Geothermal Resources Worldwide

Grades: 6-12

Topic: Geothermal Energy

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Geothermal Resources Worldwide

Power plants at The Geysers Geothermal Field, Northern California, U.S.A.

Courtesy of Pacific Gas & Electric Company

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This publication is an introduction to the geology and development of geothermal resources around the world, with a strong focus on electrical power generation from very hot water and steam. It also covers some other historical and modern uses of geothermal waters.

We encourage teachers to reproduce this publication for classroom use. To order additional copies, or for more information about geothermal energy, contact:

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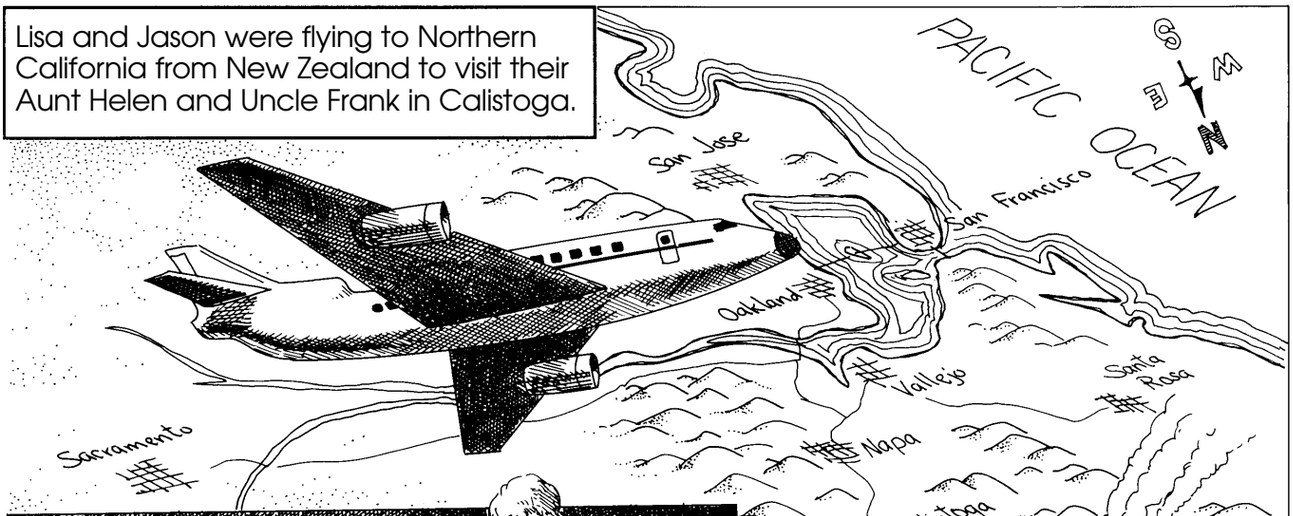
Lisa and Jason were flying to Northern California from New Zealand to visit their Aunt Helen and Uncle Frank in Calistoga.

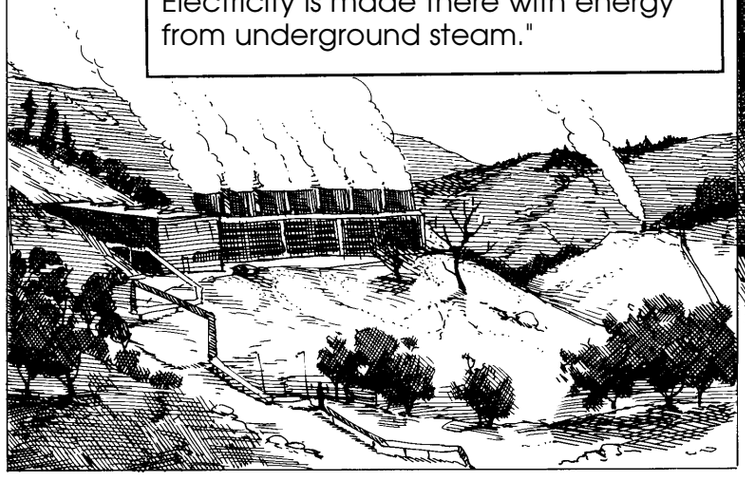


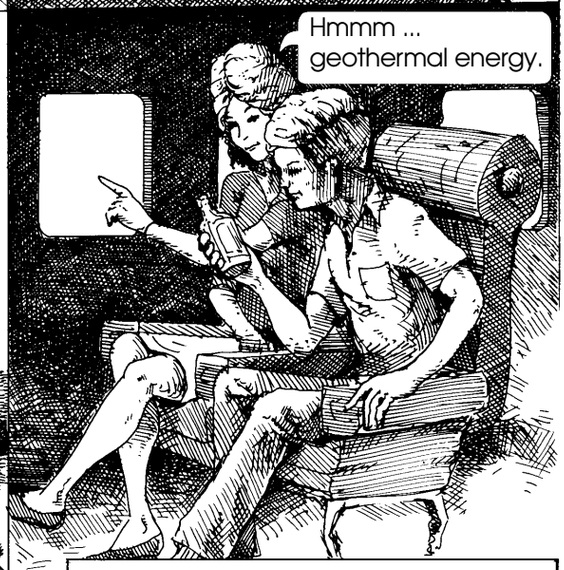
On the plane, the flight attendant served them bottles of mineral water. As he drank, Jason read the label.

"Look Lisa, this water comes from Calistoga."

The plane passed near Calistoga. Lisa and Jason saw white puffs rising from rugged, green hillsides.

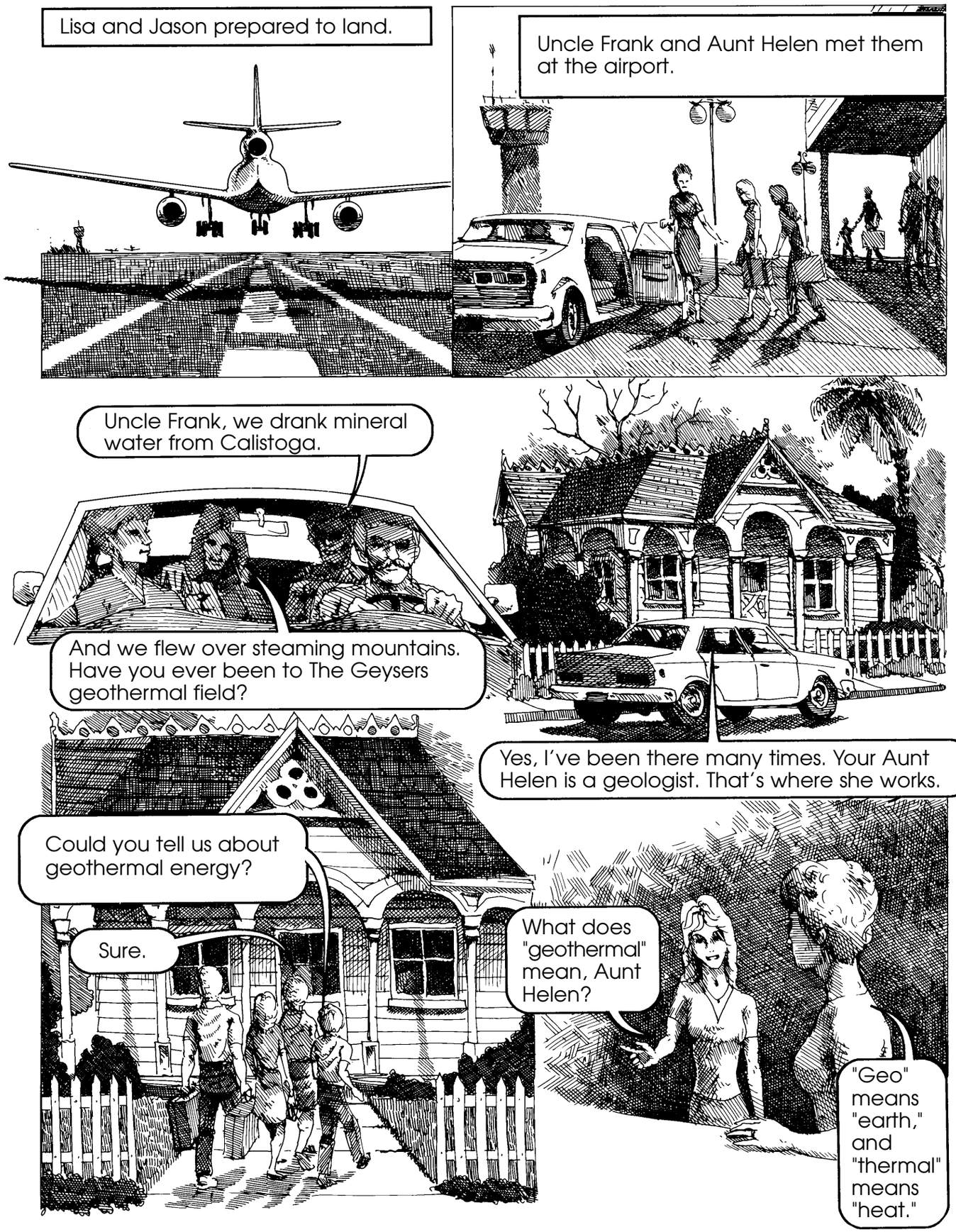
"Below is The Geysers geothermal field," said the pilot, "the largest in the world. Electricity is made there with energy from underground steam."





Hmmm ... geothermal energy.

"Where does the steam come from? I hope we can visit The Geysers and find out."


Lisa and Jason prepared to land.
Uncle Frank and Aunt Helen met them at the airport.
Uncle Frank, we drank mineral water from Calistoga.
And we flew over steaming mountains. Have you ever been to The Geysers geothermal field?
Yes, I've been there many times. Your Aunt Helen is a geologist. That's where she works.
Could you tell us about geothermal energy?
Sure.
What does "geothermal" mean, Aunt Helen?
"Geo" means "earth," and "thermal" means "heat."

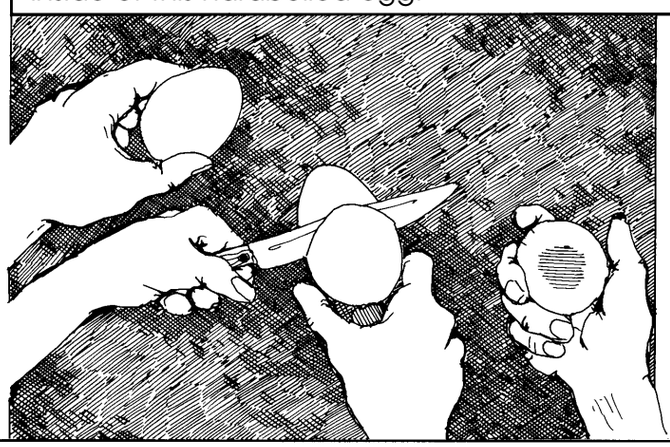
"Geothermal" means the "heat from the earth."

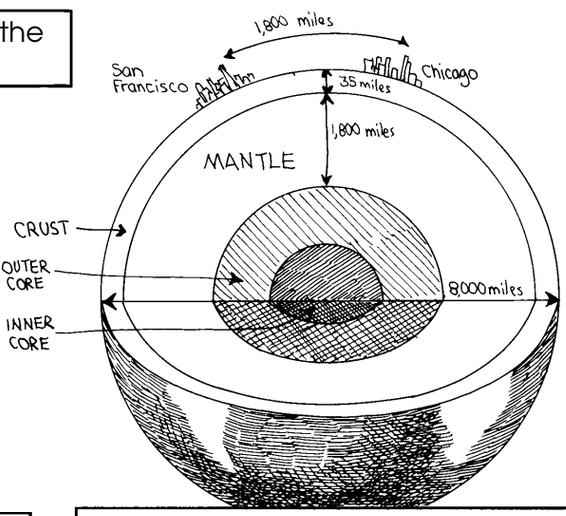
You mean, the earth is hot inside?

Oh, yes. Even though it may be cold outdoors, the deeper in the earth you go, the hotter it gets, all the way to the center, about 4,000 miles below us. Enough heat is in the earth to supply our energy needs for millions of years. Some of this heat is shallow enough for us to use.

"Even in oil fields, water and oil pumped from wells over 2 miles deep are almost as hot as boiling water," said Aunt Helen, as she lifted a pan of eggs from the stove.

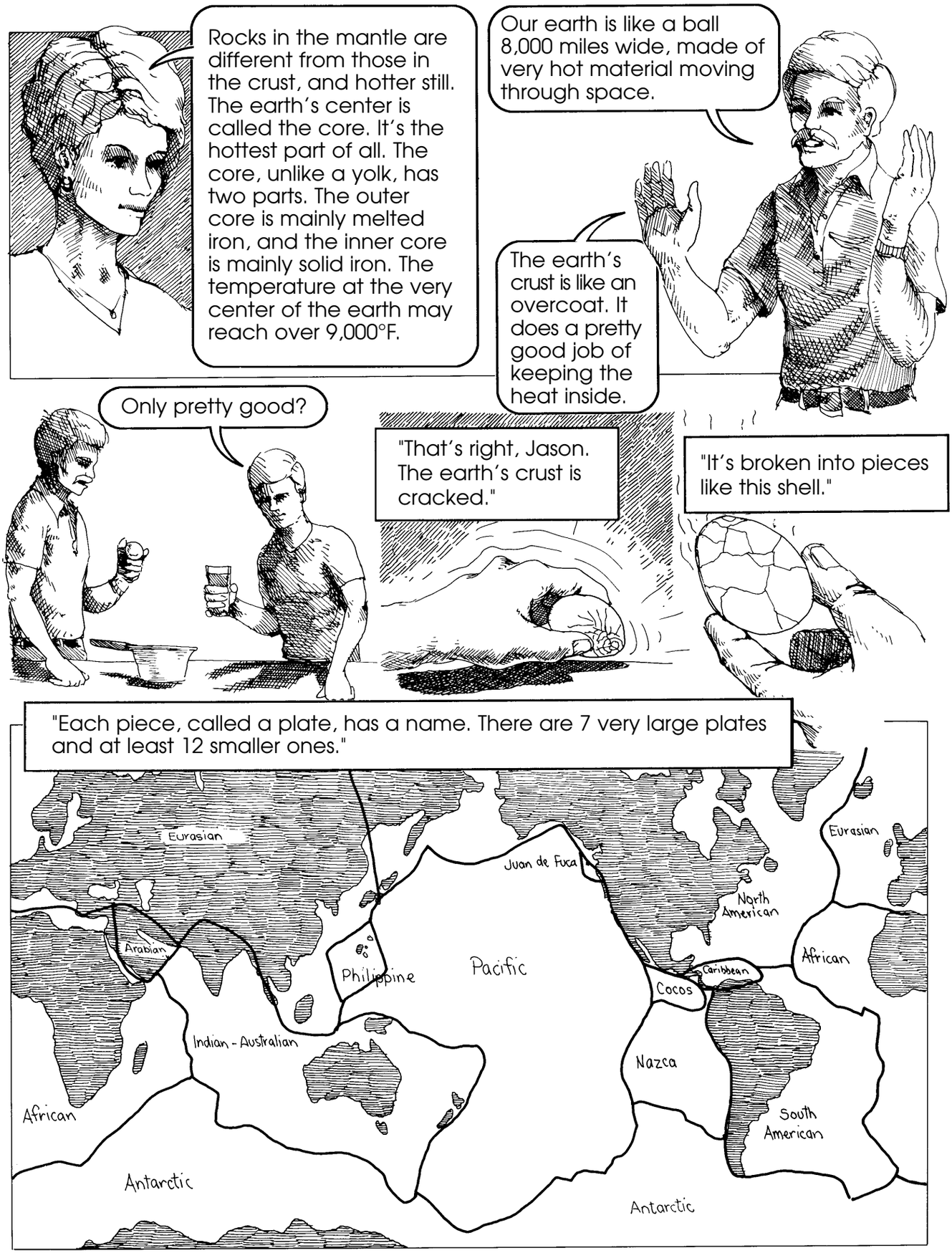
"In fact, the inside of the earth is something like the inside of this hardboiled egg."

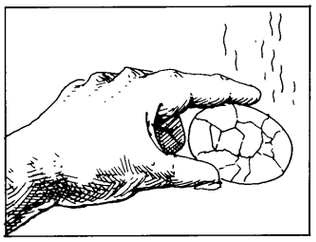




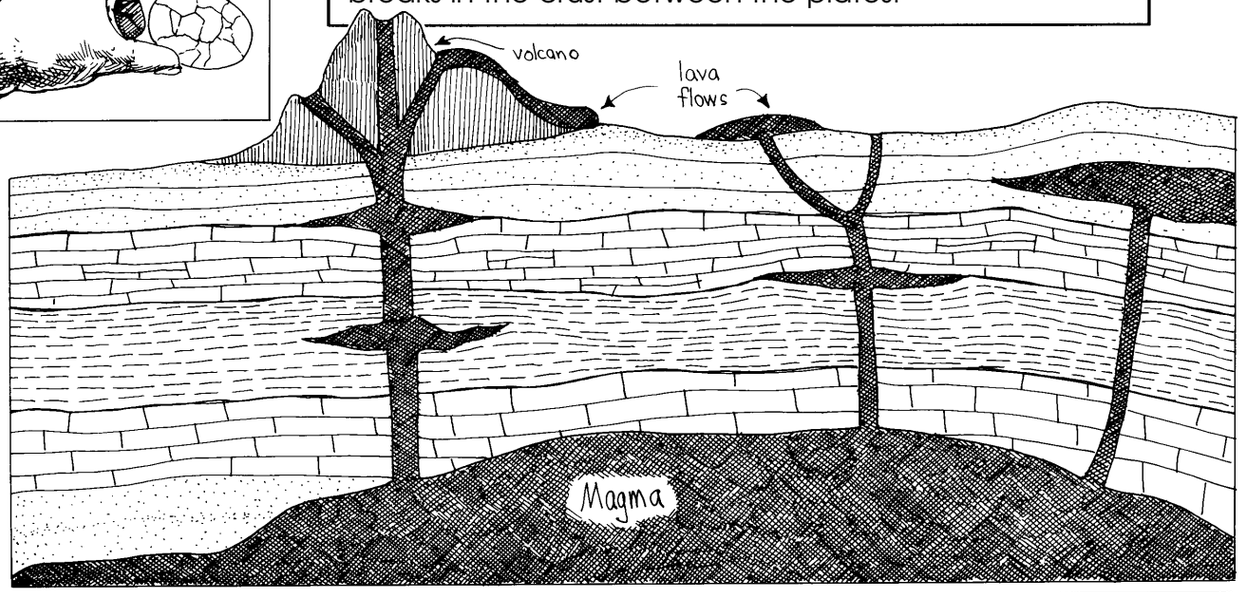
"Pretend the eggshell is the land we live on, the crust of the earth. The shell, or crust, is about 3 miles thick under the oceans and up to 35 miles thick under the land. The crust gets hotter the deeper you go -- about 2 degrees Fahrenheit (°F) for every 100 feet."

"Below the crust is the white of the egg, the part of the earth we call the mantle. It is about 1,800 miles thick, the distance between San Francisco and Chicago. The mantle ends about halfway to the center of the earth."


Rocks in the mantle are different from those in the crust, and hotter still. The earth's center is called the core. It's the hottest part of all. The core, unlike a yolk, has two parts. The outer core is mainly melted iron, and the inner core is mainly solid iron. The temperature at the very center of the earth may reach over 9,000°F.
Our earth is like a ball 8,000 miles wide, made of very hot material moving through space.
The earth's crust is like an overcoat. It does a pretty good job of keeping the heat inside.
Only pretty good?
"That's right, Jason. The earth's crust is cracked."
"It's broken into pieces like this shell."
"Each piece, called a plate, has a name. There are 7 very large plates and at least 12 smaller ones."
Eurasian
Juan de Fuca
North American
Eurasian
Arabian
Philippine
Pacific
Caribbean
African
Cocos
Indian - Australian
Nazca
South American
African
Antarctic
Antarctic



"Like the steam rising through the cracks in the shell, streams of hot melted rock, called magma, rise through breaks in the crust between the plates."



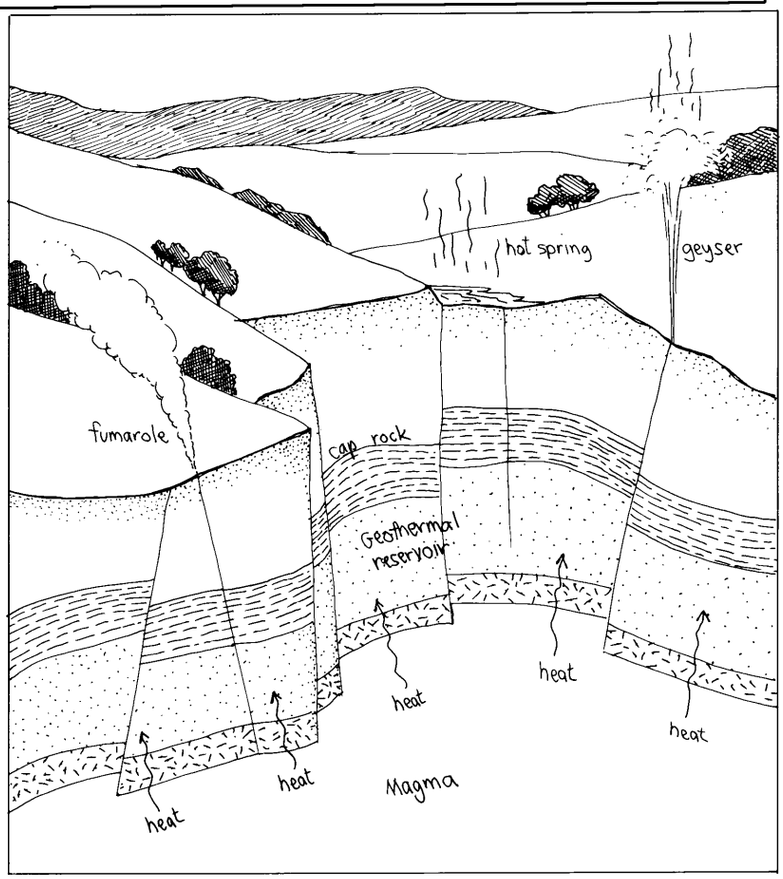
"Some of the magma reaches the surface, where it's called lava. The lava cools and hardens quickly, forming features like volcanoes and lava flows. The magma still underground cools and hardens much more slowly. For a long time, maybe thousands of years, it heats nearby rock and water."

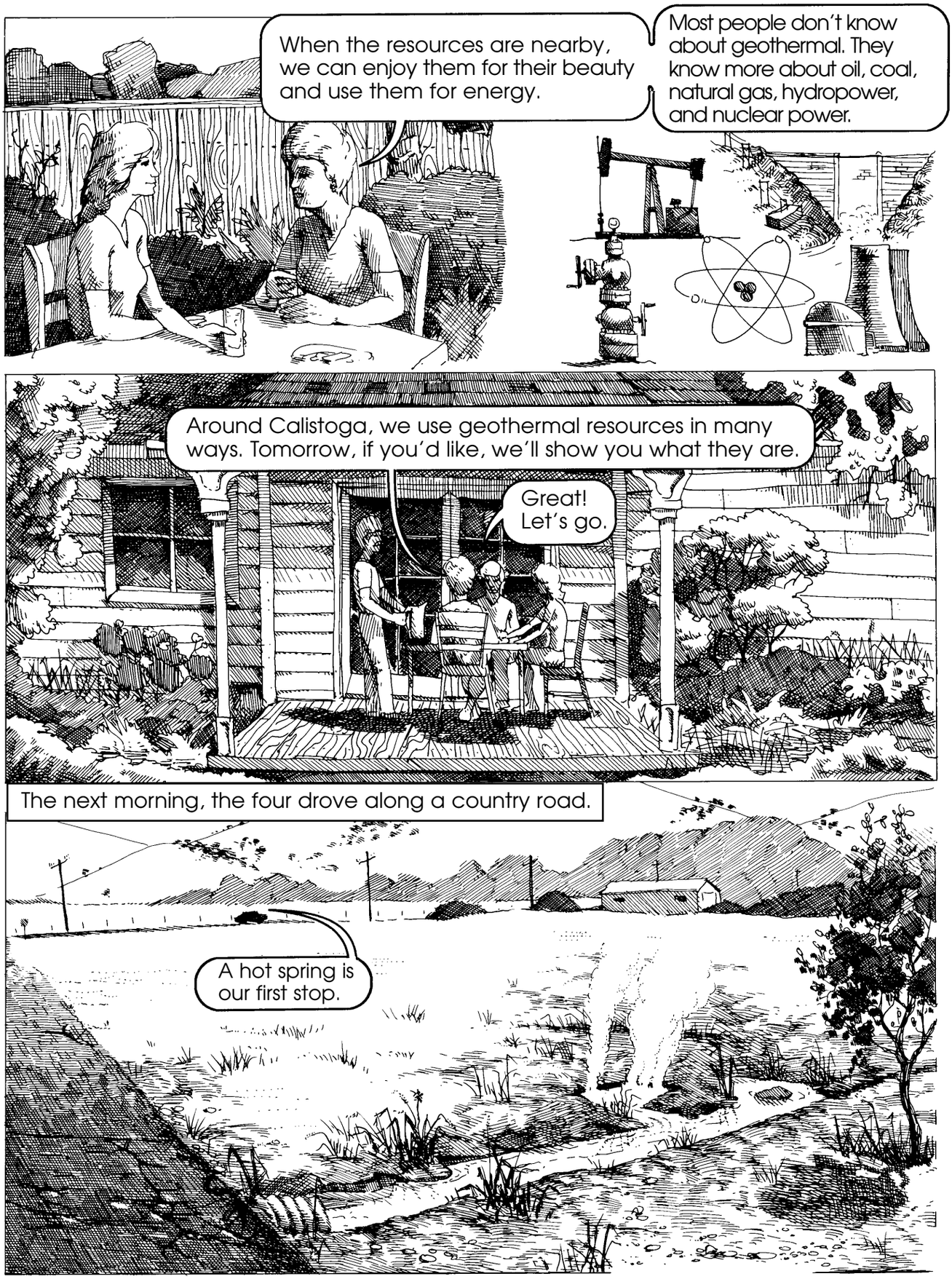
"The hot underground water is called geothermal water.

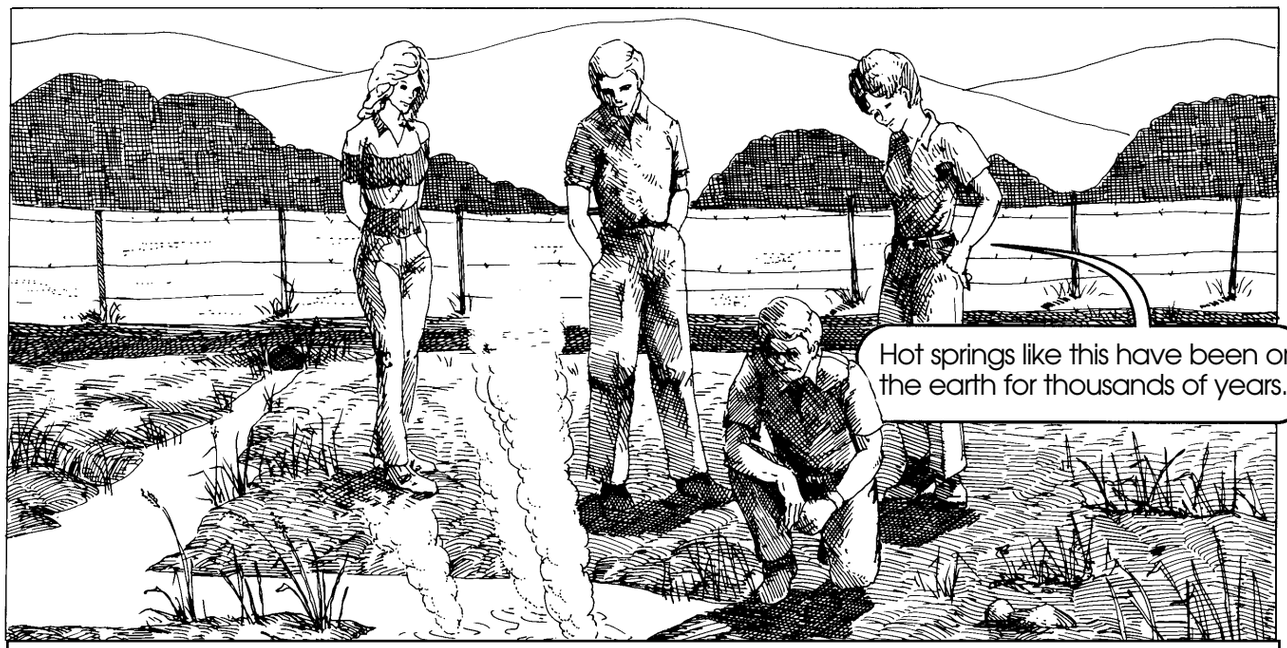
"If the water flows up to the surface, it's a hot spring. If it spurts out like a fountain, it's a geyser. If it puffs out as steam, it's a fumarole.

"Sometimes the geothermal water stays underground, trapped in the hot rock. Now it's a geothermal reservoir.

"In California, we have hundreds of hot springs and fumaroles, and many geothermal reservoirs. Geothermal resources like these are found around the world."

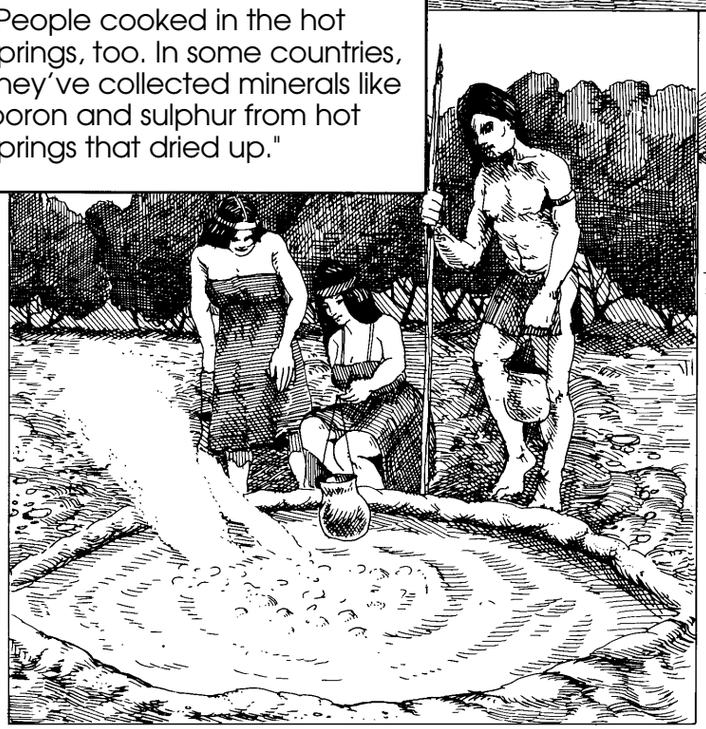


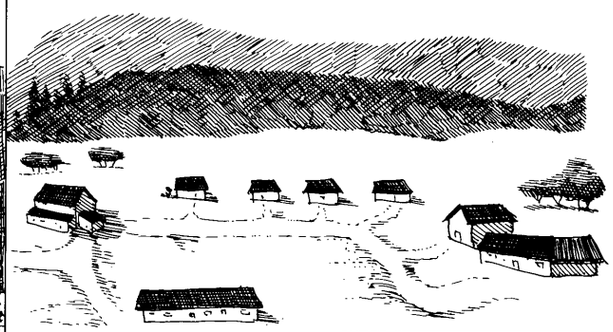

When the resources are nearby, we can enjoy them for their beauty and use them for energy.
Most people don't know about geothermal. They know more about oil, coal, natural gas, hydropower, and nuclear power.
Around Calistoga, we use geothermal resources in many ways. Tomorrow, if you'd like, we'll show you what they are.
Great! Let's go.
The next morning, the four drove along a country road.
A hot spring is our first stop.



"Like other people around the world, the Native American Indians and early settlers bathed in them, soaking away aches and pains."

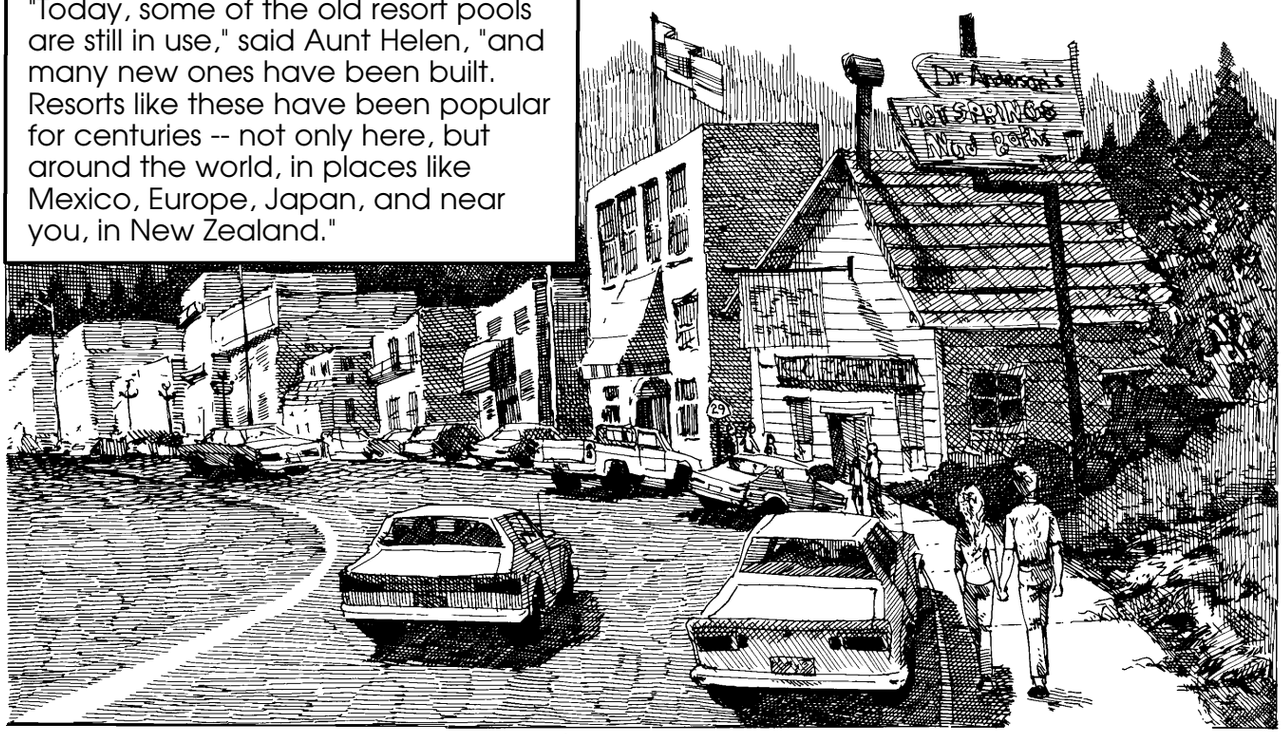
"People cooked in the hot springs, too. In some countries, they've collected minerals like boron and sulphur from hot springs that dried up."



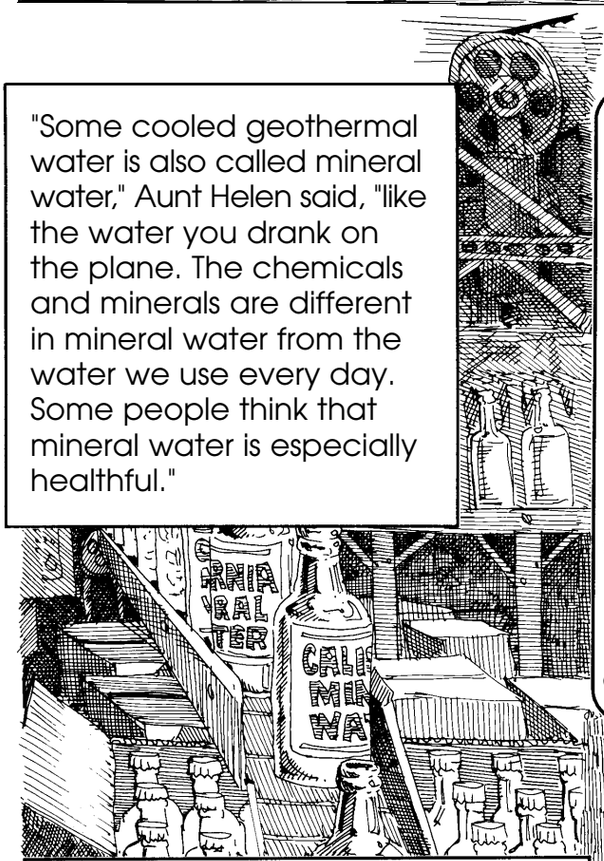


"About 125 years ago," said Uncle Frank, as they returned to the car, "people in Calistoga advertised the hot springs and built health resorts. Soon, the hot springs weren't large enough for all the tourists who came. So wells were drilled to reach more hot water, and pools were made to hold it."

"Today, some of the old resort pools are still in use," said Aunt Helen, "and many new ones have been built. Resorts like these have been popular for centuries -- not only here, but around the world, in places like Mexico, Europe, Japan, and near you, in New Zealand."



"Some cooled geothermal water is also called mineral water," Aunt Helen said, "like the water you drank on the plane. The chemicals and minerals are different in mineral water from the water we use every day. Some people think that mineral water is especially healthful."

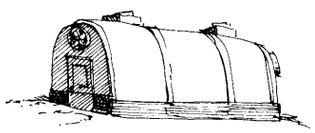


"Through the ages, people have found many ways to use natural hot water," said Uncle Frank.

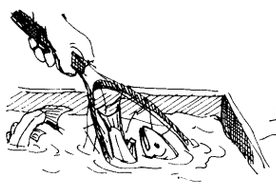
"How else is geothermal water used, Uncle Frank?" asked Jason.

"For heating buildings and houses like ours,

for heating businesses like greenhouses and food-drying plants,

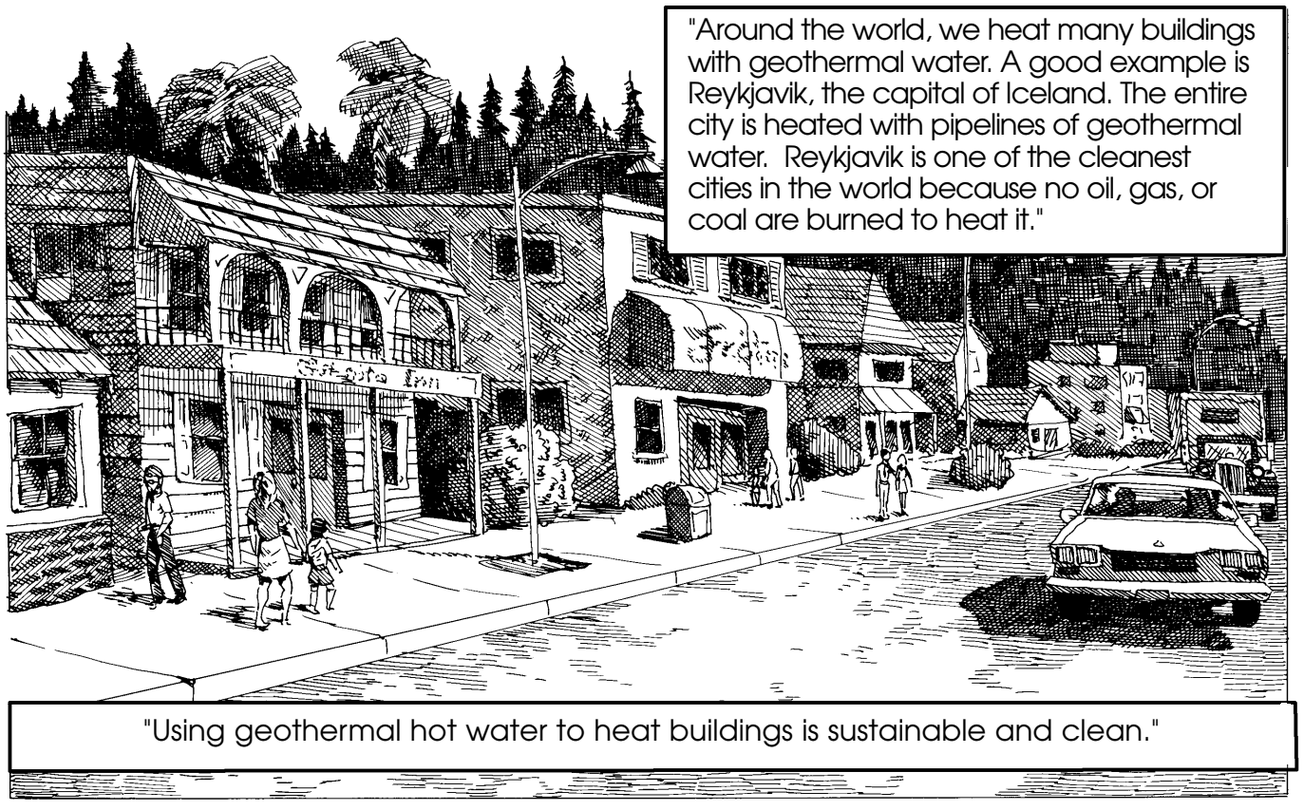


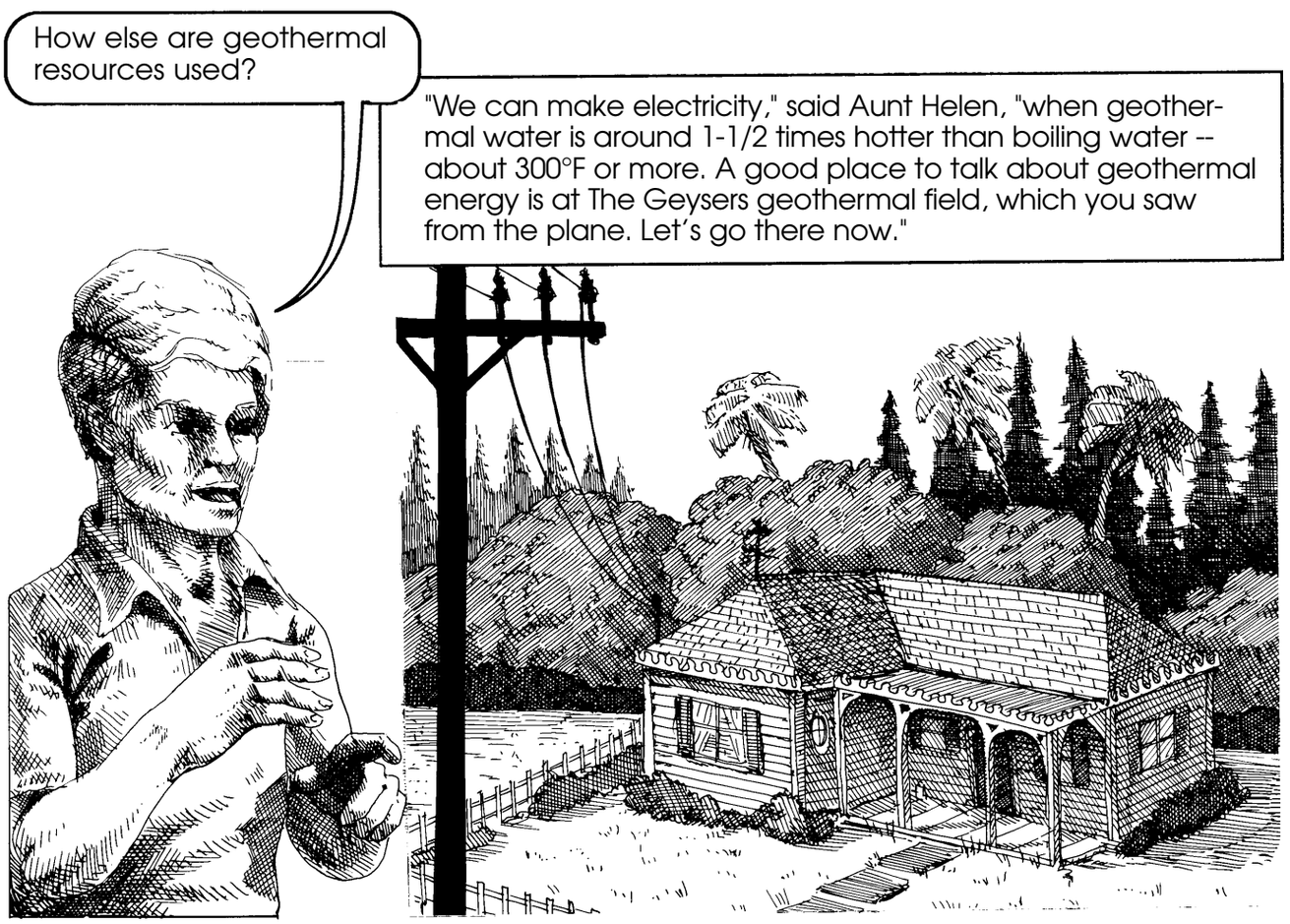
for fish farms,

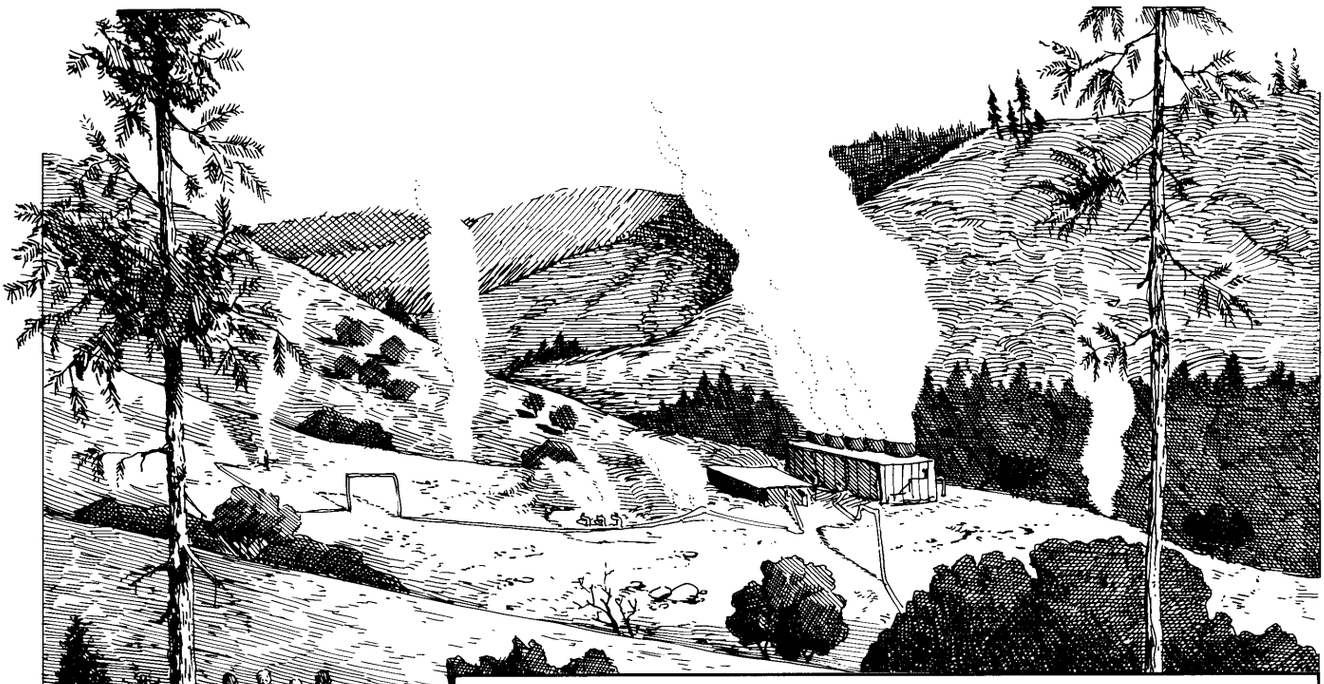


for heating soil in cold climates,

and for melting snow and ice on streets and sidewalks."

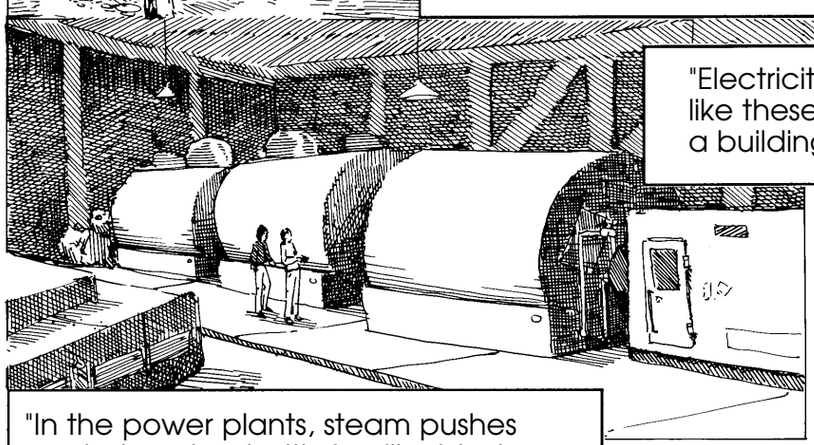

"Around the world, we heat many buildings with geothermal water. A good example is Reykjavik, the capital of Iceland. The entire city is heated with pipelines of geothermal water. Reykjavik is one of the cleanest cities in the world because no oil, gas, or coal are burned to heat it."
"Using geothermal hot water to heat buildings is sustainable and clean."

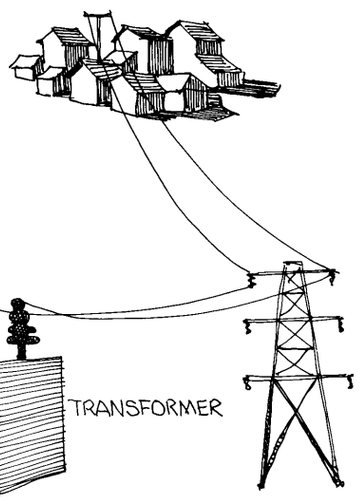

How else are geothermal resources used?
"We can make electricity," said Aunt Helen, "when geothermal water is around 1-1/2 times hotter than boiling water -- about 300°F or more. A good place to talk about geothermal energy is at The Geysers geothermal field, which you saw from the plane. Let's go there now."



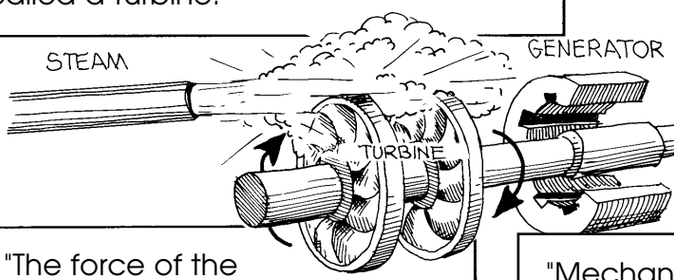
After a short drive, they stopped the car on a ridge overlooking the geothermal field. White puffs of steam billowed from power plant cooling towers and from geothermal wells.

"Electricity is made inside power plants like these," said Uncle Frank, pointing to a building on the hillside.





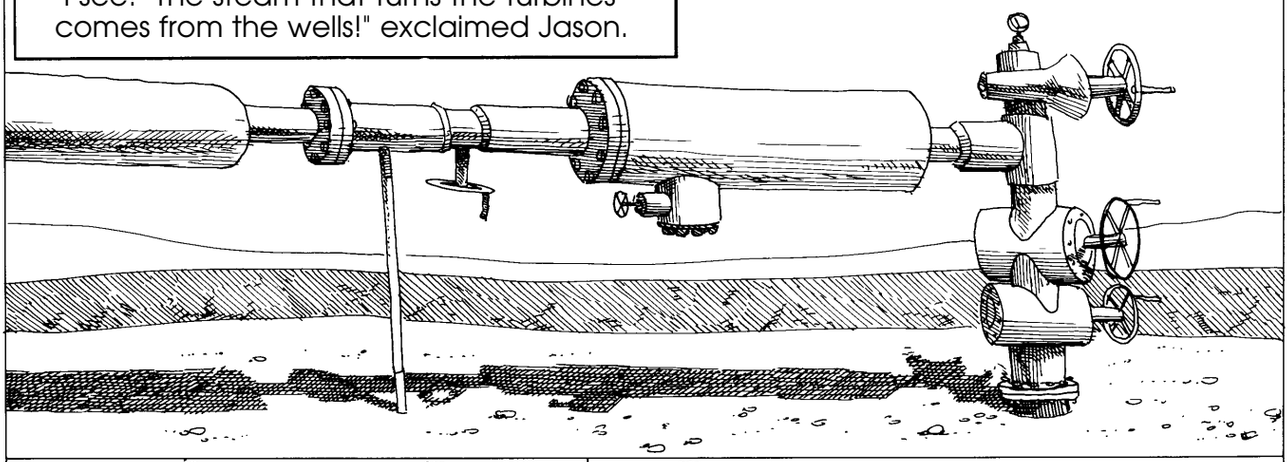
"In the power plants, steam pushes against a wheel with fan-like blades, called a turbine."



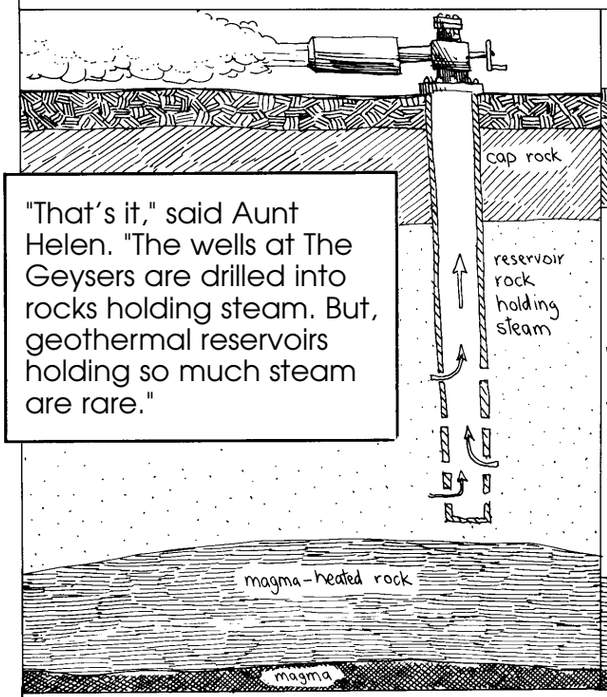
"The force of the steam turns the turbine and a machine attached to it, called a generator."

"Mechanical energy from the spinning turbine is changed into electrical energy inside the generator. The electricity is sent through lines that lead to our homes. In most power plants, natural gas or coal are burned, heating water to make steam. In geothermal power plants the steam is natural. Nothing is burned to produce it, so the air stays cleaner."

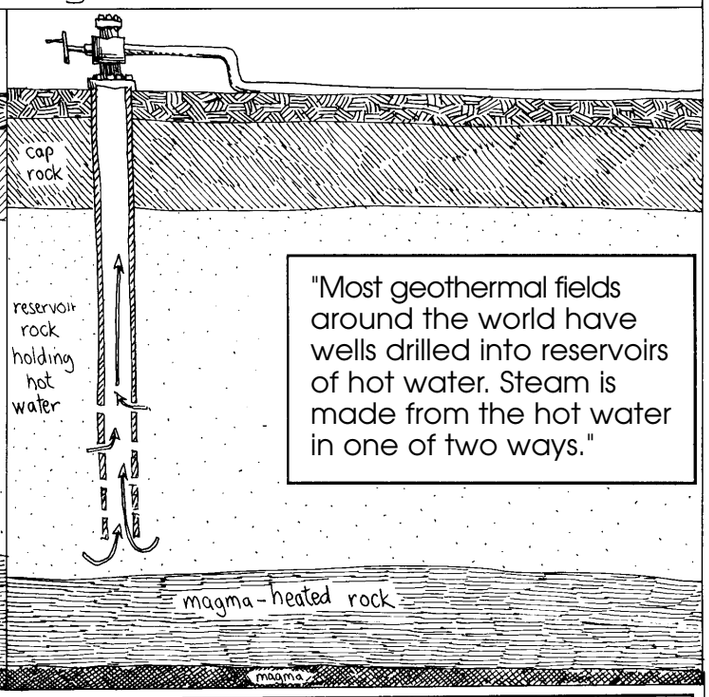
"I see! The steam that turns the turbines comes from the wells!" exclaimed Jason.



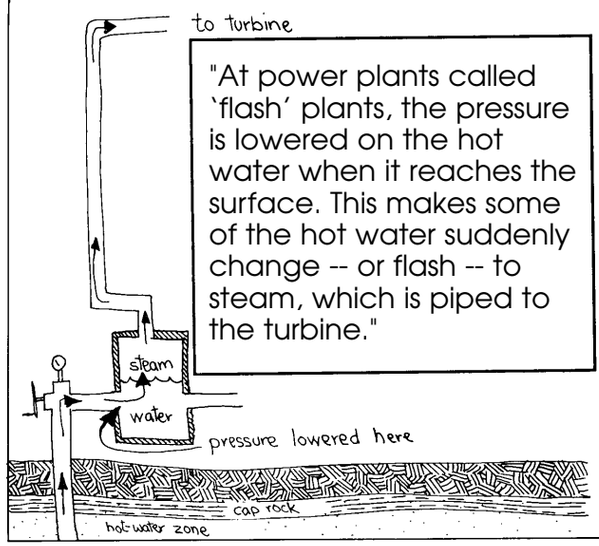
"That's it," said Aunt Helen. "The wells at The Geysers are drilled into rocks holding steam. But, geothermal reservoirs holding so much steam are rare."



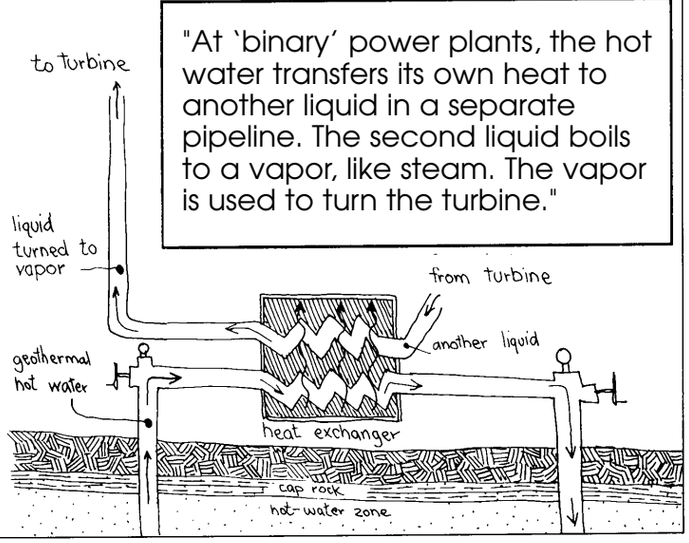
"Most geothermal fields around the world have wells drilled into reservoirs of hot water. Steam is made from the hot water in one of two ways."

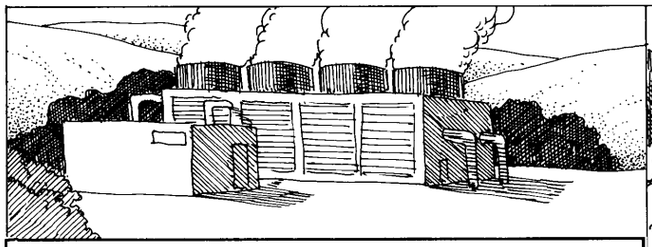


"At power plants called 'flash' plants, the pressure is lowered on the hot water when it reaches the surface. This makes some of the hot water suddenly change -- or flash -- to steam, which is piped to the turbine."



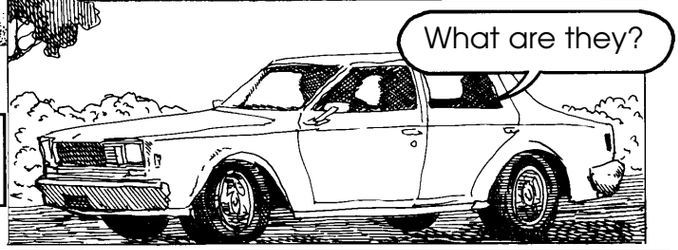
"At 'binary' power plants, the hot water transfers its own heat to another liquid in a separate pipeline. The second liquid boils to a vapor, like steam. The vapor is used to turn the turbine."





"Today, electricity is generated from geothermal energy in over 20 countries."

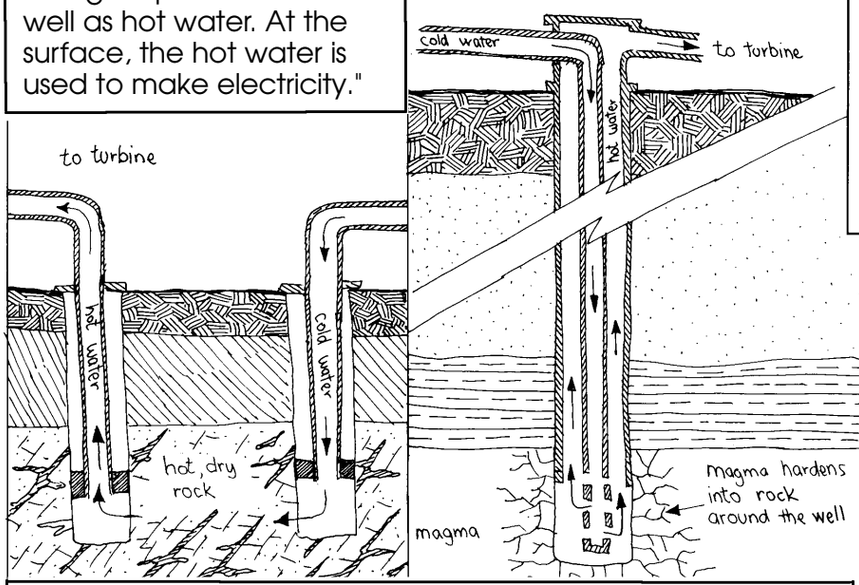
"More ways are being studied to produce electricity from geothermal resources," said Aunt Helen.

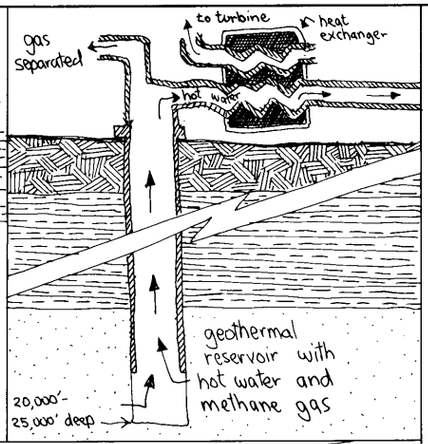


"One way is to drill two wells into hot rock holding little-or-no steam or water. The wells are connected through cracks in the rocks. Cold water is pumped down one well and brought up the second well as hot water. At the surface, the hot water is used to make electricity."

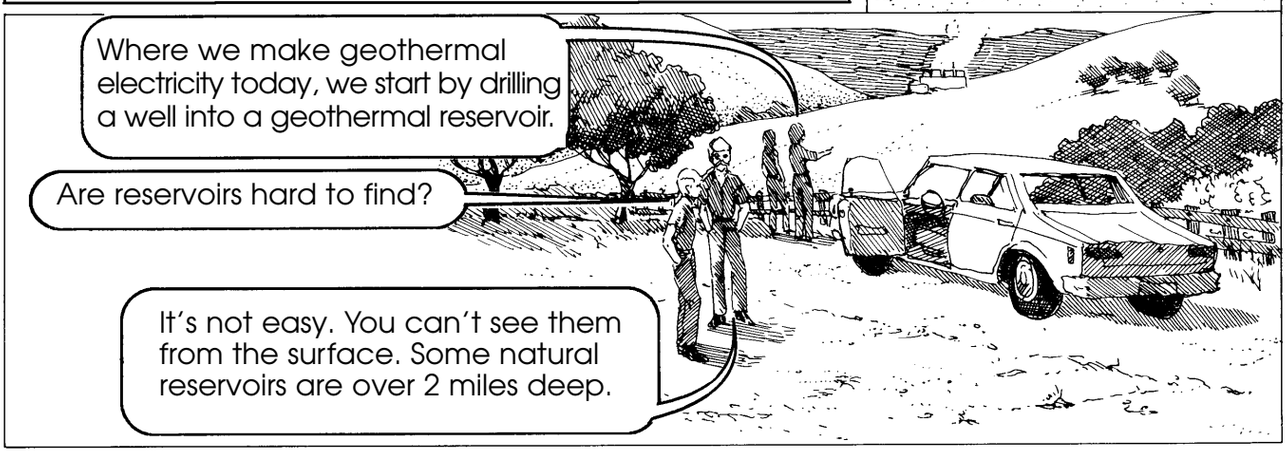
"People are working at drilling directly into magma. Cold water pumped down the well would heat up, and the hot water would be used at the surface to make electricity."

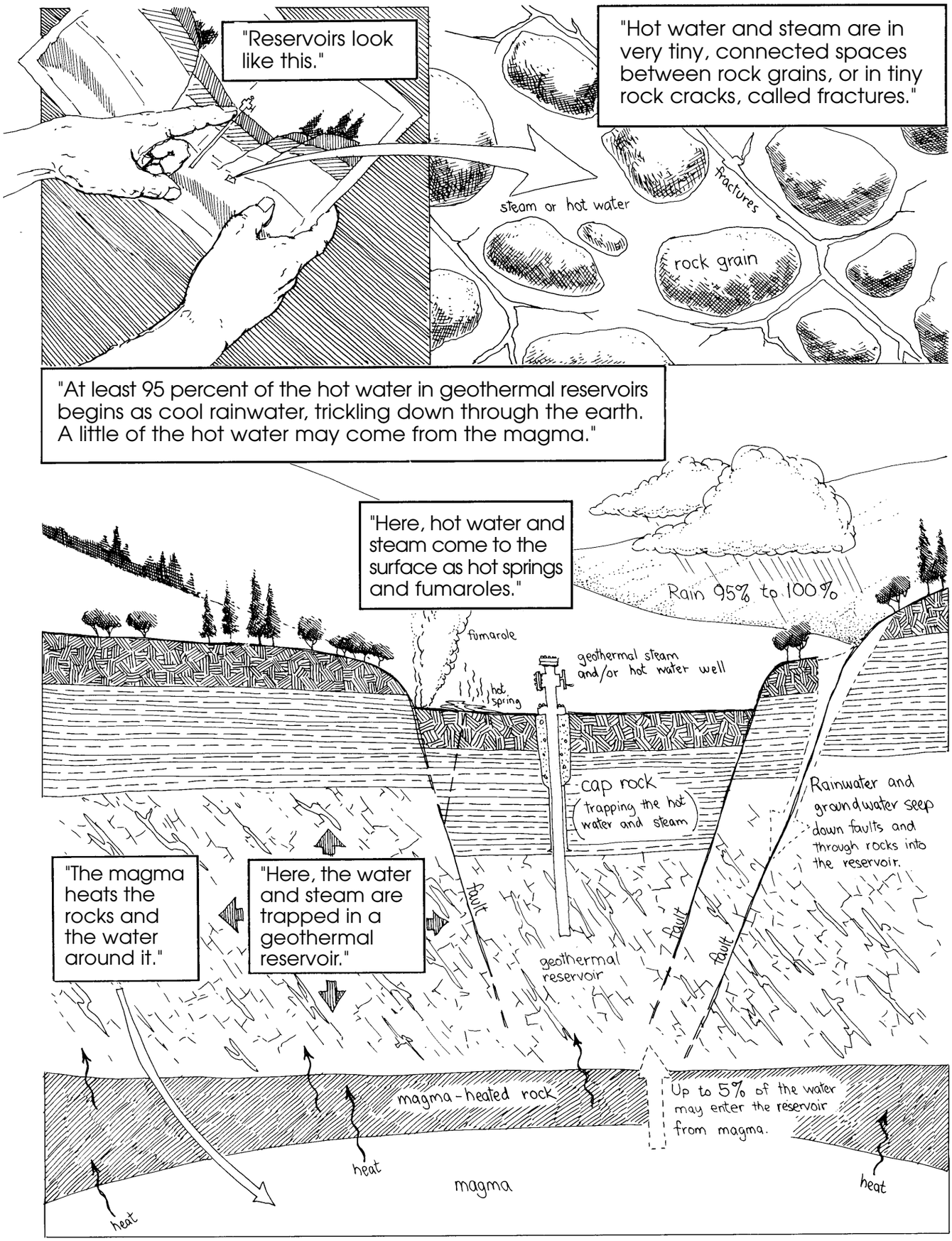
"We are also developing another type of well, called a geopressured well. This well is both a geothermal and a natural gas well. It's drilled into a reservoir holding hot water and natural gas under very high pressures. When the hot water and natural gas reach the surface, the gas is sold and the hot water is piped to a binary power plant. Here it boils another liquid, which turns into vapor that spins the turbine, making electricity."





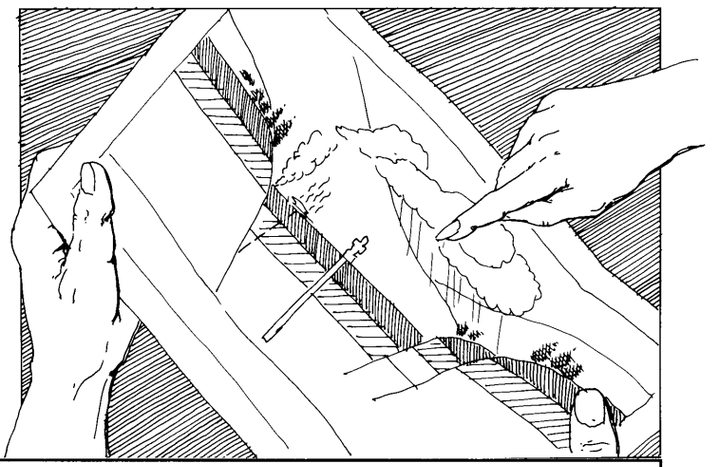
"Of these studies, hot rock is the most promising. We call it EGS, which means *enhanced geothermal systems*."




"Reservoirs look like this."
"Hot water and steam are in very tiny, connected spaces between rock grains, or in tiny rock cracks, called fractures."
steam or hot water
fractures
rock grain
"At least 95 percent of the hot water in geothermal reservoirs begins as cool rainwater, trickling down through the earth. A little of the hot water may come from the magma."
"Here, hot water and steam come to the surface as hot springs and fumaroles."
Rain 95% to 100%
fumarole
hot spring
geothermal steam and/or hot water well
cap rock (trapping the hot water and steam)
Rainwater and groundwater seep down faults and through rocks into the reservoir.
"The magma heats the rocks and the water around it."
"Here, the water and steam are trapped in a geothermal reservoir."
fault
fault
fault
geothermal reservoir
magma-heated rock
Up to 5% of the water may enter the reservoir from magma.
heat
heat
heat
magma

"I see!" Lisa said. "The rainfall continues to refill the fractures and the spaces between the hot rock grains."

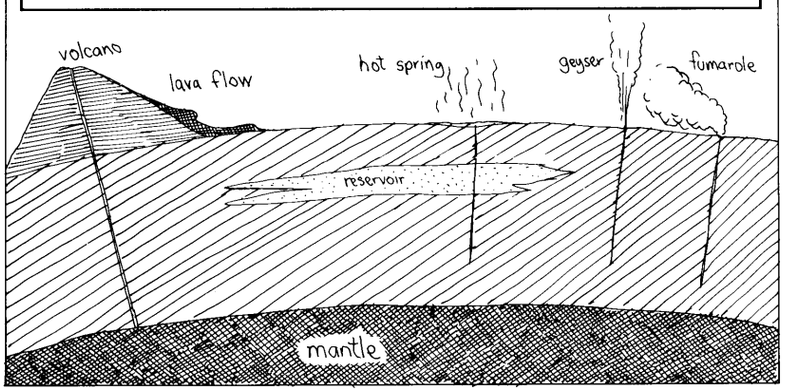
"Yes," said Uncle Frank, "and the hot rocks continue to heat the rainwater.



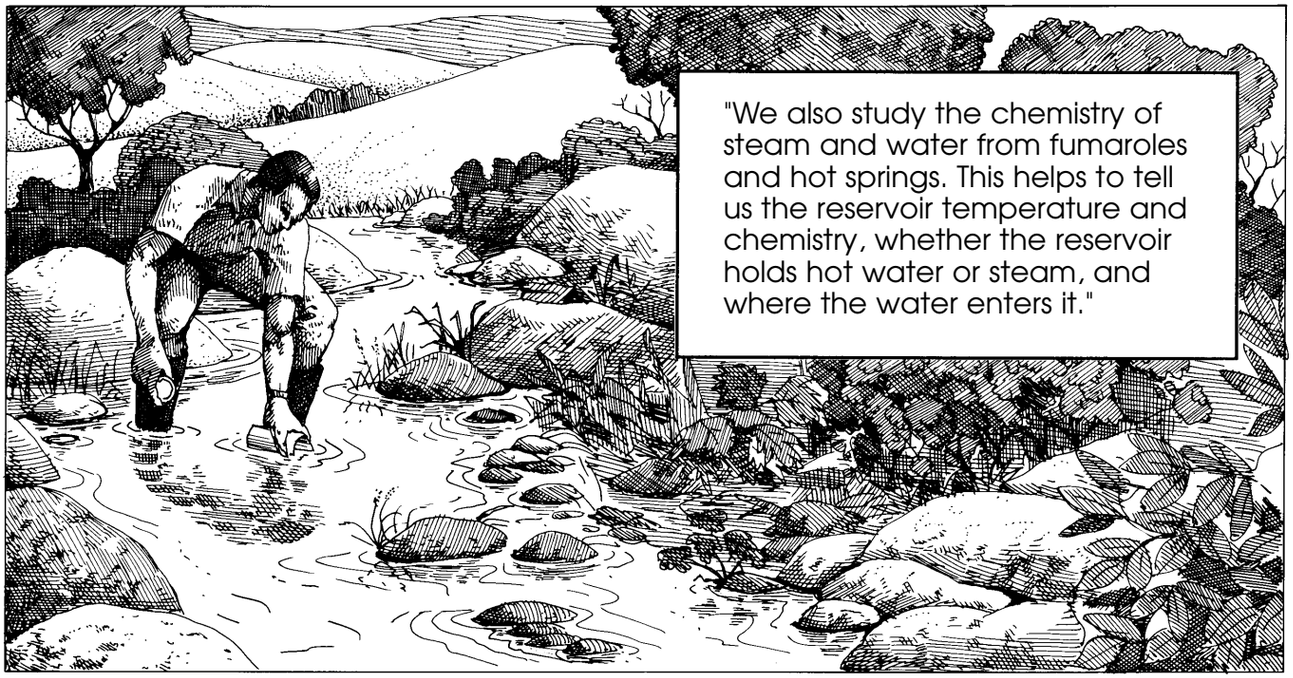
"This is why we call geothermal energy renewable. Geothermal reservoirs can be used over and over, maybe for hundreds of years. Coal, oil, natural gas, and other mineral resources are not renewable. They are used once and gone forever."

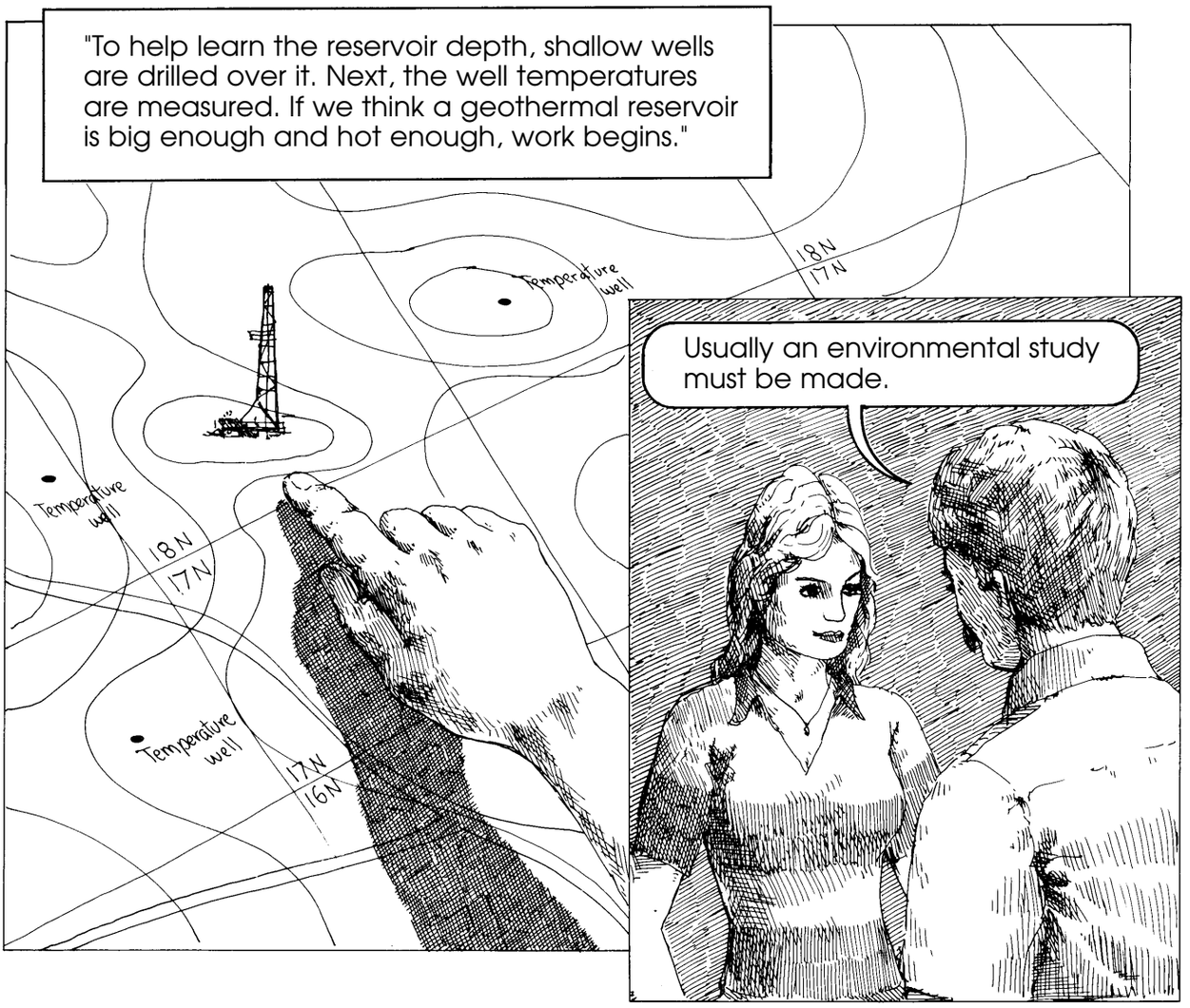
Are geothermal reservoirs near hot springs?

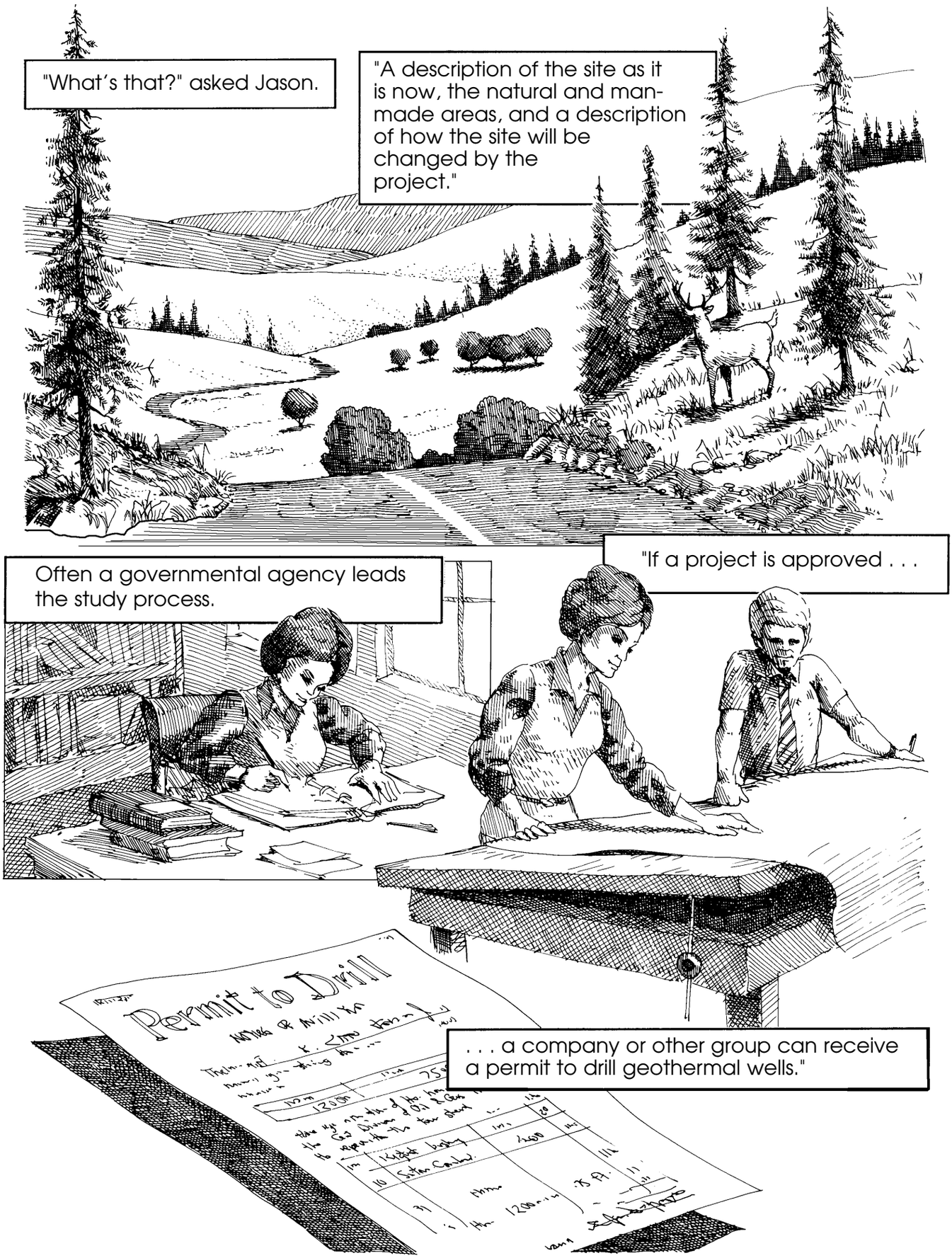
"Sometimes. Hot springs, fumaroles -- all are signs, but not proof,that a reservoir is near," said Aunt Helen. "Special scientific information and tools help us discover the reservoirs."

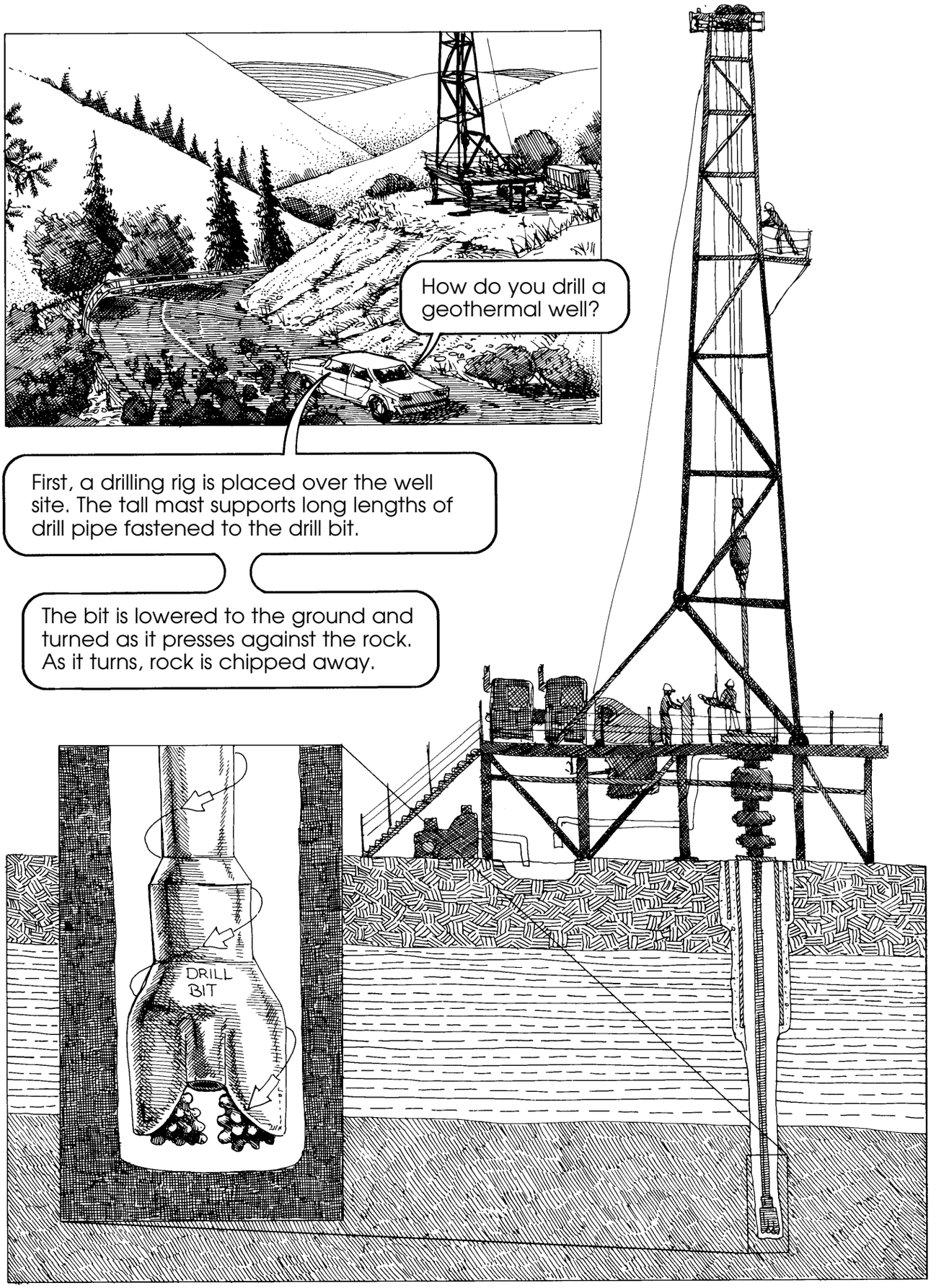


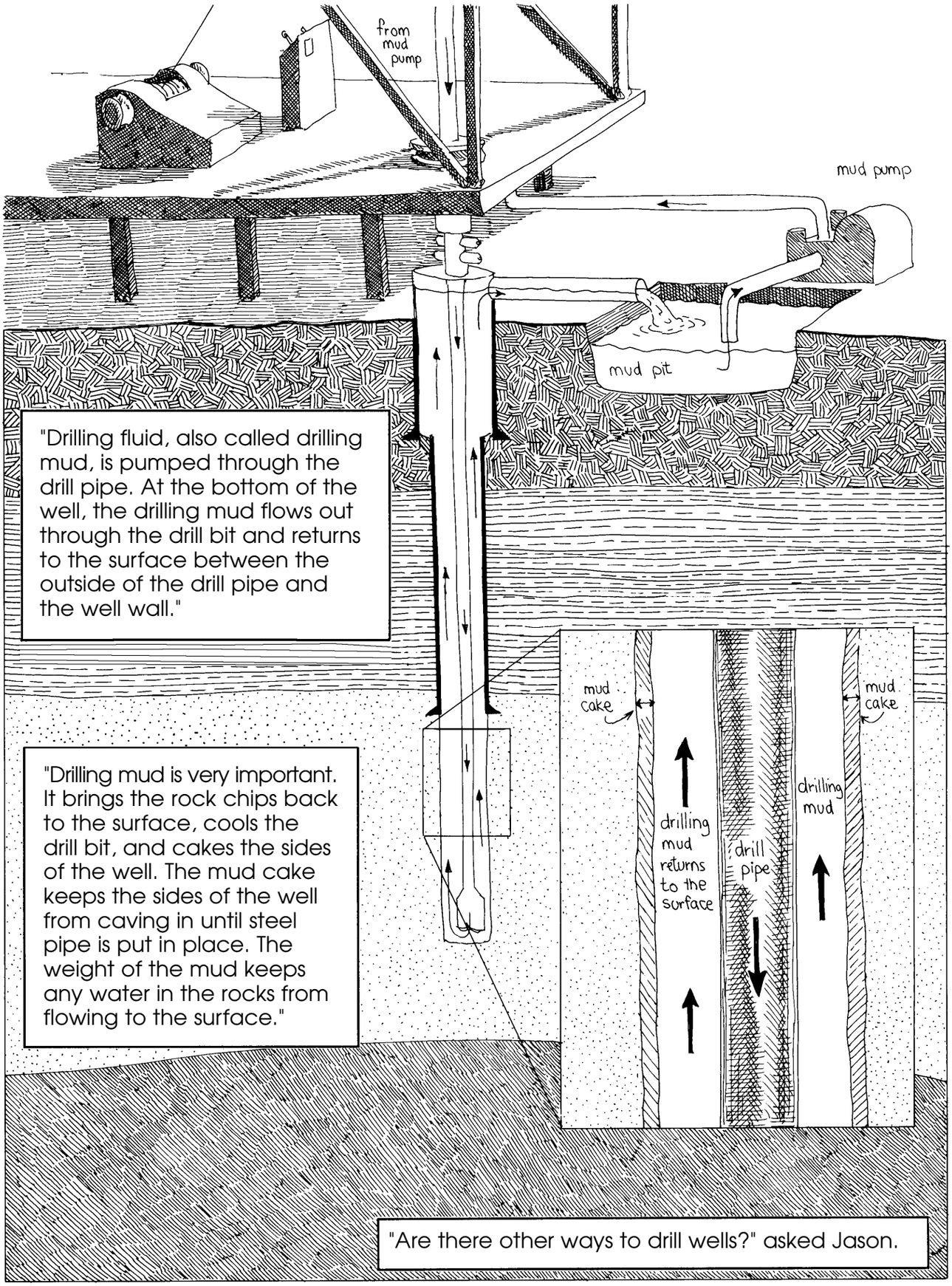
"We draw maps from geophysical information to learn more about the location, shape, size, and temperature of the reservoir."

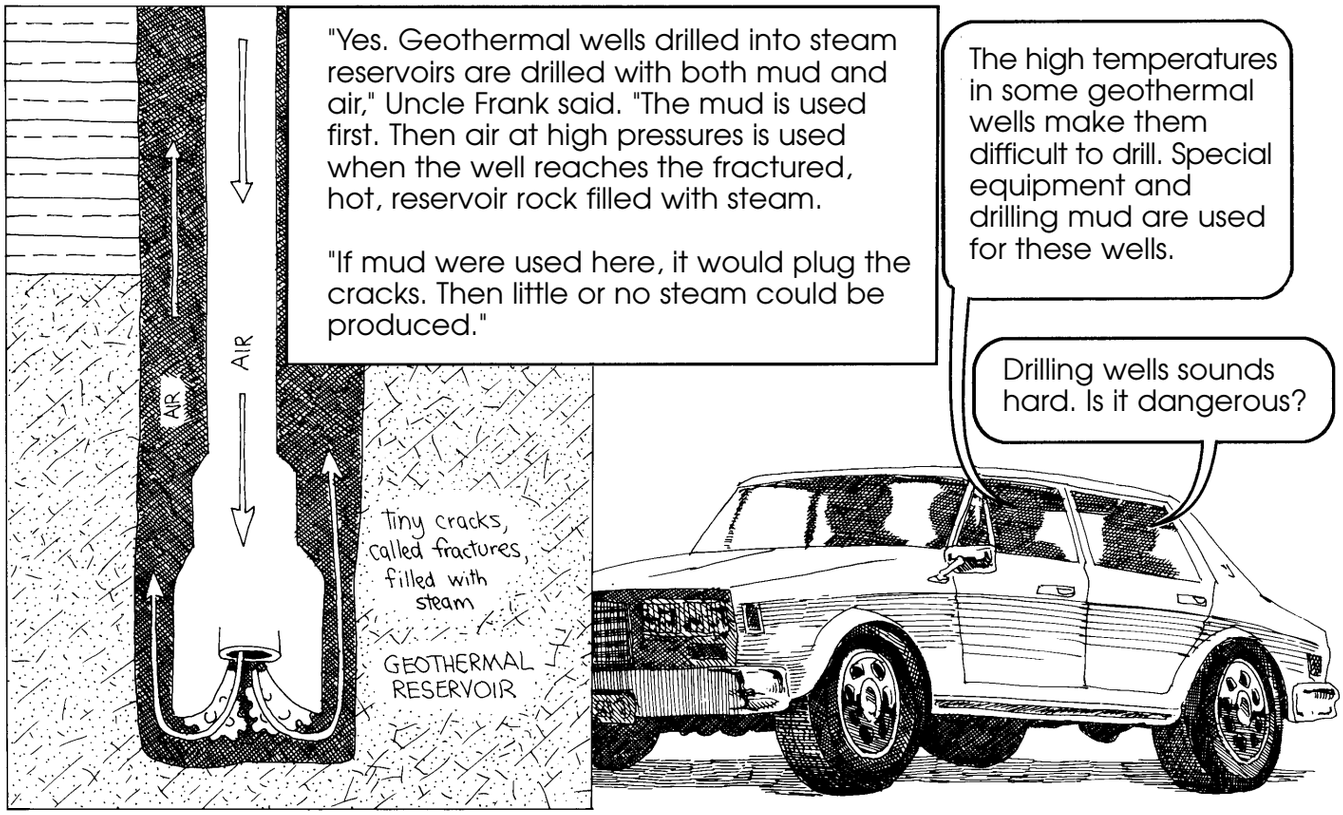

"We also study the chemistry of steam and water from fumaroles and hot springs. This helps to tell us the reservoir temperature and chemistry, whether the reservoir holds hot water or steam, and where the water enters it."

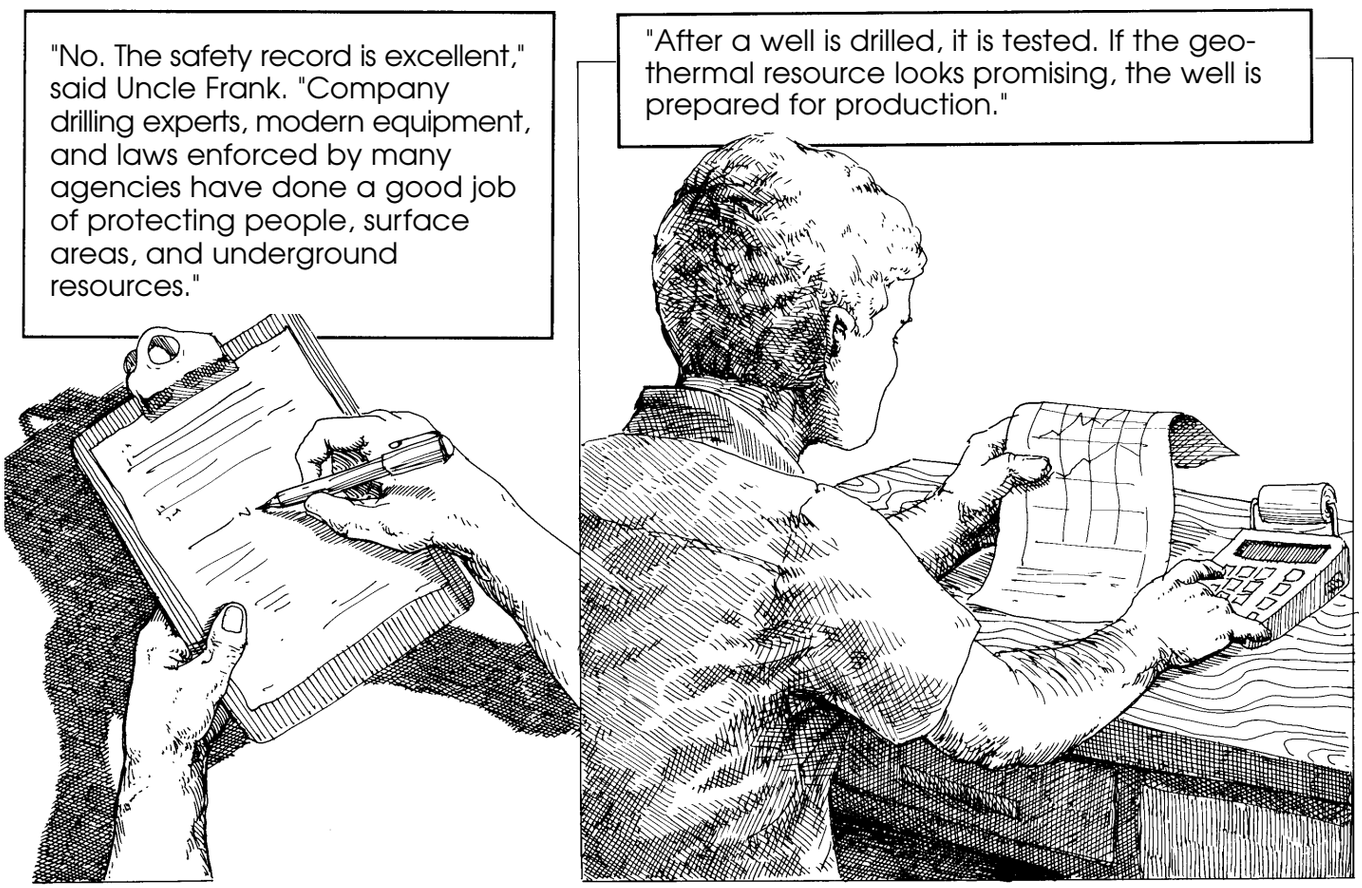

"To help learn the reservoir depth, shallow wells are drilled over it. Next, the well temperatures are measured. If we think a geothermal reservoir is big enough and hot enough, work begins."
Temperature well
18N
17N
Temperature well
18N
17N
Temperature well
17N
16N
Usually an environmental study must be made.

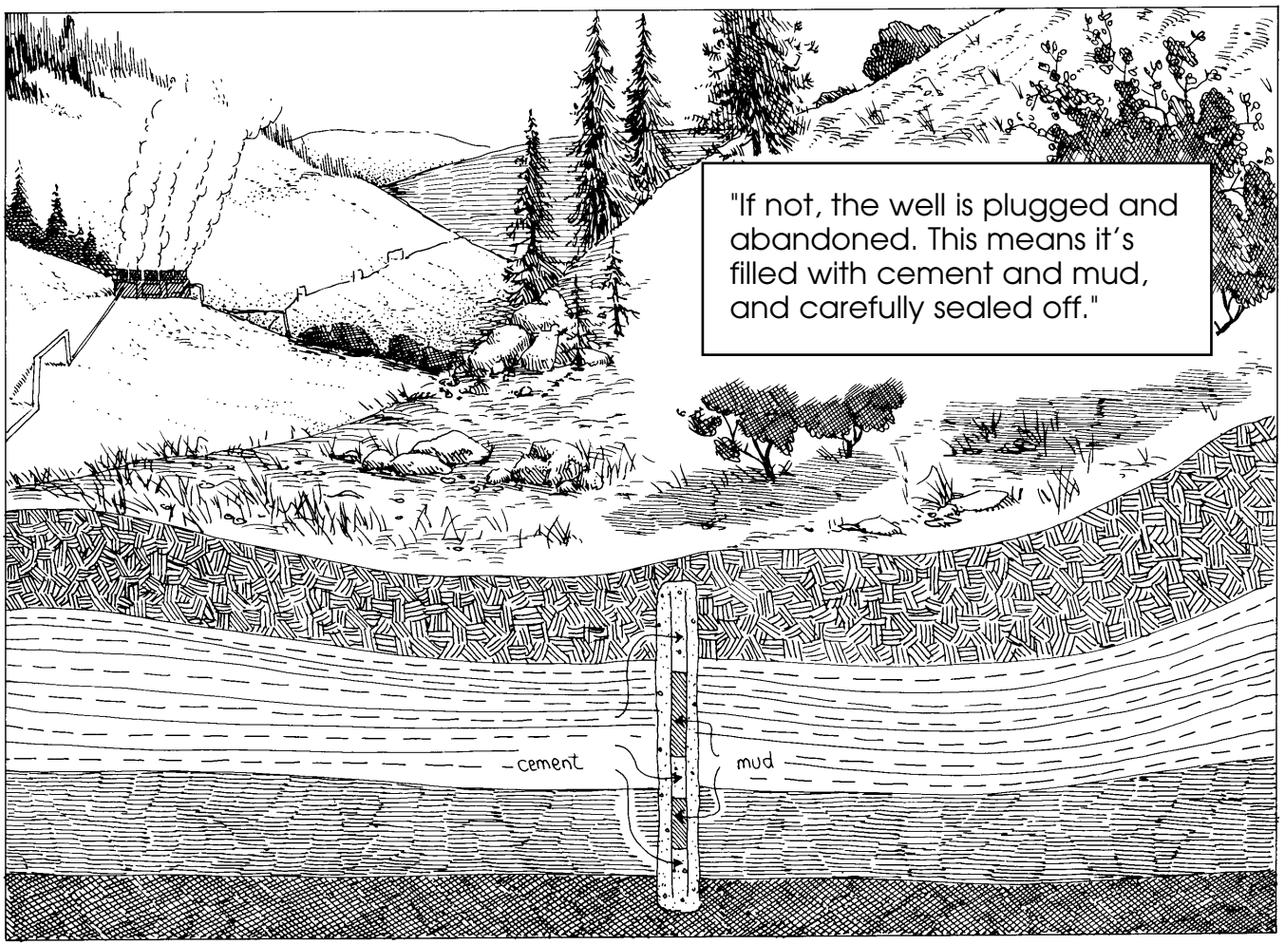

"What's that?" asked Jason.
"A description of the site as it is now, the natural and man-made areas, and a description of how the site will be changed by the project."
Often a governmental agency leads the study process.
"If a project is approved . . .
Permit to Drill
. . . a company or other group can receive a permit to drill geothermal wells."

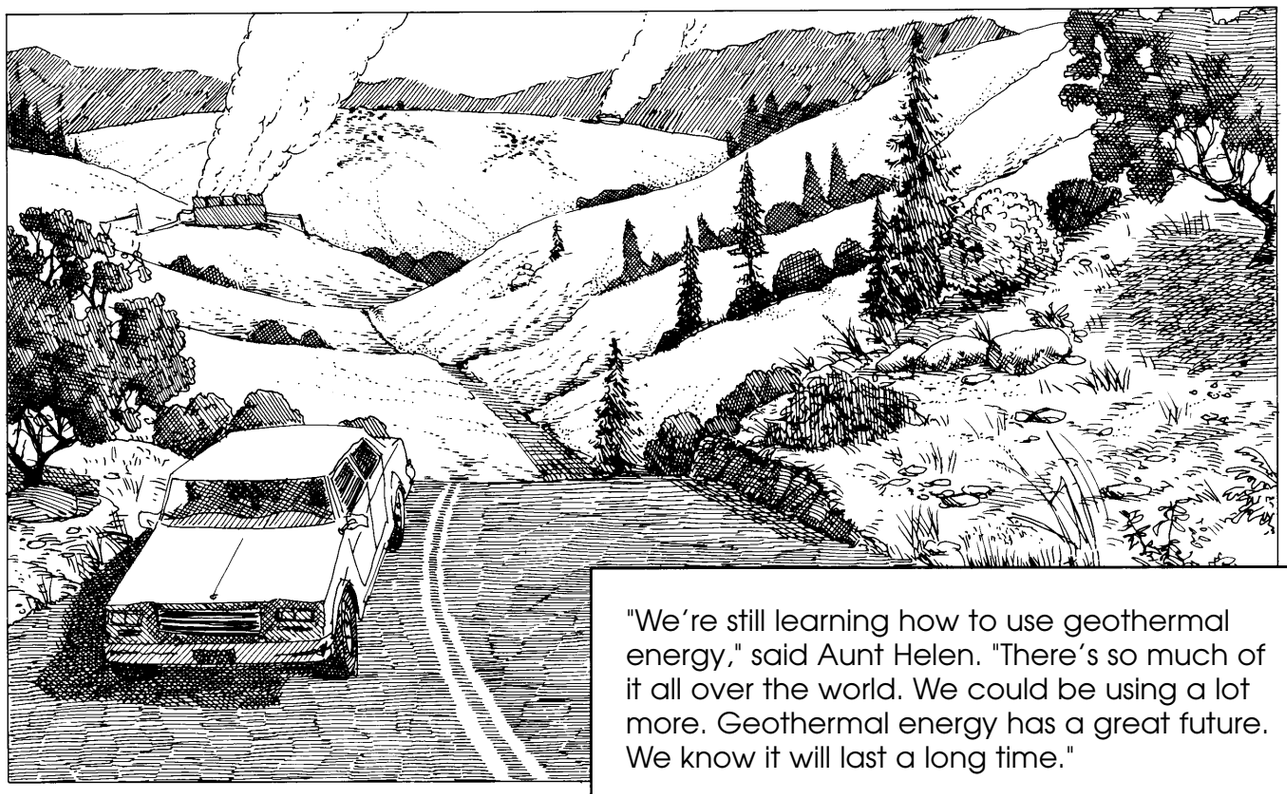

How do you drill a geothermal well?
First, a drilling rig is placed over the well site. The tall mast supports long lengths of drill pipe fastened to the drill bit.
The bit is lowered to the ground and turned as it presses against the rock. As it turns, rock is chipped away.
DRILL BIT


from mud pump
mud pump
mud pit
"Drilling fluid, also called drilling mud, is pumped through the drill pipe. At the bottom of the well, the drilling mud flows out through the drill bit and returns to the surface between the outside of the drill pipe and the well wall."
"Drilling mud is very important. It brings the rock chips back to the surface, cools the drill bit, and cakes the sides of the well. The mud cake keeps the sides of the well from caving in until steel pipe is put in place. The weight of the mud keeps any water in the rocks from flowing to the surface."
mud cake
drilling mud returns to the surface
drill pipe
drilling mud
mud cake
"Are there other ways to drill wells?" asked Jason.

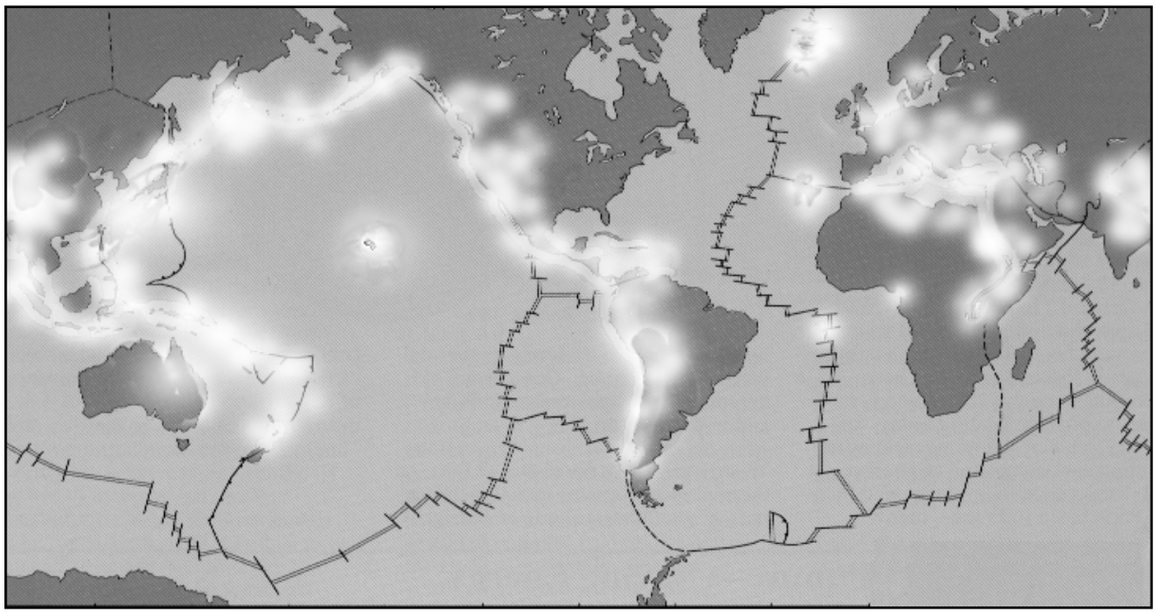

"Yes. Geothermal wells drilled into steam reservoirs are drilled with both mud and air," Uncle Frank said. "The mud is used first. Then air at high pressures is used when the well reaches the fractured, hot, reservoir rock filled with steam.
"If mud were used here, it would plug the cracks. Then little or no steam could be produced."
The high temperatures in some geothermal wells make them difficult to drill. Special equipment and drilling mud are used for these wells.
Drilling wells sounds hard. Is it dangerous?
AIR
AIR
Tiny cracks, called fractures, filled with steam
GEOTHERMAL RESERVOIR


"No. The safety record is excellent," said Uncle Frank. "Company drilling experts, modern equipment, and laws enforced by many agencies have done a good job of protecting people, surface areas, and underground resources."
"After a well is drilled, it is tested. If the geothermal resource looks promising, the well is prepared for production."


"If not, the well is plugged and abandoned. This means it's filled with cement and mud, and carefully sealed off."
cement
mud


"We're still learning how to use geothermal energy," said Aunt Helen. "There's so much of it all over the world. We could be using a lot more. Geothermal energy has a great future. We know it will last a long time."

Geothermal Regions Worldwide



Map courtesy of Energy & Geoscience Institute, University of Utah. Adapted by the Geothermal Education Office.

Generating Electricity with Geothermal Resources

Australia
Austria
China
Costa Rica
EI Salvador
Ethiopia
France (Guadeloupe)
Germany
Guatemala
Iceland
Indonesia
Italy
Japan
Kenya
Mexico
New Zealand
Nicaragua
Papua New Guinea
Philippines
Portugal (Azores)
Russia (Kamchatka)
Thailand
Turkey
United States

Using Geothermal Resources Directly

hot spring bathing, fish farming, agriculture, heating, food processing, and more...

Algeria
Argentina
Armenia
Australia
Austria
Azerbaijan
Belgium
Bolivia
Bosnia & Herzegovina
Bulgaria
Canada
Caribbean islands
Chile
China
Columbia
Costa Rica
Croatia
Czech Republic
Denmark
Djibouti
Egypt
EI Salvador
Equador
Eritrea
Ethiopia
Fiji
Finland
France
F.Y.R. of Macedonia
Georgia
Germany
Greece
Guatemala
Honduras
Hungary
Iceland
India
Indonesia
Israel
Italy
Japan
Jordan
Kenya
Korea
Lithuania
Malawi
Mexico
Myanmar
Nepal
Netherlands
New Zealand
Nicaragua
Norway
Panama
Peru
Philippines
Poland
Portugal (Azores)
Romania
Russia
Slovak Republic
Slovenia
Spain
Sweden
Switzerland
Taiwan
Tanzania
Thailand
Tunisia
Turkey
Uganda
United Kingdom
United States
Venezuela
Vietnam
Yemen
Yugoslavia
Zambia
and others...