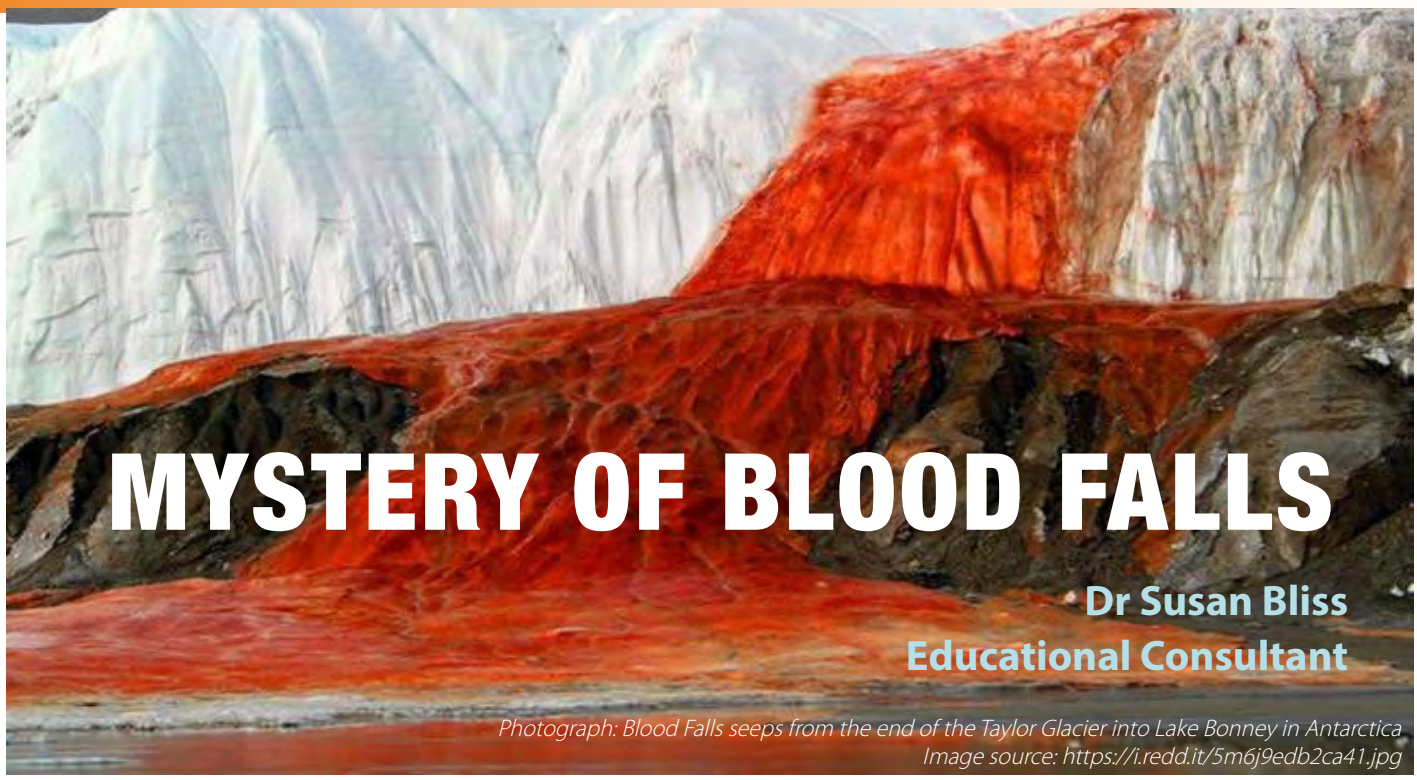


MYSTERY OF BLOOD FALLS

Dr Susan Bliss
Educational Consultant

Photograph: Blood Falls seeps from the end of the Taylor Glacier into Lake Bonney in Antarctica
Image source: https://i.redd.it/5m6j9edb2ca41.jpg

CURRICULUM

- Landforms and Landscapes
- Ecosystems

An Antarctic glacier appears to be bleeding! Observed is a five-story high, rust-coloured waterfall seeping from a glacier's terminus. The unique, above-ground landform known as 'Blood Falls', indicates a subterranean world with an ancient system of salt water rivers and an underground salt lake, swarming with microbial life in a place devoid of light and oxygen.

However, scientists appear less interested in the waterfall's weird colour but fascinated by the microbes living in the ancient underground ecosystem. They ask- *'Is this primordial ooze the source of all life'?*

As geographers the mystery requires investigation by determining answers to key questions such as:

- What is it?
- Where is it located?
- How was it formed?
- Why is it red in colour?
- Why is it hyper saline? What are the impacts?
- How does an ecosystem survive below hundreds of metres of ice in cold and dark conditions over millions of years?
- What can scientists learn from the 'time capsule' ecosystem?
- Why should it be protected?
- Who was the Australian who discovered 'Blood Falls'?

What is Blood Falls?

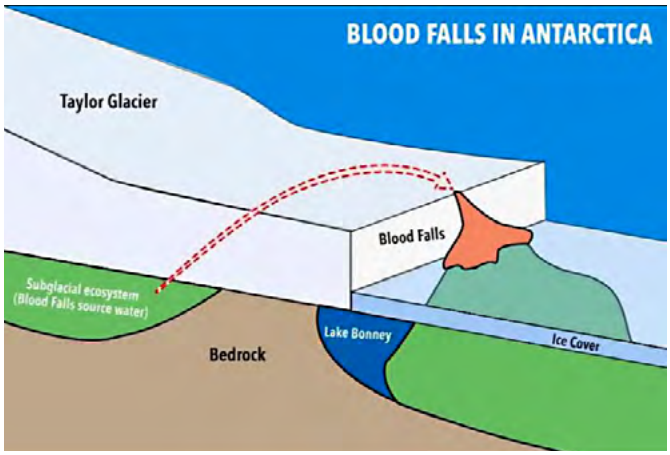
> *"Blood Falls is an outflow of an iron oxide-tainted plume of saltwater, occurring at the tongue of the Taylor Glacier onto the ice-covered surface of West Lake Bonney in the Taylor Valley of the McMurdo Dry Valleys in Victoria Land, East Antarctica".*
>
> *"Iron-rich hypersaline water sporadically emerges from small fissures in the ice cascades. The saltwater source is a subglacial pool of unknown size overlain by about 400 metres of ice at several kilometres from its tiny outlet at Blood Falls."*
>
> https://geog.ucsb.edu/antarcticas-blood-falls/

Blood Falls is a unique landform, as it did not originate from glacial melted water typically found in other continental glaciers. Instead a cascade of **iron rich hypersaline water,** originally trapped underground for millions of years, escaped to the Earth's surface via fissures under **Taylor Glacier** in **East Antarctica**.

When the water reached the surface it became **oxidised**, colouring the water blood red. A **red salt**

cone, known as **Blood Falls**, was formed at the end of Taylor Glacier.

Diagram shows how water from an ancient lake travels to Blood Falls



Source: https://www.thesun.co.uk/tech/3416557/antarctic-blood-falls-mystery-finally-solved-by-scientists-who-claim-natural-wonder-is-caused-by-a-secret-lake-thats-been-hidden-for-one-million-years/

Where is Blood Falls located?

- Blood Falls, is located in **Taylor Valley**.
- Taylor Valley is one of the **McMurdo Dry Valleys (MDV)** in the Transantarctic Mountains. It is located between Asgard Range in the north and Kukri Hills in the south, containing numerous glaciers, lakes and rivers.
- Approximately 29 kilometres long, Taylor Valley extends from the retreating **Taylor Glacier** in the west to **McMurdo Sound** in the east.
- Subglacial water flows to Earth's surface from the terminus of Taylor Glacier onto ice covered **Lake Bonney** in Taylor Valley.

Map illustrating the location of Taylor Valley and Taylor Glacier in Antarctica

Source: https://en.wikipedia.org/wiki/Taylor_Valley#/media/File:Mcmurdo_sound_USGS_map.jpg

Image: Scientists arrive at Blood Falls, Antarctica. https://www.reddit.com/r/photographs/comments/ev9mvb/scientists_arriving_to_blood_falls_antarctica/

Satellite image of Taylor Glacier, Blood Falls and Lake Bonney

Source: https://en.wikipedia.org/wiki/Taylor_Valley#/media/File:Taylorvalley_ast_2000334.jpg

What is the environment surrounding Blood Falls?

Climate

Taylor Valley, one of the McMurdo Dry Valleys (MDV)**,** encounters a **freezing desert environment.** Located in a rain shadow area behind mountains, the valleys experience low precipitation**,** mean annual temperature -19.8°C, and strong katabatic winds that reach 320 kilometres per hour. The winds evaporate all moisture, hence hindering the formation of ice and snow that covers most of Antarctica.

Taylor Valley and the other MDV encompass the **largest ice-free region in Antarctica,** with a combined area of 4500km^2. The average moisture is less than 6mmpa, generally falling in the form of snow and summer glacial melt.

- Scientists consider the MDV to be one of the Earth's most extreme deserts, and these dry conditions are thought to have endured for about fifteen million years.

A seal carcass in one of the Dry Valleys of Antarctica in a stage of advanced mummification.

Source: https://www.livescience.com/18343-seal-mummies-antarctic-microbes.html

Researchers analysed microbes living under a carcass of a seal naturally mummified by the Antarctic cold and aridity. These centuries-old mummies have been seen up to 66 kilometres inland in the Dry Valleys and 1,800 meters above sea level; why the seals roamed so far away from the coast to their death remains a mystery, with potential culprits including viruses and bad weather.

Flora and Fauna

There are no large plants, birds or mammals in the MDV. This was supported by Scott in 1903 when he first discovered MDV and saw extensive exposed rocky surfaces and believed the region 'lacked life'. However, biota was restricted to **microbial communities** as well as **aquatic ecosystems** that thrived in glacial melt-streams that flowed into ice-covered lakes.

Soils are the oldest, driest and coldest on Earth. They are poorly developed, low in biological activity, possess large quantities of salt, register a high pH, and as the ground is frozen (permafrost), growth of vegetation in hindered, especially complex plants.

Lack of precipitation in **Taylor Valley,** leaves exposed rock with sparse patches of moss, algae and cyanobacteria in the permafrost, a source of moisture during the thawing season for top soils. In fact cyanobacteria is able to start the photosynthesis process within 48 hours of receiving liquid water.

Climate is important for scientific research in Taylor Valley. The legacies of past climates exert a strong influence on the structure and function of current ecosystems. While ecosystems depend on water for survival, a minor change in climate can affect the growth and reproduction of organisms.

What are the landforms surrounding Blood Falls?

The McMurdo Dry Valleys such as Taylor Valley exposes bedrock and prominent geological features as there has been little erosion and minimal vegetation coverage.

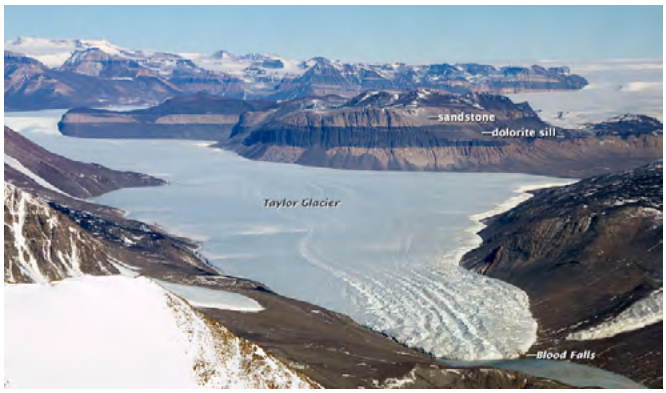


Image: Blood Falls at the toe of Taylor Glacier, 2013. Source: https://commons.wikimedia.org/wiki/File:Taylorglacier_pho_2013_studinger.jpg

Landforms

- **Glacier:** Taylor Glacier in Taylor Valley is located in the centre of the photograph. It is a '**cold-based glacier'** unlike other glaciers that are 'wet based'. A cold-based glacier 'flows', pushed forward by its own weight. The glacier gathers minimal debris, causes little erosion, and leaves behind only small moraines. The glacier also differs on the surface-instead of **crevasses** it is comparatively flat and smooth.

  Adapted: https://en.wikipedia.org/wiki/Taylor_Glacier; https://earthobservatory.nasa.gov/images/82524/taylor-valley-antarctica

- **Sandstone:** The sandstone layers were formed at the bottom of a shallow sea between 250 million and 400 million years ago. Around this period, the Earth's southern continents were part of the supercontinent Gondwana.

- **Dolerite:** The dark rock is dolerite, a remnant of volcanic eruptions about 180 million years ago. The eruptions contributed to forcing Gondwana apart.
- **Blood Falls:** At the lower right of the preceeding photograph is located **Blood Falls** that emerged from an ancient hypersaline lake trapped beneath **Taylor Glacier's 400 metres of ice**. It then flowed towards frozen **Lake Bonney**.
- **Lake Bonney** is unique within the MDVs due to its extreme salinity from hypersaline, anoxic, and iron-rich subglacial brine that exists beneath Taylor Glacier and pours out at Blood Falls.

The area covering the Lower Taylor Glacier, Blood Falls and McMurdo Dry Valleys were designated to be protected because of their unique physical properties, unusual microbial ecology and geochemistry, as well as an important site for paleoclimatic and glaciological research.

How was Blood Falls formed?

During a geological period called the **Pliocene Epoch,** about five million years ago, global warming caused East Antarctica's ice sheets to melt and sea levels to rise about 20 metres. Taylor Valley was flooded and developed into a deep fiord.

- Around 5 million years ago sea levels rose, flooding East Antarctica. This created a salty inland lake
- Around 3 million years later, glaciers formed over the saline lake
- Around 2 million years ago a sub-glacial lake of saltwater became trapped and isolated. The frozen glacier surrounding the lake acted as a 'time capsule', preserving microbial species.

Research from University of Alaska, calculates that salt water took approximately 1.5 million years to finally reach Blood Falls as it made its way through fissures and channels in the glacier.

Adapted: from https://www.forbes.com/sites/trevornace/2017/04/28/mystery-of-antarcticas-blood-falls-is-finally-solved/?sh=8d507c22ef8d

What caused the red colour in Blood Falls?

- Earliest explorers noticed the stain at the terminus of the glacier and speculated that **red algae** was responsible for the bright colour. Investigations later found the water was unsuitable for the growth and survival of algae.
- In 2009, scientists discovered the red colour was due to high levels of **iron oxide in saltwater** from a network of subglacial rivers and a subglacial lake.
- **Iron** is a common substance in Antarctic bedrock. Glaciers scraping the bedrock contributed to iron in the water.
- When the iron in the water reached Earth's surface at Blood Falls, oxygen in the atmosphere changed the colour to deep red in the same process human's salty, iron-filled blood turns red when makes contact with the atmosphere.

Ripley's Believe It or Not!

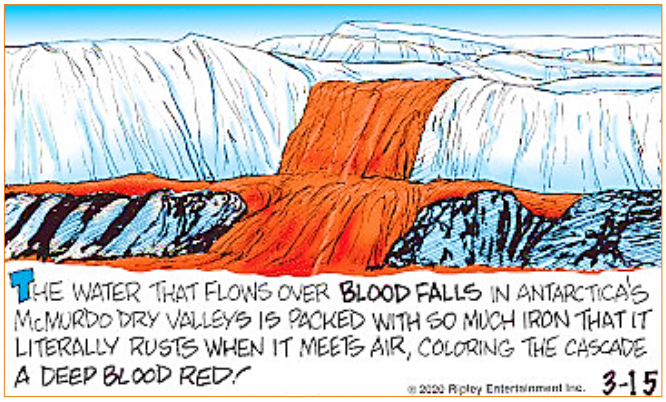


Image source: https://www.ripleys.com/weird-news/cartoon-03-15-2020/

Why does salt affect water flow?

The large very salty lake beneath Taylor Glacier occasionally overflows due to water moving at the back. This then causes Blood Falls to flow.

> *Using echolocation technology scientists were able to "see" how water flowed under the Taylor Glacier. Scientists were shocked to find that the lake hadn't frozen despite being entombed in ice for millions of years.*

Source: https://www.thesun.co.uk/tech/3416557/antarctic-blood-falls-mystery-finally-solved-by-scientists-who-claim-natural-wonder-is-caused-by-a-secret-lake-thats-been-hidden-for-one-million-years/

Taylor Glacier is the coldest known glacier, to possess **constantly flowing water.** With freezing temperatures and little melting from Taylor Glacier, one wonders why water slowly oozes out of Taylor Glacier at Blood Falls, rather than freezes. The answer is **hyper salinity** described as brine – too salty to freeze and releases heat when frozen.

Water too salty to freeze

Geochemical analyses of Blood Falls show the brine is of marine origin. Around 5 million years ago sea levels rose creating a salty inland lake, later covered by glaciers.

As a result the subglacial lake is three times saltier than seawater and too salty to freeze.

Salt water releases heat when it freezes

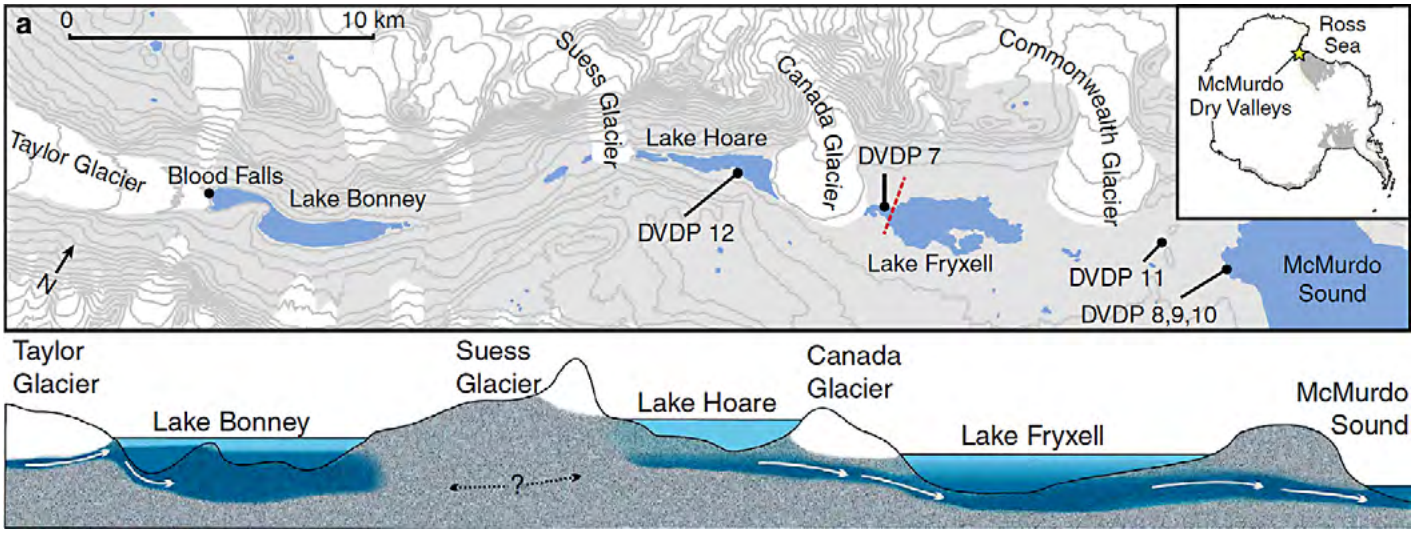
It melts the surrounding ice enabling it to flow through the extremely cold Taylor Glacier and emerge out at Blood Falls on the Earth's surface.

The brine is hypersaline, anoxic with high concentrations of ferrous iron, silica, and sulphate.

Scientific data strongly supports the marine origin of Blood Falls with its chemistry resembling cryo-concentrated seawater.

The process called salt cryo-concentration refers to the high concentration of salt in the encapsulated lake. When the climate cooled, the freezing seawater increased saltiness in the lake, since crystallised ice rejects salt.

Map and simplified cross section of Taylor Valley and its salt groundwater



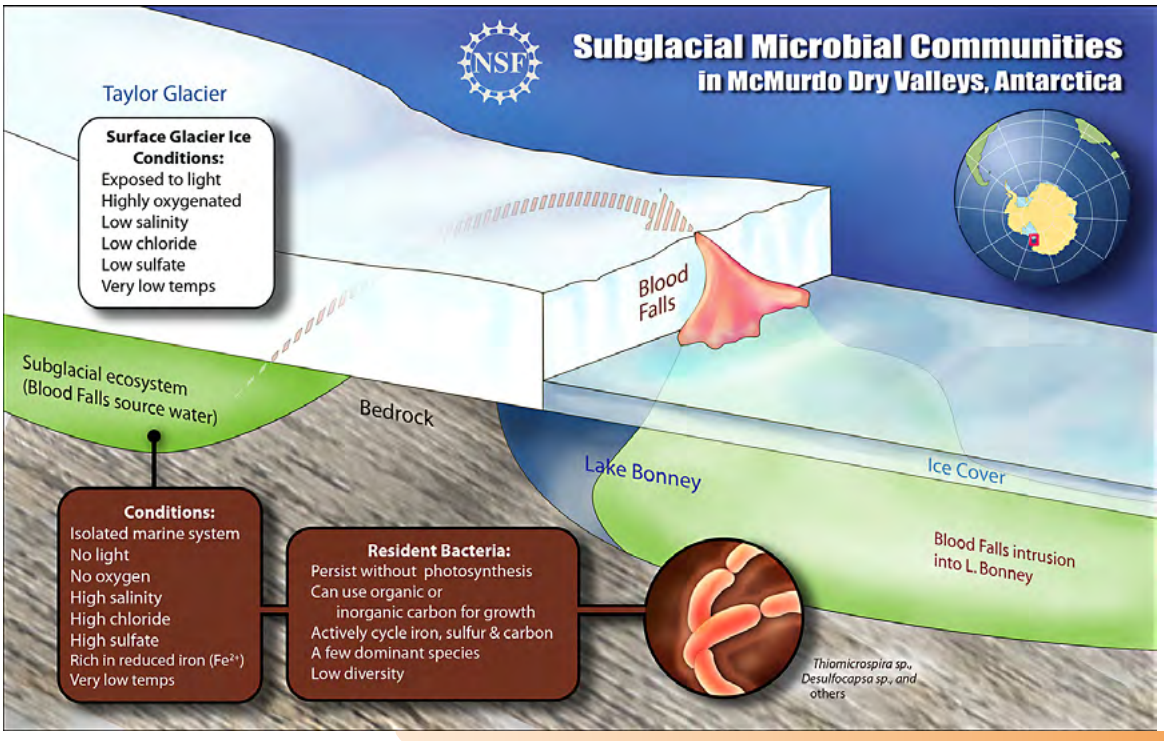
Source: https://arstechnica.com/science/2015/04/salty-groundwater-supports-life-in-antarcticas-extreme-dry-valleys/

What lives in a hyper-saline subglacial lake?

Millions of years ago, when glaciers covered salt lakes in Taylor Valley, microbes living in the water became isolated. Without sunlight, devoid of oxygen, frozen temperatures, extreme quantities of salt, and complete darkness buried 400 metres below the glacier, a unique ecosystem evolved.

Taylor Glacier is completely frozen to the bedrock preventing surface derived water from penetrating below ground. This ensured the maintenance of pristine conditions in the subglacial hyper saline basin.

A schematic cross-section of Blood Falls showing how subglacial microbial communities have survived in cold, darkness, and absence of oxygen for a million years in brine water below Taylor Glacier.



Source: https://en.wikipedia.org/wiki/Blood_Falls#/media/File:Blood_falls1_f_Low_Res_nsf.gov.jpg

Grand Prismatic Spring, Excelsior Group, Yellowstone Hotspot, northwestern Wyoming.
Image source: https://upload.wikimedia.org/wikipedia/commons/d/d4/Grand_Prismatic_Spring_%285_June_2013%29_28_%2814299472538%29.jpg

The microbes use Iron II (Fe2+) and sulphate (SO4-) in the lake that comes from the underlying bedrock.

The microbes obtain energy from breaking **sulphates.** Then the iron in the water restores the sulphates. Recycling occurs and life continues in these extreme conditions, resembling the beginning of life on Earth, before oxygen was principally present in the atmosphere.

What is the significance of microbes?

Tiny microbes are capable of surviving in super salty, high-iron, very cold water, without sunlight, under a glacier. It turns out these extremophiles were even more extreme than previously recognised, and studying them further can help us understand how life might survive in other extreme environments, such as outer space.

https://www.vice.com/en/article/7xq7ba/scientists-finally-solved-the-mystery-of-antarcticas-blood-falls

Extremophiles *are able to withstand and even thrive in extremely harsh environments, including freezing temperatures.*

The extremophiles of Blood Falls, however, do not use photosynthesis. They use a more unusual process called chemosynthesis. Chemosynthetic organisms are able to convert sulphur and iron compounds (not sunlight and oxygen) into energy. As Blood Falls' chemosynthetic bacteria extract iron from the rocks they come in contact with, they gradually erode the bedrock around the lake.

https://www.nationalgeographic.org/media/blood-falls/

The salt water contains a diverse microbial community that is metabolically active and influences ***weathering*** *and the* ***geochemistry*** *of the subglacial fluid by liberating ions such as iron and silica from subglacial bedrock.*

https://www.nature.com/articles/ncomms7831

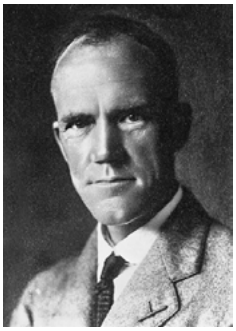
Jill Mikucki at Dartmouth College, investigated water samples from Blood Falls. The samples contained at least ***17 different types of microbes****, and* ***almost no oxygen****. An explanation may be that the microbes use sulphate as a catalyst to respire with ferric ions and metabolise the microscopic amounts of organic matter trapped with them. Such a metabolic process had never before been observed in nature.*

https://geog.ucsb.edu/antarcticas-blood-falls/

The McMurdo Dry Valley region is one of the coldest and most inhospitable places on Earth often compared to the frigid and dry deserts of Mars, or Jupiter's moon, called Europa. This hidden ecosystem of microbial life now has scientists wondering if Mars too, could support a similar ecosystem. This ecosystem could also help explain the scientific hypothesis known as "Snowball Earth" which states that our planet was once completely (or almost completely) frozen – probably around 650 million years ago. If this was the case, how did living forms survive? Well, much like they did within the frozen Taylor Glacier.

Source: https://www.bustle.com/p/what-is-blood-falls-antarcticas-mysterious-red-waterfall-has-puzzled-us-for-decades-55336

When was Blood Falls discovered? Who discovered it?



Blood Falls in Antarctica, is one of the coldest and inhospitable places on Earth. As a consequence it was not until 1911 when it was discovered by the Australian geologist and geographer Thomas Griffith Taylor on Scott's Terra Nova expedition.

Taylor Valley and Taylor Glacier are named after the noted geographer who was originally a teacher in Sydney and later lectured at Sydney University.

"It's unearthly, it's unreal," Steve Martin, an Antarctic historian, stated in the episode of Science Solved It. "So when [explorer] Griffith Taylor and his friends saw the Blood Falls flowing red out of the end of the Taylor Glacier, they must have thought it was just another incredible oddity in a very strange part of the world."

https://www.vice.com/en/article/7xq7ba/scientists-finally-solved-the-mystery-of-antarcticas-blood-falls

Preceeding image and notes: Griffith Taylor Source: https://en.wikipedia.org/wiki/Thomas_Griffith_Taylor#/media/File:Griffith_Taylor.png

What is the significance of Blood Falls?

There are numerous reasons for studying Blood Falls in Geography and Science, such as:

- Few glaciers possess **hyper saline outflows** and fewer are **coloured red**.
- Unlike surrounding glaciers in Antarctica, the underground water is **hyper saline** and does not freeze in extremely low temperatures.
- Investigations aim to assist scientists address questions about life on **'Snowball Earth'**, when large ice sheets covered Earth's surface millions of years ago.
- Taylor Glacier sealed off a body of water for millions of years making it a **'time capsule'**. This led to the evolution of **isolated microbes** that evolved independently from the rest of the world.
- As the area contains a rich laboratory of life in the super salty, high-iron, freezing water and dark environment, it could possibly provide scientists with a better understanding of life below the ice caps on **Mars**.

The ability of sub-cryospheric environments such as this one to support life on Earth hints at an increased possibility of finding life in similar environments elsewhere in our solar system.

Source: https://earthsky.org/earth/what-makes-blood-falls-red-antarctica

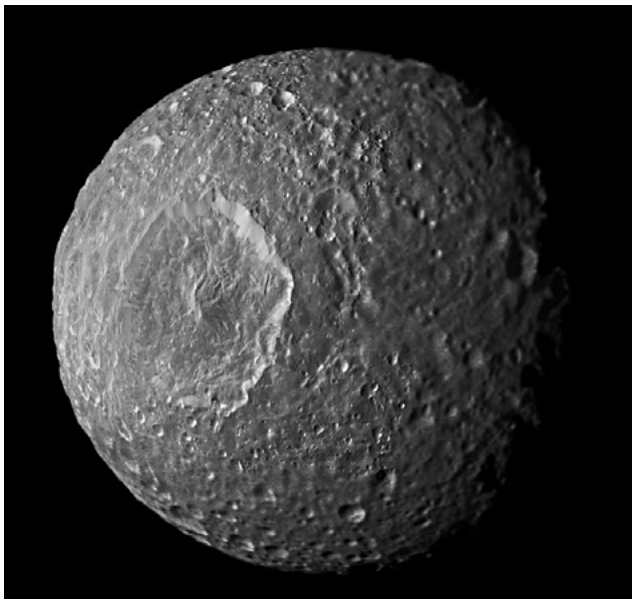
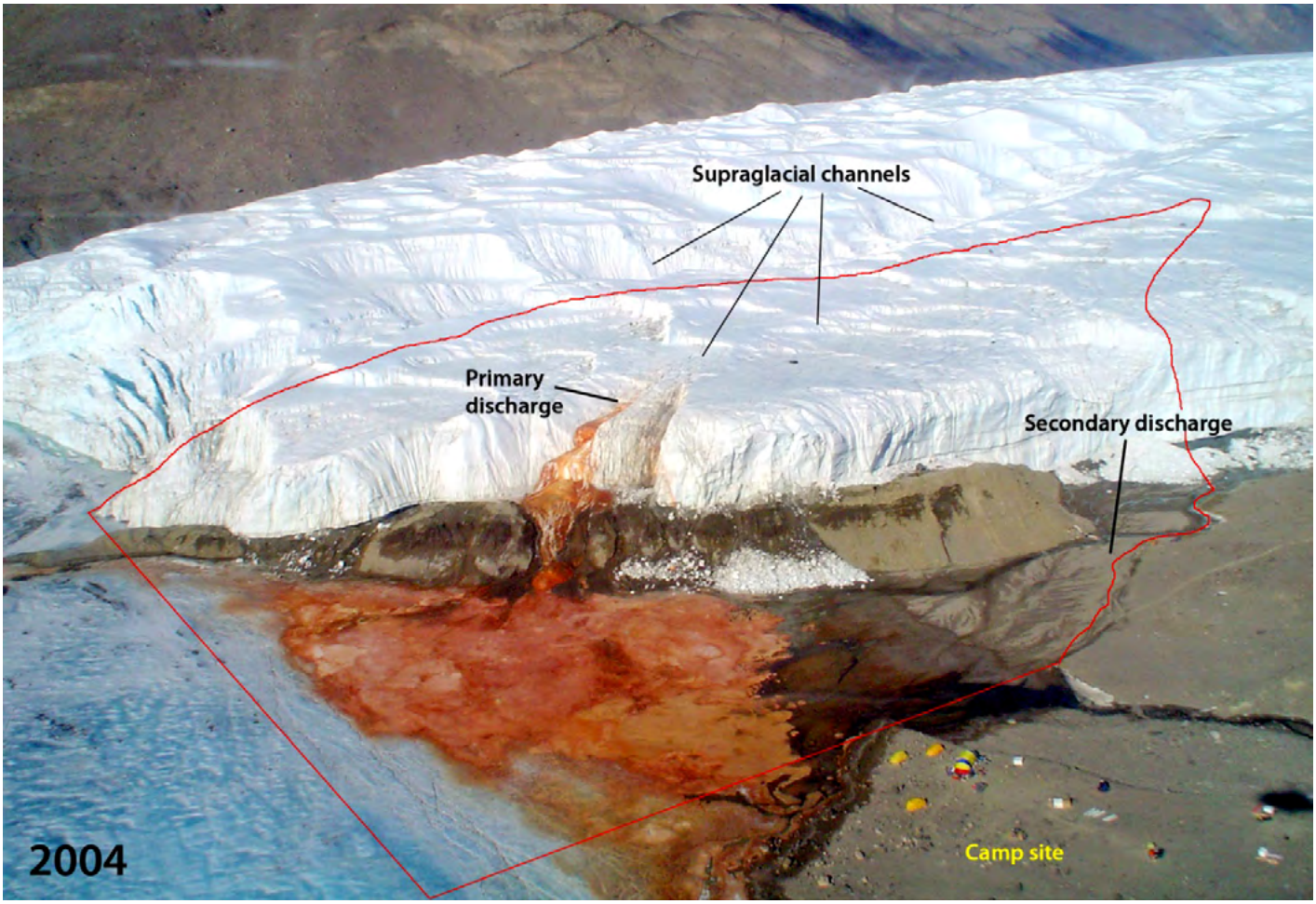


Image: Could similar microbial life as found in Antarctica be found on Mimas? NASA/JPL-Caltech/Space Science Institute
Source: https://theconversation.com/discovery-of-microbe-rich-groundwater-in-antarctica-guides-search-for-life-in-space-40931



Aerial view of the terminus of the Taylor Glacier in 2004, with Blood Falls at centre and Lake Bonney at lower left. Primary and secondary discharge are noted. Photographer unknown: 18 Nov 2004. Source: https://documents.ats.aq/recatt/att513_e.pdf

Aerial view of Blood Falls. Wikimedia Commons Source: November2014-Blood-Falls-Taylor-Valley-HR (2).jpg

The volume and physical extent of the **primary Blood Falls surface outflow varies over time**. The active flow events range from a few hundred to several thousand cubic metres of saline icing. The discharge events occur at episodic intervals of one to about three years and flow onto ice-covered Lake Bonney. A secondary, much smaller and less distinct, surface discharge has been observed on a few occasions.

Why should Blood Falls be protected?

Management Plan for Antarctic Specially Protected Area No 172 (https://documents.ats.aq/recatt/att513_e.pdf)

The Taylor Valley Visitor Zone in the McMurdo Dry Valleys **Antarctic Specially Managed Area (ASMA)**, permits tourism and research, while protecting the environment.

Reasons for protection

- The primary reasons for the designation of the Area to be protected are its **unique physical properties**, **unusual microbial ecology** and **complex and dynamic geochemistry**.
- The **lower Taylor Glacier subglacial brine reservoir** and **Blood Falls** are globally unique and a site of **outstanding scientific importance**.
- Blood Falls outflow contains a unique microbial community of marine origin.
- The **microbes** in the subglacial environment have survived for millions of years without external input.
- Geochemical analysis of Blood Falls outflow resembles a concentrated seawater remnant from the **Pliocene intrusion of marine waters**, combined with products of weathering.
- Provides an example of the **diverse physical** and **chemical places** for life in the polar desert of the McMurdo Dry Valleys.

GLOSSARY

Antarctic Ice Sheet: Thick glacier covering most of Antarctica.

Bacteria: Single-celled organisms found in ecosystems.

Bedrock: Solid rock beneath Earth.

Environment: Conditions that influence an organism or ecosystem.

Extremophile: Microbe that adapted to very harsh environments such as freezing water.

Fissure: Narrow opening or crack.

Glacier: Mass of ice that moves slowly over land.

Hypersaline Lake: Type of lake containing very high salt content.

Isolate: Separate organism, apart from others.

Landscape: Geographic features of a region-lithosphere, atmosphere, hydrosphere and biosphere.

Microbe: Tiny organism, usually a bacterium.

Outflow: Water, sediment and chemicals discharged by a river or flowing water.

Oxidation: Substance combined with oxygen changes its physical and molecular structure.

Plume: Upward flow of a fluid, such as water from underground sources.

Pristine: Pure or unpolluted.

Snout: End of a glacier. Often called a terminus.

Subglacial lake: Inland body of water that exists under a glacier or ice cap.

ACTIVITIES

Classify the following statements as either true (T) or false (F):

- Blood Falls is a natural, not a supernatural phenomenon.
- Taylor Glacier in located in West Antarctica.
- Taylor Valley is one of the McMurdo Dry Valleys in the Transantarctic Mountains.
- Dolerite is a sedimentary rock.
- Blood Falls is the melted residue of Taylor Glacier.
- An ancient hypersaline lake is trapped beneath Taylor Glacier's 400 metres of ice.
- Around one million years ago sea levels rose, flooding East Antarctica.
- McMurdo Dry Valleys encompass the largest ice-free region in Antarctica.
- Water in the hyper-saline lake beneath Taylor Glacier is about three times saltier than the ocean.
- Extremophiles are unable to thrive in extremely harsh environments.
- Blood Falls outflow contributes to salinity in Lake Bonney.
- Reddish particles formed in the Blood Falls is the result of a chemical reaction between iron and oxygen.

Read through the text on Blood Falls, either individually or as a class

- Express the ideas in the text in your own words. Share your ideas with other class members.
- Re-write the text by illustrating the **main concepts** in one of the following activities:
- Draw an annotated diagram
- Design a series of illustrative/cartoon panels
- Create an animated video
- In groups answer the key questions on the first page.

RESOURCES

YouTube

- Antarctica's Blood Falls Scientists Solve the Mystery – https://www.youtube.com/watch?v=e-jPIVlC7Wg
- Weird Places: Blood Falls – https://www.youtube.com/watch?v=plaf9LDJR9c

ICT

- Blood Falls
  - https://www.researchgate.net/figure/Location-of-Blood-Falls-The-McMurdo-Dry-Valleys-are-located-in-East-Antarctica-A-west_fig1_6362251
  - https://www.researchgate.net/figure/Map-of-Taylor-Valley-in-Antarctica-a-Map-of-major-lakes-glaciers-and-DVDP-boreholes_fig4_276126491
- Science behind Antarctica's mysterious Blood Falls – https://sharethe.buzz/science/the-science-behind-antarcticas-mysterious-blood-falls
- Mystery of Antarctica's Blood Falls is finally solved – https://www.forbes.com/sites/trevornace/2017/04/28/mystery-of-antarcticas-blood-falls-is-finally-solved/?sh=8d507c22ef8d
- National Science Foundation: Unusual Antarctic Microbes Live Life on a Previously Unsuspected Edge – https://www.nsf.gov/news/news_summ.jsp?org=NSF&cntn_id=114488&preview=false

Other References

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- Mikucki et al., 2009: "A Contemporary Microbially Maintained Subglacial Ferrous Ocean".
- NSF Press Release: "Unusual Antarctic Microbes Live Life on a Previously Unsuspected Edge".
- Smithsonian Magazine: "Antarctica's Blood Red Waterfall". https://www.smithsonianmag.com/travel/antarcticas-blood-red-waterfall-180949507/
- Forbes – Mystery of Blood Falls. https://www.forbes.com/sites/trevornace/2017/04/28/mystery-of-antarcticas-blood-falls-is-finally-solved/?sh=8d507c22ef8d