frontiers FOR YOUNG MINDS

THE EARTH AND ITS RESOURCES
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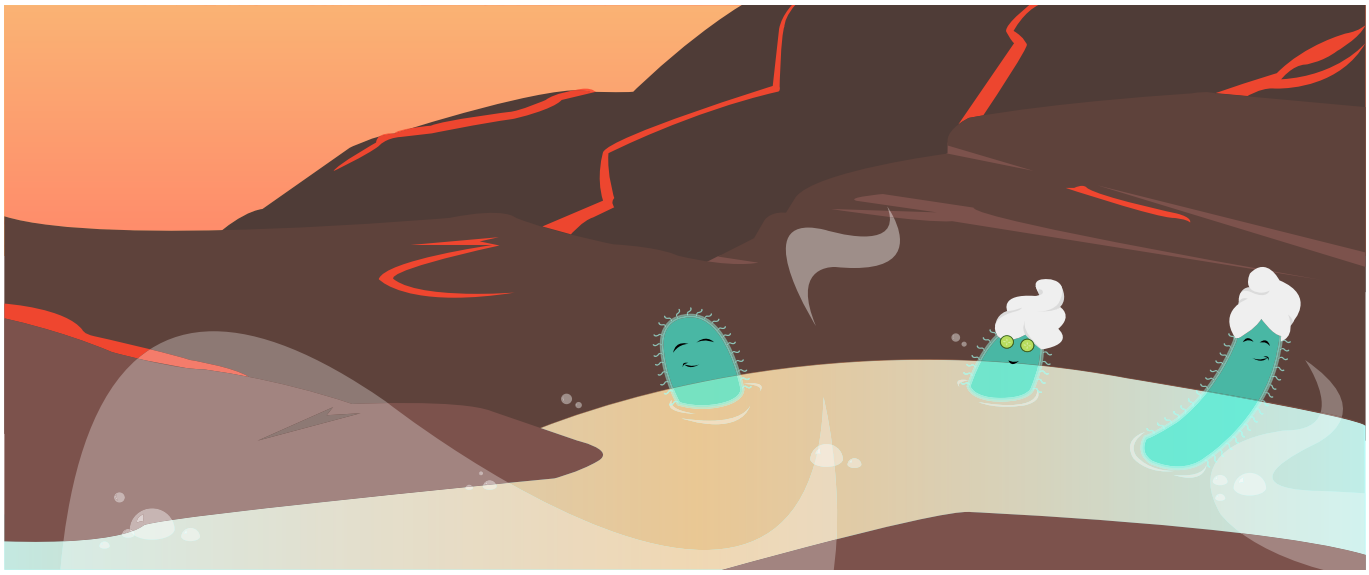

"BOILING WATER IS NOT TOO HOT FOR US!"—PREFERRED LIVING SPACES OF HEAT-LOVING MICROBES

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MICROBES/ MICROORGANISMS

Mainly one-celled organisms, including bacteria, some algae, and fungi. The baker's yeast is an example of a one-celled fungus.

Do you like to stay at the beach on a hot summer day? Sun bathing, chilling, and playing beach games? If it gets too hot, you can quickly cool off in the lukewarm ocean. Can you believe that there are living organisms on our planet that would still freeze on the hottest day of the year? These tiny creatures are called heat-loving microbes, and they do not grow at temperatures lower than 50°C, but they feel most comfortable in boiling water near volcanoes at the bottom of the ocean or in hot springs. Can you imagine that most of these hot places are not located in deserts, but on volcanic islands in the Atlantic Ocean and near the North Pole? And do you have an idea about the importance of such microbes for use in industry and in scientific laboratories?

DID YOU KNOW THAT THERE ARE MICROBES LIVING AT TOTALLY UNCOMFORTABLE PLACES ON OUR PLANET?

The smallest living organisms, called **microbes** or **microorganisms**, are invisible to the naked eye [1]. More than 300 years ago, the Dutch microbiologist

Antoni van Leeuwenhoek was the first person to see microbial cells under a microscope. A microbiologist is a scientist who studies microbes. Basically, microbes can be found everywhere on Earth. Soil, water, and air are fully colonized by these tiny microorganisms, but we also find them in and on food, in animals or even in our own bodies. By the way, every man, woman, and child contains more microbial cells in their digestive system than they have cells in their entire body! Of course, there are also some microbes that can cause severe diseases including diarrhea and flu, but most microbes are not harmful for human beings. In fact, some microbes are used to produce yogurt, or cheese, or for the treatment of wastewater. Some microbes grow best in darkness, some like living spaces without oxygen, and some prefer the sweet sugars in fruits or the evil-smelling environments on the surface of and inside cheese.

However, it is not really impressive for microbes to be able to survive in the ocean or at a pleasant body temperature at 37°C, but there are groups of amazing microbes that colonize the most astonishing places on the planet. Interestingly, these microbes can thrive under different kinds of extreme conditions, and they are probably some of the oldest life forms on Earth. These microbes were the first to adapt to extreme lifestyles and nowadays they colonize places that do not support any other forms of life. These organisms are called the *extremophiles* (meaning "they love the extreme"). The next question that needs to be answered is: where do we find these heat-loving organisms?

WHERE DO THE MOST EXTREME HEAT-LOVING MICROBES LIVE?

The hottest areas on Earth are often located near volcanoes on the Earth's surface and in the depth of the oceans. The Mid-Atlantic Ridge is an underwater ridge and the boundary between huge rock plates along the floor of the Atlantic Ocean (Figure 1). These rock plates are called tectonic plates, and they are so huge that the North American plate lies under Cuba, the United States, Canada, and Greenland, while the Eurasian plate lies under Europe and most of Asia. At several spots, beautiful volcanic islands came up from the ocean floor after a very long period of time. One group of such volcanic islands in the Atlantic Ocean is called the Azores. The Azores are located almost halfway between the United States and Portugal, while Iceland can be found in the very north between Greenland and Norway. These islands are covered with **hot springs**. Heated water from underground reaches the Earth's surface. Hot springs naturally discharge hot water, and they occur, because there is a lot of heat deep underground and the water circulates into these deep areas before it reaches the surface. If you go for a walk on the Azores, you will see that the water is constantly fuming and boiling (Figure 1).

HOT SPRING

A spring where heated water from underground reaches the Earth's surface. The water in such springs can be moderate to high temperatures, resulting in water boiling.

FIGURE 1

A map and some living spaces of some heat-loving microbes in the Azores and Iceland. The Mid-Atlantic Ridge is located in the Atlantic Ocean where the American, Eurasian, and African tectonic plates slowly collide and is shown by the purple line in the figure. The positions of volcanic islands, namely, the Azores and Iceland, are shown. Pictures of certain hot springs on Iceland are boxed in green, and examples from São Miguel, Azores are boxed in orange.

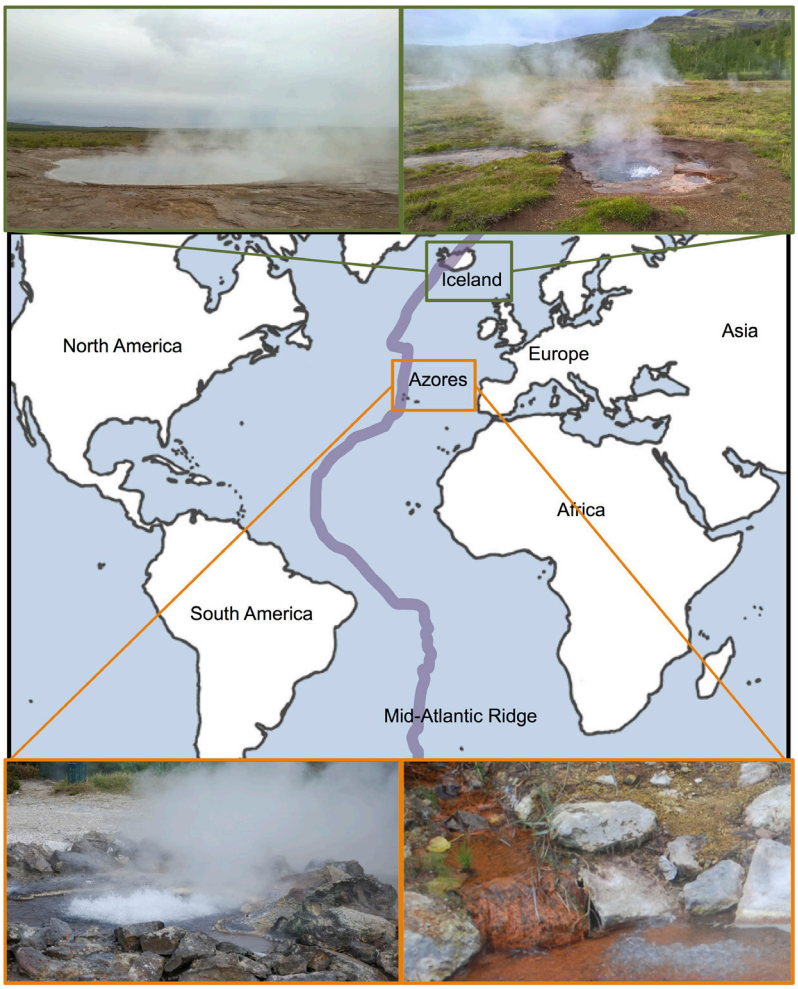

FIGURE 1

GEYSER

A spring that usually releases hot water and steam in a fountain. Most geysers (about 50%) are located in Yellowstone National Park in Wyoming, USA.

Most hot springs and **geysers**, which eject hot water and steam in a fountain, can be found in Yellowstone National Park in Wyoming, USA. This is where the first heat-loving microbes were discovered almost 50 years ago by the microbiologist Thomas Brock. Until then, the world's scientists believed that such hot environments must be sterile, meaning that living organisms could not exist in those areas, because the high temperatures would kill all life. Thomas Brock isolated and described the first heat-loving microbe and gave it the beautiful name *Thermus aquaticus* [2] (Figure 2). Since there are no English names for most microbes, we will use scientific names in this article, which will be explained in detail (Box 1).

The name *T. aquaticus* tells us that this microbe is a heat-loving (*thermos* means hot in Greek) organism that has been found in water (*aqua* means water in Latin). *T. aquaticus* populates several hot springs in Yellowstone National Park and other locations with temperatures around 70°C. Interestingly, this microbe freezes at 40°C and is not willing to grow at temperatures lower than that. A temperature above 79°C is lethal to this microbe. Although Thomas Brock found this first heat-loving microbe, he did not find one that could

FIGURE 2

Illustration of *Thermus aquaticus*.
A. A microscopic picture of cells that were grown to a high density. **B.** Two single cells. **C.** A cartoon highlighting the cellular structure. Note that 1 µm is equal to one millionth of a meter.

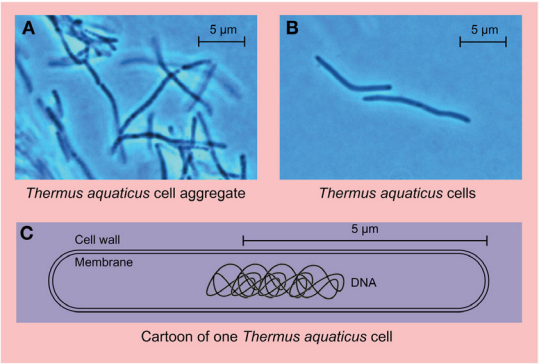

FIGURE 2

BOX 1 – THE MYSTERY OF SCIENTIFIC NAMES

Scientists often use words that are hard to understand, including Latin or Greek names for well-known organisms. Ok, it is quite easy to understand that *Rattus rattus* is the scientific name for the black rat. *Hippopotamus amphibius* is the hippopotamus, and it is even simpler to recognize that *Gorilla gorilla* is the western gorilla, but what does *Thermus aquaticus* mean? Note that the first word of a scientific name indicates the genus, or category in which the organism belongs. The genus name is abbreviated by its first letter in scientific writing when used for the second time in an article (*T. aquaticus*). The second word in the name is the species name, which indicates the specific kind of organism. There are often several species existing that belong to the same genus, e.g., *Rattus norvegicus* is the brown rat.

withstand boiling water. However, the discovery of *T. aquaticus* triggered a global hunt for the most heat-resistant microorganisms and relatives of *T. aquaticus*. It wasn't long until other heat-loving microbes not related to *T. aquaticus* were discovered at different spots on Earth. Scientists quickly realized that extremophiles are very common. They are so common that it is impossible to estimate how many more species will be discovered in the future.

Another important step in the discovery of extremophiles was reached when Karl Stetter from Germany presented another interesting microbe to the microbiology community. Stetter and his team found this microbe in the deep sea, where hot water streamed out through a chimney from below the tectonic plates, and they called this microbe *Pyrolobus fumarii*. This microbe displays a strange, lumpy-looking cell structure. Its cell structure, preference for heat, and its natural habitat are all reflected in its name: *Pyro* is Greek for fire, *lobus* means lobe (the lumpy structure), and *fumarii* refers to a fuming chimney. *P. fumarii* is even more heat-loving than *T. aquaticus*! The discovery of *P. fumarii* expanded the upper temperature limits of where life can exist up to 113°C—hot enough for water to boil! Temperatures below 90°C are already much too cold for *P. fumarii* to grow (Figure 3) [3].

FIGURE 3

Thermometer indicating the temperatures at different organisms are able to grow.

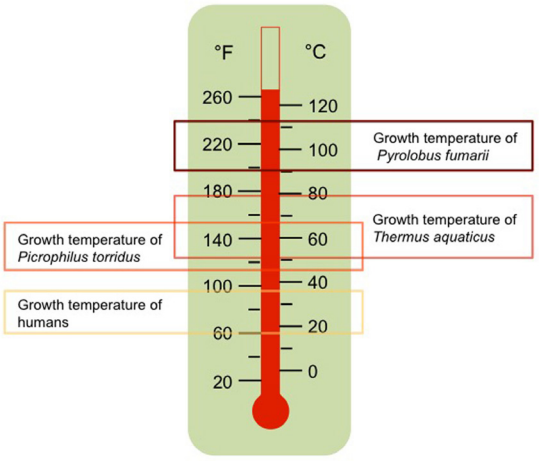

FIGURE 3

ARE THERE OTHER ENVIRONMENTS THAT WOULD BE UNCOMFORTABLE FOR US BUT NOT FOR MICROBES?

Humans do not like temperatures around 100°C except in a sauna and for a very short time, while heat-loving microbes successfully live their whole lives in such conditions. However, there are other extreme natural environments that are populated by the most resistant and tolerant microbes. These microbes live in the deep sea, in extreme salty lakes or in glacial ice. And have you ever heard of microbes that prefer to live in hot acids?

Probably the most impressive extreme microorganism was discovered by the group of Wolfram Zillig (1925–2005). The microbe *Picrophilus torridus* prefers moderately hot temperatures between 55 and 65°C, but in combination with a very acidic environment. Basically, these conditions might be comparable to living in hot and diluted battery acid. This microbe was isolated in acidic and hot soil in Japan [4]. Its preferences and lifestyle are also reflected by its scientific name: *Picros* means acid in Greek, *philos* means loving, and *torridus* is Latin, meaning dried and burned.

In addition, there are also some microbes that are perfectly adapted to man-made environments. They thrive in toxic industrial wastewater or near nuclear power plants. Several of these microbes were isolated at Chernobyl, the site of a terrible nuclear power plant accident in 1986. These microbes are exposed to dangerous and life-threatening radiation, but they have managed to convert the radiation into energy, which they can use to grow [5].

COULD EXTREME MICROBES BE USED TO HELP HUMANS?

Due to their ability to withstand different extreme conditions, these microbes and some of the chemicals within them are of major interest for use in

TAQ-POLYMERASE

An enzyme that is capable of copying DNA at high temperatures. Polymerases are essential for cellular DNA replication and are commonly used in laboratory procedures to produce millions of copies of DNA.

certain kinds of industry. A particular kind of protein (an enzyme) from *T. aquaticus* has been of great help to scientists in the field of microbiology. The enzyme is called ***Taq*-polymerase**, and it is used in laboratories to produce millions of copies of DNA molecules in a process called polymerase chain reaction (PCR). Since one of the reaction steps takes place at 95°C, normal enzymes quickly become inactive, but the *Taq*-polymerase from *T. aquaticus* withstands such conditions and keeps working. Nowadays, PCR is routinely used in the life sciences (like biology), in criminal investigations, and in the diagnosis of diseases. Extremophilic microbes can also be used in a process called bioremediation, which is used to remove the toxins from contaminated environments by breaking them down. Other extreme microorganisms are interesting to industries, because the enzymes of these microbes can be used to decompose starch or plant waste materials—these processes can be used for the production of bioenergy or valuable chemical compounds. In contrast to heat-loving microbes, enzymes from cold-loving microbes can be used as detergent ingredients to help us clean our laundry at energy-saving low temperatures. It is also important to know that extremophiles are not evil! Since these microorganisms love to inhabit environments that are extreme from a human point of view, they are usually not able to cause illnesses in humans, because the human body temperature of 37°C is just too cold for them.

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CONFLICT OF INTEREST STATEMENT: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

REVIEWED BY

ECOLE MOSER GENÈVE, 13–15 YEARS OLD

We are a biochemistry class, and our teacher is M. Bustamante. We belong to a swiss school which is called Moser. We are between 13 and 15 years old, and we are in year 11. We chose biochemistry as our extra subject since it is all of our passion. We learn different subjects about science, going once a week to the laboratory.

AUTHORS

SKANDER ELLEUCHE

I am microbiologist/molecular biologist by training with a life-long curiosity for biology. In middle school, I started my scientific career when I began to carefully observe and try to control the spawning behavior of my aquarium fishes. Now I am a lecturer and project leader at the Institute of Technical Microbiology working with microbes from extreme environments. Outside of work, I enjoy reading, meeting with friends and travel to ancient and natural places such as Greenland or Iceland. *skander.elleuche@tu-harburg.de

CAROLA SCHRÖDER

When I started studying biology, I dreamed about starting a zoo with ponies and donkeys to pet. During my studies, I learned more and more about microbes, and I became fascinated by the diversity and the abilities of the tiniest organisms that can be found everywhere. Consequently, I started to work in the field of microbiology and became a research associate at the Institute of Technical Microbiology. I still enjoy spending time with larger animals like my pony, but my profession deals with organisms invisible to the naked eye.

NADINE STAHLBERG

I work in the Center for Teaching and Learning at Hamburg University of Technology (TUHH). Here, I am engaged in higher education development, especially in the field of writing practice and research. I deal with questions of how to improve ways of teaching and learning, how to motivate students to learn about science and technology, and how to involve reading and writing as a tool to support learning. I like the idea of sharing scientific knowledge by providing young learners with an active part in the process of knowledge distribution like this journal does.

GARABED ANTRANIKIAN

I was trained in microbiology at the American University of Beirut, Lebanon and the Georg-August University in Göttingen, Germany. Since 1990, I am the head of the Institute of Technical Microbiology at Hamburg University of Technology (TUHH). Our field of expertise is in studying microorganisms from extreme environments, especially from the Azores and the deep sea near Japan, and we also investigate their potential for industrial applications. Since 2009, I have also been the vice president for academic affairs, and I became the university president in 2011. In my leisure time, I enjoy cooking Armenian and international cuisines.