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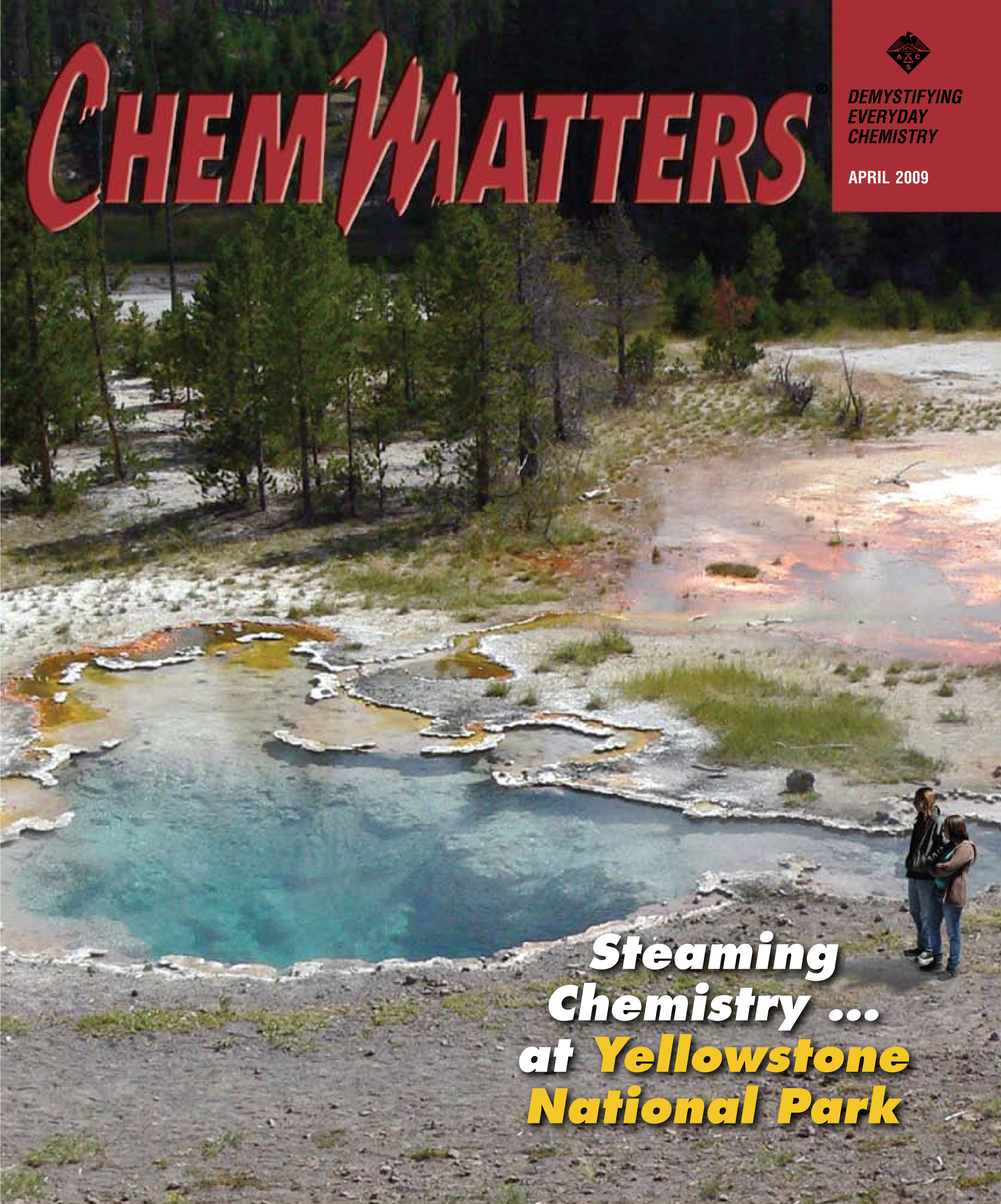
DEMYSTIFYING EVERYDAY CHEMISTRY

APRIL 2009



Steaming Chemistry ... at Yellowstone National Park

Health Benefits of Chocolate, p.13

QUESTION FROM THE CLASSROOM

By Bob Becker

Q. I was reading an article about global warming that described scientists analyzing samples of air from 800,000 years ago. From this analysis, they found that current carbon dioxide levels in the atmosphere are at their highest level in more than 800,000 years. How do scientists find samples of 800,000-year-old air?

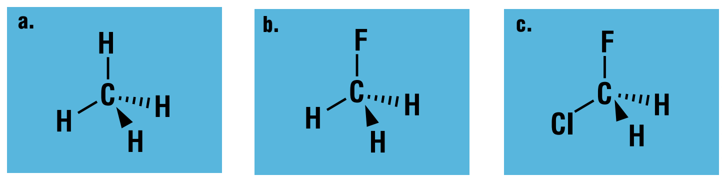
A. They find them in tiny bubbles that are trapped at the bottom of ice sheets, sometimes as much as 3.5 kilometers thick. These ice sheets formed over the years, as snowfall upon snowfall accumulated in areas such as Antarctica, Greenland, and in high-altitude mountain ranges like the Andes in South America.

What scientists do to extract and analyze ice core samples is pretty remarkable. They set up camp in these extremely cold regions and spend years drilling through the ice with large hollow coring drills. The technique allows them to bring up ice core samples that are typically 2-6 meters long, carefully remove them from the drill, and then send the drill down for more.

It is interesting to note that beyond 300 meters, the ice is under such great pressure that it tends to flow and deform. (Even though ice is a solid, it is considered a plastic material and deforms under substantial pressure.) This deformation would close off the hole each time a core sample is removed. To avoid this problem, the hole must be filled to within 100 meters from the surface with a fluid—typically a hydrocarbon, which is a compound made of carbon and hydrogen atoms (such as n-butyl acetate)—to supply equal pressure outward and keep the hole from sealing off.

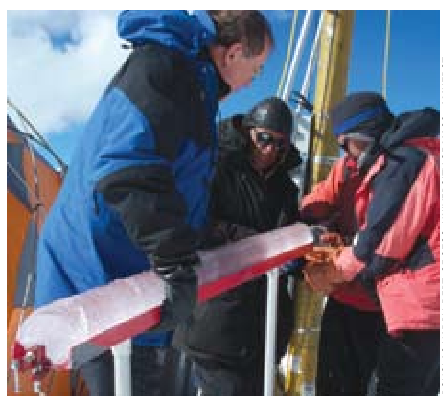
This drilling fluid must not freeze at these subzero temperatures; is environmentally safe, nontoxic and nonhazardous; is relatively inexpensive; can be easily cleaned off the core samples and recovered for reuse; and must have just the right density to match that of the ice so that the pressures inward and outward are equalized.

Although no liquids meet all these requirements, *n*-butyl acetate ($C_6H_{12}O_2$) comes fairly close. Kerosene (a mixture of hydrocarbons ranging from $C_{10}H_{22}$ to $C_{16}H_{34}$) can also be used, but it must be mixed with an additive—typically a halogenated hydrocarbon, in which one or more hydrogen atoms in a hydrocarbon molecule are replaced by halogen atoms,



CESAR CAMINERO

Figure 1. Methane (a) and two examples of halogenated hydrocarbons: fluoromethane (b) and chlorofluoromethane (c).


DOUGLAS HARDY, DEPT. OF GEOS, UNIVERSITY OF MASS., AMHERST

Ice core extracted from the Andes in Bolivia.

such as fluorine, chlorine, or bromine (see Fig.1)—to increase its density.

Once they are ready to be analyzed, the ice core samples are placed in an ultra-clean and very cold flask, where they are crushed up into tiny pieces to release the trapped air bubbles. This air and the ice from which it came can then be analyzed to obtain a wealth of information.

So how can scientists have any idea of what the temperatures were back when the snow fell hundreds of thousands of years ago? One clue involves the ratio of oxygen-18 to oxygen-16.

More energy is needed to get the heavier water molecules into the atmosphere and keep them there. This means that the isotopic content of water falling as rain or snow depends on the temperature of the sea from which it evaporated and on the air that carried the water vapor. So, the isotopic content is related to temperature, and the higher the ratio of oxygen-18 to oxygen-16, the warmer the year. By measuring the ratio of these two isotopes in the ice samples, researchers can track how temperatures change over the years.

Also, you would think that dating the air would be as simple as dating the ice in which the bubbles are imbedded. But snow remains porous for quite some time and to depths of up to 100 meters. As it gets compacted beneath more and more layers of snow, this porosity decreases, and the bubbles of air eventually seal themselves off, but scientists have determined that this can create a lag time between the age of the air and the age of the ice in which it is imbedded.

This lag time can be anywhere from 50 to 500 years. In other words, the age of trapped air can only be linked to the time at which the bubbles completely sealed themselves off under the pressure of all the snow above. This sealing off time introduces some degree of uncertainty into the information the scientists obtain.

Uncertainty is a part of any scientific research, and although 500 years may not seem like much in comparison with 800,000 years, it does make it challenging to show direct correlations between periods of rapid temperature change—determined from the ice itself—and periods of carbon dioxide increases in the ice-embedded bubbles occurring at the same time.

There is a lot of discussion these days about greenhouse gases and global warming. Among all of these discussions, it is easy to lose sight of the fact that dedicated men and women are working tirelessly and meticulously in bitter cold trenches in the middle of Antarctica and above the Arctic Circle to help us understand how climate has changed in the past and how it is changing now.

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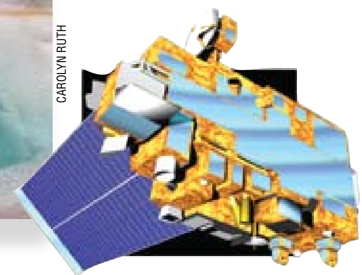
JUPITERIMAGES

CAROLYN RUTH



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Letting Off Steam

By Carolyn Ruth

Hundreds of visitors sit on benches or gather around the grassless, barren-looking geyser site. Some check their watches. Others get their cameras ready. One of nature's most spectacular events, the eruption of Old Faithful in Yellowstone National Park, is about to occur.

Soon, hot water bubbles upward and then something gives. Steam well over 100 °C shoots up through a single nozzle-like vent. Each cone-shaped eruption of Old Faithful lasts between 90 seconds and 5 minutes, with jets shooting as high as 30 to 55 meters in the air, expelling between 13,000 to 30,000 liters of water.

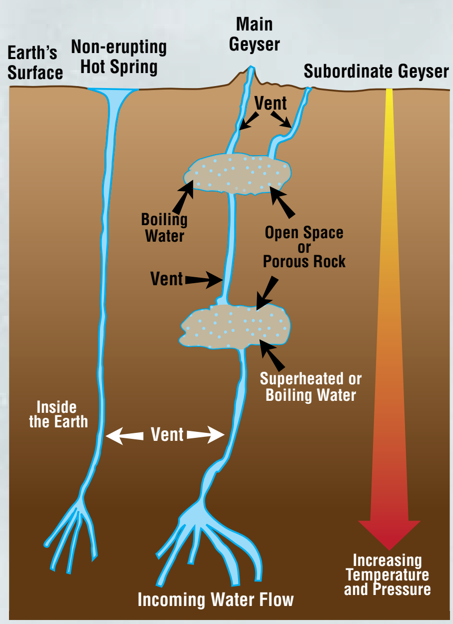
CAROLYN RUTH

Cone-shaped eruption of Old Faithful at Yellowstone National Park.

Yellowstone contains more than 10,000 geysers, hot springs, and steaming volcanic vents that can erupt at any moment in various locations. Because these eruptions are not as big as volcanoes, they can be seen from a short distance, offering a unique experience. Imagine staring at Old Faithful when, suddenly, you hear the hissing sound of another geyser erupting a few hundred yards away to your right, followed by mud bubbling out not far away. Then, you turn around, realizing the presence, to your left, of hot, bubbling water flowing out of the ground continuously.

BACKGROUND PHOTO: JUPITERIMAGES

Many scientists are as fascinated by this spectacle as the 2 million tourists visiting the park each year. Those scientists also seek to understand how these geysers and hot springs come to life and the chemical composition of the water they generate. It turns out that the water contains chemicals unique to that area as well as bacteria that thrive at very high temperatures. Also, scientists have discovered that the geysers and hot springs are caused by the upward movement of molten rock and hot water through an elaborate network of vents and caves, although the details of how this happens are still being fleshed out.



TONY FERNANDEZ, BASED ON A DRAWING BY CAROLYN RUTH

Figure 1. Schematic representation of the underground plumbing system for geysers and hot springs.

Plumbing system underground

On the basis of data gathered so far, scientists suggest that the network of vents and caves under Yellowstone National Park looks like the one represented in Fig. 1.

Most of the water ejected by Yellowstone's hot springs and geysers—250 million liters per day!—started out as rain or snow that trickled through small cracks and around mineral grains in the rocks and went down thousands of meters below the surface. There, the water sits in underground caves called chambers.

West Thumb Geyser Basin blue hot spring.

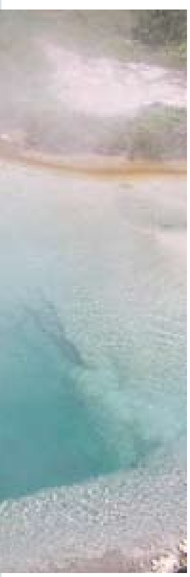
Although temperatures in these chambers reach 300 °C or more, the water does not vaporize but remains liquid because it is under great pressure from the rocks and water lying above. (Note that under high pressures, the boiling temperature of water changes. For example, water at twice the atmospheric pressure boils at 121 °C—instead of 100 °C—and water at 10 times the atmospheric pressure boils at 180 °C!) The superheated water pushes its way up through openings, and, as the water rises, the pressure is reduced and the water begins to boil.

If the pressure decreases rapidly, the boiling water is released as steam, triggering a geyser eruption. But if the pressure is released more slowly or the opening on the surface is wide, the water bubbles to the surface into a pool of hot water, creating a hot spring (Fig. 1).

The underground plumbing system for geysers is different from that of hot springs. In the case of a hot spring, the plumbing system is usually open enough to allow water to flow freely to the top (Fig. 1).

In a geyser, the plumbing system contains at least one narrowing, usually close to the surface. Water above the narrowing acts like a lid, helping to maintain the pressure on the boiling water below. So, when the geyser erupts, it blows off this lid and shoots upward, its size being determined by the width of the narrowing. The narrower the constriction, the higher the plume of steam.

After a geyser erupts, the underground chamber is emptied, so surrounding cooler water starts moving downward to replace the erupted water, and the cycle of water accumulating underground and erupting begins again. The entire trip from the surface and back probably takes at least 500 years. The water erupting today fell as rain or snow about the time that Christopher Columbus was exploring the New World!



CAROLYN RUTH

Occasionally, the vents become clogged and the water moving upward is stopped. The clogs are usually cleared by earthquakes, which occur frequently in the Yellowstone area. About 2,000 earthquakes shake the Park each year, which corresponds to an average of more than five earthquakes per day. Most are too small to feel, but some are significant.

Heat, earthquakes, and carbon dioxide

The heat source for Yellowstone's geysers and hot springs is about six kilometers below the surface in the form of partly molten rock called magma. The magma is located in a reservoir that extends from 8 to 16 kilometers underground and that was discovered by seismologists at the University of Utah, Salt Lake City. Before reaching this reservoir, the magma originates in a mantle plume that is 80 to 650 kilometers deep underground. This magma likely rises through fractures from the plume to the reservoir.

Robert Smith, professor of geophysics at the University of Utah and colleagues have recently determined the size of the upper magma reservoir horizontally and vertically. While studying how earthquakes occur around Yellowstone, the scientists noticed that underground waves caused by these earthquakes moved slower than usual in a particular area. This is because sound is delayed in melted rock compared to surrounding, cooler rocks.

Smith and his team suggest that this area, located more than 6 kilometers underground, consists of a large quantity of partly molten magma. As a result, rocks in that area are melted, which explains why earthquake waves move slower there than in surrounding rocks.

The scientists also measured unusual speeds for earthquake waves in a nearby area, located 2 kilometers underground. This time, the scientists suspect that fractures in the Earth may contain gases such as carbon dioxide, which would come from the partly molten rock area when some of the rocks crystallize.

"When an earthquake happens in that area, this carbon dioxide could migrate to the surface and cause significant damage," Smith says. "For example, an earthquake in California in 1989 caused a massive killing of trees, which could be due to release of carbon dioxide located underground, as seems to be the case in Yellowstone."

These results suggest that Yellowstone staff should not only monitor geysers and hot springs, but the possible emission of carbon dioxide as well, since it may pose a risk to human safety.

Water full of unique chemicals

What bubbles or erupts from geysers and hot springs is not pure water. As water goes downward through the ground and becomes hotter, it dissolves some of the minerals from the rocks. The rock underneath Old Faithful is primarily made of a type of highly viscous magma called rhyolite, which contains at least 70% of silicon dioxide (SiO_2).

As long as the water stays at high temperatures and pressures, the dissolved silicon dioxide stays in solution. But as the hot water rises up in a vent, it cools, the silicon dioxide becomes less soluble, and it deposits on the sides of the vent. The pathway in the vent narrows.

CAROLYN RUTH

Minerva terrace at the top of Mammoth Hot Springs, showing deposits of white calcium carbonate.

Water that erupts from Old Faithful cools on the surface, and an increasing amount of silicon dioxide settles around the vent in the form of a cone.

At Mammoth Hot Springs, the emerging water contains calcium carbonate ($CaCO_3$). As water erupts, white terraces of porous calcium carbonate called travertines form around the hot springs as the calcium carbonate settles out of the cooling water.

Silicon dioxide and calcium carbonate are not the only chemicals that are found in geyser and hot spring waters. Scientists have also found arsenic.

Kirk Nordstrom, a geochemist at the U.S. Geological Survey in Boulder, Colo., and colleagues have studied the arsenic concentrations in Yellowstone hot springs for many years. The testing conditions are hazardous. Protective measures, such as wearing rubber gloves and using clean collection procedures, are necessary.

"Any equipment that gets hot spring water on it is washed with distilled water in the field before packing up," Nordstrom says. "We also try to avoid being downwind of hot spring vapors. We sample upwind and don't sit or kneel near hot, vaporous areas more than necessary. The vapors from hot springs may contain toxic levels of mercury (Hg), carbon dioxide, (CO_2), and hydrogen sulfide (H_2S)."

Norris Geyser Basin in Yellowstone National Park has the highest arsenic concentrations. Arsenic tends to associate with gases such as hydrogen sulfide. Also, the water is multicolored, thanks to minerals such as porous silicon dioxide; yellow sulfur; red, yellow, and orange arsenic compounds; and gray and black iron sulfides.

New types of bacteria

Yellowstone's hot springs also contain bacteria that flourish near boiling temperatures and add bright green, yellow and orange colors to the water. There are so many bacteria that they form mats consisting of series of bacteria next to each other. Not only that, but many bacterial mats are formed, sitting on top of each other.

DAVID WARD,MONTANA STATE UNIVERSITY

Mushroom Spring in Yellowstone National Park, with an enlarged inset showing a cross section of a microbial mat.

"These bacterial mats look like a piece of spinach lasagna," says Don Bryant, professor of biotechnology at The Pennsylvania State University, State College. "You can find different species of bacteria in the different layers, yet all these bacteria live together and cooperate to help one another."

Recently, Bryant and David Ward, a microbial ecologist at Montana State University, Bozeman, made an unexpected discovery. While studying the photosynthetic bacteria on the upper surface of a hot spring called Octopus Spring, they found a totally new bacterium. By looking at its DNA, they found that not only was it using light as energy for growth—a process called photosynthesis—but that it was a new species of bacteria.

Like other photosynthetic bacteria, plants, and algae, this new type of bacterium, called *Candidatus* Chloracidobacterium thermophilum, uses chlorophyll molecules to capture sunlight, but in a way different than other bacteria.

In some chlorophyll-containing bacteria and all plants, light absorbed by the chlorophyll molecules is used inside cells to produce the energy necessary to transform carbon dioxide and water into carbohydrates and oxygen, a process called photosynthesis:

$$CO_2 + H_2O \xrightarrow{\text{light}} \text{carbohydrates} + O_2$$

The new bacterium has specialized antenna-like structures called chlorosomes, each of which contains about 250,000 bacteriochlorophyll molecules—a special type of chlorophyll molecules found in bacteria. This way, this bacterium can collect light more efficiently than other bacteria—meaning that it can perform photosynthesis with much less light than its neighbors.

"We estimate that this bacterium can efficiently grow at light intensities that are 1000 times lower than that required by a blade of grass," Bryant says. "Based on further studies in my lab, we are starting to understand how this is accomplished and how it differs from the photosynthesis that occurs in other bacteria."

"The discovery of this new bacterium may provide new insights into how life can thrive without too much light," Ward says. "It may tell us how photosynthesis started on Earth—at a time when there was little or no oxygen—and whether life can exist in extreme environments with very high temperatures and low light intensity, as on some other planets."

A constantly changing landscape

Even though scientists have a better understanding of Yellowstone National Park's underground structure and the chemistry and life on its surface, this is not the end of the story. The park is constantly changing, making it hard to know what will happen in the future.

"Our understanding of what happens in the deep Earth is limited by our inability

CAROLYN RUTH

Calcium carbonate formations at Mammoth Hot Springs in Yellowstone National Park.

to get down there for a direct look," says Hank Heasler, a geologist at Yellowstone National Park. "Current techniques—such as radar interferometry and Global Positioning System—can tell us fairly accurately what is happening on the surface but not what goes on underground."

Scientists suggest that the upward and downward movements result from the nearly continuous movement of hot water and molten volcanic rocks called basalt and granite that are coming from the magma chamber discovered by the University of Utah scientists. In some areas, the magma and hot water flow faster, resulting in an uplift of the soil surface, and in other areas, the circulation of magma and hot water is slower, leading to downward movements. But what causes theses changes in magma and hot water circulation is still a mystery.

Even Old Faithful is changing. Its eruptions have been occurring further apart in recent years. It could even stop to erupt in the future. Someday, visitors may sit in anticipation at another site in the park as they do in front of Old Faithful now.

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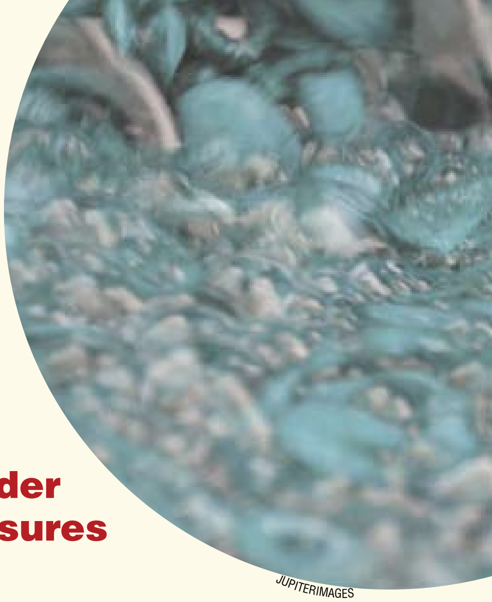
Carolyn Ruth is an adjunct professor of chemistry at Mercyhurst College, Erie, Penn. Her most recent *ChemMatters* article, "Extracting Medicine from Plants", appeared in the February 2003 issue.

ACTIVITIES



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Activity 1

Make your own volcano

ANNE HELMENSTINE

You will need

Safety goggles
1-liter bottle
6 cups flour
2 cups salt
4 tablespoons cooking oil
2 cups water
Red food coloring
Enough warm water to almost fill the bottle
6 drops of detergent
2 tablesppons baking soda
5%-vinegar solution

What to do

Wear the safety goggles.
Knead the flour, salt, oil, and the 2 cups of water together to make a dough. Stand a bottle in a baking pan and mold the dough around it into a volcano shape. Don't cover the hole or drop dough into the bottle.
Fill the bottle most of the way with warm water and a bit of food color.
Add detergent.
Add baking soda.
Add vinegar slowly until the volcano ceases to produce bubbles.

How it works

The detergent and the baking soda ($NaHCO_3$) dissolve in the warm water. When the vinegar, which contains acetic acid (CH_3COOH) is added, the following chemical reaction occurs:

$$NaHCO_3 + CH_3COOH \rightarrow NaCH_3COO + CO_2 + H_2O,$$

in which $NaCH_3COO$ is sodium acetate, CO_2 is carbon dioxide, and H_2O is water.

Carbon dioxide gets trapped inside the soap bubbles, and the combination of carbon dioxide and soap emerges from the top of the bottle and flows down the sides of the volcano-shaped dough. You are witnessing a volcano explosion!

– Carolyn Ruth

Activity 2

Boil water under different pressures

You will need

Safety goggles
250-mL vacuum filtration flask
Rubber stopper to close off the top of flask
Faucet with suction filtration attachment
Heavy-walled tubing to connect side arm of flask to faucet projection; this tubing should be heavy-walled so that it won't collapse under reduced pressure
50-mL slightly warm water

What to do

Wear the safety goggles
Securely clamp the flask to a heavy stand to prevent it from falling over and breaking; never hold this flask with your hands while doing this activity.
Put the slightly warm water into the flask.
Insert a stopper in the flask.
Attach tubing to the sidearm of the flask and the side of the faucet suction filtration attachment.
Turn on water to highest flow.
At the end of the activity, turn off the water and break the vacuum by gently removing the rubber hose from the side of the faucet suction filtration attachment.

How it works

Boiling is defined as the temperature at which the vapor pressure of water equals the air pressure above the surface of the water. The temperature at which water boils can vary significantly, as revealed by this activity.

Here is what happens: As the tap water flows past the tubing attached to the faucet, air from the tube is drawn into the water that is pouring down the drain. This in turn removes air from the flask. Air from the flask is flowing from the high pressure area inside the flask to the low pressure area in the tubing.

The water in the flask is under atmospheric pressure before the faucet is turned on and does not boil. When the air above the surface of the water in the flask is reduced significantly, the water in the flask is now under very low pressure and boils.

– Carolyn Ruth

Chocolate: the new health food. Or is it?

By Gail Kay Haines

MIKE CIESIELSKI

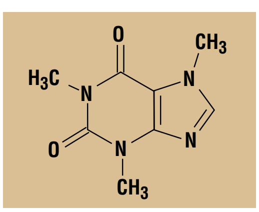
There is a word for you: "chocoholic," when you *need* chocolate. Nothing else will do. Just thinking about hot fudge drizzling over ice cream raises your spirits. You crave a truffle, a Kit-Kat, a mug of velvety hot cocoa. Few, if any, other foods evoke such passion.

So what is unique about chocolate? Recent scientific findings are providing new evidence that chocolate may be healthier than is usually assumed.

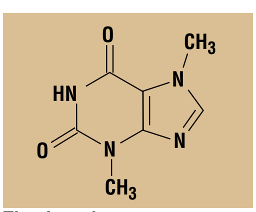
So many good chemicals …

One of the reasons chocolate is unique is the temperature at which it melts: between 94 °F and 97 °F. A morsel of chocolate slides across your tongue and liquefies into a perfect puddle of taste sensation. The human body, at 98.6 °F is just above the chocolate's melting temperature. "Melts in your mouth"? Definitely true.

Chocolate contains more than 300 chemicals. Caffeine, a stimulant, is the most well known, but it is present only in small amounts. Another stimulant is theobromine, found in amounts slightly higher than caffeine. The two molecules are identical except for one methyl group (CH_3), but it is not yet clear how they act together in chocolate.



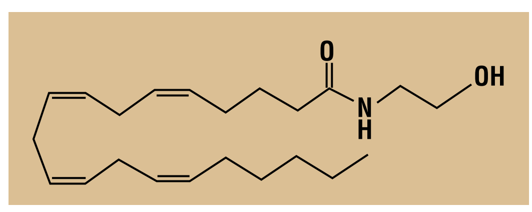
Caffeine



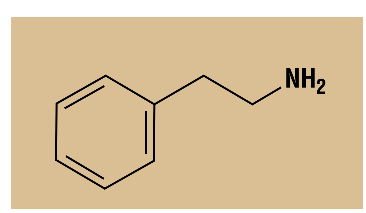
Theobromine

Another chemical known to make us happy when we eat chocolate is anandamide, so named because it means "bliss" in Sanskrit. Not only is it present in chocolate, but it is also produced by the brain and blocks out pain and depression.

But when anandamide is produced by the brain, it is broken down quickly, so its effects don't last. Emmanuelle diTomaso, an assistant biologist at Massachusetts General Hospital, Boston, Mass., and Daniele Piomelli, professor of pharmacology at the University of California-Irvine, have shown that chemicals in chocolate may inhibit this natural breakdown of anandamide. This means that when you eat chocolate, anandamide molecules from chocolate stay in the body longer.



Anandamide



Phenylethylamine

ALL STRUCURES: CESAR CAMINERO

MIKE CIESIELSKI

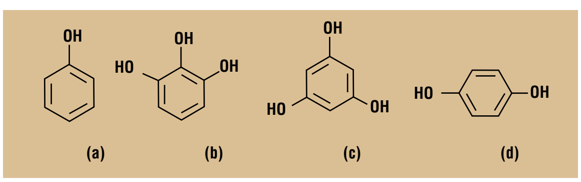
Then, there is phenylethylamine (PEA), a natural brain chemical which stimulates the parts of the brain that keep you alert and mimics the brain chemistry of a person in love.

Is chocolate healthy?

Recent studies have explored chemicals in chocolate called polyphenols, which belong to a larger group of chemicals called antioxidants. These chemicals protect cells against damage from free radicals—atoms, molecules, or ions with unpaired electrons.

Inside cells, free radicals damage DNA and have been associated with Alzheimer's disease, heart disease, and cancer. Antioxidants prevent this damage from happening by blocking the action of free radicals and may therefore reduce the risk of being affected by these diseases.

Antioxidants work by slowing or preventing a chemical reaction called oxidation, which can produce free radicals. Antioxidants terminate this reaction by preventing free radicals from being formed. Examples of antioxidants include thiols, which are organic compounds that contain a functional group composed of a sulfur atom and a hydrogen atom (-SH) and polyphenols, which are organic compounds that contain OH groups attached to six-membered benzene rings.



Phenol (a) and three examples of phenol derivatives: pyrogallol (b), phloroglucinol (c), and hydroquinone (d). These molecules are components of large molecules called polyphenols.

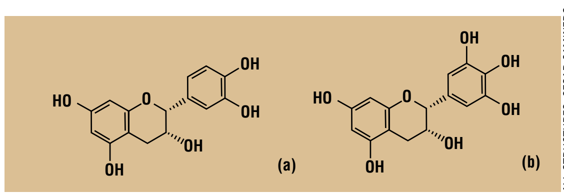
The health benefits of some polyphenols—such as quercetin, which is found in citrus fruit, buckwheat, and onions—are well established, while other polyphenols' health effects are still being investigated. The largest and best studied group of polyphenols are the flavonoids, a group of several thousand compounds present in various fruits, vegetables, and chocolate.

Joe Vinson, professor of chemistry at the University of Scranton, Pa., and his research students have found that polyphenols in chocolate have beneficial effects against heart disease. The scientists showed that cocoa polyphenols acted as antioxidants in the body, compared with coconut butter and sugar alone. Also, the scientists discovered that in hamsters, cocoa powder at a dose equivalent to two dark chocolate bars per day significantly inhibited atherosclerosis, a type of heart disease in which fat clogs up arteries, and raised the levels of good cholesterol.

Cocoa is especially rich in chemicals called flavanols, which are flavonoids also found in tea, wine, and nuts. Ian Mcdonald, professor of metabolic physiology at The University of Nottingham, and colleagues have shown that people who consumed a flavanol-rich cocoa beverage had increased blood flow in their brains. This result suggests that cocoa flavanols could be used to prevent vascular impairments in the brain resulting from, say, a stroke.

Norman Hollenberg, professor of medicine at the Harvard Medical School and Brigham and Women's Hospital, and colleagues have observed that the consumption of a flavanol-rich cocoa beverage also increases the amount of nitric oxide in the blood vessels, allowing them to dilate and stay pliable. This result suggests that cocoa flavanols could also be used to improve heart health.

Also, Juan Carlos Espin de Gea, a senior research scientist at the Spanish Research Council in Murcia, Spain, and colleagues are working on processing the cocoa beans differently to include the flavonoids usually lost in the processing of the beans. They asked six volunteers to consume a milk beverage made with flavonoid-enriched cocoa and later to drink chocolate milk made from traditional cocoa. When they drank the flavonoid-enriched cocoa, these volunteers had eight times more of antioxidants epicatechin and procyanidin B2 than when they drank regular chocolate milk.



Examples of flavanols: epicatechin (a) and epigallocatechin (b).

ALL STRUCTURES: CESAR CAMINERO

Another piece of good news: You might think that chocolate causes acne, decays teeth, and makes you fat. Not so. No current research connects specific foods to skin problems. Chocolate husks contain chemicals that prevent tooth decay (although they don't offset the added sugar), and too much food causes weight gain.

But how about all this saturated fat, usually blamed for the ills of chocolate? Let's look at how chocolate is made to understand why chocolate is not *totally* healthy.

How chocolate is made

The cacao beans used to make chocolate come from a tree called *Theobroma cacao* (food of the Gods) that is cultivated in the tropics. Tiny flies called midges pollinate the

trees, and each pod contains 20 to 60 seeds in a sweet pulp. The pods are removed from the tree, split with a machete, and the pulp and beans are removed and fermented under banana leaves in the sun.

Then, the sugary pulp breaks down, heating the beans. Many chemical changes take place, affecting flavor, aroma, and color. The rich cocoa aromas develop, and the beans change from purple to chocolate brown. After fermentation, the beans are dried on bamboo mats or wooden floors.

These dried beans are shipped to the manufacturing plants, where they are cleaned, sorted, and roasted. This roasting loosens the bean shells so they can be easily removed. What is left are dark chips called nibs, which are crushed to form a liquid paste called chocolate liquor.

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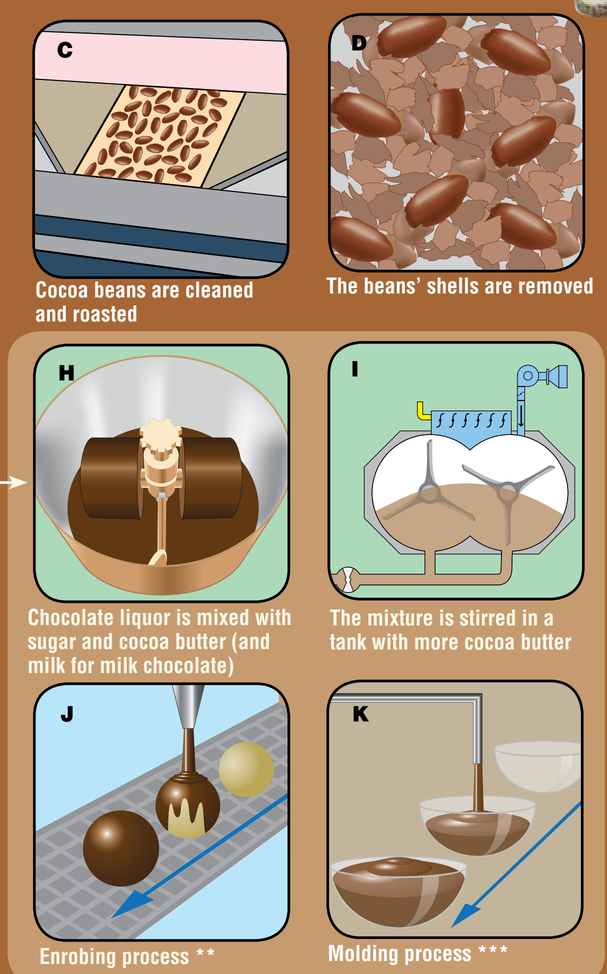

ANTHONY FERNANDEZ

To make dark, semisweet, and bittersweet chocolates, nibs and sugar (and sometimes additional cocoa butter) are mixed together for up to 72 hours to further smooth and blend all particles, creating creamy chocolate.

So here's the bad news: Cocoa butter is essentially all fat. There are three major kinds: a "bad-for-you" saturated fat called palmitic acid; oleic acid, a heart-healthy monounsaturated fat; and stearic acid, part of which later converts to oleic acid in the liver. Overall, one-third of chocolate's fat is known to be unhealthy. All three kinds of fats produce high amounts of calories in the body, although they do not cause an increase in blood cholesterol when consumed in chocolate.

Here's the good news: Chocolate straight from the tree has more beneficial chemicals than possibly any other food, including blueberries, red wine, or green tea. They are not only antioxidant, but anti-inflammatory, anti-allergic, anti-cancerous, and anti-viral.

So why is chocolate often rated junk? It's all in the processing. Processing determines whether chocolate is a healthy food or a high-calorie indulgence. Roasting and fermenting tends to decrease the amount of antioxidants. Food stores sell mainly milk chocolate, with sugar, milk, and extra cocoa butter added because they taste good, but the more noncocoa items are added to cocoa, the more dilute the healthy chemicals become.

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Making healthier versions of chocolate

W. Jeffrey Hurst, principal scientist at Hershey Co., Hershey, Penn., and colleagues have compared the amount of antioxidants in cocoa-containing products. The products they considered were natural cocoa, unsweetened baking chocolate, dark chocolate, semisweet baking chips, milk chocolate, and chocolate syrup. They discovered that natural cocoa contains the most antioxidants, followed by baking chocolates, dark chocolates, baking chips, and finally milk chocolate and syrups, when compared on an equal weight basis. So if you want to consume a lot of chocolate, you may be better off choosing natural cocoa or dark chocolate rather than milk chocolate or chocolate syrup.

Over the past two decades, various candy makers—including The Hershey Co. and Mars, Inc.—have been trying to use this scientific knowledge by making chocolate-based candies that are high in antioxidants and flavanols. The most recent trend is "premium" chocolate, often made of top-quality beans with high cacao content, no milk, and fewer additives.

Scientists may even be able to modify the genes of the cocoa tree in the future. Last June, Mars, Inc., partnered with IBM and the U.S. Department of Agriculture to launch a five-year project to unravel the genome of the cocoa bean. The team of scientists from these three institutions may find ways to make the cocoa tree more resistant to pests and disease and provide healthier, more nutritious, and better-tasting chocolate.

Want the most for your calories? And your dollars? Check out the nutrition information on the labels. The fewer additives, the better. Meanwhile, dark chocolate or chocolate nibs are a healthy alternative to milk chocolate or chocolate syrup.

So, is chocolate a healthy food, a luxury item, or junk? It can be all three, just not all at the same time. The choice is yours. Go easy! Go dark! Go chocolate!

SELECTED REFERENCES

Beckett, S. P. *The Science of Chocolate*, 2nd ed; The Royal Society of Chemistry: Cambridge, UK, 2008.

American Chemical Society: The Elements of Chocolate http://acselementsofchocolate.typepad.com/elements_of_chocolate/ [February 2009].

The Exploratorium, Science Museum in San Francisco: The Sweet Lure of Chocolate http://www.exploratorium.edu/exploring/exploring_chocolate/ [February 2009].

Gail Kay Haines is a science writer and book author from Olympia, Wash. Her most recent article, "Coffee: Brain Booster to Go?" appeared in the December 2008 issue.

CHEM.MATTERS.LINKS

Geysers

Check out the GeyserWorld Web site, prepared by Alan Glennon, a scientist at the University of Santa Barbara, Calif.: http://www.geyserworld.com/. The site contains information about geysers from around the world with many stunning pictures. Geysers can be found on other planets or moons, such as Enceladus, a moon of Jupiter, as revealed by the NASA's Cassini-Huygens spacecraft: **http://www.sciencedaily.com/releases/2008/11/081126133405.htm.**

Rainforests

An entertaining Web site about rainforests describing the animals, plants, and peoples that live in the rainforest has been prepared by scientists at the California Institute of Technology, Pasadena: **http://www.srl.caltech.edu/personnel/krubal/rainforest/serve_home.html.**

MIKE CIESIELSKI

Another entertaining site on rainforests (prepared by the educational Web site Enchanted Learning) can be found at **http://www.enchantedlearning.com/subjects/rainforest/Animals.shtml.**

Algal blooms

The Woods Hole Oceanographic Institution provides an overview of toxic algal blooms throughout the world at **http://www.whoi.edu/redtide/page.do?pid=14899.** Also, the National Oceanic and Atmospheric Administration's National Ocean Service has dedicated a Web site to toxic algal blooms: **http://oceanservice.noaa.gov/topics/coasts/hab/**, and the Centers for Disease Control and Prevention describe their efforts to better understand toxic algal blooms at **http://www.cdc.gov/hab/.**

WHOI

Chemistry of chocolate

Chemist Joanna Marie Millward, from the University of Bristol's School of Chemistry, United Kingdom, has prepared the following Web site on the chemistry of chocolate: **http://www.chm.bris.ac.uk/webprojects2001/millward/introduction.htm.**

JUPITERIMAGES

An entertaining and informative Web site on the making of chocolate, its chemistry, and the latest news about chocolate can be found at **http://www.lottachocolate.com/.**

Also, some universities offer courses on the chemistry of chocolate, such as Princeton University, N. J.: **http://www.princeton.edu/main/news/archive/S17/61/34M17/index.xml?section=science.**

Weather satellites

Explore pictures taken by weather satellites worldwide at **http://internationalweatherarchive.org/satellite.php.** The National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service offers updated pictures taken by its weather satellites at **http://www.weather.gov/sat_tab.php?image=ir.** You can also track NASA and NOAA's weather satellites in real time at **http://science.nasa.gov/Realtime/JTrack/NOAA.html.**

Celebrate Earth Day

To celebrate this year's Earth Day (April 22) and its theme, "Air—The Sky's the Limit," the American Chemical Society encourages you to tour a recycling center or a laboratory or government facility that monitors the Earth, soil, or the atmosphere. Also, K-12 students are invited to participate in a haiku poem contest by submitting entries to their Chemists Celebrate Earth Day local section coordinator. Winners will be entered in the national contest and the national winner will be announced on Earth Day. More information about Earth Day is available at **http://www.acs.org/earthday and http://www.earthday.net/**

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