Worksheet answers

Stunning outlook!

Body of super-heated water available, featuring astonishing temperatures of 70–113 °C, mildly alkaline conditions included. Enjoy the colourful scenery, courtesy of the neighbours, and the excitement of nearby volcanic activity. Hurry, won't last long!

This could be an alkaline hot spring such as Grand Prismatic Spring, Yellowstone National Park, Wyoming.

Extremophiles that might be found in such an environment include thermophiles (organisms that grow optimally at temperatures above 45°C) and hyperthermophiles (organisms that flourish at temperatures above 80°C).

Background information

Hot springs are the result of ancient volcanic activity deep in the Earth's crust. Water is heated to high temperatures by sub-surface molten rock and forced to the surface under high pressure. Yellowstone National Park, Wyoming, boasts some of the most dramatic hot springs in the world. They are vividly coloured by microbial life. Hot spring environments can be alkaline, acidic or neutral.

Photosynthetic bacteria survive in hot springs at temperatures up to 70°C. Above this temperature non-photosynthetic bacteria such as *Thermus aquaticus* are the only inhabitants. Above 80°C, hyperthermophilic archaea are the only residents. These include super-survivor *Sulfolobus acidocaldarius*.

Extremophiles living in hot springs are often poly-extremists. As well as being thermophilic they may also flourish at high acidity (acidophilic) or high alkalinity (alkaliphilic).

Icy retreat!

Want to get away from it all? Habitat available for lease in permafrost location, extremely low temperatures (-10 to -12 °C). Experience a genuine iced-in period of dormancy. Enjoy being nutrient poor and completely inactive for thousands of years. Limited spaces, an opportunity not to be missed!

Permafrost environments are found in Siberia, Alaska and Antarctica.

A psychrophile is a type of extremophile found here. This is an organism with optimal growth at temperatures less than 15°C. Psychrophiles are also found in deep oceans and polar ice.

Background information

Permafrost refers to soil that has been continuously frozen for periods greater than two years. Permafrost is found in the Arctic, Eurasia and Antarctica. Scientists have found preserved microbe communities in permafrost that has existed for thousands and even millions of years. Some of these microbes show signs of low metabolic activity and others have been revitalised under laboratory conditions.

Bacteria genera discovered in permafrost include *Exiguobacterium*, *Flavobacterium*, *Psychrobacter* and *Arthrobacter*. The species *Psychrobacter cryohalolentis* has been found in Siberian permafrost at temperatures around -9°C.

Shared accommodation

Heat-loving extremophile seeks hydrothermal vent accommodation, willing to share with like-minded organisms. Prefer temperature range of 80–120 °C and an abundance of sulphur. No sunlight, must tolerate total darkness.

Hydrothermal vents are found in the deep ocean.

Extremophile species that inhabit hydrothermal vents include thermophiles (organisms that grow optimally at temperatures above 45°C) and hyperthermophiles (organisms that flourish at temperatures above 80°C).

Background information

Hydrothermal vents are fissures in the ocean floor formed by movement of tectonic plates. Water within these vents erupts into the ocean at extremely high temperatures (300–400°C). Hydrothermal vents usually form along mid-ocean ridges at average depths of 2100 m. Hydrothermal vents often form 'chimneys' or 'smokestacks'. These are caused by dissolved minerals that precipitate when super-hot vent water meets cold ocean water.

Thermophilic bacteria inhabiting hydrothermal vents are chemotrophs. They oxidise dissolved minerals emitted by vents to produce energy. In the absence of sunlight these bacterium are the cornerstone of vent communities as they provide the primary energy source other organisms need to survive. Many of these thermophilic bacteria are also acidophilic.

Hyperthermophilic archaean species *Pyrolobus fumarii* and *Pyrolobus abyssi* inhabit hydrothermal vents.

Part B: Holiday destinations

Describe characteristics an Earth-based extremophile would need to survive a holiday in the following Solar System destinations. Do similar destinations to these exist anywhere on Earth?

Mars escape holiday

Spend twelve unforgettable days in the northern arctic of Mars. Be enchanted by the iron-rich landscape and relax in an average temperature of -60 °C. Enjoy an atmosphere loaded with carbon dioxide and experience the thrill of digging for your own water, frozen of course. Proximity to Earth will suit the budget-minded extremophile.

- *psychrophilic (ability to grow at low temperature)*
- *xerophilic (ability to grow in conditions of low water)*
- *endolithic (ability to live in rocks or spaces between minerals)*
- *chemotrophic (ability to derive energy from chemical synthesis)*

Astrobiologists hypothesise that Mars might harbour life beneath the surface. Here microbes would be protected from high levels of radiation, experience slightly warmer temperatures and liquid water may exist. Contenders for survival on Mars include radiation-tolerant Deinoccus radiodurans *and the salt-loving* Halobacterium halobium*, capable of persisting in salt deposits long after water has frozen or evaporated.*

On Earth there are no completely analogous locations to the Martian northern arctic. The closest might be Lake Vostok in Antarctica. Scientists are investigating this sub-glacial liquid lake for signs of microbial life.

Soak up the sulphur

Looking for adventure? Visit the magnificent sulphur-choked plains of Io's popular equatorial region. Take in the constantly changing landscape of the most volcanically active location in the Solar System. Enjoy spectacular mountain views, an atmosphere saturated with sulphur dioxide and the complete absence of water.

- *psychrophilic (ability to grow at low temperature)*
- *hyperthermophilic (ability to flourish at extremely high temperature)*
- *xerophilic (ability to grow in conditions of low water)*
- *chemotrophic (ability to derive energy from chemical synthesis)*

High levels of volcanic activity are generally associated with production of chemicals needed for life, which is a good sign for possible life on Io. A downside to all this volcanic activity is absence of water, which limits the likelihood of this Jovian moon supporting life.

The most similar places on Earth to the plains of Io are hydrothermal and geothermal sites created by volcanic activity. These include hot springs, deep ocean hydrothermal vents, geysers and volcanic crater lakes. Sulfur-oxidising microbes such as Thiobacillus *and* Sulfolobus *are likely candidates to survive a visit to Io — at least they'd have plenty to eat.*

Re-invigorate on an organic get-away

Encounter the wonders of Titan on an unforgettable methane lake escape. Encounter the restorative wonders of an environment rich in organic molecules yet poor in sunlight. Relax in the cool temperatures provided by underground volcanic out-gassing and soak up the abundant hydrocarbons. Occasional breaks in the nitrogen-soaked clouds allow the discerning traveller breathtaking views of Saturn and its rings.

- *psychrophilic (ability to grow at low temperature)*
- *chemotrophic (ability to derive energy from chemical synthesis)*
- *methanotrophic (ability to use methane as an energy source)*
- *anaerobic (ability to grow without oxygen)*

Titan is rich in organic molecules and has an active weather system. It is considered to possess many conditions needed to support life. Water is considered to be likely on Titan, although at such low temperatures it is probably frozen. Volcanic activity deep below the surface might create enough heat to support sub-surface liquid lakes or oceans. Astrobiologists are particularly interested in Titan as it is considered to be representative of early Earth and may help explain how life developed on Earth.

Titan might include habitats similar to cold seeps found on the ocean floors of Earth. Cold seeps are rich in hydrocarbon and methane, and support unique ecosystems. Chemotrophic bacteria synthesise methane and provide an energy source for more complex organisms like the ice worm. Volcanic activity below the surface of Titan might support microbial life similar to that found in hydrothermal vents on Earth. This includes heat-loving acidophile Sulfolobus acidophilus*, or* Verrucomicrobia*, a recently discovered methanotrophic acidophile.*

Part C: The search for life on Mars

- Read the fact sheet *The search for life*, then research humankind's search for life in the Solar System to answer the questions. The following websites may be useful:

  NASA http://www.nasa.gov
  European Space Agency http://www.esa.int

1. What sort of technology is used to search for life on planets, other than Earth, in the Solar System?

   Rocket technology is required to launch all spacecraft including planetary probes.

   Unmanned interplanetary probes have been sent to other planets in our solar system since the early 1960s. The early probes performed 'fly-by' missions that beamed the first close-up images of these worlds back to Earth.

   Orbiters and landers have since been sent to planets, including Mars, Venus, Jupiter and Saturn. In all of these missions, images and other data are sent back to Earth by the spacecraft's communications equipment, and all functions of the spacecraft are operated by controllers on Earth.

   Orbiters may remain in orbit for many years, recording information about the planet as it changes over time.

   Some landers, such as Mars Pathfinder, have the ability to move around the surface, image the surrounding landscape and even take samples of soil and rock for on-board analysis. Some landers work in coordination with orbiters to relay information back to Earth.

2. How did the Phoenix Mars mission differ from previous missions to Mars?

   Phoenix was sent to the arctic region of Mars where it is believed frozen water exists.

   Phoenix included a robotic arm to excavate soil, and an on-board laboratory to perform analysis of soil samples to confirm the existence of water.

   Phoenix also took close-up images of soil. It found what appeared to be ice below the surface.

3. What successes and failures have humans encountered in searching for life on other planets?

   Early missions to the planets, such as Venus, were short-lived. The Venera spacecraft only survived a few minutes to send back a couple of images before succumbing to harsh temperatures and pressures.

   A number of missions to Mars have ended in failure. In 2003, contact with the Beagle spacecraft was lost shortly after it was due to arrive at Mars. It was never heard from again.

   Numerous rover and lander missions have enjoyed great success on Mars with many of them, including Spirit and Opportunity, outliving their expected duration by many months.

   Missions to the outer Solar System have also been successful. The Voyager missions to the outer planets provided our first true reconnaissance of the outer Solar System, with breathtaking images of Jupiter, Saturn, Uranus and Neptune, as well as dozens of moons.

   The Cassini spacecraft has been in orbit around Saturn for many years and continues to send back new information and images about Saturn and its many moons. This includes Titan which is a world that may have conditions capable of supporting extreme life.

4. Describe three missions to other worlds, highlighting similaries and differences in mission objectives and technologies used.

   (Answers will vary, depending on the missions chosen by students.)

   Pioneer I & II and subsequent Voyager I & II spacecraft were fly-by missions sent to explore the outer Solar System in the 1970s. In a mission that lasted for over a decade, Voyager spacecraft imaged all outer planets and dozens of moons. As these spacecraft were 'fly-by' missions, they have since left the Solar System for interstellar space.

   The Viking Landers were sent to Mars in the 1970s. These were the first spacecraft to land on Mars. They successfully imaged the surface close-up, and performed some basic analysis of the soil. Numerous landers have followed in Viking's footsteps including rover missions in which the space lander can be 'driven' around the surface of Mars to extend our remote exploration of this planet. More recent missions to Mars, such as Phoenix, have concentrated on establishing conditions for supporting life on Mars, including confirmation of the existence of water.

   The Galileo and Cassini orbiters were sent to Jupiter and Saturn respectively. These spacecraft spend years in orbit around these giant planets. The orbits are large, which allows the spacecraft to make close encounters with the moons of Jupiter and Saturn. Cassini included a lander which successfully landed on the surface of Titan and sent back the first ground images of this world. The Galileo spacecraft spent its final hours on a collision course with Jupiter and beamed back information about the composition of Jupiter's atmosphere.