et al., 2011).

Teide itself provides a good site for planetary mission simulations for analogue rovers and equipment due to its good and stable weather based above the cloud base; easy accessibility by car; minor restrictions to access; good navigability of terrain for a rover; good analogue lithologies to test tools and analytical equipment; good accessibility to outcrops by rovers and little vegetation cover.

27.3 Environmental

Climate/Weather	Temperate/maritime/alpine conditions.
Temperature	Temperatures on the island rarely stray from the averages which dip to 20ºC in the winter months and peak at 28ºC during the summer months.
Precipitation Type	Rain; snow at the summit of Mt. Teide.
Annual Precipitation	On average, the wettest month of the year for Tenerife is November with an estimated 38 mm of precipitation. The driest months are June, July, August & September with close to no precipitation.
Humidity	The average humidity is between 60% - 70% all year round.
Wind	Ranges from 5.63 m/s (October) to 7.89 m/s (July).
Insolation	Ranges from 3.26 kWh/m²/day (December) to 6.97 kWh/m²/day (May).

27.4 Infrastructure

27.4.1 Existing

A network consisting of two fast, toll-free motorways (TF1 and TF5) encircles nearly the entire island, linking all the main towns and resorts with the metropolitan area. The exception is in the West, from Adeje to Icod de los Vinos, which is traversed by a smaller winding mountain road. Roads in general vary in quality however those into the El Teide National Park are well maintained. An IAC Observatory is available.

27.4.2 Accessibility

Access is by a public road running across the caldera from northeast to southwest. The public bus service TITSA runs a once per day return service to Teide from both Puerto de la Cruz and Playa de las Americas. The Teleférico cable car goes from the roadside at 2356 metres most of the way to the summit, reaching 3555 metres. Each car carries 38 passengers (34 in high wind) and takes 8 minutes to reach the summit. In peak season, queues can exceed two hours. You cannot access the summit without special permissions. A 4x4 car is recommended.

27.4.3 Nearest Airport

The island of Tenerife is served by Tenerife North - Los Rodeos Airport (GCXO) and Reina Sofía Airport (GCTS) in Tenerife South (nearest to Teide) and a port: Port of Los Cristianos.

27.4.4 Logistics

Working at altitude so less oxygen and quick changes in temperature throughout the day. Be prepared for both by taking it slowly, resting if needed and bringing extra clothing. The hotel "Parador de Canadas del Teide" is the only hotel within the Teide National Park. It is located in the natural Cañadas del Teide crater, more than 2,000 metres above sea level. There are many additional hotels outside of the park from which you can take day trips to Mt Teide. The nearby village of Vilaflor (20 – 25 min by car, down the mountain towards the south) are several restaurants and bars, supermarkets, pharmacies and shops are at a driving distance of at least 20 – 25 minutes.

27.4.5 Permissions

The volcano and its surroundings, including the whole of the Las Cañadas caldera, are protected in a national park, the Parque Nacional del Teide. Environmental Impact Reports will have to be filled out. Access to the summit itself is restricted; a free permit (obtainable from the Park office in Santa Cruz, Calle Emilio Calzadilla, 5 - 4th floor) is required to climb the last 200 metres. For research permits is it useful to get contacts at the IAC (Instituto de Astrofisica de Canaries) who can advise on any administrative issues such as getting permission from the National Parks Authorities to access sites, and import/export equipment. Off-roading is difficult to get permissions for.

27.4.6 Cost

Rooms in the Parador de Canadas del Teide start at 80 EUR. Flights from Europe to Tenerife are generally cheap and frequent due to it being a popular holiday destination.

27.4.7 Scheduling

Any time of year is good in terms of weather conditions. Summer months will be busier with tourists.

27.5 Key References

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Waugh, L., Draper, C., Lee, C., Richter, L. (2006) Locomotion Field Trials for a Mars Rover Testbed – Tenerife – 2006. In Proceedings of the 9th ESA Workshop on Advanced Space Technologies for Robotics and Automation (ASTRA).

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27.6 Site Specific Details

27.6.1 Minas de San Jose

27.6.1.1 Co-ordinates

27.6.1.2 Physical Characteristics
Area devoid of vegetation with variable topography, including various rock textures and outcrops, crater-like dips, and pumice banks.

27.6.1.3 Geochemical Characteristics

27.6.1.4 Astrobiological Characteristics

27.6.1.5 Prior Analogue Usage

27.6.2 Llano De Ucanca

27.6.2.1 Co-ordinates

27.6.2.2 Physical Characteristics
A flat landscape with fine grained volcanic sand, pebbles and occasional rocky outcrops visually similar to that encountered on the surface of Mars

27.6.2.3 Geochemical Characteristics

27.6.2.4 Astrobiological Characteristics

27.6.2.5 Prior Analogue Usage

27.6.3 Cuevas Negras and Sima de Vicky

27.6.3.1 Co-ordinates

27.6.3.2 Physical Characteristics
Caves.

27.6.3.3 Geochemical Characteristics

27.6.3.4 Astrobiological Characteristics

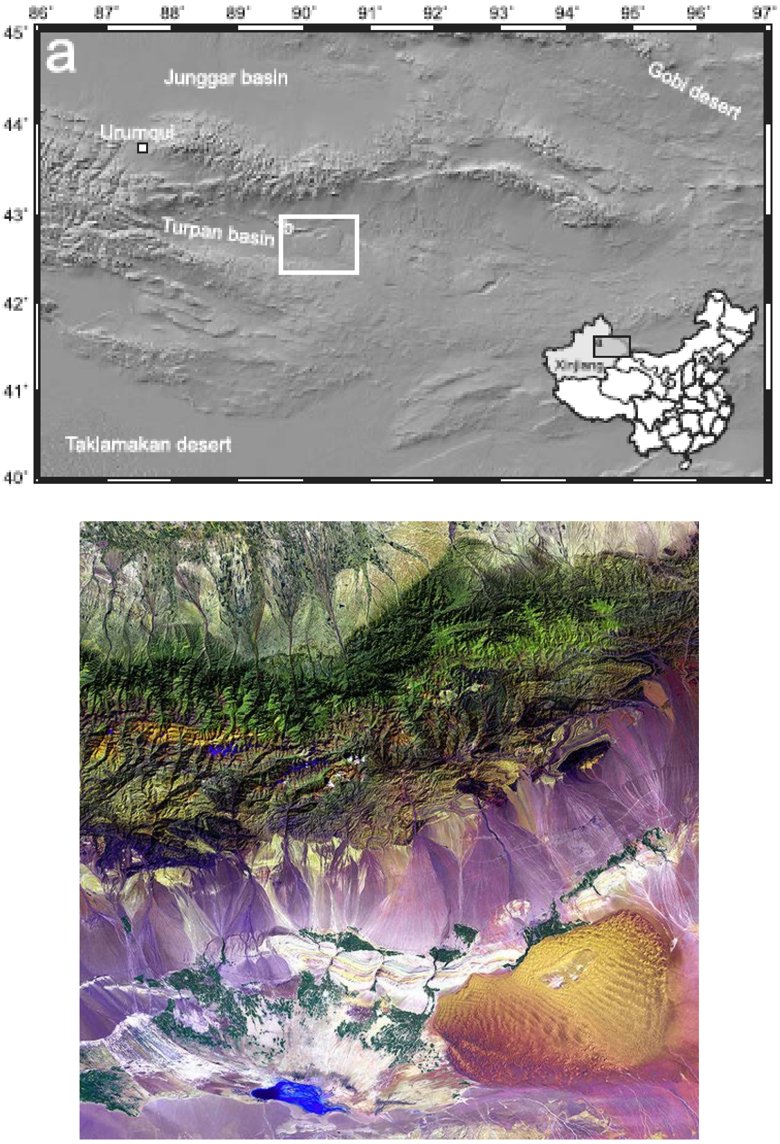
27.6.3.5 Prior Analogue Usage

28 The Turpan Desert

28.1 Location

Coordinates	42.63°N, 89.86°E.
Country/State/Province	China / Xinjiang Province
Continent	Asia

28.1.1 Map

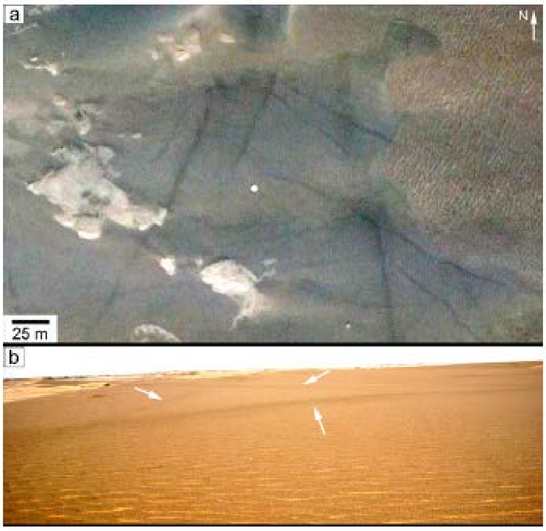


Top: The Turpan depression desert (Shaded relief derived from Aster GDEM data.) (Adapted from Reiss et al., 2010). Bottom: The Turpan Depression (NASA/USGS (Landsat 7)).

28.1.2 Elevation

Highest peak in the Flaming Mountains is at 831.7 metres above sea level but the basin is about 150 metres above sea level.

28.1.3 Images



The Turpan (Turfan) Depression in northwest China (a) High resolution satellite image of the study region acquired at 03 April 2005 (Quickbird image catalogue id 10100100004247600 with a resolution of ~0.6 m/pxl, from Google Earth) showing several linear and curvilinear dust devil tracks. White dot in the middle of the image marks the location of the dust devil track in b. (b) View of the study region from northeast. Three dust devil tracks (arrows) were identified on 14 April 2010.

28.2 Context

28.2.1 Geological Setting

Dust devils are low pressure vortices formed from unstable near surface warm air generated by insolation and they can be visible due to the entrainment of dust and possibly sand (for further details, see Balme and Greeley (2006)). On Earth, dust devil tracks are rare. Rossi and Marinangeli (2004) first observed dust devil tracks in ASTER satellite imagery in the Ténéré desert, Niger. These low albedo tracks have been identified on different terrain types as transverse dune fields, sand sheets and interdune zone of seif dunes. The tracks have an average width of a few tens of metres and average length of 3 kilometres. The orientation of the tracks is orthogonal to the prevailing wind direction in this region. Their formation might be due to the bimodal sand characteristics of the soil, with a layer of fine sands overlying coarser sand. The passage of a dust devil removes fine sand and exposes the coarser sands beneath, which increases the surface roughness causing the albedo contrast of the tracks to the surroundings in satellite imagery (Rossi and Marinangeli, 2004).

China has one the world's largest desert basins, the Tarim Basin and the Taklimakan Desert just north of the Tibetan Plateau. It also has the tallest sand dunes and the largest desert alluvial fan (playa) in the world. Both are located in the western portion of the Alxa Plateau in the Badain Jaran Desert of north central China. The Turpan depression dune field is a fault-bounded trough located in the Xinjiang province of northwestern China, south of the city of Shanshan, and covers an area of approximately 2500 km^2. It includes the third lowest exposed point on the Earth's surface (dry Lake Ayding, -154m). Sandy depositional landforms are created here by deposits of sand that were carried there and shaped by the wind. Gobi deserts are also found in the Turpan Depression and are erosional landforms. Their characteristics result from wind eroding sand and dust from the surface, leaving only gravel and bedrock. Dust devil tracks are found here, restricted to flat interdune and peripheral areas. Three main surface types can be distinguished in the desert based on their morphology and albedo: bright dune surfaces characterized by small ripples with heights ~1 cm and wavelengths ~5 cm; darker flat areas of ripple surfaces with heights of ~3 cm and wavelengths of ~20 cm; and larger ripples on low inclined surface areas with heights of ~20 cm and wavelengths of ~100 cm. The bright dune surfaces are dominated by fine sand (125 – 250 µm), ripple surfaces by coarse sand (500 – 1000 µm), and large ripple surfaces by very coarse sand (1000 – 2000 µm) (Reiss et al., 2012).

28.2.2 Relevance

Martian Aeolian processes and features such as dunes, ripples and dust devils can be studied in the Turpan Desert. Dust devil tracks are studied here in situ and from orbit to understand the formation of those observed on Mars.

28.3 Environmental

Climate/Weather	Arid continental climate; desert
Temperature	July average max ~ 39.7°C and January average max ~ -2.2°C.
Precipitation Type	Rain
Annual Precipitation	< 2cm.
Humidity	
Wind	Variable and high.
Insolation	High.

28.4 Infrastructure

28.4.1 Existing

City oasis of Turpan.

28.4.2 Accessibility

The Tarim Desert Highway, the first built across the Taklimakan, was opened to traffic in 1995. This amazing paved road gives access to the very heart of one of the world's most gruelling deserts. It is the longest highway crossing a mobile desert in the world. The ~500 kilometres long highway cuts across the Taklimakan Desert from Luntai (41.78N, 84.24E) in the north to Minfeng (37.06N, 82.69E) in the south. The Silk Road also exists.

28.4.3 Nearest Airport

28.4.4 Logistics

28.4.5 Permissions

28.4.6 Cost

28.4.7 Scheduling

Winter months have less rainfall and cooler temperatures.

28.5 Key References

Balme, M., and R. Greeley (2006) Dust devils on Earth and Mars, *Rev. Geophys*., 44:RG3003, doi:10.1029/2005RG000188.

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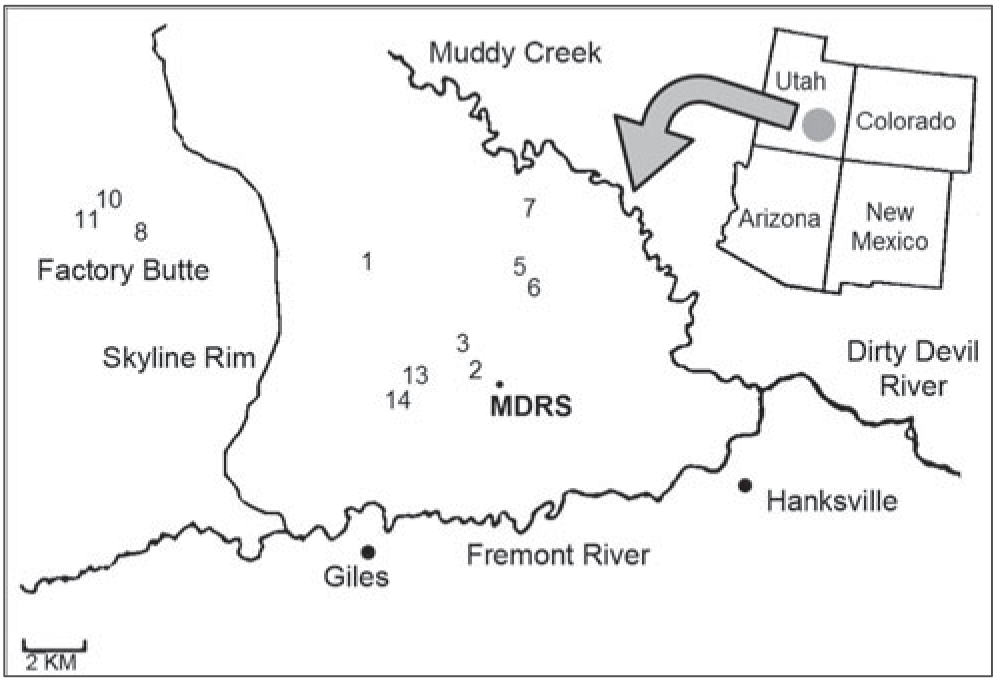
29 Utah Desert

29.1 Location

Coordinates	38°24’23.25”N 110°47’30.85”W
Country/State/Province	USA / Utah
Continent	North America

29.1.1 Map

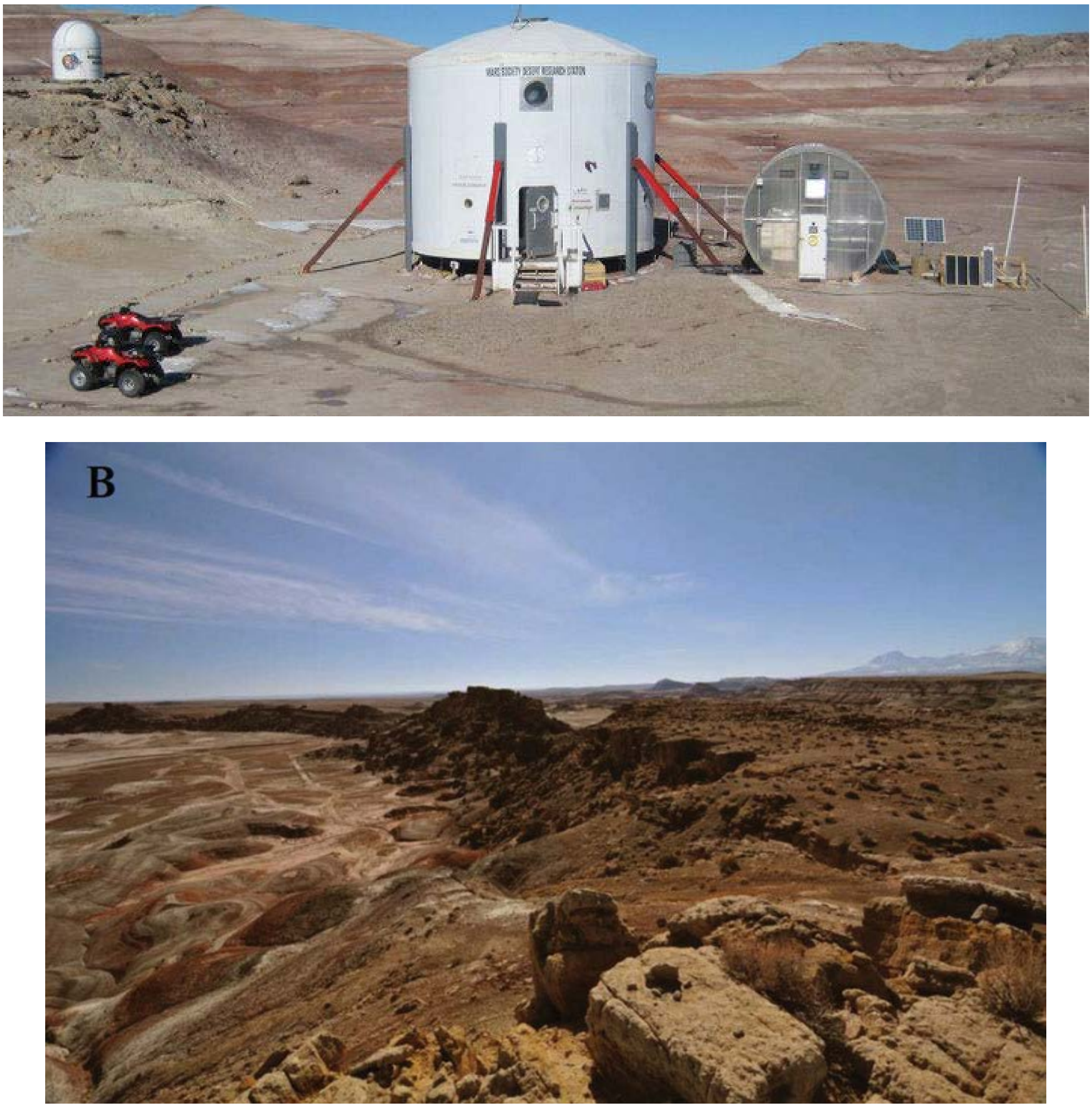


Map showing the locations where the MDRS is located (south-east area of Utah, USA). The right corner inset shows the states surrounding the state of Utah (USA). Taken from Direito et al. (2011).

29.1.2 Elevation

Study areas are located between 1340 and 1400 metres.

29.1.3 Images



Picture of MDRS Hab, observatory and greenhab. ‘Kissing Camel Ridge’ formed by exhumation of a fluvial channel within the Brushy Basin member of the Morrison Formation (adapted from Clarke and Stoker, 2011).

29.2 Context

29.2.1 Geological Setting

The stratigraphy of the area around the Mars Desert Research Station (MDRS) consists of a dissected succession of near flat-lying Cretaceous and Jurassic sandstones and shales. The main unit studied is the Jurassic Morrison Formation, in particular the uppermost Brushy Basin Member (Hintze & Kowallis 2009). The landscape consists of mesas and scarp-bounded surfaces resulting from erosion of the flat-lying succession of alternating units of sandstone and clay with a greater and lesser resistance to erosion respectively. Surrounding the MDRS, the landscape includes rocky and smooth plains, steep smooth and scree-mantled slopes, cliffs, gullies and dunes.

The MDRS was launched by the Mars Society to develop key knowledge needed to prepare for the human exploration of Mars. Their goals are to develop field tactics based on environmental constraints to test habitat design features and tools, and to assess crew selection protocols. Although much warmer than Mars, the desert location was selected because of its Mars-like terrain and appearance. The MDRS is the second analogue research station to be built by the Mars Society, following the Flashline Mars Arctic Research Station deployed on the northern slope of Haughton Crater on Devon Island.

Each crew establishes different scientific goals they hope to accomplish during their time at MDRS. The majority of the biological studies carried out involve extremophiles. Bacteria and algae isolated from the surrounding desert are common subjects of study. These microorganisms have been studied for their DNA, diversity and the environments they live in. Soil samples and vapour samples from the vicinity of the MDRS have been found to have signs of viable methanogens. The areas around the MDRS provide a unique opportunity to combine geology and biology by studying the endoliths found in rocks around the Hab.

Other experiments include a study of the effect of EVAs on the heart rates and blood pressures of crew members, a human factors study that examine the correlation between cognitive ability and mood and a study on how much a space suit inhibits dexterity in comparison to regular street clothes.

29.2.2 Relevance

The Utah Desert surround the MDRS provides a number of physical, chemical and astrobiological analogues. Mars-analogue soils and regolith exist here with mineralogies similar to Mars plus deposits of sands, evaporites, clays, sulphates and weathered volcanic ash. Analogues also exist for exhumed and inverted Martian fluvial channels and ancient lake beds with concretions. The fluvial channels are composed of more permeable sediments such as sands and gravels. In the supposed barren Mars-like landscape of the desert, studies into organic compounds within the Mars-like soils are conducted to enable understanding of how life can survive in dry soils; and how we could detect similar life on Mars.

The MDRS programme allows extensive long-duration geology and biology field exploration operations to be conducted in the same style and under many of the same constraints as they would be on Mars.

29.3 Environmental

Climate/Weather	Arid desert.
Temperature	Hottest month, July av. Daily max. 37.1 °C, min. 16.3 °C; coldest month, January, av.daily. Max of 5.2 °C, min. -10.9 °C.
Precipitation Type	Rain and Snow.
Annual Precipitation	Average annual 141.22 mm of which 14.73 mm occurred as snow
Humidity	Ranges from 17 to 90 %.
Wind	0 m/s to 8 m/s.
Insolation	Between 9 and 15 hours over the year.

29.4 Infrastructure

29.4.1 Existing

The MDRS station is situated on the San Rafael Swell of southern Utah; and is available for logistic support and habitat even if you are not working with them.

29.4.2 Accessibility

The MDRS is located 11.63 kilometres (7.23 mi) by road north-west of Hanksville, Utah. Hanksville is located at the junction of State Routes 24 and 95.

29.4.3 Nearest Airport

Hanksville has its own small light aircraft airport; nearest international airport is Salt Lake City.

29.4.4 Logistics

MDRS can be used for field support if needed. Outside of MDRS; desert survival equipment needed; take lots of water; and take rubbish out of desert with you.

29.4.5 Permissions

MDRS applications are needed to use the facility and be part of the analogue campaign. To work in the desert outside of the MDRS programme requires no permissions, except those of local landowners.

29.4.6 Cost

Variable. To be part of the MDRS, crew members will be required to pay for their own transportation to/from Grand Junction, Colorado and also provide a $1,000 participation fee (reduced to $500 for students) to cover station expenses.

29.4.7 Scheduling

MSRS field seasons from January to May. Utah Desert best to visit in spring or Autumn.

29.5 Key References

MDRS: http://www.marssociety.org/.

Special Issue: "Astrobiology field research in Moon/Mars analog environments": *International Journal of Astrobiology*, volume 10, 2011. Includes:

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Jonathan D. A. Clarke and Carol R. Stoker (2011) Concretions in exhumed and inverted channels near Hanksville Utah: implications for Mars. International Journal of Astrobiology, 10:161-175. doi:10.1017/S1473550411000048

Carol R. Stoker, Jonathan Clarke, Susana O.L. Direito, David Blake, Kevin R. Martin, Jhony Zavaleta and Bernard Foing (2011) Mineralogical, chemical, organic and microbial properties of subsurface soil cores from Mars Desert Research Station (Utah, USA): Phyllosilicate and sulfate analogues to Mars mission landing sites. *International Journal of Astrobiology*, 10:269-289. doi:10.1017/S1473550411000115

29.6 Site Specific Details

29.6.1 Kissing Camel Ridge (KCR)

29.6.1.1 Co-ordinates

29.6.1.2 Physical Characteristics

29.6.1.3 Geochemical Characteristics

29.6.1.4 Astrobiological Characteristics

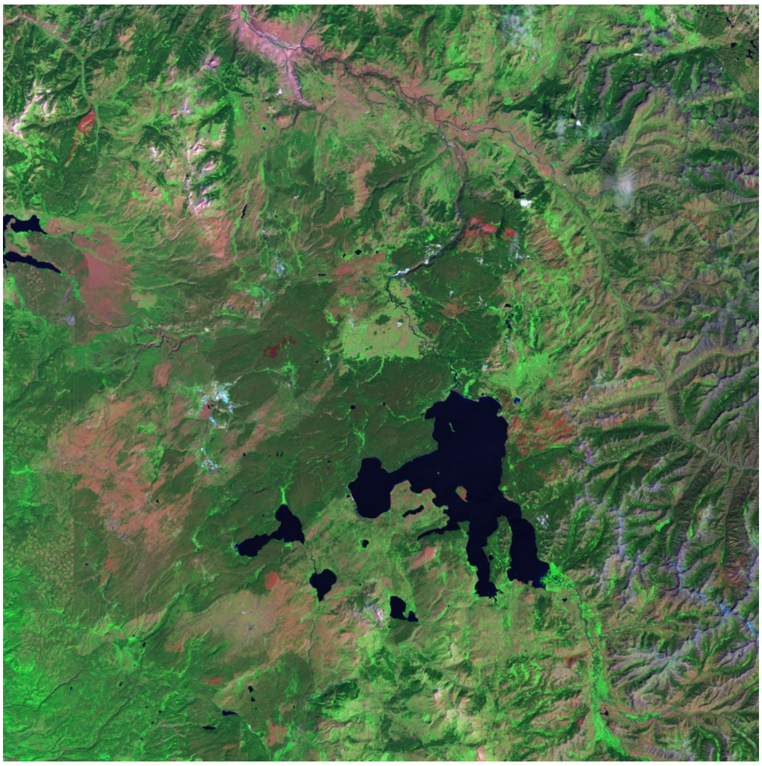
29.6.1.5 Prior Analogue Usage

30 Yellowstone

30.1 Location

Coordinates	44°36’N 110°30’W
Country/State/Province	USA
Continent	North America

30.1.1 Map



Top: Map of Yellowstone and Grand Teton National Parks. Bottom: NASA Earth Observatory image created by Jesse Allen, Earth Observatory, using data provided by Laura Rocchio, Landsat Project Science Office.

30.1.2 Elevation

The park sits on the Yellowstone Plateau, at an average elevation of 2,400 metres.

30.1.3 Images

Grand Prismatic Springs (courtesy of N. Parenteau). Columnar Basalts along the roadside at Yellowstone. Bottom: Photo of Steve Ruff using a field-based version of the Miniature Thermal Emission Spectrometre (Mini-TES) at Yellowstone collecting spectra of the silica deposits (Photo: N. Parenteau).

30.2 Context

30.2.1 Geological Setting

North American Plate has moved over the last 17 million years by plate tectonics across a stationary mantle hotspot. The landscape of present-day Yellowstone National Park is the most recent manifestation of this hotspot below the crust of the Earth. The Yellowstone Caldera is the largest volcanic system in North America. There are 300 geysers and a total of at least 10,000 geothermal features.

30.2.2 Relevance

Yellowstone features are predominantly analogues for those proposed to have existed on Mars. Hot springs and mineral deposits such as silica sinters that are related to giant calderas and super volcanoes are the main analogue features for Mars. Associated extremophilic microorganisms that thrive in the hot springs and geothermal areas are astrobiological analogues to those that might have existed with martian geothermal features in the past.

30.3 Environmental

Climate/Weather	Depends upon altitude.
Temperature	Summer: 21to 27 C; winter: −20 to −5 °C
Precipitation Type	Rain; Snow is possible in any month of the year, with averages of 3800 mm annually
Annual Precipitation	Highly variable and ranges from 380mm annually near Mammoth Hot Springs, to 2000 mm in south-western sections of the park.
Humidity	
Wind	
Insolation	

30.4 Infrastructure

30.4.1 Existing

Roads into the Park, plus a Visitors centre, park rangers, and camp sites.

30.4.2 Accessibility

Grand Teton's gateways are from the north, south, and east. Drivers naturally enter from whichever side they approach the parks. From the west, U.S. 20 or U.S. 191 takes you to West Yellowstone, Montana. From the south, U.S. 191 runs through Jackson and the length of Jackson Hole before entering Yellowstone. From the east, U.S. 20 bisects Cody, Wyoming, and continues west 53 miles to the east entrance of Yellowstone. The northeast entrance of Yellowstone is accessible via U.S. 212 via Cooke City, Montana. Finally, the north entrance is just outside Gardiner, Montana, on U.S. 89. Unless otherwise authorized on your permit, you must carry out all of your activities out of public view. Paths are available and hiking is permitted in the park.

30.4.3 Nearest Airport

The closest airport to Yellowstone is the West Yellowstone Regional Airport in Montana, where the airport sits just 1 mile north of town (and the west entrance) on U.S. Hwy. 191. Other airports include Jackson, Wyoming (56 miles); Bozeman, Montana (87 miles); Cody Wyoming (53 miles).

30.4.4 Logistics

You are required to notify the district ranger in charge of your work area/s one week in advance of your trip. If you collect specimens that are to be permanently retained, regardless of where they are kept, they must be accessioned and catalogued into the National Park Service's catalogue system, and must bear National Park Service accession and catalogue numbers.

30.4.5 Permissions

Yellowstone is a UNESCO World Heritage Site. To conduct research in the park you need to obtain a National park Service permit for research: https://science.nature.nps.gov/research/ac/ResearchIndex. The Research Coordinator: Christie Hendrix

30.4.6 Cost

Variable.

30.4.7 Scheduling

July is the busiest tourist month which makes conducting research out of the public eye difficult.

30.5 Key References

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Brock, T.D., (1978) Thermophilic microorganisms and life at high temperatures, ed. M.P. Starr, New York: Springer-Verlag.

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Ruff, S.W., et al. (2011) Characteristics, distribution, origin, and significance of opaline silica observed by the Spirit rover in Gusev crater, Mars. *Journal of Geophysical Research E: Planets*. 116(4).

Wade, M.L., Agresti, D.G., Wdowiak, T.J., Armendarez, L.P. and Farmer, J.D. (1999) *Journal of Geophysical Research E: Planets* 104 (E4), 8489-8507.

Walter, M.R. and D.J. Des Marais, (1993) Preservation of Biological Information in Thermal Spring Deposits: Developing a Strategy for the Search for Fossil Life on Mars. *Icarus* 101(1): p. 129-143.

30.6 Site Specific Details

30.6.1 Chocolate Pots

30.6.1.1 Co-ordinates
6°43’19”W; 30°42’01”N.

30.6.1.2 Physical Characteristics
The chocolate pots comprise 42+ vents on and under the Gibbon river near Gibbon Cascades. There are 8 main vents which have formed small cones and comprise the so-called chocolate pots due to their yellow red and brown colouring. There are a further 28+ minor seeps and 6 vents in the river. The major cones spout up to 2 feet due to hydrostatic pressure. These geysers and vents are unique in that the effluent contains more than 5.5 mg L^{-1} Fe(II), more than 10 times higher than the next comparable hot spring. The geology surrounding the vents is of a thin cm scale accumulation of flocculent iron oxide precipitate atop a 640 ka Lava Creek ash-flow tuff.

One of the chocolate pots cones (N. Parenteau).

30.6.1.3 Geochemical Characteristics

The chocolate pots hot springs reach a temperature of 51.8°C. The deposition surrounding the vents has formed cones of approximately 50% iron oxide, 5% aluminium oxide, 2% manganese oxide and a maximum of 17% silica. The vent fluids are anoxic and slightly acidic at pH 5.7. A full table of the geochemical composition of the fluids from a number of studies can be found in Parenteau and Cady (2010).

30.6.1.4 Astrobiological Characteristics

The effluent from the vents is a chemical model of proposed pre-Cambrian (Archean) conditions, which are currently believed to have existed concurrently on both the early Earth and Mars. The vents are all surrounded by bacterial biomats, made up of oxygenic photosynthesising cyanobacteria, anoxygenic photosynthesising *chloroflexus* and a small proportion of purple phototropes. This environment is of particular interest as it replicates the iron oxide sedimentation process that is believed to have formed the bulk of iron oxide formations on the Earth and potentially on Mars.

30.6.1.5 Prior Analogue Usage

The vents have been used as Martian hot spring analogues in order to test Mössbauer spectroscopy for use on Mars (Wade et al., 1999). Photographic evidence has shown what appear to be many instances of ancient hot spring systems on the surface of Mars associated with either impact sites or volcanic activity. Current research focuses on the ecosystem as a model of early Earth and hence early Mars ecology (Parenteau and Cady, 2010). By studying the deposits and comparing those to modern terrestrial rocks from ancient hot springs the role of biology in producing the modern minerals can be determined. This allows the analysis of analogous Martian formations for the presence of biologically mediated processes.

30.6.2 Grand Prismatic Springs

30.6.2.1 Co-ordinates

44°31’30”N 110°50’17”W.

30.6.2.2 Physical Characteristics

Grand Prismatic Springs is the largest hot spring in America. It is located in the Midway Geyser Basin area of Yellowstone and measures approximately 100 metres in diameter and 50 metres in depth. Apart from its size it is notable for the rings of colourful heat tolerant (thermophile) bacteria that ring the lake and produce the characteristic ‘prism’ effect. Immediately adjacent is the Excelsior Geyser Crater, a hot spring and dormant geyser, with a large outflow channel leading directly into Firehole river.

30.6.2.3 Geochemical Characteristics

The springs are typical of the hot silica depositing springs that make up 70% of those in Yellowstone national park. The geochemistry of the water was catalogued by Brock (1978) and is shown below:

Name	°C	pH	Cl (mg/l)	SO4 (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Mn (mg/l)
Prismatic	67.5	8	285	18	423	18.2	1	0.2	0.01	0.027
Excelsior	88	7.6	274	19	402	15.2	0.6	0.0	0.02	0.025

The springs are situated in a basin of glassy volcanic tuff overlaid with several metres of siliceous deposits. The surface is characterised by discharge channels, conical silicate stromatolites and biological membranes. The siliceous deposits take a number of forms depending on the temperature at which they precipitate. Above 74°C silica precipitates directly out of the spring water forming geyserite, which is primarily amorphous silica. Between 74°C and ambient a sinter is formed, consisting of silica crystallising around bacterial mats. This sinter preserves much of the structure of the original bacteria and the macroscopic mat, forming stratiform layers of more or less fine filaments

30.6.2.4 Astrobiological Characteristics

The populations of thermophile bacteria that populate Grand Prismatic Springs are strictly temperature differentiated, forming the characteristic ring structure. A full description of the rings and the bacterial populations can be found in (Walter and Des Marais, 1993). The springs present a wide range of bacterial habitats, beginning with high temperature, high H_2S and low O_2 at the centre and ending with a low temperature, low H_2S high O_2 at the edge. As previously noted there is considerable photographic evidence for hot spring activity on Mars and so this environment is analogous to alkaline silica Martian hot springs.

30.6.2.5 Prior Analogue Usage

The amorphous silica deposits at Grand Prismatic are directly analogous to the amorphous silica deposits found at Home Plate in Gusev Crater by the Spirit Rover (Ruff et al., 2011). Samples of sinter produced from 54-30°C biological mats and taken near Excelsior Crater have proven a good match for instrument measurements made by Spirit. The Midway Geyser basin has also been imaged using plane and space based near infrared (NIR) sensors in order to provide calibration data for Mars orbiting spacecraft searching for hot spring deposits on the Martian surface (Hellman and Ramsey, 2004). The remote sensing data was then correlated with ground level high resolution NIR spectroscopy. This study provided analogue data sets for both active and extinct hot springs and a wide variety of bacterial ecologies.

31 Acknowledgements

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