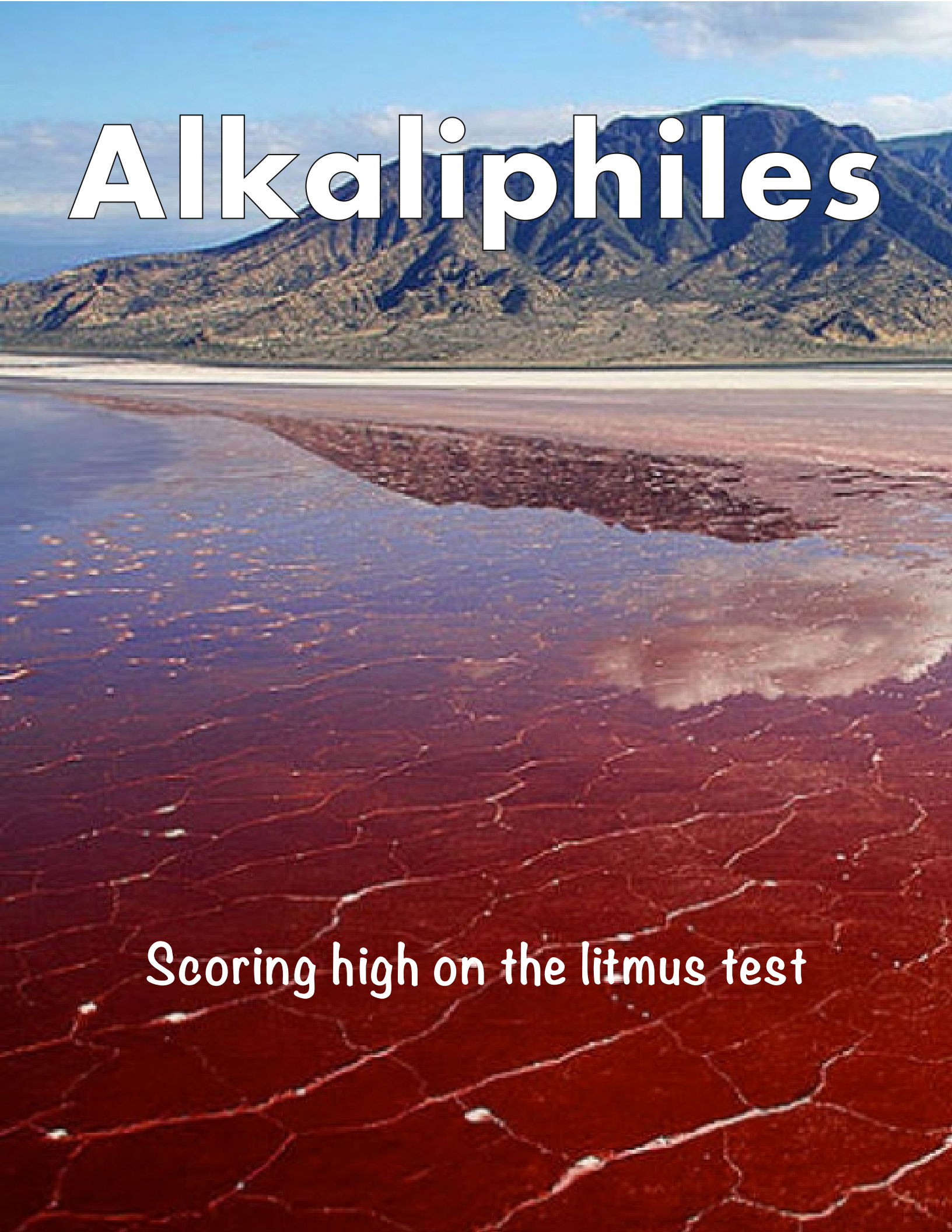
Alkaliphiles



Scoring high on the litmus test

Naturally alkaline environ

Many bacteria create acids and so make their environments more acidic, often to the detriment of other bacteria. However, no bacteria are known to do the opposite, create bases to make their environment excessively basic. Basic conditions are those above pH 7 (see "Acidophiles" for a definition of pH). Some bacteria produce ammonia when they grow on proteins, and in the laboratory such cultures can reach a high pH. This is unlikely to occur in nature as the accumulation of ammonia is toxic to most organisms, even the ones producing it.

Geological conditions or conditions produced by human activity can create high pH environments. These conditions are relatively uncommon and only occur naturally in arid environments. One cause of naturally occurring alkaline (high pH) conditions is the presence of high amounts of carbonate minerals, typically sodium carbonate (also called soda ash or washing soda). These help form soda lakes that can have a pH of 9-12. These lakes often also contain high concentrations of salts and so can also be saline. These often form in dry areas and the salt and high pH are caused by the accumulation of salts as water evaporates faster than fresh water enters the lake.

Soda lakes are found in dry areas around the world, including the East African Rift Valley and in the western United States. Mono Lake, California, USA is one of the most studied of these. Mono Lake is partially neutralized by the inflow of water containing calcium, which removes the carbonate and forms large accumulations of calcium carbonate (limestone) some of which reach above the water line forming tufa towers. Despite this, it still is quite alkaline, with a pH of 10, too alkaline for fish.

Because of the high carbonate content of Mono Lake, it has a very high level of photosynthesis, the fixation of dissolved carbon dioxide into carbon compounds by photosynthetic bacteria (cyanobacteria). They grow to such an extent that the water can turn green by early spring.

Although fish cannot live in Lake Mono, brine shrimp can and they

nments are relatively rare

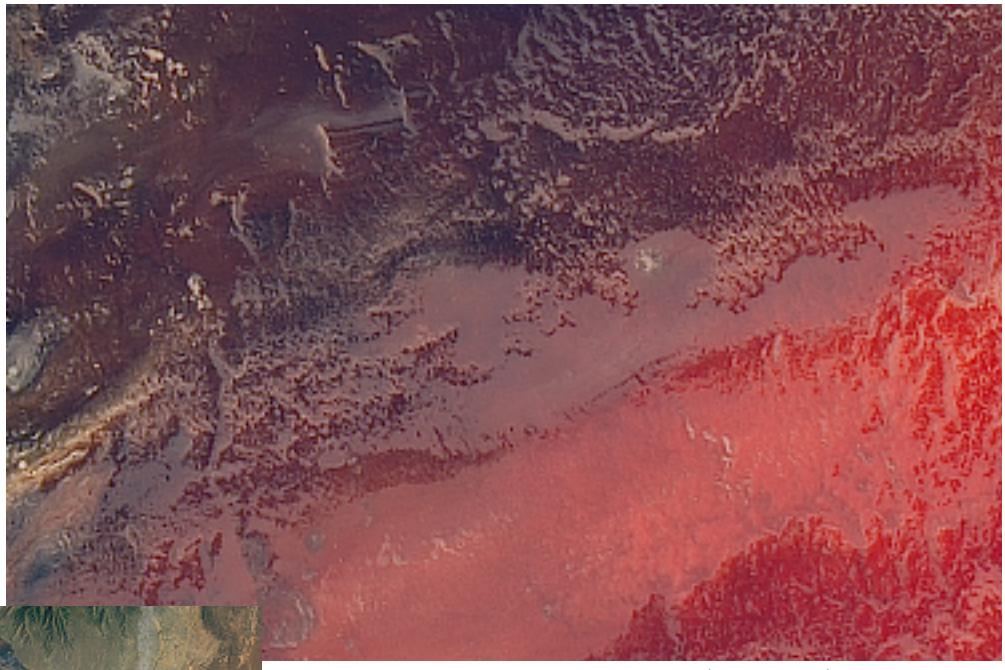
feed on the cyanobacteria. Small alkali flies live along the shore and venture underwater to lay their eggs and graze on cyanobacteria.

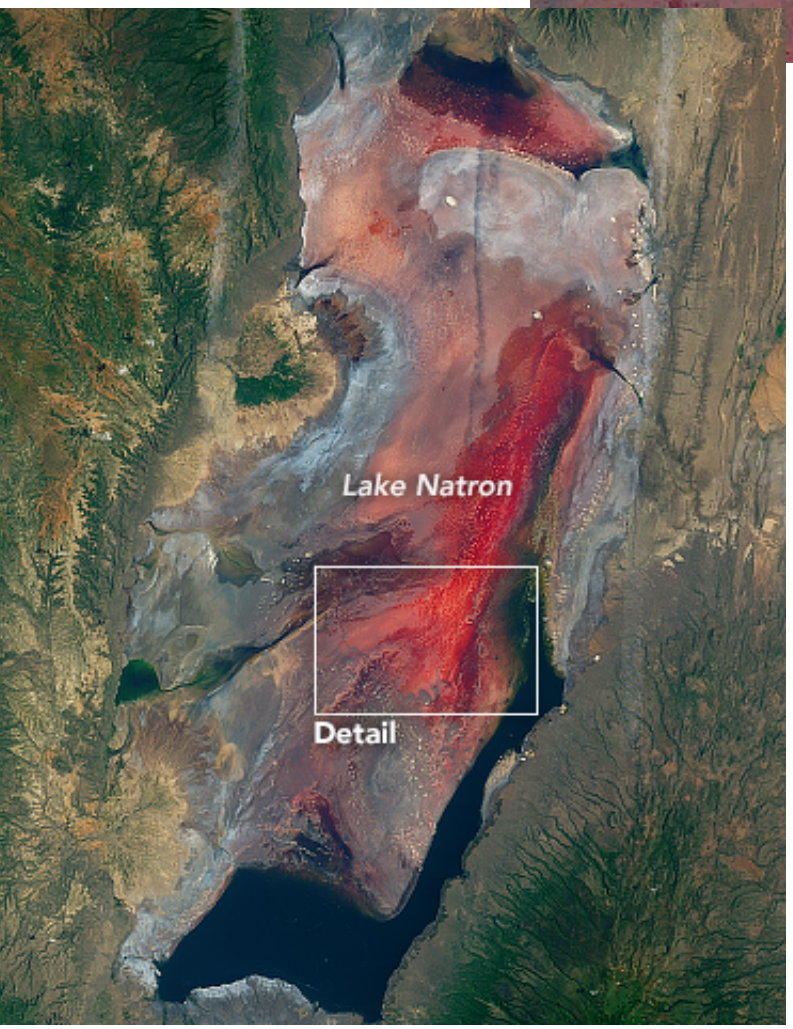
Lake Magadi, Kenya and Lake Natron in Tanzania are fed by alkaline hot springs and are also highly salty. The water in both lakes is around pH 10. In its saltiest regions, the lakes are inhabited by alkalinophilic, halophilic archaea that sometimes color the water red

Tufa formations at Mono Lake, California USA. Tufa is calcium carbonate formed by intrusion of calcium-rich spring water up from the bottom of the lake. The calcium combines with the dissolved carbonate in teh water to form calcium caronate, the same mineral in limestone. When thew water level of the lake dropped, these underwater chimeny swere revealed.

because of their pigment they use to harvest light. In shallower, less salty and lower pH regions, brine shrimp and a single kind of fish are found. This fish has adapted to the higher temperatures and higher pH. Flamingos feed on the brine shrimp and pigments in the shrimp cause their feathers to be pink.

Mildly alkaline conditions can occur in hot springs if hydrogen sulfide is not present in the source water. Octopus Springs is the best studied alkaline hot spring in Yellowstone National Park, Wyoming, USA. Its source water is 95°C (203°F) and its pH is around 8. The source water contains hydrogen gas, so many microbes growing near the source use hydrogen and carbon dioxide gasses to grow.





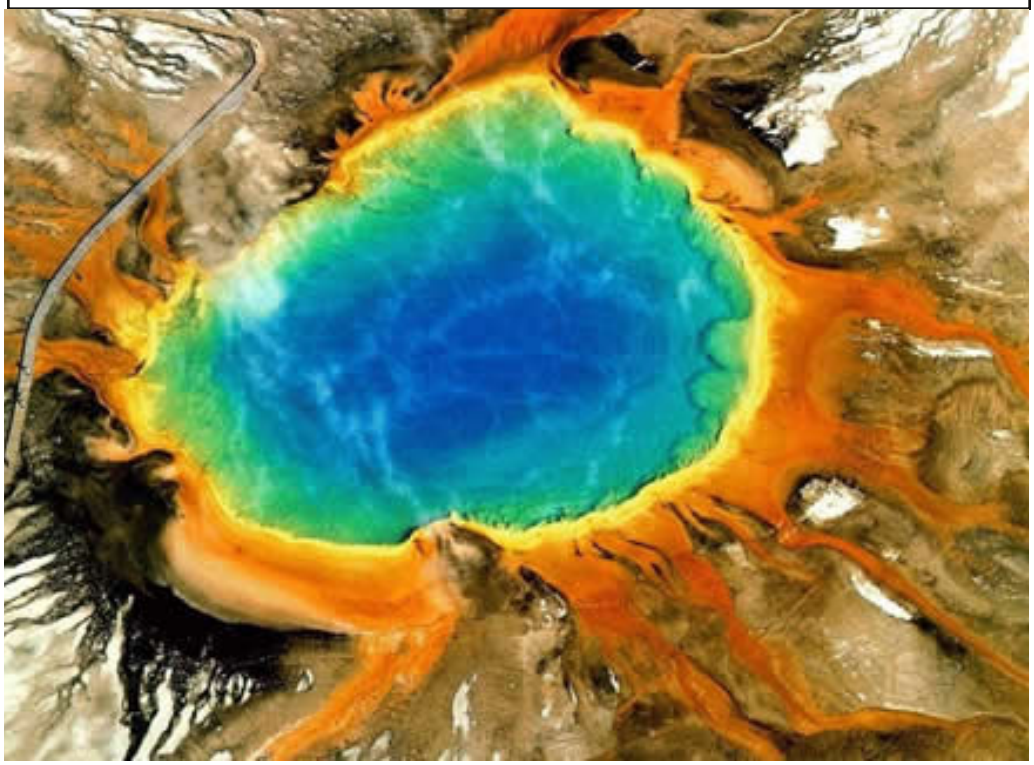
Commercial processes such as cement manufacture, and paper and hide processes also generate alkaline wastes. Processes that use or generate lime (calcium oxide or hydroxide) are typical examples of this. Any waste waters at these sites could provide habitats for alkaliphilic bacteria.

Lake Natron, Tanzania

YELLOWSTONE ALKALINE HOT SPRINGS

Many of the hot springs in Yellowstone National Park have a pH higher than that of pure water, pH 7. This makes them alkaline. Their pHs can range from that of the Ojo Caliente Spring (pH 8.3), Octopus Spring (pH 8.4), Grand Prismatic Spring (pH 8.4), and up to that of Crested Pool Spring (pH 9.4). These waters become alkaline when the carbon dioxide and hydrogen sulfide gasses that are dissolved in the water react with silica in the subterranean rock, so removing them. Since these gasses are rather acidic when dissolved in water, the resulting spring waters are more alkaline. There is hydrogen gas dissolved in the water, because in the hottest parts of the spring where temperatures can approach 90°C (194°F), bacteria called Aquifex can grow using the gas. These are the kind of bacteria that grow at the highest temperature known to support bacterial growth. Lower temperature bacteria grow in the outflows of these springs where the water cools as it runs downhill away from the spring. When the temperature reaches about 75°C (167°F), bacteria that use sunlight, the cyanobacteria and green non-sulfur bacteria, can grow. These streams can become quite colorful because of the pigments of these photosynthetic bacteria. Dark green, Kelly green, orange, and yellow pigments are used to harvest different parts of the spectrum of sunlight to energize the metabolism of these bacteria.

Grand Prismatic Spring, Yellowstone National Park, USA



African Rift Valle

The Great Rift Valley runs south to north through northern East Africa. Starting in Tanzania, just east of Lake Victoria, it runs north to the juncture of the Red Sea and the Gulf of Aden. It formed by the breaking of a tectonic plate and the separation of the resulting two smaller plates. As they separate, material from the mantle rises to near the surface forming volcanoes and geothermal hot springs. The low valley also provides for the formation of lakes lacking outflows, the conditions necessary to create alkaline soda lakes.

Lake Natron, Tanzania

Lake Magadi, in Tanzania in the south of the Valley, lies at the lowest point in the Valley. Lake Natron lies just south of Lake Magadi. Both lakes have a pH over 11.5 and both are highly salty, having sodium chloride concentrations 10-20 times that of seawater.

Despite these harsh conditions, these lakes have about 10 times higher productivities (measured by the amount of biological material produced per day) than average streams and lakes. Cyanobacteria dominate the phototrophic communities. The populations of these

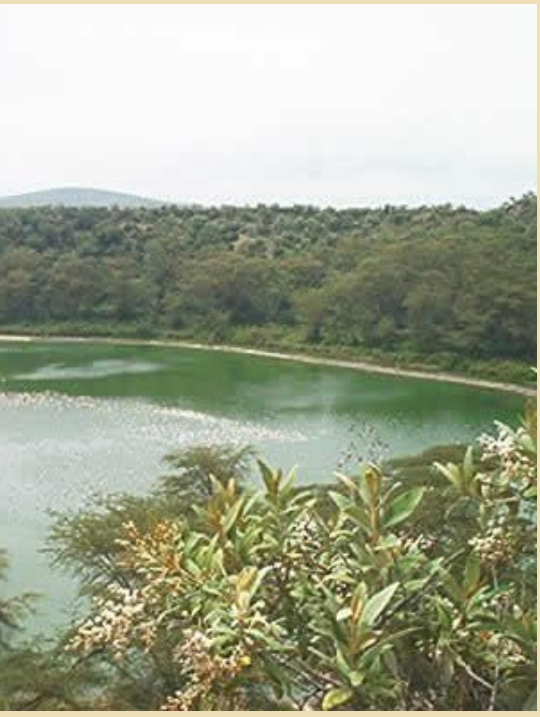
Lake Sonachi. Kenya

ey Alkaline Lakes

cyanobacteria can get so high that the lakes become colored. The pigments of the cyanobacteria species dictate what the color is. Some have predominantly green pigments, others have red pigments. Since the lakes have high salt concentrations, at their edges, where the water evaporates, salt crusts can form. As these form, the remaining water is saturated with salt allowing the growth of colored halophilic archaea, so the salt is often red or pink.

Parts of the lake can also be hot, since they are deep and receive water underground heated indirectly by the rising magma below. Temperatures up to 60°C (140°F) can be found in places.

In marshes were streams enter the lakes, the water is less salty and alkaline, so plants grow and fish are found. These can serve as feeding grounds for birds like flamingos who eat the red cyanobacteria and shrimp that also live there, giving the birds their distinctive coloration.



In 2010, photographer Nick Brandt photographed animals that had died along Lake Natron and whose corpses had become preserved by the alkaline and salty conditions. He posed them in haunting, "living" positions for photos.

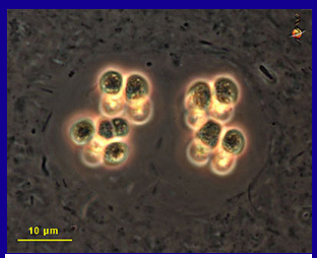
Calcified dove, Lake Natron. Photo by Nick Brandt.

Alkaline Lakes in

Soda lakes, so called because they contain high concentrations of sodium c around the world. In the United States, they are found in the arid regions of causes evaporation from lakes that are fed by streams, but that lack an outfl Lake in California (pH 10) is the largest soda lake in the US. Black Lake, in (pH 8.5), has a similar chemistry.

Weathering of surface carbonate rocks by these streams leaches minerals f rocks. The rock around soda lakes is especially deficient in calcium and mag similar, non-alkaline lakes, like the Great Salt Lake, those two elements wou carbonate and precipitate, forming mineral deposits. This lowers the carbon so, keeps the pH neutral (near pH 7). Rocks around soda lakes contain sodiu those dissolve in their waters and cause the waters to have a relatively high

In Mono Lake, calcium-rich groundwater seeps into the lake causing form carbonate columns to form, called tufa columns. These originally formed on lake, where the streams entered. The level of the lake has subsequently drop columns. The lake also has about twice the salinity of sea water.



Microcystis cyanobacteria isolated from Black Lake.

The combination of high pH and high salt has made the lake u Photosynthetic cyanobacteria, like *Microcystis*, however, grow th high dissolved carbonate as their food. The lake can become gree abundant growth in early spring. These organisms provide food for brine shrimp, which are then a food source for birds.

In addition to the cyanobacteria, other microbes are abundant in the waters of US soda lakes. Bacteria representing several groups consume the organic carbon compounds produced by the cyanobacteria. Most of these belong to the group of Gram-positive bacteria that have thicker cell walls, perhaps providing better protection from the alkaline conditions. Some members of the archaea are found there, too, including those that can grow in relatively high salt conditions (the halophiles) and some methanogens.

Alkaline hot spring at Paoha Island, Mono Lake, California.

the United States

Black Lake, Eastern Sierra mountains, California, USA

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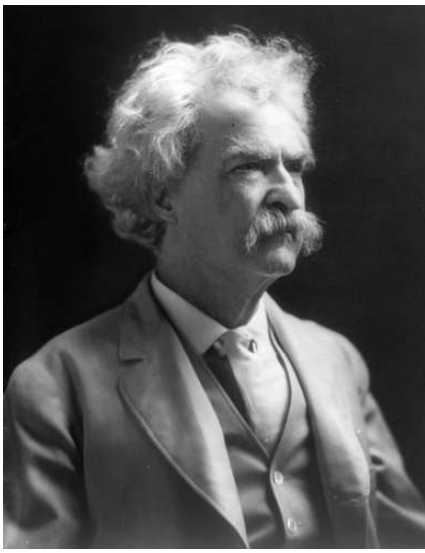
Mark Twain at Mono Lake

Mark Twain visited Mono Lake in 1860s, during the California gold rush. He later wrote about the experience in his 1872 book, "Roughing It." The quotes here are taken from that work.

"There are no fish in Mono Lake—no frogs, no snakes, no pollywogs—nothing, in fact, that goes to make life desirable. Millions of wild ducks and sea-gulls swim about the surface, but no living thing exists under the surface, except a white feathery sort of worm, one half an inch long, which looks like a bit of white thread frayed out at the sides." Well, maybe not desirable to Mr. Twain, but heaven on earth to the alkaliphilic microbes that live in Lake Mono. Twain was impressed, however, about the detergent properties of the alkaline waters. "The lake is two hundred feet deep, and its sluggish waters are so strong with alkali that if you only dip the most hopelessly soiled garment into them once or twice, and wring it out, it will be found as clean as if it had been through the ablest of washerwomen's hands."



Twain noted the volcanic origin of the lake and its continuing connection with that origin. "It is an unpretending expanse of grayish water, about a hundred miles in circumference, with two islands in its centre, mere upheavals of rent and scorched and blistered lava, snowed over with gray banks and drifts of pumice stone and ashes, the winding sheet of the dead volcano, whose vast crater the lake has seized upon and occupied." He found the islands were used by sea gulls for nesting, and that the islands also provided a convenient means to eat those eggs. "Nature has provided an unfailing spring of boiling water on the largest island, and you can put your eggs in there, and in four minutes you can boil them as hard as any statement I have made during the past fifteen years."

The picturesque tufa around the lake intrigued him. "In speaking of the peculiarities of Mono Lake, I ought to have mentioned that at intervals all around its shores stand picturesque turret-looking masses and clusters of a whitish, coarse-grained rock that resembles inferior mortar dried hard; and if one breaks off fragments of this rock he will find perfectly shaped and thoroughly petrified gulls' eggs deeply imbedded in the mass. How did they get there? I simply state the fact—for it is a fact—and leave the geological reader to crack the nut at his leisure and solve the problem after his own fashion."

These were about the only things that intrigued him, however. "This solemn, silent, sailless sea—this lonely tenant of the loneliest spot on earth—is little graced with the picturesque."

Traditional Alkaline-Fermented Foods

Some traditional foods are made by fermenting plant materials, by creating conditions to allow the growth of alkaliphilic bacteria. These foods are particularly found in Asian and African cultures. These include Japanese natto, Thai thua-nao, and kinema (from cooked soybeans); dawadawa from African locust beans; ogiri from melon seeds; ugba from African oil beans; kawal from fresh legale leaves; and owoh from cotton seeds. Like all fermentations, the bacteria break down compounds in the raw ingredients and produce products that prevent the growth of harmful bacteria, so the fermented foods can be safely stored for longer periods. The fermentations also produce desirable changes in the textures, taste, and digestibility of the raw ingredients.

Dawadawa (or soumbala) and unfermented African locus beans

In the case of alkaline fermentations, proteins and peptides in the ingredients are broken down and release ammonia that causes the pH of the fermentation broth to increase to about pH 8. Consequently, these foods may have an ammoniacal smell and taste. Bactria of the genus *Bacillus* are often responsible for these fermentations. *Bacillus* bacteria are live in soils and so are naturally found on the surface of natural materials. They can form spores that allow the cells to enter a quiescent form that resists dryness and other conditions harmful to growth. The spores can germinate when conditions improve. The preparation of the raw ingredients by one or more boiling steps kills most bacteria, including the harmful ones, but leaves the Bacillus spores to germinate and carry out the fermentation.

left, Ugba and, right, unfermented African oil bean seeds

Photo credits:

Cover, Lake Natron, Tanzania
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Mono Lake tufa, California, USA
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Satellite photo of Lake Natron, Tanzania
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Lake Natron, Tanzania
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Hot springs on Paoha Island, Mono Lake that contain high sulfide and arsenic.
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Lake Sonachi, Kenya a soda lake in an old volcanic crater is green due to algal growth in the high pH waters
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