

Yellowstone

Seen Through Water and Glass

A Geologist Shares His Recollections of Discovery and His Concern for the Future of Yellowstone's Geysers



Photo courtesy Irving Friedman

Irving Friedman earned a Ph.D. in geochemistry at the University of Chicago. His doctoral research was on phase equilibria at high temperature and pressure; "in other words, things that make rocks." This was followed by a post-doctoral appointment to study the stable isotope abundance of natural materials in the laboratory of Dr. Harold Urey in the Institute for Nuclear Studies. Hired by the U.S. Geologic Survey (USGS) in 1952, he worked on mass spectrometry and the stable isotopes of oxygen, hydrogen, and carbon to study geologic and hydrologic processes. He has a long association with Yellowstone's geothermal features and issues. Dr. Friedman was interviewed for Yellowstone Science in March of 1997.

YS: What was the purpose of your first work in the park?

IF: I was studying the deposition of calcium carbonate in Mammoth Hot

Springs to determine whether the deposit was organically or inorganically deposited, or both, and under what conditions it was deposited. I was also dating some of the volcanic flows in the park as part of the Geological Survey's mapping effort. We were attempting to apply obsidian hydration dating to volcanic glass—obsidian—that is present in many of the flows.

YS: Tell me about the obsidian hydration dating technique. Was this method originally developed to date rocks?

IF: I and Robert. L. Smith of the Geological Survey developed the method because of our interest in obsidian—volcanic glass of rhyolitic composition—how it formed, and how it reacted with its environment. This was one of those serendipitous discoveries that we thought might be used as a dating tool, particularly in Yellowstone, where lava flows were thought to vary in age from less than

a hundred thousand to perhaps half a million years but hadn't been precisely dated, and there was some question as to the validity of the dates.

YS: How is obsidian formed, and is it found in other places besides Yellowstone?

IF: When volcanic flows of rhyolitic composition—that is, magma enriched in silicon, sodium, and potassium compared to the more common basalt—is extruded onto the earth's surface, the outer surface of the flow is chilled, forming a glass called obsidian. The interior of the flow cools slowly, allowing time for individual crystals of various minerals such as quartz and feldspar to form, resulting in a rock called rhyolite, a fine-grained relative of granite. Obsidian is a glass that resembles bottle glass; it can be black, brown, and even red, and it contains very little water in its structure. Rhyolitic rocks are found in most places

where there has been extensive volcanic activity—New Mexico, Utah, Nevada, Oregon, Arizona, California, as well as Mexico, Guatemala, Peru, Iceland, Turkey, New Zealand, and Russia.

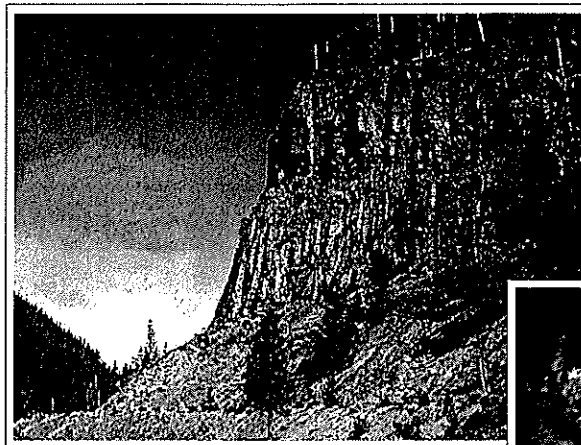
In many places (but not in Yellowstone), the obsidian is found in close association with another volcanic glass called perlite, which is mined in huge tonnages. Perlite sometimes encloses small pieces of obsidian. Both materials have the same chemical composition except that perlite has a much higher water content. Perlite is not as transparent as obsidian, and instead of being hard and strong, it is opaque and friable and made up of thin layers giving it a pearly luster, hence the name. Although obsidian typically has less than 0.3 percent water, perlite has something in the order of 3, 4, 5 percent water.

At one time it was thought that since obsidian was certainly a product of volcanism—it's just a super-cooled rock, if you will—perlite was similarly a primary product of volcanism. In this case, then, the magma that produced the perlite must have a high water content. But this was contrary to what Bob Smith and I thought, because other evidence indicated that these magmas did not have a high water content. Well, where did the water come from that is present in perlite?

We thought that there must be some explanation other than the fact that perlite is originally from a melt of high water content. The only other conclusion would be that the additional water arrived secondarily, after the rock cooled. And if that was so, it would indicate that water could penetrate into obsidian rather quickly, geologically speaking—in hundreds of years. This seemed unlikely, and I looked for proof.

YS: Does a geologist look for proof only in the rocks, or elsewhere?

IF: I remember visiting the Field Museum in Chicago and seeing obsidian artifacts recovered from earth mounds in Ohio—ceremonial blades and chipped obsidian—that had been manufactured by ancient people of the Mound Builder culture. These mounds had been dated as approximately 3,000 years old by carbon-14 dating of associated charcoal. It occurred to me that here is obsidian that had been chipped, creating new surfaces



Obsidian Cliff in Yellowstone National Park and a close-up of obsidian rock.

NPS Photos



3,000 years ago. If water would penetrate into obsidian at a significant rate, you should be able to detect it in these artifacts. I was able to convince the curator to let me take a few of these obsidian chips with me. We cut little slices of some of these chips, ground down the slices until they were thin enough to see through, and examined them under the microscope. Sure enough, there was evidence of water penetration into the obsidian: We measured the depth of penetration of water into the obsidian during the 3,000 years since the surface had been chipped. This allowed us to determine a rate at which water traveled by diffusion into these obsidian artifacts—a rate that proved that perlite was not a primary product of volcanism, as was obsidian, but that perlite might have been formed *from* obsidian. Also, we discovered that the rate of penetration of water was easily measured and might be used to date geological material, such as the Yellowstone rhyolite flows, as well as archeological material.

YS: Did you apply this new dating technique to Yellowstone?

IF: In cooperation with several geologists, I collected many obsidian samples, made thin sections, and examined them under the microscope. As I expected, they all contained hydration layers of various thicknesses, and from the hydration thickness we calculated ages of the volcanic flows. Most of these ages agreed with those derived by other techniques.

In addition, U.S. Geologic Survey geologist Kenneth Pierce and I discovered that in some localities, the samples contained several different hydration thicknesses, implying that multiple events pro-

duced the surfaces at different times in the past. For example, at Obsidian Cliff the obsidian has some very thick hydration rinds that correspond to the age of the flow, which is about 180,000 years old. But many samples also contained cracks having two different hydration thicknesses which yielded ages that corresponded to what we thought was the time of the Bull Lake Glaciation and the Pinedale Glaciation.

We postulated that these cracks were created by the weight of ice—there was 3,000 feet of ice above the Obsidian Cliff flow during the Pinedale glacial advance and probably the same amount during the earlier Bull Lake advance. That's a lot of ice that resulted in lot of pressure on the obsidian, and it must have caused cracks to form. Well, as soon as you form a crack, water begins to penetrate the crack and to diffuse into the obsidian itself to form a hydrated surface. If you had cracks formed during the first glaciation (the Bull Lake) and 80,000 years later another similar event causing additional cracking, you'd see some cracks formed by one event and some by the second. And indeed, the dating of the cracks matched up with the previous estimates of the dates of Pinedale and Bull Lake glacial deposits. That was another interesting

utilization in Yellowstone of obsidian hydration dating.

YS: Wasn't the cultural resource connection an important breakthrough, with the dating of obsidians quarried in Yellowstone and traded across the continent by Native Americans?

IF: At the very beginning we depended on archeologists to provide us with obsidian from sites dated by carbon-14 so we could get some idea of hydration rates. Later, when the obsidian hydration technique was developed, archeologists really seized on the technique because it's relatively cheap and in many parts of the world, particularly Central America, archeologists don't have any other datable material except obsidian artifacts—often obsidian chips that remain after the manufacture of knives or points. In the tropics, wood doesn't persist, and there isn't much to date except artifacts, and the artifacts in many cases are rocks. You can often date the time a rock was formed by geologic processes, but that's not what the archeologists want to date; they want to date the time the rock was fashioned by man, not the time that nature fashioned it. As a geologist, I'm interested in the latter, but the archeologist is interested in the former.

YS: I understand that you have been measuring ground temperature in Yellowstone. Is this connected with obsidian hydration dating?

IF: Yes. Early on we postulated and determined that the ground temperature—the temperature to which the obsidian had been exposed while buried in the ground—would have influenced the rate at which the obsidian hydrated. In the laboratory we hydrated obsidian at high temperature under controlled conditions, causing it to hydrate at temperatures from 95°C to as high as 200°C. In this way we determined the rate at which obsidian samples from Obsidian Cliff would hydrate at different temperatures. If we knew the temperature, we could determine at what rate it would hydrate, which then meant that you could actually date things more precisely. If you had an obsidian artifact that an Indian had created and left buried in the ground for 2,000 or 3,000 years, by measuring the present day temperature you'd have a good estimate of the temperature that existed during the

past 3,000 years during which the obsidian hydrated.

One problem is that the present-day temperature may not be exactly the temperature it was in the past. However, in most places the temperature hasn't changed greatly for the past 5,000 years, and the small temperature changes that have occurred are not enough to affect our results. It's only where you're dealing in very ancient (>10,000 years) man-made objects or older geologic samples that you have to worry about what the past temperatures were. In any case, you have to start from some datum—usually present day—and then estimate what changes might have occurred in the past.

YS: And this complicates dating the human activity. Elaborate on the relationship between your geologic investigations and the archeological ones, if you will.

IF: My latest effort in the park was with NPS archeologist Ken Cannon, who collected obsidian artifacts from occupation sites along the shores of Yellowstone Lake in areas that may be disturbed because of road construction. There's a lot of geothermal activity along the lake shore—it's probably one reason the Indians occupied the sites. Obsidian found at these sites would have been exposed to higher temperature, and hydrated at a higher rate, than obsidian collected from sites where the ground was not heated geothermally.

Our ground temperature measurements will also be useful for archeological materials found in non-hydrothermal areas. In addition to their use in calculating obsidian hydration ages, ground temperature measurements are useful in other ways. For example, researchers who study soil formation; they need to know the rates of formation of soil—and this is temperature dependent. In biological studies temperatures are also a factor. Like all research, there are always other uses for data than the investigator realizes when he starts.

YS: Another piece of work that I know you've been involved in is chloride flux monitoring.

IF: Its original aim was to develop a data-base to help protect Yellowstone Park from oil and gas and geothermal development that could influence the ther-

mal features in the park, particularly the geysers.

YS: Did this start back in the late 1970s or early 1980s when there was discussion about opening up the Island Park area for geothermal leasing?

IF: Yes. It was the time of the Arab oil boycott, oil prices were sky-high, energy companies were looking for alternate energy sources, and geothermal was a big thing at the time. As an aid to prospecting for geothermal resources, the U.S. Geological Survey was asked to issue a bulletin listing the world's geothermal resources. Well, it turns out that the Island Park area was listed as having the highest potential in the United States, which generated interest in geothermal exploration in this area. The Forest Service proposed to issue geothermal leases in the area adjacent to the west boundary of Yellowstone and issued an Environmental Impact Statement (EIS) as required by law before proceeding. At the time, officials in Yellowstone were unaware of these proceedings since notices were not sent to them. Just before it was too late to respond to the EIS, someone brought it to my attention, as well as to the attention of park officials. I don't know if it was done with malice and forethought or if it was just stupidity.

YS: And you got involved because of the park's concern?

IF: Yes. At about the same time, concern had been raised in Congress, and Congress asked the Geological Survey to comment on the possibility of damage to thermal resources by geothermal development. The request was passed to USGS geothermal experts who wrote a letter to the Secretary of Interior who then sent it to the Senate. The letter pointed out that in all cases where there had been geothermal development adjacent to active geysers—in New Zealand, Iceland, and Nevada—the geysers had permanently ceased erupting.

However, the letter concluded, they saw no problem with geothermal development adjacent to the park as long as it was properly monitored and controlled. The monitoring was to be carried out from two wells drilled close to the park boundary—between the park and the Island Park area—to measure the pressure in the wells as an indication of what was

going on in the geothermal aquifer. If the pressure was to fall, further utilization of energy from the geothermal wells would be stopped.

Well, I saw the report to Congress and got mad (I was younger), and I wrote a letter to the Director and sent copies to a lot of other people, pointing out how impractical this was. I said that the Survey didn't have a very good record of being able to control development adjacent to anything.

YS: Who ever said government scientists couldn't disagree! What was the substance of your concerns?

IF: First, it is difficult to be sure that the aquifer being monitored by the two wells is the same aquifer being tapped for energy some miles away. Second, we don't know what degree of pressure drop would cause damage to Yellowstone's geysers. Third, we don't know if the natural aquifer pressure is a constant. It may vary from year to year, and in a seismically active area such as Yellowstone, quakes could cause episodic changes. The developers could claim that pressure changes, if observed, were not significant. Obviously, developers with perhaps a billion dollars invested in a geothermal field and power plant are not going to quietly fold their tents and walk away because of a small pressure change in a monitoring well. In short, we don't know what to monitor, and we can't control it, and therefore we shouldn't play Russian roulette with Yellowstone.

So I thought of what could be done that would cost very little, and might give a database which would be useful in the future in determining that Yellowstone's geothermal system had been disturbed. The total heat flow from a geothermal system, or portion of it, is one important component in geyser activity (the plumbing system that supplies water is another). But it's very difficult to monitor heat flow. A number of people have suggested that monitoring be carried out with some constituent that comes up with the heat. Chloride is the one usually chosen because it is easy to measure cheaply and is a conservative constituent. In other words, it's something that does not disappear before you get to measure it. In Yellowstone all the chloride that leaves the park has to come through four major

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rivers that drain the park—the Falls, Madison, Snake, and Yellowstone. Therefore, if you just monitor the chloride in these four rivers you can at least determine if the whole system has been disturbed by geothermal or other development.

YS: By monitoring, do you mean river gauging?

IF: To measure the chloride *flux* you need two things. You want to end up with how many grams or pounds or whatever of chloride come out each year from each river. It is necessary to measure the water discharge by gauging streamflow on each river, and to sample the water for its chloride *concentration*—the amount of chloride in a given volume of water—periodically (about 30 times during the year). The amount of chloride that leaves per year—the chloride *flux*—can then be calculated for each river, and the sum of the fluxes from the four rivers is the total chloride flux from the park.

When USGS chemist Dan Norton and I began this project, the discharge from the Yellowstone and the Falls was being monitored by the Water Resources Division of the USGS. The Madison had been monitored, but measurements had stopped the year before. The Snake had been monitored for a few years in the 1930s and then stopped due to lack of funding. The park provided funding to reactivate stream gauges on the Snake and Madison. Later on we thought it'd be useful to monitor the Firehole and Gibbon, which separately drained the two most active thermal areas in the park.

I originally thought at least 20 years of baseline data would be necessary. This might not be finished in my lifetime, but the work could be continued by others.

YS: So, do we understand about the relationship between the surface waters

in the streams, the ground water, the aquifer and what the disturbance effects might be?

IF: These are some of the things we are learning. The original concept of chloride flux monitoring was to protect the park, but also, it's for research. The variations in chloride flux over the years will allow a better understanding of the underground system and how it responds to

magma movement beneath the park, earthquakes, and other tectonic-induced changes.

Because of the immediate concerns over potential development at Island Park, the first thing we did was to consider the thermal features in the Boundary Creek area close to Island Park and the southwestern border of the park. In the 1960s, I had taken a traverse across Boundary Creek to the Bechler River and discovered a thermal area—I'm sure people had seen it, but it was not on the maps. It's a small valley with boiling springs and other thermal features at the headwaters of Silver Scarf Falls, which are warm. We also discovered other thermal features; in fact, middle Boundary Creek is warm enough to bathe in. And I thought we should look at these thermal features, with the thought that if geothermal development in Island Park disturbed the Yellowstone system, the disturbance would first affect these nearby small thermal areas which are not very deep-seated.

We installed small weirs to measure discharge from several small hot springs in this very remote area. There's no easy way to get in except walking 8 or 10 miles. We equipped the weirs with newly developed electronic monitoring devices that we thought would be able to monitor these springs and store the information, so we would only have to go back every few months and retrieve the data. The system worked for eight months, and then, as usual, everything quit. It became expensive and impractical to send people several times a month, winter as well as summer, to service the equipment. It's a long hike in the summer, but it's a hell of a thing to do on skis. It's at least 30 miles round trip. There's nothing. No shelter.

We finally got a few thousand dollars to go in once a year, in the winter, by



One of the weirs in the Boundary Creek area of Yellowstone that was equipped with electronic monitoring devices to store information on chloride flux that could be retrieved every few months.

helicopter to make a single measurement at the time of minimum flow of 11 springs and streams. That continued for eight years and was quite successful. We had the usual close escapes—I almost got killed a few times!—but these things happen.

YS: And the results of what you found out from that work?

IF: We found that the chloride flux in these small hot springs changed seasonally in a surprising manner. The chloride flux went up in the spring and down in the fall. In the past it was assumed that the chloride flux, unlike concentration, would be constant; even in the springtime, though the hot spring discharge increased due to snowmelt, the snow contains little chloride, so the chloride flux would not change in spite of the increased discharge. If this was how the system worked, the chloride concentration in the hot spring discharge should decrease in the springtime, due to presumed dilution, and increase during low water in the fall. Well, it didn't. The chloride concentration remained constant; it *isn't* being diluted by snowmelt. And in the fall, what little water that came out had the same chloride concentration as the water that discharged during high flow following snowmelt. No matter how much water came out of the hot spring,

the chloride concentration was the same. That threw us for a loop.

Our explanation was that these hot springs are tapping a groundwater layer that may be 1,000 feet thick and is mixing with chloride-rich volcanic steam. The rate of discharge of the spring is influenced by the height of the water table above the spring. During snowmelt the height of the water table increases, increasing the pressure, which causes an increased flow out of the hot spring. However, the *local* water table above the hot spring does not mix with the *deeper* water that feeds the spring, and therefore the chloride concentration in the hot spring does not change even as the discharge rises during the time of snowmelt.

We recognized a similar pattern in the chloride flux in the major rivers, where the chloride concentrations change a little because of snowmelt, but the changes were relatively small. Therefore the chloride flux in the rivers is also related to the height of the water table, which is seasonal, and it also varies from year to year. That's one reason that we need 20 years of records to establish a long-term, reliable, data baseline.

YS: So, subtle changes in groundwater levels and pressure caused by drilling might affect the park's thermal features.

IF: Yes. We believe this cannot help but affect geysers, which are very sensitive to changes in these things: heat, water, and pressure.

YS: Will chloride flux monitoring allow us to be able to detect small changes due to extracting hot water or steam from a geothermal well, and not only detect them, but do so in time to do something about it?

IF: That we don't know. There's some doubt that it might. My original thought was that we having nothing to lose. It doesn't cost much, and it gives us a base from which to assess changes caused by earthquakes and the movement of magma. It may or may not have use as a warning tool, but in any case, it tells us more about what's going on in the natural system. So from several points of view it should be continued.

YS: What do you think is the biggest threat to Yellowstone's geologic resources, and what is the biggest geologic research need?

IF: A big threat could still be geothermal, but the biggest threat is gas and oil extraction. Gas and oil extraction is worse than geothermal energy utilization, because during geothermal development, normally what you take out of the system is the heat; the extracted water is usually pumped back into the ground. But in the case of gas and oil, you're removing more; you're removing the gas and oil. Historically this extraction of material in oil fields has caused earthquakes and subsidence. Normally, these effects haven't been serious enough to cause serious concern, particularly in view of the large monetary gains associated with oil development.

It has been proven that a series of earthquakes about 35 years ago in Denver were caused by pumping liquid waste down a deep well at the Rocky Mountain Arsenal near the old airport. Denver had been a seismically quiet area until the pumping began, which coincided with the occurrence of swarms of earthquakes—the largest was, I believe, 4.2—strong enough to rattle the bed and shake the house. A geologist pointed out the perfect correlation between the amount of pumping and the earthquake incidence. To confirm the relationship between addition or removal of subsurface material

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and earthquakes, a test was carried out in the recently abandoned Rangely oil field in central Colorado. When pumping was instigated, local earthquakes were generated; the more they pumped, the greater the earthquakes.

Earthquakes are known to be some of the events that cause changes in Yellowstone. We can't control those that occur naturally, but we don't want to generate shallow earthquakes close to the major geysers of Yellowstone.

YS: The biggest research need, then, is?

IF: We don't even know the extent of the geothermal resource here. Rick Hutchinson was inventorying these resources. He did a damn good job, but he's not around to continue it. Where are the thermal features? How big are they? How do they change with time, and how are they affected by tectonic events in and near the park? The inventory needs to be continued and expanded.

We need to have a system in place to do continual and better monitoring, not just for geothermal resources but for other components of the Yellowstone system. For example, the fluxes of heavy metals is not known. How much contamination of the park is caused by adjacent mines? We should be looking at many constituents—copper, zinc, lead, arsenic, to name a few. We need to know more about what's happening—are the fluxes of these and other components increasing, or changing in various ways? There should be more geochemical monitoring, other than just chloride flux.

A serious problem in attempting to protect the park is the lack of basic detailed geologic knowledge of areas surrounding the park. Geologic mapping



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Above top: Boundary Creek thermal area. Lower photo: Silver Scarf Falls. Photos courtesy Jennifer Whipple.

should be initiated to fill the gaps.

YS: Geologists bemoan the fact that Yellowstone's geothermal curiosities were the major reason the park was created, but because they don't stand up and move across the boundaries and don't cause many legal problems, they tend to receive less attention than do animals, which have more vocal constituencies.

IF: That's right. I believe there should be more discussion of the geologic resource issues. I'm sure that this has been done in the biologic sphere, but there needs to be more consideration given to the geologic

aspects. The New World mine situation did one good thing: it did mobilize interest and the realization among people that you can affect the park's resources in many ways, not just by killing off the buffalo or the elk or whatever, but by contaminating them with the residue from mining and by ruining the geothermal features. And that's the only good thing about the New World situation. But we need to take advantage of the public concern and not let the momentum created by this real danger to the park be dissipated without action.