Lite Geology

Geothermal Energy

FALL 2010 ISSUE 28

Flowers growing in a geothermal greenhouse at Masson Radium Springs Farm, New Mexico.

In This Issue ...

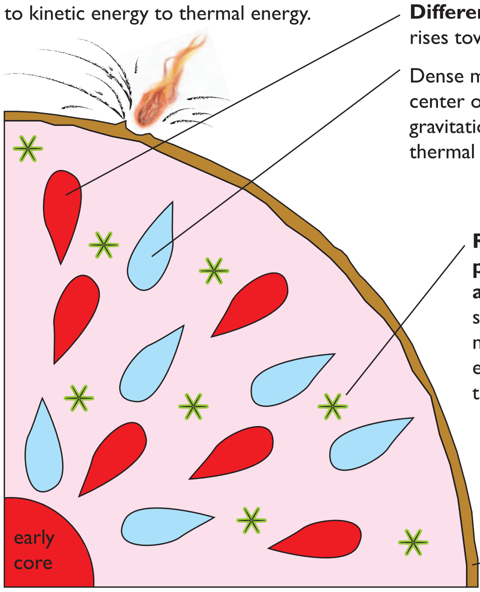
New Mexico Bureau Of Geology & Mineral Resources a division of New Mexico Tech

Geothermal Energy

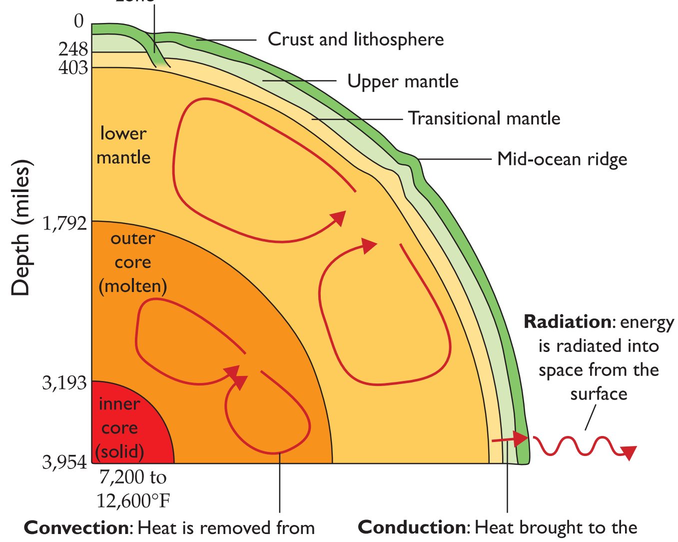
Shari Kelley

Geothermal energy is derived from heat that is naturally generated and stored within the interior of the earth. The temperature of the earth increases with depth in a curvilinear fashion. The rate of temperature increase with depth varies from 1.1 to 1.5°F per 100 feet (20 to 30°C/km) at depths shallower than 60 miles (100 km) and from 0.03 to 0.05°F per 100 feet (0.5 to 1°C/km) at depths greater than 60 miles (100 km). The temperature at the center of our planet at a depth of 3,955 miles (6,364 km) cannot be measured directly, but it is estimated to be an impressive 7,200 to 12,600°F (4,000 to 7,000°C), based on earthquake records and laboratory experiments. What causes the temperature inside the earth to be so high? One of the sources of high temperature in the earth is heat that was generated during the formation of our planet, as meteorites and planetary bodies collided and the molten sphere separated into dense inner layers (core) and less dense outer layers (mantle and crust). This heat has been stored in the core and mantle for the 4.6 billion years since the earth was formed. Heat is also produced by the decay of radioactive elements, including potassium, uranium, and thorium. Early on, these elements were distributed throughout the earth's interior, but now most radioactive elements are concentrated in the crust. Radioactive decay accounts for approximately 80 percent of the heat generated, and residual heat from earth's formation accounts for the remaining 20 percent. In addition, the uppermost 30 feet of the ground surface absorbs solar energy during the summer and releases that energy during the winter.

Just like cold hands being warmed by holding a mug of hot tea, heat in the earth flows from areas of high temperature to areas of low temperature. Although heat escapes from the planet by convection, conduction, and radiation over the entire surface of the earth, two processes, volcanic activity and ground water movement, operate to concentrate geothermal energy in certain places at or near the earth's surface. Volcanic activity is the result of heat escaping from the hot interior by convection in the mantle. Hot rock melts when the pressure decreases or fluids, such as water, are added. Fault activity associated with extensional plate boundaries triggers volcanic activity at mid-ocean ridges and continental rifts. Fluid released from subducting plates induces melting in the mantle above the descending plates, causing eruptions at volcanic arcs. Hot molten rock erupted by volcanoes delivers heat to the surface along weaknesses in the crust. Thus significant geothermal resources are commonly located in the vicinity of plate boundaries.



Cross section of the earth illustrating the processes (accretion, differentiation, radioactive decay) that created heat early in the history of our planet. The red blobs are warmer, lighter materials rising toward the surface, and the blue blobs are cooler, more dense materials sinking toward the interior during differentiation. The stars indicate energy generated by radioactive decay.



Cross section of the modern earth showing the processes that control the release of heat from the earth. Conduction is the transfer of heat from warm areas to cold areas without the significant movement of material (except at the molecular scale; straight red arrow). In contrast, movement of material is an essential component of heat transfer by convection (curved red arrows). Radiant heat is energy transmitted by electromagnetic radiation (squiggly red arrow).

Ground water moving through rock near the earth's surface can pick up heat and concentrate the energy in fractured rock near fault zones. When hot ground water systems intersect the earth's surface, hot springs form. Conventional geothermal systems can be used by drilling wells into fractured reservoirs of hot, naturally pressurized water and steam in areas of faulted or fractured rock. The water and steam may flow to the surface naturally, or if the pressure is too low, the fluids can be pumped to the surface through the drill hole.

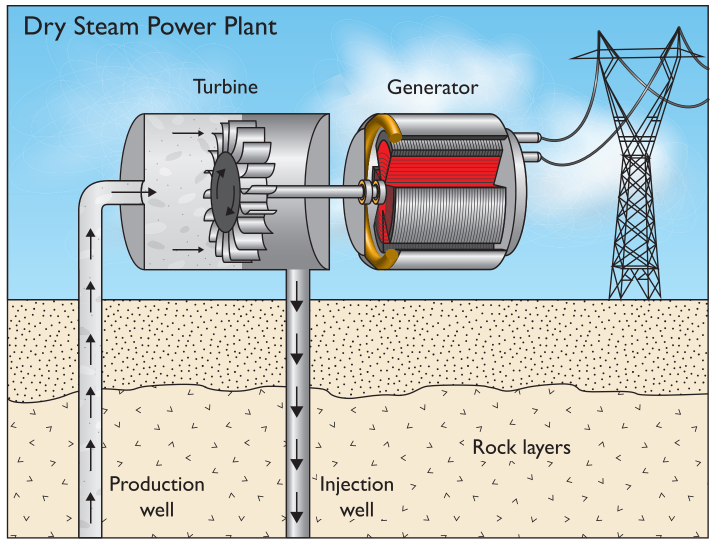
Uses

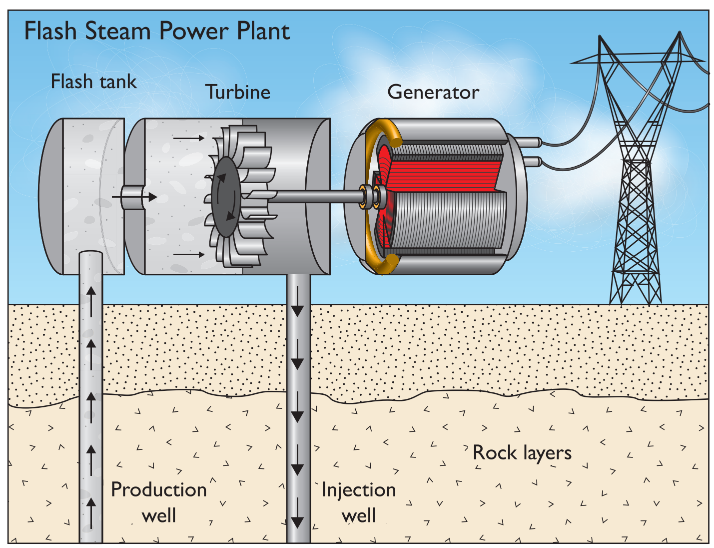
As our fossil fuel resources diminish and concerns about greenhouse emissions increase, the search for alternative "green" energy sources has intensified. Geothermal energy has been used to produce electricity, to heat homes, greenhouses, and fish farms, and to dry agricultural products. Hot springs supply the water used in spas and bathhouses. The temperature of the water determines how a geothermal resource is used. Water with temperatures above 350°F is considered to be a high temperature resource capable of producing significant quantities of electricity that can be sent to a regional-scale power grid. Water with temperatures between 190 and 350°F can be used for power generation on a more local scale. Water with temperatures between 100 and 190°F is a low temperature resource that can be used for direct heating. Low temperature applications in New Mexico are discussed in the sidebar that accompanies this article.

Geothermal energy is generally "green" energy as long as the usage is well designed. Hot water commonly contains elevated levels of arsenic, salt, and other dissolved solids that can precipitate when the water evaporates, causing scaling and corrosion of equipment, and potentially polluting the environment. This problem is solved by keeping the hot water in a closed loop. The geothermal water is brought to the surface, the heat is extracted using a heat exchanger, and the cooled water is reinjected back into the ground. Geothermal energy is renewable energy as long as the heat is used in a sustainable manner and the heat extraction system is carefully engineered. Geothermal power plants do emit small amounts of carbon dioxide, nitric oxide, and sulfur that are entrained in the hot water, but the quantities released are about fifty times less than the amounts emitted by a typical coal-fired power plant.

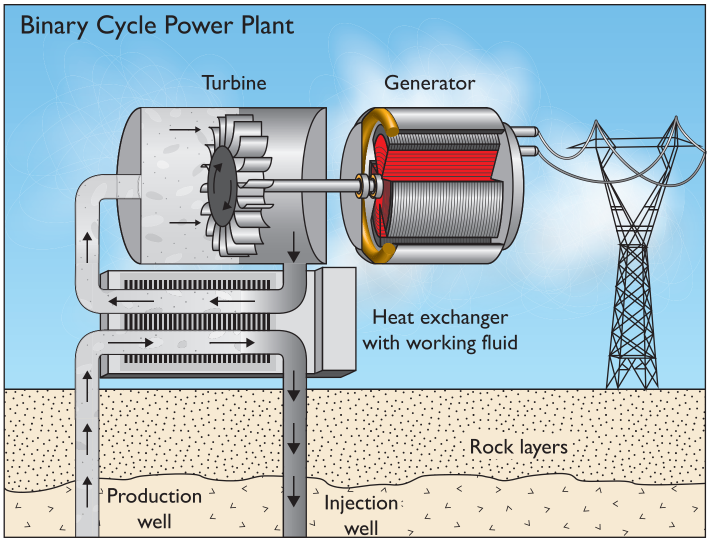
ELECTRICITY

Geothermal resources with temperatures that are high enough to produce electricity are relatively rare and are typically found in tectonically or volcanically active areas. Older geothermal power plants built in the 1970s and 1980s directly use steam from boiling water to turn turbines to produce electricity. These types of power plants are located in California, Nevada, Utah, and Hawaii. No steam-powered plants are located in New Mexico. Dry steam power plants use extremely hot (over 455°F) steam from a geothermal reservoir. The steam goes straight from the well to a turbine to spin a generator that produces electricity. Very little water is produced from this type of resource. In contrast, flash steam power plants use hot water (over 360°F) from the geothermal reservoir to generate electricity. The boiling point of water is pressure dependent. Hot water at depth has a higher boiling point than water at the surface. When water is pumped from deep in the reservoir to the surface, the sudden drop in pressure causes some of the water to vaporize to steam. In a flash steam power plant, the steam is used to turn a turbine to generate electricity. Hot water not flashed into steam may be used for direct heating before the water is returned to the geothermal reservoir through injection wells.





Schematic diagrams of dry steam and steam powered geothermal plants. In both cases, steam from the production well turns a turbine attached to a generator, which produces electricity. The electric generator converts mechanical energy (the turning turbine) into electricity as an electric conductor (gray wires on the rotor attached to the turbine) moves through a magnetic field (copper-colored stationary disk on the exterior part of the generator).



Schematic diagram of a binary geothermal power plant. Hot water from a production well passes through a heat exchanger and causes a working fluid that has a boiling point lower than that of water to "boil." The vaporized fluid turns a turbine attached to a generator, which produces electricity.

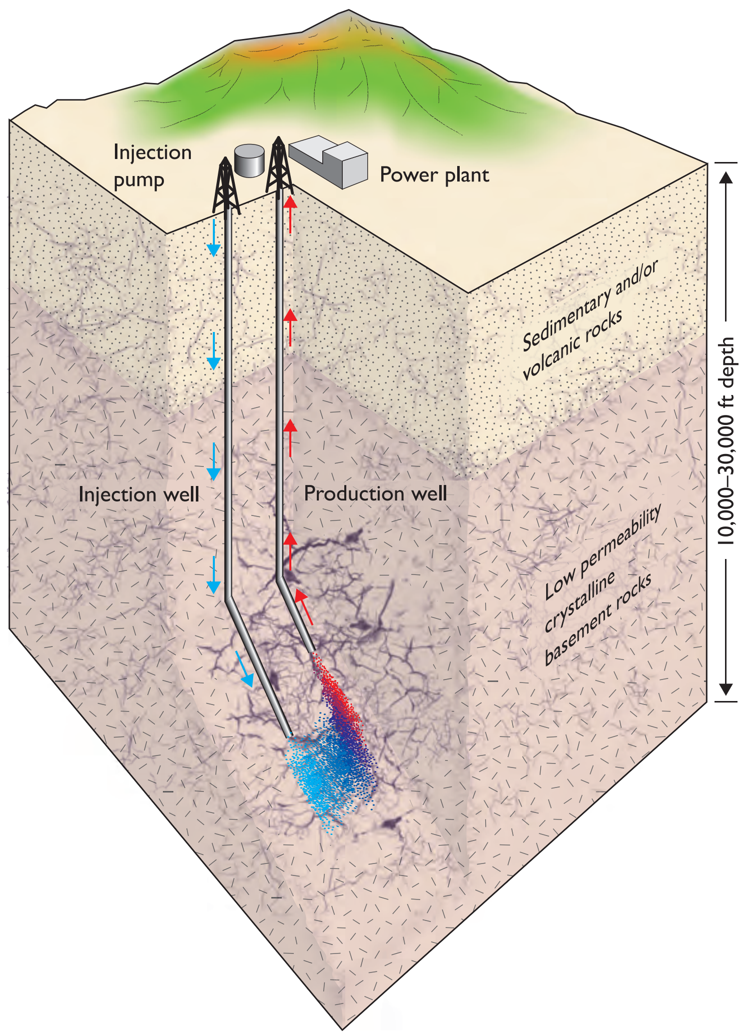
Newer power plants, called binary power plants, do not directly use geothermal fluids. Instead, these plants use heat exchangers to extract the energy from the geothermal water that is pumped to the surface. The hot water (less than 360°F) is used to boil a second fluid that has a boiling point that is lower than that of water. The most common fluids used for this purpose are the organic compounds isopentane or isobutane. Some power plants use an ammonia-water mixture as the working fluid. The isopentane is vaporized in the heat exchanger, which causes a build up of pressure in a closed loop that is used to drive turbines to produce electricity. After the isopentane passes through the turbine, the vapor is cooled to a fluid in a condenser and the fluid recycled through the loop. The cooled geothermal water is pumped back into the ground after it passes through the heat exchanger. Binary power plant technology is constantly evolving, and new transfer media are being investigated; this research will allow lower temperature resources to be used to produce electricity in the future.

ENHANCED GEOTHERMAL SYSTEMS (EGS)

High rock temperatures and extensive fracturing are characteristics of an ideal geothermal reservoir. Hot water flows through rocks along the fractures that are typically less than 0.25 inch wide toward a drill hole or hot spring. However, as time passes, fractures in geothermal systems can become clogged with minerals precipitating from the hot water. As the fractures close, the quality of the geothermal reservoir diminishes because the hot water can no longer easily flow to the drill hole or hot spring. When the water can no longer easily flow through rock, the rock is considered to have low permeability.

The productivity of geothermal systems can be improved by increasing the permeability of rocks through a combination of physical and chemical methods that cause fractures to open, lengthen, and interconnect. Pressurized fluids are injected into the reservoir, forcing pre-existing cracks in the rock to open. Often, the high fluid pressures keep the fractures open. In some cases, sand-sized particles are forced into the newly opened cracks to prop them open, thus enhancing the permeability of the rock.

Natural geothermal systems are in only a few special places where geologic conditions are right. Enhanced (or engineered) systems open up the possibility of extracting heat from deep, hot but naturally dry rock units. In this scenario two wells are drilled, pressurized fluids are injected into both wells, and existing cracks in the rocks are opened. The wells are drilled to depths of 2 to 6 miles (3 to 10 km). Once the rock has been fractured, cool water from the surface is



Block diagram of an enhanced geothermal system. The blue represents cold water, the purple is warm water, and the red is heated water.

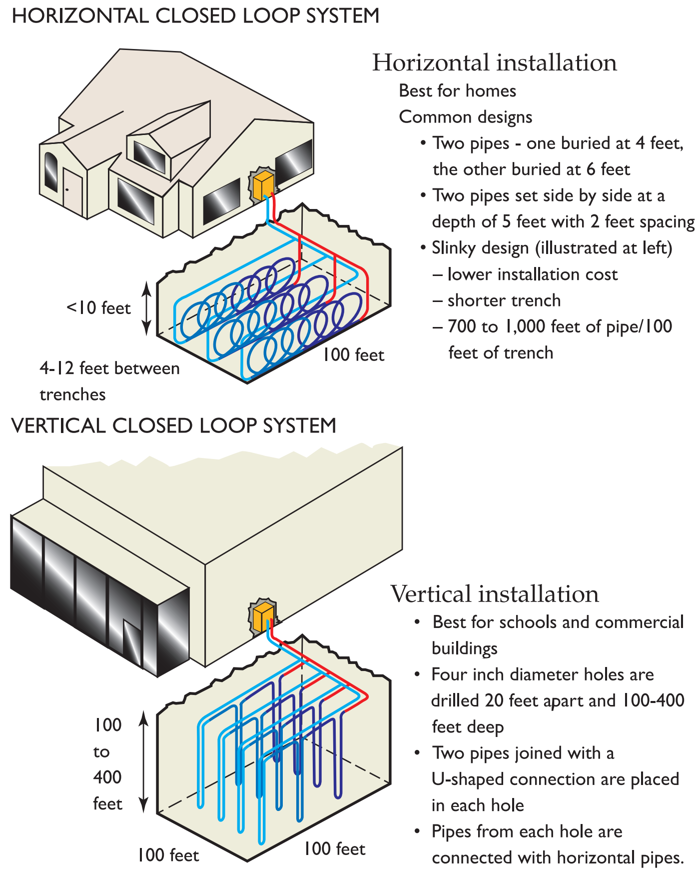
pumped down one well. The water moves along the fractures through the hot rock, picking up heat. The heated water is then pumped out of the second well, where the heat is used to provide energy. Los Alamos National Laboratory (LANL) developed an enhanced geothermal system on the southwestern margin of the 1.2-million-year-old Valles caldera in north-central New Mexico during the 1970s to 1990s. This project was called the Hot Dry Rock experiment. LANL engineers and scientists successfully drilled two wells, connected fractures, and produced hot water during an initial shallow-depth, small-scale phase of the project. Unfortunately, the phase of the experiment that tested the system at greater depths and higher temperatures was less successful. The fractures were difficult to connect and keep open at greater depth.

Two problems are associated with enhanced geothermal system development. First, an earthquake might be triggered if the pressurized fluid used to open cracks in rocks interacts with a fault that is under stress. Small earthquakes in the Cooper Basin of Australia (magnitude 3.7) and at the Basel prospect in Switzerland (magnitude 3.4) were caused by EGS development. These small-magnitude earthquakes caused only minor damage, but production was stopped in both cases to evaluate the situation. The second issue with EGS is the availability of water. Finding water to charge and maintain the initially dry reservoir of an enhanced geothermal system can be challenging in an arid environment. Although this system is nominally a "closed loop," small to moderate amounts of water are lost into the fractured reservoir.

Investigators at LANL and Lawrence Livermore National Laboratory are exploring the possibility of using dry carbon dioxide to extract heat from enhanced geothermal systems. Carbon dioxide does not strongly interact with rocks at high temperature, in contrast to water, which actively both dissolves and precipitates minerals at high temperature. Carbon dioxide easily expands and compresses and has low viscosity; these properties help drive circulation through the system. The heat storage capacity of carbon dioxide is low compared to water, but pumping large volumes of gas through rock can offset this disadvantage. The sequestration of this greenhouse gas through loss into the fractured reservoir is a fortunate byproduct of using carbon dioxide as a working fluid in an EGS.

GROUND-SOURCE HEAT PUMPS

Although the extraction of heat by ground-source heat pumps is sometimes referred to as a geothermal process, these devices are not considered to be geothermal systems. Traditional geothermal power is derived from rocks with temperatures significantly higher than the mean annual air temperature. The mean annual air temperature is 64°F in southeastern New Mexico and is 40°F in the mountains of north-central New Mexico, within the range of ground temperatures used by heat pumps.

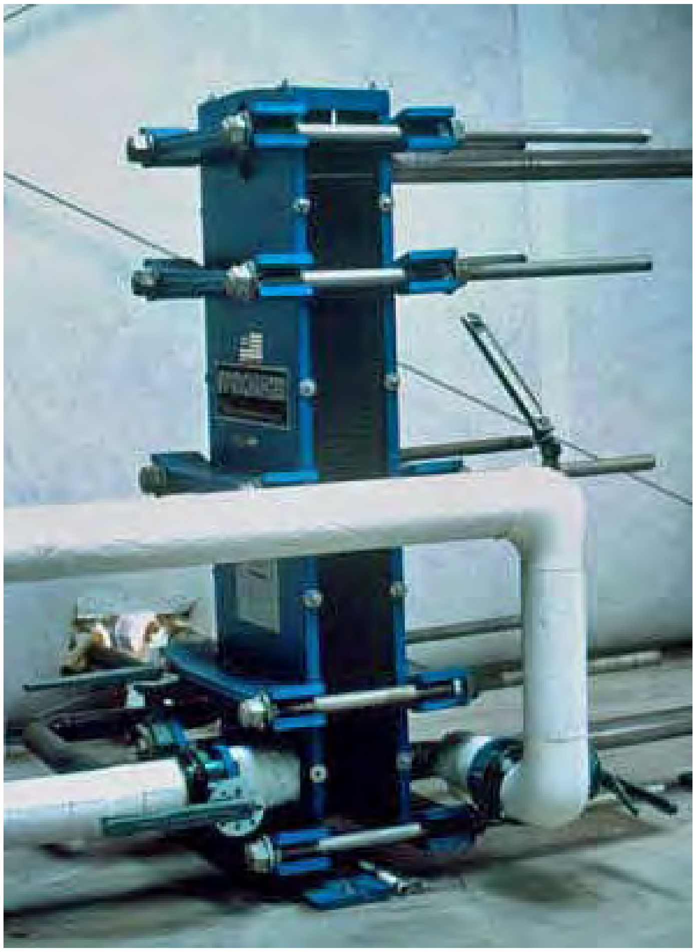


Schematic diagrams of ground-source heat pump systems. The blue represents cold water, the purple is warm water, and the red is heated water. Modified from: **http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640**

The Future Of Geothermal Energy

Last year the U.S. Department of Energy (DOE) distributed $400 million in grant money to geothermal companies, universities, and federal and state agencies to encourage the development of geothermal resources in the United States. Much of the research money (85 percent) is devoted to creating EGS systems. Researchers realize that such systems take a long time to develop, based on the Hot Dry Rock experience here in New Mexico, so the time to start working on this challenge is NOW. The Geysers field in California, the Bradys and New York Canyon fields in Nevada, the Raft River field in Idaho, Naknek in Alaska, and Newberry volcano in Oregon have been chosen as EGS demonstration sites. Improvements in power plant and ground-source heat pump design are also topics of new research. A significant percentage of the funding is dedicated to finding new exploration techniques and technologies that can be used to find "blind" resources located at great depth that have no surface manifestation. Finally, DOE is supporting the construction of a national geothermal database that will provide critical data to spark a new wave of exploration for unconventional geothermal prospects.

Here at the Bureau, we are working with TBA Power, Los Alamos National Laboratory, and the Pueblo of Jemez to develop a geothermal project at Jemez Pueblo. In addition, we are compiling a database of geothermal resources in New Mexico.



Heat exchanger. Photo courtesy of Jim Witcher

Lightning Dock geothermal resource pump test, Animas Valley, New Mexico. Photo courtesy of Jim Witcher

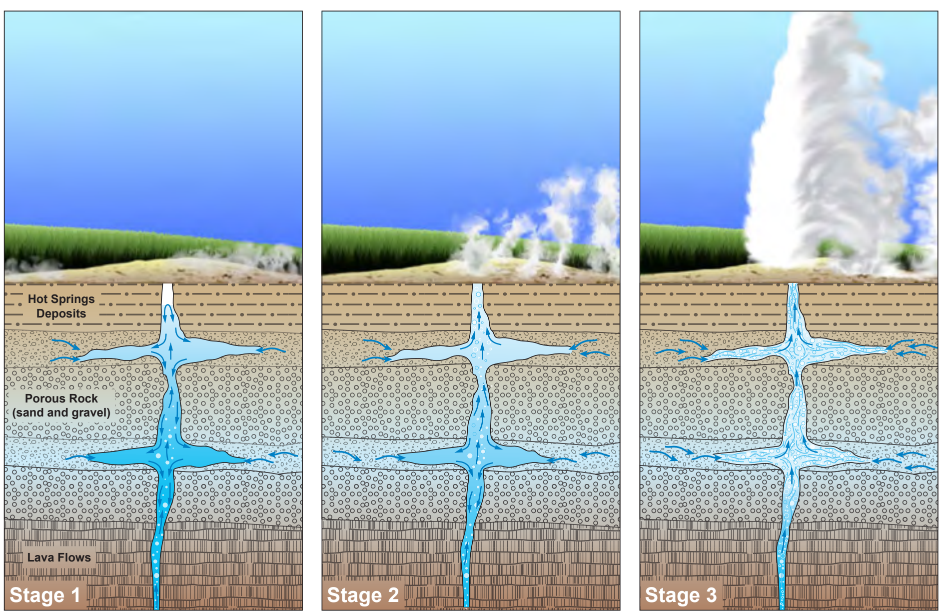
How Do Geysers Work?

Nelia Dunbar

Geysers are a type of geothermal activity that is familiar to most people. "Old Faithful," the famous geyser in Yellowstone National Park, sends jets of hot water and steam to a height of 200 feet (60 meters) into the air about every 65 minutes. There are many other geysers in Yellowstone and other geothermal areas around the world, some of which erupt with similar regularity, and others more erratically. What geological forces make these hot water jets happen again and again, often with a very predictable time between explosions?

The most important ingredient to make a geyser is heat, supplied by magma below the earth's surface. As magma cools, it gives off heat into the surrounding rock. The second important ingredient for a geyser is water, and if there's water near cooling magma, this water will be heated up. Most of the water that forms geysers is called "meteoric" water, meaning that it comes from rain or snow that makes its way deep into the earth's crust through cracks and fissures. A small amount of geyser water can come directly from the magma that provides heat. Because the water circulates deep in the earth's crust and is under high pressure, it can be heated up to high temperatures without boiling. For example, water at 100 feet (~30 meters) below the earth's surface boils at a temperature of 288°F (142°C), whereas at the earth's surface, boiling temperature is 212°F (100°C). This pressure effect is the reason that food cooks faster in a pressure cooker than in a normal pan, because the high pressure generated in a pressure cooker causes the water to achieve a higher temperature without boiling.

Heat and water are available in lots of geothermal systems, but a special combination of other factors allows geysers to exist. The underground plumbing of a geyser is usually within 300 feet (~100 meters) of the earth's surface and consists of a near-vertical tube that interconnects areas where lots of water can be stored, like porous rock or open side chambers. All of the chambers, porous rock, and central tube slowly fill with water (Stage 1). Gas bubbles are present in the water, and rise through the system. Once the system is full of water and rising gas bubbles, the bubbles can build up in a constricted part of the vertical pipe. When the bubbles break free from the constriction, their rapid upward motion can force some overlying water out through the main vent (Stage 2). When this happens, the removal of some water causes the rest of the system to rapidly depressurize, which causes the boiling point to become lower, and much of the water flashes instantly to steam, causing a huge volume expansion. This rapid depressurization and volume increase of water causes a chain reaction into the deepest parts of the system and forces all of the water and steam to erupt dramatically out of the geyser vent (Stage 3). The eruption continues until all of the water has been emptied out of the central pipe, as well as the surrounding chambers and porous rock. At this point, the system begins to refill, preparing for the next eruption. The shape and size of the subterranean geyser plumbing system controls the size and frequency of eruption.



Schematic depiction of the successive stages of a geyser eruption. The direction of flow of water is shown by arrows, and the processes operating at each eruptive stage are described in the text. Illustration and caption modified from US Geological Survey Bulletin 1347

Classroom Activity

Infrared Yellowstone Lesson Plans

This activity explores the use of infrared imaging to study geothermal activity at the earth's surface. Yellowstone National Park, the setting for this lesson, provides many geothermal sites including geysers, mud pots, and hot springs that can be studied using infrared imaging. Infrared and visible images of various geothermal features allow students to compare details that are unique to each method.

The following excerpts are reprinted courtesy of the Cool Cosmos Web site, which is hosted by the Infrared Processing Analysis Center (IPAC) at California Polytechnic Institute. The main Web site link is
http://coolcosmos.ipac.caltech.edu/

We are used to seeing the world around us in visible light. However, there are many other types of light, including x-rays, gamma rays, ultraviolet, infrared, microwaves, and radio waves that we cannot see with our eyes. Each of these types of light gives us a unique view of the world around us. All objects emit infrared. The amount of infrared emitted depends on the object's temperature. Hot objects emit more infrared than cold ones do. Infrared images give us special information that we cannot get from visible light pictures. In these lessons a special infrared camera was used to create infrared images which will be used to help students learn about infrared light. Infrared images of geothermal features and everyday objects will provide students with a unique and interesting view of the infrared world.

In 1872 Yellowstone National Park was established as the world's first national park. It is located in northwest Wyoming and extends into Montana and Idaho. Covering 2,219,791 acres, it is about the size of Rhode Island and Delaware combined! Yellowstone National Park is in a huge volcanic basin which was the site of several massive volcanic eruptions, the last of which occurred about 600,000 years ago. Yellowstone National Park is a region of incredible beauty, abundant wildlife and amazing geothermal features. Among the geothermal features found in Yellowstone are numerous geysers, hot springs, bubbling mud pots, fumaroles and hot spring terraces. These features can be explored in a unique way through infrared imaging.

Infrared images show the relative distribution of heat as a false color map and can reveal information not found in visible light images. By comparing and contrasting visible light images and infrared images, learners will discover the importance of using different regions of the electromagnetic spectrum to study objects. Though not expressed in this particular lesson, this infrared exploration can be extended into exploring additional applications of infrared imaging on Earth and in space. Viewing objects using different types of light gives us a more complete understanding of these objects.

To access the complete Infrared Yellowstone Lesson Plans and images used in the lessons, please visit:
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/

DESCRIPTION OF LESSON 1

Learners explore the differences between visible light images and infrared light images of geysers, mudpots, hot springs, and hot springs terraces located at Yellowstone National Park. The explorations focus on compare and contrast skills, observation skills, and learning about infrared images.
By using the features of Yellowstone National Park as the backdrop they will also gain a basic understanding of some characteristics of geothermal features, though the geology is not the focus of this lesson. A pdf of this lesson plan can be found at: **http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_Lesson.pdf**

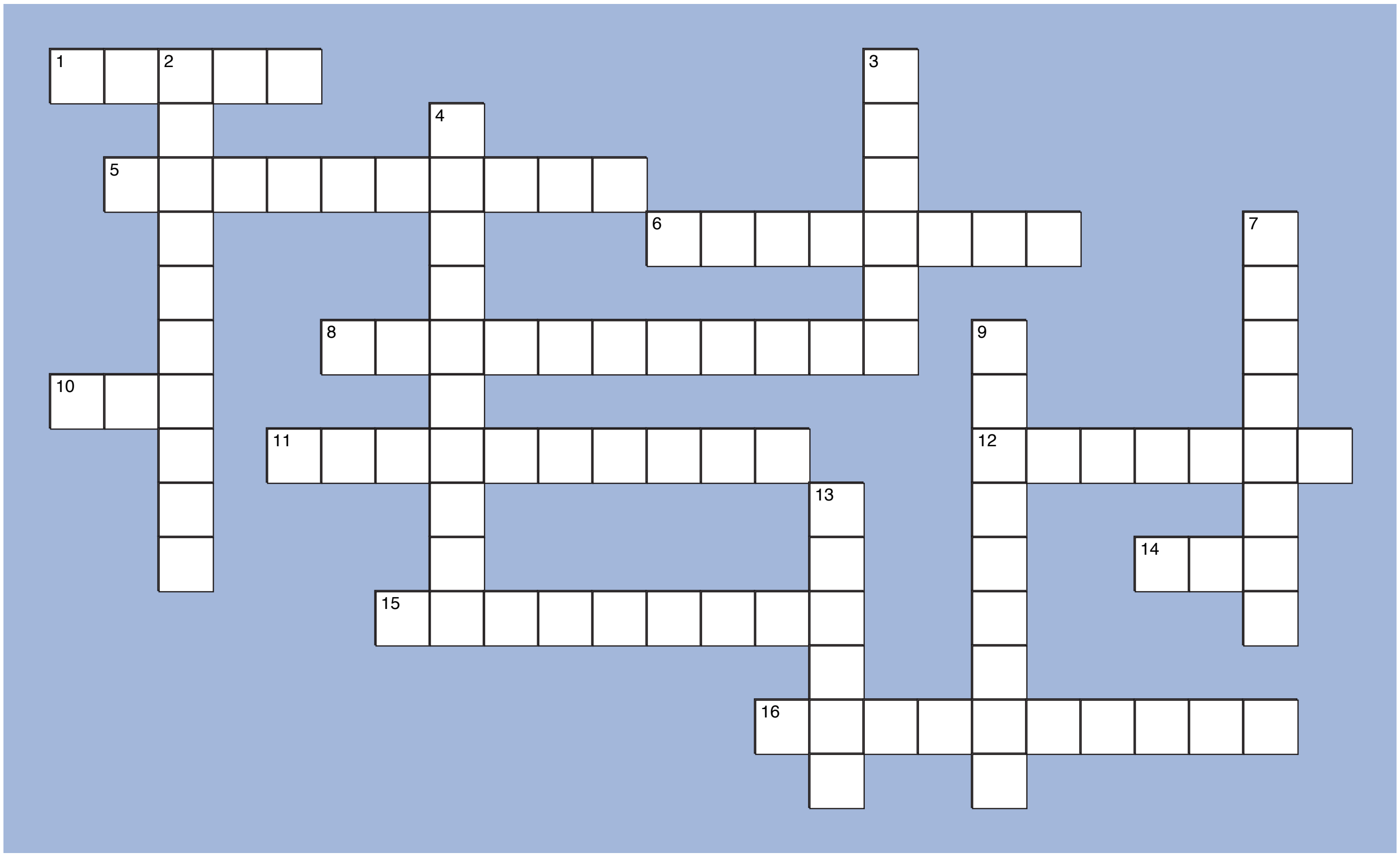
DESCRIPTION OF LESSON 2

Learners discover new perspectives on fascinating geothermal features like geysers, mudpots, hot springs, and hot spring terraces. Already familiar with the basic characteristics of these features, they explore the geology of Yellowstone National Park in a new light, infrared light! During this lesson, they will gain an understanding of infrared light and infrared imaging as well as deepen their content knowledge on geothermal features. The pdf for Lesson 2 is found at:

http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/WhatsHot_Lesson.pdf

Here is an example of the visible light and infrared images of Old Faithful geyser in Yellowstone National Park found at: http://coolcosmos.ipac.caltech.edu/image_galleries/ir_yellowstone/lessons/InvYNP_ImgSet1.pdf; (Image Set I). Accessed July 27, 2010.
Images and lesson courtesy of NASA/JPL-Caltech

Geothermal Crossword Puzzle



Across

1. Power plant that directly uses geothermal fluid
5. A growing use of low-temperature geothermal water
6. Man-made geothermal system
8. A powerful use of high temperature geothermal resources
10. Heat needed to raise the temperature of a pint of water 1°F.
11. Energy derived from the earth's interior
12. Fish grown in geothermal water
14. A soothing use of hot spring water
15. Well to which cooled water is returned to the earth
16. Well from which hot water is extracted

Down

2. A potential problem associated with EGS
3. Heat pump system for homes
4. Hot buoyant material rises and cooler dense material sinks
7. Heat pump system for big buildings
9. Radioactive element that is the source of much of the earth's heat
13. Power plant using a heat exchange

The answers to the clues are found in the geothermal articles in this issue of Lite Geology.

Geothermal Applications in New Mexico

Douglas Bland

New Mexico is fortunate to have low (less than 190°F), moderate (190 to 300°F), and high (over 350°F) temperature geothermal resources in many locations. Some of the best resources are found along the Rio Grande corridor and in the southwest corner of the state. However, relatively few have been developed. The only functional electric power plant is a small binary plant at the Burgett Geothermal Greenhouse near Cotton City in the Animas Valley that is currently shut down. Raser Technologies is evaluating a possible 15 megawatt power plant at Lightning Dock, also in the Animas Valley. All other commercial geothermal applications in the state use low-to-moderate temperature resources for space heating, greenhouse heating, aquaculture (fish farms), spas, and bath houses.

Geothermal greenhouses at the Masson Radium Springs Farm, Radium Springs, New Mexico. Photo courtesy of Rob Williamson, NREL

Geothermal space heating uses hot water from springs or wells to heat industrial, commercial, or residential buildings. This can be accomplished by pumping hot water directly from the ground through piping into buildings, or through a heat exchanger that extracts heat and transfers it to a separate closed-loop water system, which then heats the buildings. This process is economically feasible where shallow geothermal resources are located adjacent to the spaces to be heated. Due to up-front drilling and pipeline costs, geothermal space heating is more attractive financially where the heating demand is large.

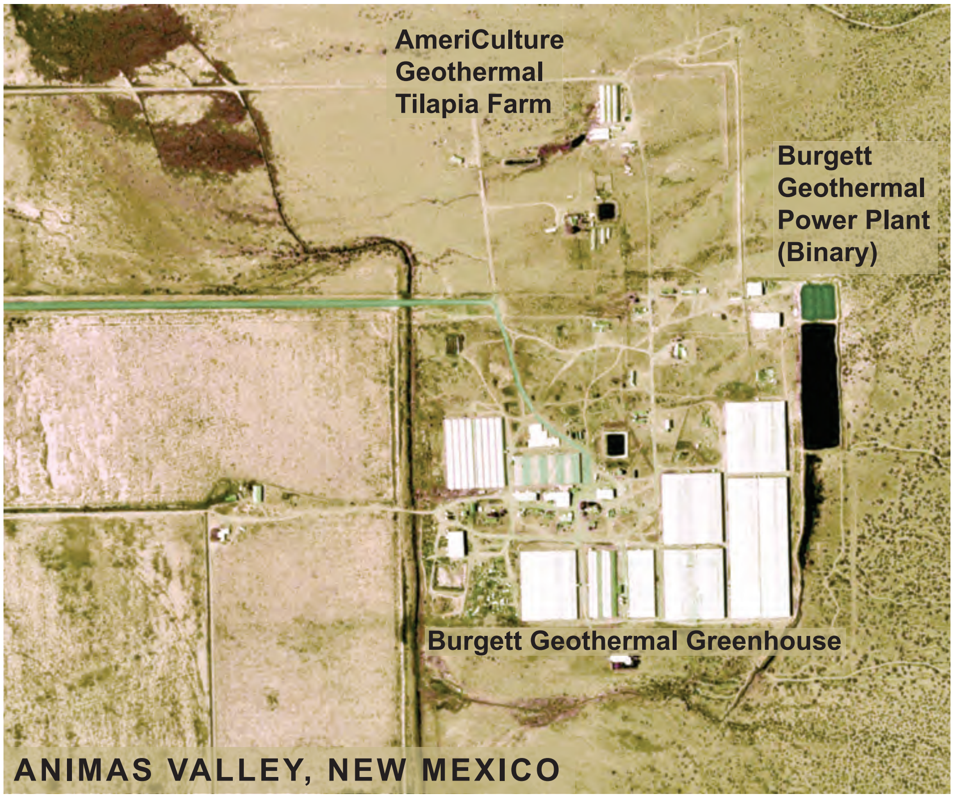
Greenhouses must be kept warm for ideal growing conditions, requiring significant supplemental heat. New Mexico has two large greenhouses that are heated using geothermal energy at a fraction of the cost compared to traditional energy sources. The Burgett Geothermal Greenhouse and the Masson Radium Springs Farm north of Las Cruces together have more than 45 acres of greenhouses, comprising almost half of the total greenhouse acreage in the state. Annual energy cost savings exceed $2.5 million.

Damon Seawright, owner of the AmeriCulture geothermal tilapia fish farm in Animas, New Mexico, grows tilapia fry for resale to fish farms across the country. Adult fish are also marketed to distributors across the region. Photo courtesy of Rob Williamson, NREL

As wild fish populations across the globe dwindle, fish farms (also known as aquaculture) are being developed to help meet the growing demand. Some fish species grow only in warm water, and others have more rapid growth rates in warmer water. As with greenhouses, geothermal waters can cut heating bills. If the quality of the water is acceptable, the water can be used directly to grow fish. The AmeriCulture Tilapia Farm adjacent to the Burgett Geothermal Greenhouse extracts heat with a down-the-hole heat exchanger in a 400-foot well to grow tilapia fry (baby fish) year around for sale to other growers nationally. They also produce and sell live adult tilapia to restaurants across the region.

Perhaps the best known use of geothermal water in New Mexico is direct use of the hot water from either springs or wells for spas and bath houses. Eleven establishments across the state allow people to soak in the soothing waters, many of them in Truth or Consequences (formerly Hot Springs). One of the most popular is the Ojo Caliente Mineral Springs Resort and Spa in north-central New Mexico. It has been renovated and expanded in recent years, and also uses the hot water for space heating. Used water is cleaned and injected back into the aquifer.

Currently geothermal energy is under-utilized in New Mexico, but a number of additional projects are in the planning stages or under evaluation. As prices rise for energy from traditional energy sources, New Mexico's naturally hot waters are likely to be tapped for new uses.



Aerial photo showing a commercial complex in Animas, New Mexico that uses hot water from the Lightning Dock geothermal resource. Image courtesy of the U. S. Geological Survey

Active Commercial Geothermal Facilities in New Mexico

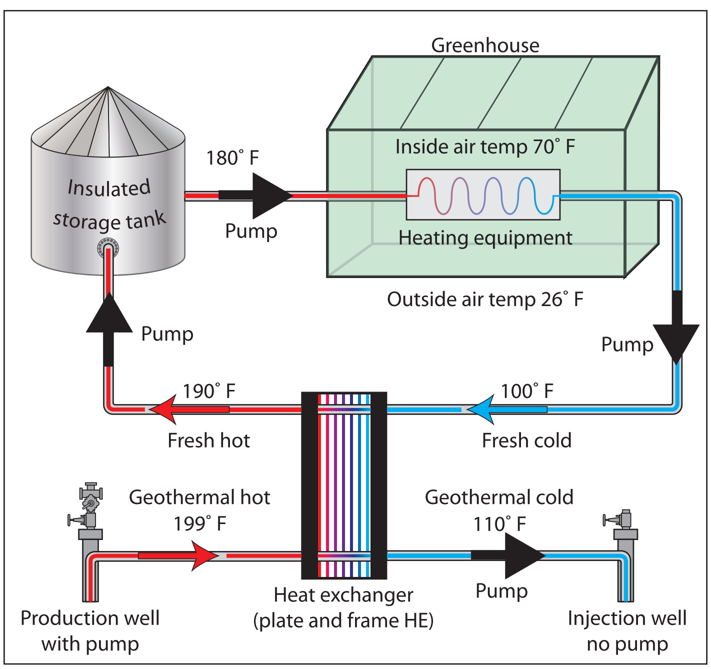
Site	County	Use
Southwest Technology Development Institute @ NMSU	Doña Ana	aquaculture and greenhouse
Masson Radium Springs Farm	Doña Ana	16–acre greenhouse
Faywood Hot Springs	Grant	spa
Gila Hot Springs Ranch	Grant	space heating
Burgett Geothermal Greenhouse	Hidalgo	30–acre greenhouse
AmeriCulture Tilapia Farm	Hidalgo	aquaculture
Ojo Caliente Mineral Springs	Rio Arriba	spa and space heating
Jemez Springs Bath House	Sandoval	spa
Giggling Star, Jemez Springs	Sandoval	spa
Artesian Bath House, Truth or Consequences	Sierra	spa
Charles Motel, Truth or Consequences	Sierra	spa
Fire Water Lodge, Truth or Consequences	Sierra	spa
Geronimo Springs Museum, Truth or Consequences	Sierra	space heating
Hay-Yo-Kay Hot Springs, Truth or Consequences	Sierra	spa
Marshall Hot Springs, Truth or Consequences	Sierra	spa
River Bend Hot Springs, Truth or Consequences	Sierra	spa
Sierra Grande Lodge, Truth or Consequences	Sierra	spa

Geothermal Greenhouse Heating at Radium Springs, New Mexico

James C. Witcher

Greenhouses grow crops in a controlled environment and take maximum advantage of sunlight for plant growth through photosynthesis, and for daytime heating in winter. During the day in summer, evaporative cooling is used. What about at night? Don't greenhouses trap heat? At night, the glass or plastic roof of the greenhouse will allow heat to radiate outward almost as though no roof existed. Strangely, the "greenhouse effect" does not apply to a greenhouse at night. Heat is not trapped. Infrared radiation, invisible to the eye, radiates heat upward through the greenhouse roof cover. We can feel intense infrared radiation on our skin near a fireplace or when we're in the sun. The air in a greenhouse heats up during the day when the sun heats indoor greenhouse surfaces, which then heat the air in the greenhouse. The greenhouse walls and roof prevent mixing with cooler outside air, allowing the inside temperature to rise.

All greenhouses are heated to optimal conditions for plants at night, even on many summer nights, and on winter days when solar heating is limited. Conventional greenhouses use a fossil fuel boiler. In this case, natural gas is burned to heat water in the boiler. Circulation of the hot water through pipes and radiators heats air in the greenhouse. The hot water circulation system is a closed loop that returns water to be reheated by the boiler for another heating pass through the greenhouse.



Schematic diagram of a geothermal heat exchange system for the Masson Radium Springs Farm greenhouse, New Mexico.

Greenhouses require enormous amounts of heat even in the mild winter climate of New Mexico deserts. An acre of greenhouse will require 4.5 billion BTUs of heat during a year. What is a BTU or British thermal unit? One BTU is the amount of heat energy required to raise the temperature of a pound of water (roughly equal to a pint of water) a single degree Fahrenheit. A cubic-foot volume of natural gas will provide about 1,000 BTUs of heat when burned. Therefore, an acre of greenhouse will require at least 4.5 million cubic feet of natural gas each year. However, 30 percent of the heat from burning gas will be lost up the "smoke stack." So in reality, more than 5.8 million cubic feet of natural gas is required to heat an acre of greenhouse each year. Sounds like a lot, and it is, especially when the cost is considered.

Wholesale or commercial natural gas is typically sold in units of 1,000 cubic feet (abbreviated as "1 Mcf"), or the same as a million BTUs ("1 MMBTU"). These units are different than the Therm unit used by the gas company for residential metering and billing. A Therm is 100,000 BTUs or about 100 cubic feet of natural gas. Since 2007 the cost for 1 Mcf (equal to 1 MMBTU) of natural gas has varied from $9 to $15. Hold your breath! This translates into an annual natural gas heating bill of $58,500 for an acre of greenhouse based on $10 per Mcf.

Is there a less expensive way to heat a greenhouse? The Masson Radium Springs Farm north of Las Cruces uses "direct-use" geothermal energy with significant heat energy savings. Geothermal heating for the Masson greenhouse is about $1.50 per MMBTU without any "smoke stack" heat losses that make natural gas actually cost $13 per MMBTU, using a $10 per Mcf charge at the meter. The $1.50 MMBTU equivalent energy cost is for electricity to operate the well and circulation pumps, maintenance, and to pay back well drilling costs. There is no fuel cost. What are the savings with geothermal? The cost difference between $13 and $1.50 is $11.50 per MMBTU, equal to $51,750 per acre of greenhouse. Because the total Masson Radium Springs greenhouse acreage is 16 acres, geothermal energy saves $828,000 annually compared to heating with commercial natural gas at $10 per Mcf.

How does the Masson Radium Springs geothermal greenhouse heating work? It is very simple. A geothermal well, a heat exchanger, an insulated hot water storage tank, and an injection well replace a fossil fuel boiler and a natural gas fuel supply. The hot water circulation system inside the greenhouse remains the same, although the size may vary depending on the hot water circulation temperature. Water that is 199°F is pumped from an 800-foot-deep geothermal well. The water is piped to a heat exchanger where the heat in salty geothermal water is transferred to fresh water. Hot 190°F fresh water is then pumped into an insulated, 187,000-gallon storage tank. The geothermal water with heat removed is then injected back into the reservoir to be reheated by hot rock, using a different well some distance from the production well. Hot fresh water at 180°F is pumped out of the storage tank and circulated through the greenhouse for heating, then returned to the heat exchanger to be reheated, starting another heating cycle through the greenhouse. All of this is possible with the heat of the earth, geothermal!

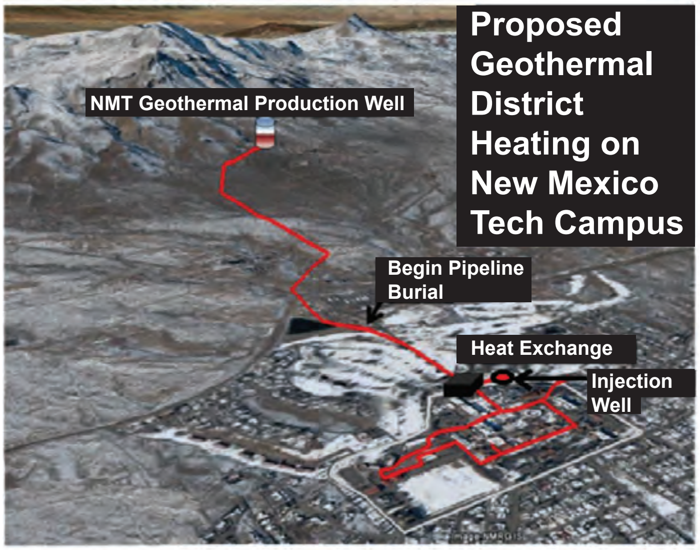
Additional Reading

Catalog of Thermal Waters in New Mexico by W. K. Summers, Hydrologic Report 4, New Mexico Bureau of Mines and Mineral Resources 1976.

Geology and geothermal waters of Lightning Dock region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico by Wolfgang E. Elston, Edmond G. Deal, and Mark J. Logsdon, Circular 177, New Mexico Bureau of Mines and Mineral Resources, 1983.

Heating New Mexico Tech's Campus with Geothermal Energy

Mark Person



Schematic diagram showing geothermal district heating system proposed on New Mexico Tech campus.

Continental rift zones like the Rio Grande valley are areas where Earth's crust is being pulled apart and hot mantle rocks are drawn up toward the surface resulting in elevated temperature gradients and permeable fractured rocks. There are abundant low temperature (less than 212°F/100°C) geothermal resources across the state of New Mexico. In fact, the U.S. Geological Survey recently ranked New Mexico sixth in the nation for its geothermal potential.

Historically, academic institutions such as New Mexico State University (NMSU) in Las Cruces have played a key role in the development of the geothermal industry, with the Southwest Technology Development Institute at NMSU providing programs to develop geothermal technology and help companies get started that use geothermal resources. Now, the New Mexico Institute of Mining and Technology (New Mexico Tech) in Socorro is considering developing its own local geothermal resources to heat the campus.

It has been known for some time—at least 150 years to perhaps 500 years—that thermal springs (e.g., Socorro Spring, 91.4°F/33°C) issue from the M Mountain front about two miles southwest of the New Mexico Tech campus. In the winter of 2009, with support from the U.S. Department of Energy (DOE), New Mexico Tech drilled a test well to assess the geothermal potential. A team of four geologists monitored the drilling operation around the clock from November 2009 to February 2010. This "slim hole" (a well bore with a diameter of less than 7 inches) was drilled to a depth of 1,102 feet at the Woods Tunnel drill site. Temperatures were nearly constant 105.80°F (41°C) between a depth of 400 and 1,102 feet. Hot water flow rates measured during drilling were consistently around 1,000 gallons per minute.

A district heating system for the campus requires temperatures of 149.00°F (65°C), but the produced fluids from the geothermal well are only 105.80° F (41°C). Nevertheless, these fluid temperatures are high enough that this resource can still be used to heat the campus if heat pumps are added to the system. Using our geothermal resources would involve installing a pipeline two miles long from Woods Tunnel to New Mexico Tech and installing a series of heat pumps and heat exchangers to remove the heat from the geothermal fluids. The entire project cost is estimated to be about $3 million. Whereas the up-front construction costs are relatively high, the payback period would still be less than six years. In addition, New Mexico Tech could offset as much as about 6,000 metric tons of CO_2 production per year by switching the heating system to geothermal energy, saving the state about $510,000 per year in utility bills. In 2010 New Mexico Tech was awarded $2 million from the DOE to develop our geothermal district heating system. Unfortunately, required matching funds from the state were not available due to state budget shortfalls. We are currently looking for additional funding opportunities and state matching funds to complete the project.

Geologists who oversaw the slim hole drilling operation for the geothermal district heating project at New Mexico Tech.

Estimated New Mexico Tech Heating System Costs and Payback

Item	Cost
2.2 miles of pipe	$753,981
4 heat exchangers and heat pumps	855,000
Controls	50,000
Production well, 1,000 gpm 650 feet of casing and pump	127,000
Reinjection well, 3,000 feet	950,000
Contingency	225,000
Total Costs	**$2,960,981**
Annual utility bill savings: $510,000 Simple payback: 5.8 years	

Drill bit used in the slim hole drilling operation.

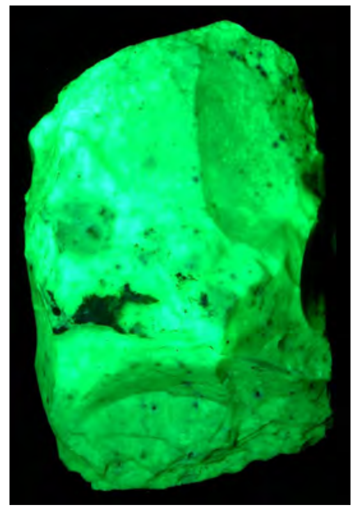
Drilling rig used in the slim hole drilling operation.

New Mexico's Most WANTED MINERALS

Virgil Lueth

OPAL

Hyalite opal from the Servilleta basalt field near Taos. Normal light image on left and ultraviolet light image on right.



DESCRIPTION: The mineral is often found in "jelly-like" masses in a wide variety of colors, usually pale: white, yellow, red, brown, green, gray, and blue. Often the color of opal is caused by the inclusion of other geological materials. The precious variety can display a rainbow of colors due to microdiffraction of light by close-packed silica spheres. Its luster can be vitreous (glass-like) to subvitreous, resinous, and pearly. Mohs Hardness is usually less than 7 (quartz) and varies from 5.5 to 6.5. A conchoidal (curved, glass-like) fracture is characteristic and often occurs as the mineral "drys out" creating a feature known as crazing. Opals are often stored in water or oil to prevent natural fracturing. Some opals are highly fluorescent (green) when associated with uranium (hyalite opal). Most opal is actually a mixture of amorphous silica and low temperature cristobalite and/or tridymite. Gem opals (precious and hyalite) are the most amorphous (noncrystalline).

WANTED FOR: The mineral has been known as a gemstone since antiquity. The word is derived from the Sanskrit, upala, meaning "precious stone." Its many varieties are used in the lapidary arts as cabochons and carvings. Some scientists have attempted to date natural sinter (hot spring) deposits using the idea that crystallization of cristobalite or tridymite from opal occurs over time, therefore, the more crystals the older the sinter. Opal is also used for ceramics, in the chemical industry, as insulation, and in acid proof materials. It is also used as a soil amendment (diatomaceous earth).

HIDEOUT: Opal is found in a wide variety of environments ranging from volcanic to sedimentary. In volcanic terrains it is commonly associated with chalcedony and agate (of which it constitutes a part). Sedimentary environments include petrified wood and deep-sea sediments. It forms the test (shell) of some diatoms and radiolarian. Opal is also found naturally in some plants, especially grasses, cotton, and hops. Opaline sinter deposits are associated with some hot springs.

LAST SEEN AT LARGE The widespread distribution of opal suggests it might be fairly common in the geologically diverse state of New Mexico, and it is. Hyalite opal is known from the basalts near Taos, volcanic rocks of the Mogollon volcanic field in the southwest, and the Manzano Mountains near Albuquerque. Most petrified wood found in New Mexico consists of opal. Deposits of diatomaceous earth can be found in ancient lake deposits in the southwestern part of the state. Agate is very abundant in the volcanic areas. Very little precious opal has been found in New Mexico.

ALIASES: Geyserite, sinter, diatomite, tripolite, and precious-, noble-, hyalite-, fire-, milk-, and plant-opal, agate, opalized wood.

Through the Hand Lens

Profile of a New Mexico earth science teacher

Marcia Barton teaches Environmental Science at Santa Fe High School and is passionate about using inquiry and project-based methods of teaching science to engage learners. She believes in creating a learning environment for all students that is safe, challenging, collaborative, and productive. Her career has led her to work with several environmental and ecological organizations, though she finds teaching young teens the most challenging and rewarding career of all. She is also a beekeeper with five topbar hives, and loves riding her bicycle to school. Recently she received several merit awards, including the Toyota International Teacher Program to the Galapagos in December of 2008, and the Fulbright U.S.–Japan Teacher Exchanger on Education for Sustainability.

GRADE LEVEL AND SUBJECTS TAUGHT

Environmental Science, Advanced Placement Environmental Science, high school juniors and seniors

Photo courtesy of Teresa Cook

EDUCATIONAL BACKGROUND

Formal:

- Master of Science Teaching, New Mexico Tech, 2007
- Post Baccalaureate Teaching Certification, University of New Mexico, 2000
- Bachelor of Science in Natural Resources, University of Michigan, 1977

Informal:

Four-month training working with draft horses in agriculture, Horsepower Farm, Blue Hill, Maine, 1993

Two-year internship in organic biodynamic agriculture, Camphill Village, Kimberton Hills, PA, 1985–1987

WHY IS IT IMPORTANT FOR STUDENTS TO LEARN ABOUT EARTH SCIENCE?

Because we live on planet Earth it is important for all of us to understand the basics of how Earth systems function in order to try to live as harmoniously as possible with these systems so that we can leave the planet in good working order for our great-great-grandchildren. How can we expect our students to make healthy decisions in the future about resource management if they don't understand the basics of how the planet works? As consumers and future homeowners, our students will make a lot of decisions that will have an impact on Earth systems.

ADVICE OR SUGGESTIONS FOR OTHER EARTH SCIENCE TEACHERS

Take students outside as much as possible, even if it is only on the school grounds, to do field research. Of course, this requires good classroom management. I tell my students before we go out that I have to be able to trust them outdoors to behave responsibly, otherwise we will not be able to go out again. I usually have them work in teams, and about half of the time I let them choose their own team members, unless they are too disruptive together. Letting them choose their team partners creates a friendly working environment, but I also want them to experience students that may be outside their comfort zone, so the other half of the time I will choose the teams. I also look for community partners that can help provide a field trip experience off of the school grounds, and this has provided some rich field work for students.

When I teach a unit about the impact of human activities on earth systems, I also try to include a project, even if it is a small one that shows how our individual activities can have a positive impact. For instance, recycling is an activity that can be done by anyone and has a positive impact.

FAVORITE LESSON IN EARTH SCIENCE

Sieving for Clast Size

Students take samples from two different geological layers and sieve (sort) them for clast (particle) size data. They will also make sketches of some of the clasts and describe the rounded versus angular aspects in each of the formations. Students then prepare a histogram showing the percentages of clast size distribution in each formation and answer analysis questions.

This activity was created with the help of Dr. Dave Love and Dr. Nelia Dunbar of New Mexico Tech. I like this activity because it begins with an outdoor activity that is accessible to all students, one that they can use to scaffold their knowledge upon. It includes both qualitative and quantitative analyses, and gives all students access points to learn about geology based on their learning style. This activity was created specifically for our school's campus, but can be adapted to any place where there is access to two geologic formations. Link to this lesson plan to download the file from the New Mexico Bureau of Geology website:
http://geoinfo.nmt.edu/education/exercises/sieving

FAVORITE WEB LINKS AND RESOURCES

U.S. Geological Survey lesson plans:
http://education.usgs.gov/common/secondary.htm

For oceanography, the Monterey Bay Aquarium features live web cams:
http://www.montereybayaquarium.org/efc/cam_menu.aspx

For learning about inquiry based science, the Exploratorium's Institute for Inquiry is fantastic:
http://exploritorium.com/IFI/library/index.html

For inquiry based activities, visit the Exploratorium's Web site: **http://www.exploratorium.edu/**

FAVORITE GEOLOGIC FEATURE IN NEW MEXICO

Tent Rocks is one of my favorite geologic features. I love the exotic formations created by the volcanic tuff deposits from the Valles caldera volcanic eruption over a million years ago, and how they have been formed over time from weathering and erosion. Kasha-Katuwe Tent Rocks National Monument is located 40 miles southwest of Santa Fe, New Mexico (near Cochiti Pueblo) and is definitely worth a visit. Another similar geological formation is found in Turkey.

Tent Rocks formation in Kasha-Katuwe National Monument. Photo courtesy of Stanley Weisenberg

New Mexico's Enchanting Geology–Navajo Church

Douglas Bland

Photo courtesy of Gary Rasmussen

Navajo Church, also known as Church Rock, is the most prominent feature seen from Red Rock State Park, ten miles northeast of Gallup. This colorful spire is an erosional remnant left behind when the surrounding rock was eroded away by wind and water. The rocks that remain are members of the Late Jurassic-age Bluff and Zuni Sandstones and Morrison Formation, formed 150 million years ago from wind-blown (eolian) sand and fluvial sediments deposited by meandering streams when this area was a low-lying plain. The base and shoulders of Navajo Church are eolian Bluff and Zuni Sandstones. The upper strata show spectacular east-dipping crossbeds, the inclined beds typically found in sand dunes. The spires of Navajo Church are fluvial sands and thin lenses of siltstone and shale of the Morrison Formation. Other similar geologic formations, such as the massive red cliffs of the Entrada Sandstone as well as the Zuni and Bluff Sandstones that underlie the Morrison Formation, are commonly exposed at the surface in the Colorado Plateau province of the Four Corners region, and in the spectacular landscapes of southeast Utah's canyon country.

Navajo Church is located just outside of Red Rock State Park at 35°33'27.22" N, 108°36'05.62" W. The UTM coordinates are 717392.4E and 3937327.7N (zone 12S, NAD27). However, the trading post in the park offers excellent views of this landmark, as does Interstate 40 just east of Gallup. For more information, see: **http://geoinfo.nmt.edu/tour/state/red_rock/home.html**

For a more detailed explanation of the rocks found at Navajo Church, see the following article:

Red Rock State Park, by Virginia T. McLemore and Shari A. Kelley, in *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, edited by L. Greer Price: New Mexico Bureau of Geology and Mineral Resources, 2010, pages 45–49.

Short Items of Interest to Teachers and the Public

The Mineral Museum on the campus of New Mexico Tech in Socorro, New Mexico

HOURS:

8 a.m. to 5 p.m., Monday through Friday
10 a.m. to 3 p.m., Saturday and Sunday
Closed on New Mexico Tech holidays

The Mineral Museum is located in the Gold Building on the campus of New Mexico Tech in Socorro. The bureau's mineralogical collection contains more than 16,000 specimens of minerals from New Mexico, the United States, and around the world, along with mining artifacts and fossils. About 2,500 minerals are on display at a time.

For teachers and other groups, we offer free tours of the museum. We like to show off our home state minerals, as well as give students an idea of how minerals end up in products we use every day. Museum staff can also identify rocks or minerals for visitors. Please call ahead to ensure someone will be available. For more information on the museum, please visit our Web site at: **http://geoinfo.nmt.edu/museum/**

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TO SCHEDULE A TOUR, CONTACT:

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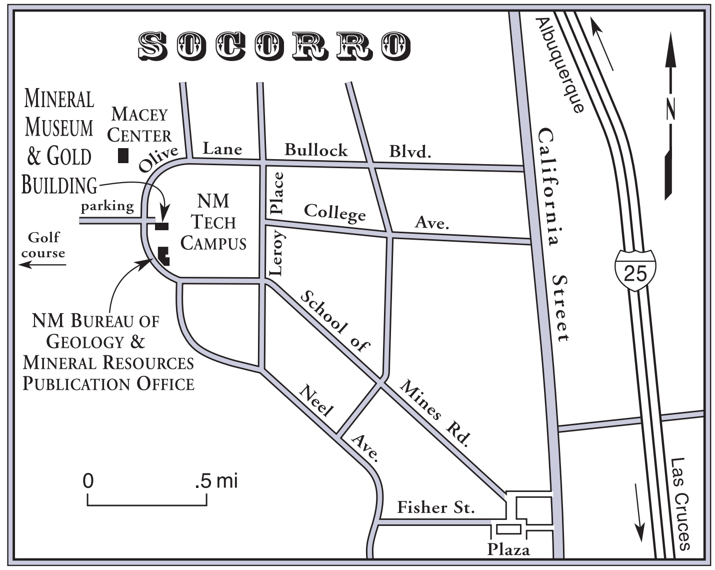

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The Publication Sales Office has many resources for teachers, including publications on New Mexico's geology, many meant for the amateur geologist and general public.

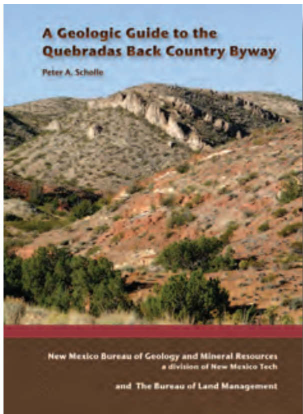
We offer:

- Topographic maps for the entire state of New Mexico
- Geologic maps for selected areas of New Mexico
- U.S. Forest Service maps
- A 20% discount for teachers

OUR NEWEST PUBLICATIONS ON GEOLOGY INCLUDE:

A Geologic Guide to the Quebradas Back Country Byway

By Peter A. Scholle, 24 pp. Free.



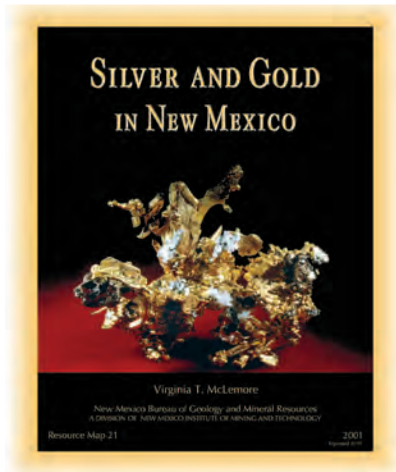
This fall the New Mexico Bureau of Geology and Mineral Resources released a new, revised, print version of this popular online field guide, which has to date been available only in electronic format on our Web site (see below). Produced in cooperation with the Bureau of Land Management (BLM), the new edition has been edited for a more general audience and is keyed to ten numbered stops along the 24-mile-long byway, which runs from just north of Socorro to just east of San Antonio, on the east side of the Rio Grande in Socorro County. The Quebradas Back Country Byway, which is managed by the BLM (Socorro Field Office) is dirt; a high clearance or 4-wheel-drive vehicle is recommended. Multiple copies for distribution will be handled through the BLM Socorro Field Office (575-835-0412); single copies are available through that office or through the Publication Sales Office at the New Mexico Bureau of Geology and Mineral Resources. For more information on the byway itself, call the BLM Socorro Field Office directly at 575-835-0412.

http://geoinfo.nmt.edu/publications/fieldguides/quebradas/home.html

Silver and Gold in New Mexico

By Virginia T. McLemore, 60 pp., 1 oversize map (1:1,000,000), Resource Map 21, ISBN 1-883905-10-9. $14.95 plus $5.50 shipping and handling and taxes where applicable.

This popular resource map, first issued in 2001, is back in print. The accompanying 60-page text is an exhaustive compilation of information on 163 mining districts and other locations in New Mexico with reported production of silver and gold or with reported silver and gold "occurrences," concentrations 200 times crustal abundance. Since the first mining claim (recognized by historians) was filed in New Mexico in 1685, the lure of mineral wealth has continued to draw would-be prospectors to our state's mountains and rivers in search of Earth's precious resources. From 1848, the year the Treaty of Guadalupe Hidalgo ended the Mexican–American War and ceded New Mexico to the United States, through 2000, almost 3.2 million ounces of gold and 117 million ounces of silver have been produced in New Mexico. This second printing of Resource Map 21 includes those production figures available through 2000. No new data have been added.



New Mexico Earth Matters, Summer 2010, ***Carbon Sequestration in the Context of Climate Change,*** by Peter A. Scholle and Richard Esser. This summer *Earth Matters* explores solutions to the problem of increasing levels of carbon dioxide (CO_2) in the atmosphere from human activities such as the burning of fossil fuels, deforestation, and various industrial processes. The capturing of CO_2 at major sources of generation and sequestering it in geologic formations deep underground is one potential solution that is being tested here in the Southwest.

You can sign up for a free subscription to ***Earth Matters*** if you live in the state of New Mexico. Call 575-835-5302 or e-mail us at pubsofc@gis.nmt.edu. If you prefer to get your information online, all of our ***Earth Matters*** issues can be found on our Web page at:

http://geoinfo.nmt.edu/publications/periodicals/earthmatters

Previous issues include many topics on New Mexico's geology including volcanoes, hydrology, caves, energy resources, climate change, earthquakes, geologic mapping, and more.

UPCOMING EVENTS FOR TEACHERS AND THE PUBLIC

National Earth Science Week october 10–16, 2010

The American Geological Institute (AGI) invites you to take part in Earth Science Week 2010! Earth Science Week will encourage people everywhere to explore the natural world and learn about the geosciences. "Exploring Energy," the theme of Earth Science Week 2010, will engage young people and the public in learning about Earth's energy resources. Earth Science Week planning toolkits and ideas about how to hold your own celebration are available from the Earth Science Week Web site:

http://www.earthsciweek.org/

New Mexico Teachers: Please visit our Web site to download a Power Point presentation titled New Mexico Energy Resources by New Mexico's State Geologist, Dr. Peter Scholle. This presentation for use in your classroom illustrates the wide spectrum of energy resources including fossil fuel, wind, solar, and geothermal energy that are available in our state. Download the presentation at:

http://geoinfo.nmt.edu/education/rockin/2010/

OCTOBER 7–9, 2010, ALBUQUERQUE, NM

Fall Conference for Environmental, Science, and Math Educators

Soaring to Greater Heights—Shaping the Future through Education

(Pre-conference workshops on October 7)
Location: Bosque School, 4000 Learning Road, Albuquerque, NM 87120

For information on how to register, present, or exhibit, visit the New Mexico Science Teachers Association Web site at:
www.nmsta.org

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SOLUTION TO GEOTHERMAL CROSSWORD PUZZLE