The Operation and Geography of Carbon Dioxide-Driven, Cold-Water "Geysers"

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Abstract

Eruptive activity of carbon-dioxide-driven, cold-water geysers is similar to hot-water geysers, except that CO_2 bubbles cause the eruption instead of steam. CO_2-driven eruptions occur as CO_2 degasses and expands, displacing overlying water. Many, if not most, cold-water geysers are actually manmade boreholes. Several such erupting wells, including Crystal and Woodside Geysers, are located near Green River, Utah. Similar to their naturally occurring counterparts, their exact eruptive activity may be erratic and change through time. Generally, however, frequency and power of Crystal and Woodside Geysers' eruptions have been observed to be fairly consistent over the past decade. Cold-water geysers are known in France, Germany, New Zealand, Serbia, Slovakia, and the United States.

The Operation of CO_2-driven Cold-Water Geysers

The activity of cold-water geysers is similar to their hot water counterparts, except that CO_2 bubbles drive the eruption instead of steam. In cold-water geysers, CO_2-laden water lies in a confined aquifer, in which water and CO_2 are trapped by less permeable overlying strata. Only in a handful of places, such as at faults, joints, or drilled wells, can the water and CO_2 readily escape the underlying aquifer. If a well is drilled through a confining layer into a CO_2-laden aquifer, the borehole provides a path for the pressurized water and CO_2 to reach the surface. Faults and joints also may provide routes for gas-laden water to penetrate an overlying confining layer. Aquifer and plumbing attributes, including plumbing depth, CO_2 concentrations, aquifer yield, and so on, combine to provide the differing scales and frequencies of eruptions.

Analogous to steam bubbles expanding to displace water in a hot water geyser, the column of water in a cold-water geyser's plumbing exerts enough pressure to keep the CO_2 in solution and in small bubbles. A decrease in pressure of the water column allows CO_2 to outgas and any existing CO_2 bubbles to expand. This "boiling" deep in the system is comparable to water flashing to steam in a hot water geyser. As the CO_2 outgasses, it displaces water and starts the eruption.

Activity at Crystal Geyser, Utah

Crystal Geyser is a CO_2-driven erupting well located eight kilometers south of Green River, Utah. The geyser itself is situated on a broad and colorful travertine terrace developed along the eastern bank of the Green River. While the borehole is manmade, the periodic eruptions occur naturally. A 1.5-by-1-meter pool is located 15 meters east-southeast of Crystal Geyser. Closely related to Crystal Geyser, this small pool periodically sputters and splashes.

Note: A *geyser* is defined as a hot spring in which eruptive activity is induced by boiling at depth within a plumbing system that forcibly ejects water out of the vent in an intermittent fashion (White 1968, Bryan 2001). Because Crystal Geyser and the other known cold-water geysers are neither hot springs nor are their vents naturally occurring, these features are not *true* geysers. However, for this report, these cold-water, CO_2-driven, periodically-erupting features will be described informally as geysers. In addition, in this report, *boiling* refers to periods of effervescent bubbling of CO_2.

Table 1 — Known Cold-Water Geysers of the World

Name	Location	Height	Interval	Duration
Crystal Geyser	Green River, Utah, USA	15–20 meters	11–18 hours	15–45 minutes
Woodside Geyser (Roadside Geyser)	Woodside, Utah, USA	6–10 meters	28 minutes	1.0–1.5 hours
Champagne Geyser (Chaffin Ranch Geyser)[1]	Green River, Utah, USA	7–8 meters	2 hours	5 minutes
Ten Mile Geyser[2]	Green River, Utah, USA	2.5–3.5 meters	6 hours 42 minutes	51 seconds
Tumbleweed Geyser[2]	Green River, Utah, USA	0.3–1.5 meters	2–8.5 minutes	46–94 minutes
Unnamed geyser[3,*]	Salton Sea, California, USA	0.1–0.5 meters	10–60 seconds	seconds
Jones Fountain of Life[4]	Clearlake, California, USA	< 1.0 meter	60 minutes	22 minutes
Cold Water Geyser[5,*]	Yellowstone, Wyoming, USA	0.5 meters	unknown	10 minutes
Source Intermittente de Vesse[6]	Bellerive, France	1–6 meters	230–270 minutes	45–50 minutes
Andernach Geyser[*]	Andernach, Germany	40–60 meters	1.5–4 hours	7–8 minutes
Boiling Fount local name: Brubbel	Wallenborn, Germany	2–3 meters	30 minutes	"a few minutes"
Mokena Geyser[7]	North Island, New Zealand	0.5–5 meters	minutes–hours	seconds–minutes
Povremeni Geyser[8]	Sijarinska, Serbia	20 meters	9 minutes	2 minutes
Herlany Geyser	Herlany, Slovakia	20–30 meters	32–34 hours	30 minutes
Perši Geyser[9]	Perši, Slovakia	"smaller than Herlany Geyser"	hours ("shorter than Herlany Geyser")	minutes (probably < 30)

[1] Murray, unpublished manuscript.; [2] Ross (1997); [3] Bryan (2003); [4] Galloway *et al*. (1997); [5] Whittlesey (1988); [6] Bellerive-sur-Alleir (2004); [7] Environment Waikato (2004); [8] Serbia Tourism (2004); [9] Rinehart (1980).

[*] when active

Figure 1. World map showing the known locations of cold-water geysers.

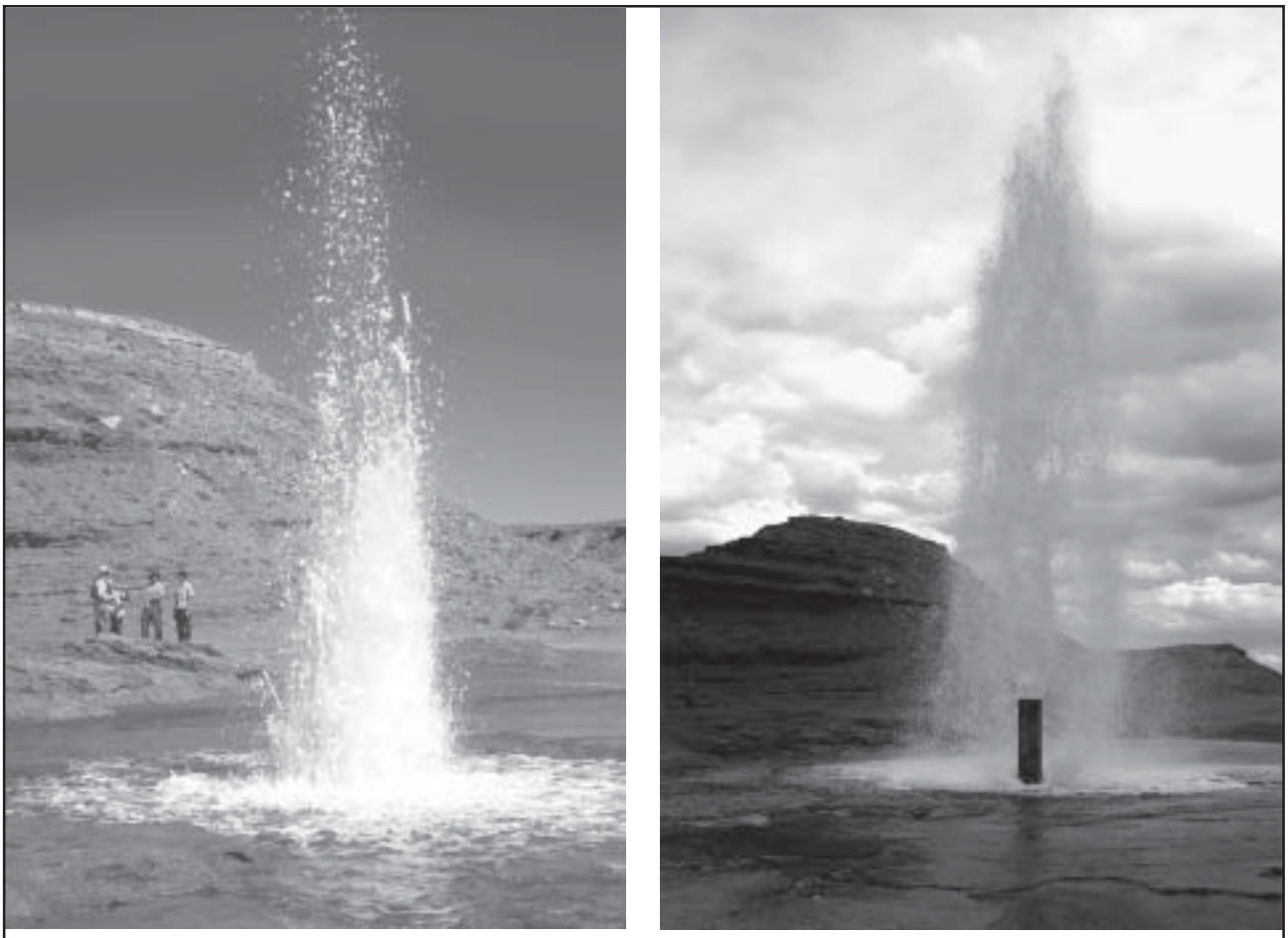

Figure 2. Crystal Geyser, Utah, comparing an eruption in 1995 (left photo) with another on June 10, 2004 (right). [Photos by Alan Glennon]

Murray and others have described the geyser and setting (Murray, 1989a; Baer and Rigby, 1978; Waltham, 2001). Research on the area's CO_2-laden groundwater reservoirs is being conducted by Utah State University (Heath *et al.*, 2003). Since Murray's article in GOSA Transactions II (1989a), a taller and somewhat wider-diameter, casing has been installed on the well. Before October 2000, a rusted metal casing rose approximately 0.3 meters above the ground surface. The well's current casing stands 1.2 meters or more above ground. Additionally, a metal screen at the ground surface allows limited inflow and outflow of water.

Crystal Geyser's well penetrates a confined aquifer with a hydraulic head above the level of the ground surface. If not for the geyser-like behavior, the well likely would possess artesian discharge. When CO_2 and water reach the surface, CO_2 outgassing creates effervescent boiling at the vent. This agitation causes a pressure release for the CO_2 in the aquifer plumbing. Eventually, one of the boiling episodes is large enough to create a chain reaction of CO_2 degassing and expanding down the well: an eruption.

During a trip to the site in 1995, the nearby erupting pool splashed up to a meter in concert with Crystal's eruptions. Between that trip and 2000, someone had attempted to seal the pool's eruptions. During visits in 2000 and 2004, the pool had fresh debris—mostly mud and gravel—filling its crater. A local gas station owner said that the pool was filled in, the upper reaches of the well redrilled, and the new casing installed in an effort to increase Crystal Geyser's frequency. The fill's effect on Crystal Geyser is unclear: although the larger-diameter casing mutes the height of the eruption, the power of activity and major eruption timing appears to be quite similar to observations in

1995 and 2000.

Alan Glennon visited Crystal Geyser on 10 June 2004; it erupted at 16:29 (Mountain Daylight Time). Upon arrival at 08:00, the terrace was dry except for a single area dampened by light overflow. At 08:04, the vent became agitated and discharge increased, wetting a larger area of the terrace. After a few minutes, the activity subsided and the vent's overflow stopped. Cycles of increased bubbling and agitation occurred approximately every 30 minutes. During these active periods, the well vent surged with frothy boiling for five to 10 minutes. At that point, overflow ceased, the water flow reversed, and water drained into the well. While the well was "taking" water, the small muddy pool nearby filled, sputtered, and boiled from CO_2 gas. The pool splashed for about five minutes to heights of several centimeters to a decimeter. When the well stopped taking water, the pool drained. Next, over a period of 15–20 minutes, the basin around the well slowly filled with water. The cycle maintained approximately the same pattern throughout the day, but the runoff from the well increased and the muddy pool's eruptions strengthened with each cycle.

Figure 3. A 2004 eruption of Woodside Geyser, Utah, as viewed from the nearby highway. [Photo by Alan Glennon]

The major eruption began during an episode of agitation in the main well. Instead of reversing flow and triggering agitation in the nearby pool as the effervescence waned, the mild boiling behavior continued in the main well. Over the next two minutes, agitation of both the pool and well increased—triggering the major eruption. The burst-and-pause major eruption lasted approximately 20 minutes with a maximum height of approximately 10 meters, which was achieved for only the first two to three minutes. The remaining play consisted of progressively weakening bursts of two to three meters. By 30 minutes after the initial eruption burst, the water column in the well had lowered to a few meters below the surface.

Unlike the observations in 1995 and 2000, no afterbursts or secondary eruptions occurred. A closed interval was not observed but the interval is estimated to be 11–18 hours based on local accounts and previous activity.

Woodside Geyser, Utah

After visiting Crystal Geyser, Glennon drove to Woodside Geyser. Woodside Geyser is located approximately 30 kilometers northwest of Green River, Utah. The geyser, an erupting drilled well, lies behind an out-of-business gas station along Highway 6/191. Glennon was unable to observe the geyser closely, but saw it in eruption from a distance of several hundred meters. A one-meter or taller casing also has been installed at Woodside Geyser. During Glennon's trip to Woodside in 1995, the geyser erupted from the middle of a shallow pool and little or no casing was visible. Murray describes the geyser in GOSA Transactions II (1989b).

The landowner reported on 10 June 2004 that the geyser erupts for periods of 1.0–1.5 hours followed by a quiet interval of 28 minutes. The play is comprised of bursts and pauses. At the start of the eruption, bursts may reach 10 meters or more, but

they quickly weaken. For the rest of the eruption, bursts reach between two and three meters.

Cold-Water Geyser Locations

Given that many, if not most, cold-water geysers are drilled wells, they rarely reside in pristine natural settings. At Source Intermittente de Vesse, France, Boiling Fount, Germany, and Herlany Geyser, Slovakia, concrete and stonework basins have been constructed around the wellheads; the geysers look like city park fountains. Only two CO_2-driven, cold-water geysers — a small unnamed spouter at Salton Sea, California, and Cold Water Geyser, Yellowstone — possess both natural vents and lie in relatively undisturbed settings. The appearance of cold-water geysers may be quite similar to their steam-driven counterparts; however, often CO_2-laden water is more white and frothy. Cold-water geysers are known in France, Germany, New Zealand, Serbia, Slovakia, and the United States (Table 1).

Several effervescent springs exist near the town of Vichy in central France. At least one of these, at the village Bellerive, the Source Intermittente de Vesse, has periodic eruptions. The geyser typically erupts one meter high for 45–50 minutes followed by a quiet period of 230–270 minutes (Bellerive-sur-Alleir, 2004). Thus, the period from the start of an eruption to the subsequent eruption start is 4.5–5.5 hours.

The Rheinland-Pfalz Region of Germany, south of Bonn, has at least two cold-water geysers. Badly damaged during the First and Second World Wars, a cold-water geyser at Andernach was redrilled and restored in 2001 (Schmitt, 2004). However, due to its location within a restricted nature preserve, the erupting well currently is capped and closed to the public. The geyser reportedly is capable of eruption heights to 40–60 meters for 7–8 minutes every 1.5 hours. A small cold-water geyser is found in a city park in the town of Wallenborn. Locally known as the Brubbel, a renovation of its well basin was completed in 2001. In the same region, eruptive activity has been reported at Bad Neuenahr (Rinehart, 1980). Postcards from the 1950s show Bad Neuenahr's Großer Sprudel erupting to 20 meters; whether eruptions still occur is unknown.

Figure 4. Mokena Geyser at Te Aroha, North Island, New Zealand. [Photo copyright Waikato Regional Council, also appeared in *The GOSA Transactions*, Volume VII]

On New Zealand's North Island, Mokena Geyser erupts to heights of less than a meter to five meters (Katherine Luketina, pers. comm.). The geyser — a well drilled in 1936 — is located at the base of an extinct volcano in the Te Aroha Domain. Mokena's eruptions produce a thin, vertical stream of 70°C water several times a day. The well's water is used for a nearby swimming pool and sometimes the well is capped to prevent eruptions (Environment Waikato, 2004). The geyser has deposited a thin coating of travertine around its opening.

Of three spouters known in Serbia, one appears to possess geyser-like periodic eruptions. In central Serbia, the spouter at Kopaonik National Park is probably a perpetually erupting well. The play commonly reaches five meters, but park visitors often modify the vent with rocks to change the water column's appearance. Sijarinska Banja, in southeastern Serbia, has two warm-water spouters:

Veliki and Povremeni Geysers (Serbia Tourism, 2004). Veliki, or Giant Geyser, perpetually erupts 70˚C water to eight meters. Povremeni, or Occasional Geyser, erupts for two minutes every nine minutes. Its 55˚C water plays to 20 meters.

In Slovakia, a well known cold-water geyser erupts in the village of Herlany. The geyser, a well drilled in 1870, plays to heights of 20–30 meters for approximately 30 minutes every 32–34 hours. Rinehart (1980) reported a cold-water geyser at Perši, Slovakia. The geyser has a shorter eruptive height, duration, and interval than Herlany.

Within the United States, cold-water geysers are found in California, Utah, and Wyoming.

A small, ephemeral CO_2-driven geyser has been observed along the southeastern shore of California's Salton Sea (Bryan, 2003; photos p. 173). Erupting less than a meter high, it is a rare example of a natural cold-water geyser. In northern California, near Clearlake, Jones Fountain of Life erupts 62˚C water. Driven by CO_2 and methane, the geyser's eruptions occur approximately every hour and last about 20 minutes (Galloway *et al*., 1997).

In Utah, near Crystal and Woodside Geysers, at least four additional erupting wells — Champagne Geyser, Ten Mile Geyser, Tumbleweed Geyser, and a capped test well near Green River — have been reported. Champagne Geyser, also known as Chaffin Ranch Geyser, is located approximately 40 kilometers south of Crystal Geyser and erupts from a well drilled in the early 1930s. Although the diameter of the pipe is only a few centimeters, water spurts 7–8 meters for five minutes from it every two hours (Clark Murray, pers. comm.; Mutschler, 1977). Several kilometers north of Champagne Geyser, Tumbleweed Geyser is small geyser that is in eruption more than quiet; Ross (1997) observed the geyser in eruption more than 70 percent of the time. The activity consists of short eruptions of 1–4 minutes, followed by a pause of several minutes. Eventually, the geyser has a long eruption of 46–94 minutes. The play is between 0.3 and 1.5 meters high. Ross (1997) also reported a cold-water geyser, Ten Mile Geyser, lying approximately 8 kilometers south of Crystal Geyser. Unlike Tumbleweed, Ten Mile Geyser's activity is marked by long quiet intervals and short durations. From 21 hours of continuous observation, Ross (1997) witnessed only four eruptions. The average interval was six hours and 42 minutes with a duration of 51 seconds. Play reached 2.5–3.5 meters. In 1991, near the City of Green River's eastern I-70 off-ramp, a test well sent water spouting 10 to 12 meters in the air; the well was capped two days after it was drilled (Murray, unpublished manuscript).

In Yellowstone National Park, Wyoming, a small cold-water geyser is located along the bank of the Yellowstone River below Nez Perce Ford (Whittlesey, 1988). Cold Water Geyser's 10-minute eruptions were regular from the 1930s until 1983 when its activity became erratic. Long dormancies are now common, although the spring does cycle between filling and draining (Taylor, 1997). When active, the CO_2-laden play reaches heights of about half a meter.

Other features displaying spouting or intermittent discharge are sometimes described as cold-water geysers. Examples include artesian springs, flowing wells, ocean blowholes, periodic springs, and sand volcanoes. Below, several features that either have been labeled by others as cold-water geysers or have eruptive activity driven by CO_2 are described.

Near Orlando, Florida, a drainage well drilled into the karst Floridan Aquifer can produce eruptions to nearly 20 meters every seven to 30 minutes (Steinman, 2002). The geyser only operates during and immediately after heavy rains. The activity apparently is driven by escaping air bubbles, which accompany the heavy volumes of water draining into the well. Short-lived spouting has been observed and described in other karst landscapes, as well as on glaciers (Veni and Crawford, 1986).

A CO_2-driven well at Soda Springs, Idaho, would spout perpetually if left uncapped. Advertised as "The World's Only Captive Geyser", once an hour the city uses a timer to allow 1–2 minute eruptions. The play reaches 20–30 meters.

Boiling Springs at Savage, Minnesota, is a periodic spring that displays intermittent surging. Usually rising a few decimeters above the spring's pool surface, surges occur every few minutes

(MPCA, 2001). Occasionally, the activity is more vigorous, and the surges reach a meter. Groundwater pumping has threatened the springs, and current behavior is unknown.

A warm-water, gas-driven geyser produced modest eruptions less than 0.3 meters high among the steam-driven geysers at Steamboat Hot Springs, Nevada (White, 1968). Labeled Spring #10, its activity ceased in the late 1980s when a geothermal power plant was constructed near the site.

Effervescing springs and erupting wells are found in Saratoga Spa State Park near Saratoga Springs, New York. One of these features, Island Spouter, sends a constant, thin stream of CO_2-laden water approximately three meters above its travertine mound.

Often described as a cold-water geyser, Periodic Spring near Afton, Wyoming, possesses behavior that alternates between discharge and quiescence. When running, the water is not ejected into the air, but flows like a typical spring. The periods of flow and calm change based on seasonal precipitation, and have been timed between four and 25 minutes. The spring, developed in a karst aquifer, likely possesses an internal conduit geometry that creates a siphon. The periodic activity is an effect of the siphon filling and draining.

Occasionally, springs at Mammoth Hot Springs, Yellowstone National Park, exhibit geyser-like behavior. At 50–70˚C, the water at Mammoth Hot Springs is cooler than boiling, and such eruptive activity tends to be driven by rapid CO_2 degassing. Recent activity at the western extension of Narrow Gauge Springs, part of the upper terrace of the Mammoth Hot Springs complex, has included weak splashing at various spring orifices. These splashes, typically less than 0.3 meters, have been observed on occasion to send droplets 2 meters high.

Levels of dissolved CO_2 are so high in some volcanic lakes that geysering pipe installations are used to reduce the possibility of catastrophic, large-scale gas release (Halbwachs, 2001). In 1984, a gas cloud emerging from Lake Monoun, Cameroon, killed 37 people. Two years later, catastrophic CO_2 degassing at nearby Lake Nyos killed over 1,700 people, some as far away as 25 kilometers. To reduce the recurrence of such events, a system has been devised to extract the CO_2 in a controlled manner. At Lake Nyos, pipes have been installed that reach from the lake surface to the bottom of the CO_2-laden lake. By artificially reducing the pressure near the bottom of the pipe, a CO_2-driven, geyser-like eruption is induced. Five installations in Lake Nyos now erupt perpetually to 50 meters high.

CO_2 also may exacerbate eruptions of steam-driven geysers. Though the geysers at El Tatio, Chile are steam-driven, the frothy, erratic eruptions of the Middle Geyser Basin appear to be caused by both steam and vigorous CO_2 degassing (Waltham 2004, Glennon and Pfaff 2003). Similarly, at Yellowstone National Park, Crater Hills Geyser and an unnamed geyser a few kilometeres west of Norris Geyser Basin appear to be at least partially gas-driven (Rocco Paperiello, pers. comm.).

In Karlovy Vary, Czech Republic, Vridlo Geyser is a warm-water perpetual spouter that plays to 12 meters. An unusual characteristic of the 73˚C spouter is that a glass and column colonnade has been built around it; thus, the geyser is indoors.

In central Madagascar, near the village of Analavory, geyser-like eruptions occur from an area of travertine mounds (Eric Sibert, pers. comm.). The travertine has deposited at the warm-water outflow of pipelines from a nearby mine. When the vents are blocked, the build up of pressure produces spouting to several meters once uncovered. Otherwise, spouting perpetually plays to 20–30 centimeters.

Historic accounts from the mining village of Marmol, Mexico, state that a nearby spring, El Volcan, erupts gasses and water once a month as high as 16 meters (Petersen 1999, page 135). Photographs of the vicinity show effervescing springs and large travertine mounds. Whether El Volcan continues to have eruptive activity is unknown.

Undoubtedly, other CO_2-driven cold-water geysers and spouters exist. Readers are encouraged to document any other known spouters, either by publishing in this journal or contacting the authors.

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An overview of the setting at Crystal Geyser, Utah. The new casing is visible at the left–center of the image, and extensive travertine terraces extend from there to the Green River. [Photo by Alan Glennon]

The beginning of an eruption by Crystal Geyser, Utah, on June 10, 2004. A muddy eruption in a small pool can be seen at the lower left. [Photo by Alan Glennon]