A Special Report

The Extraordinary Thermal Activity of El Tatio Geyser Field, Antofagasta Region, Chile

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Abstract

El Tatio Geyser Field (locally known as Los Géiseres del Tatio) is located within the Andes Mountains of northern Chile at 4,200 meters above mean sea level, 150 kilometers east, southeast of Calama, Chile. With over 80 active geysers, El Tatio is the largest geyser field in the southern hemisphere and the third largest field in the world, following Yellowstone, USA, and Dolina Geizerov, Russia. From March 19–21, 2002, the authors visited the geothermal field to inventory the geysers and their behavior. Of over 110 erupting springs documented, more than 80 were identified as true geysers and an additional 30 were perpetual spouters. Despite reports that geyser activity occurred only in the morning, no abatement in activity was observed at any time within any part of the field. Although the observed activity was vigorous, eruptions commonly reached less than one meter. Of the erupting springs cataloged, the mean spouting height was 69 centimeters. Of the true geysers cataloged, the eruptions averaged 76 centimeters. El Tatio Geyser Field contains approximately 8 percent of the world's geysers.

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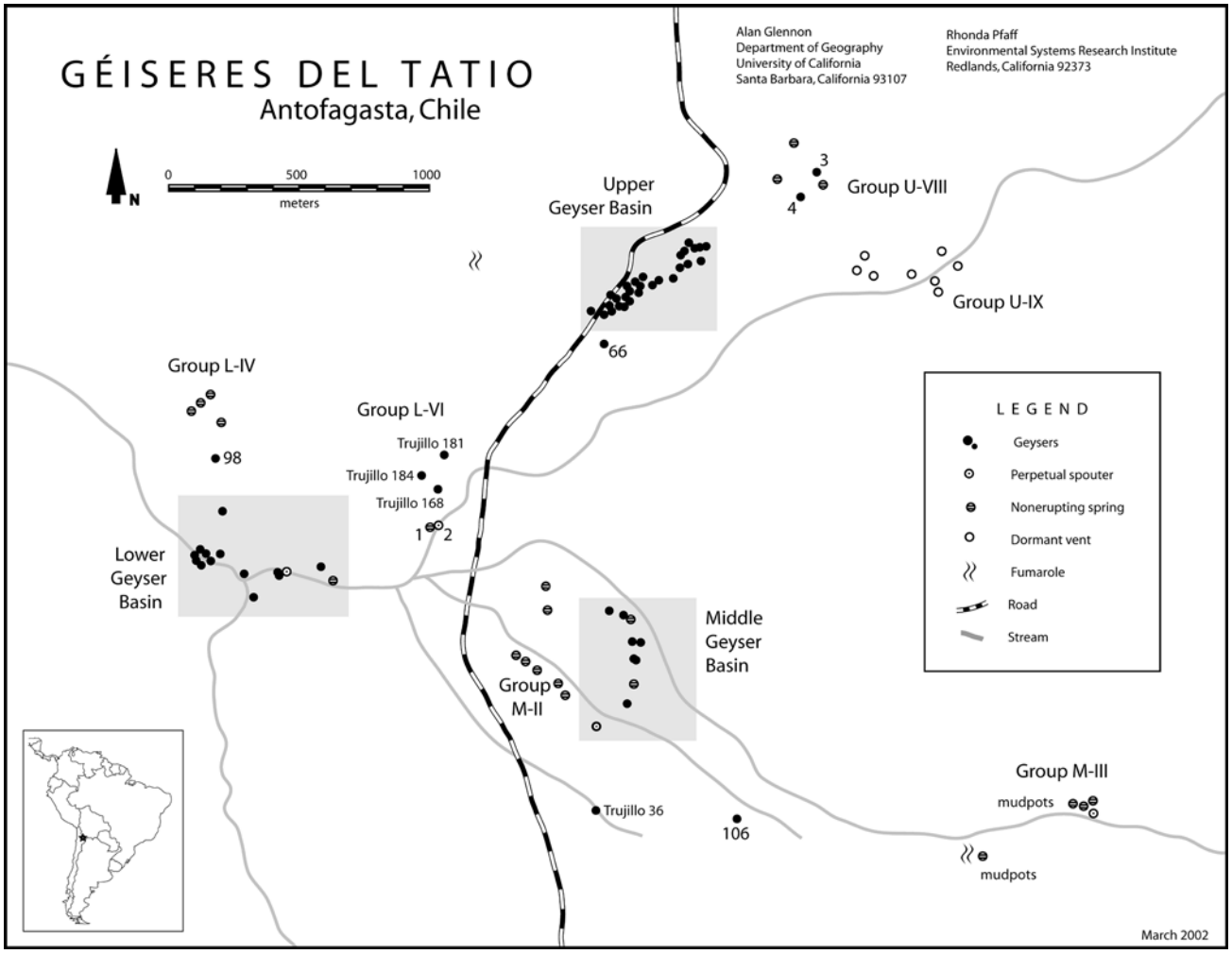
The authors among the mudpots of Group M-III. Left to right: Alan Glennon, Weldon Hawkins, Rhonda Pfaff and Shane Fryer. (Photo by Alan Glennon)

Map A — Index Map to El Tatio Geyser Field



PART I. EL TATIO GEYSER FIELD

I. INTRODUCTION

El Tatio Geyser Field, with over 100 erupting springs, is the largest geyser field in the southern hemisphere and the third largest field in the world, following Yellowstone, USA, and Dolina Geizerov, Russia. From March 19–21, 2002, a four–person team visited the geothermal field to inventory the area's geysers and their behavior. Of over 100 features documented, more than 80 were identified as true geysers and an additional 30 or more appear to be perpetual spouters (however, some of these spouters may be geysers with long durations). Three regions at El Tatio where geysers have been previously reported were not visited. An extended study at El Tatio would likely find many more true geysers. Although the observed activity at El Tatio is vigorous, eruption heights are commonly less than one meter. Numerous uncataloged springs continuously boil and occasionally eject small erratic splashes.

The Tatio geysers (locally known as Los Géiseres del Tatio) are located within the Andes Mountains of northern Chile at 4,200 meters above mean sea level, 150 kilometers east, southeast of Calama, Chile. El Tatio spans a 10 km^2 region of Andean altiplano. Geyser activity is fueled by water heated by a volcanic complex that lies primarily east of the field. Ignimbrite (which is compositionally similar to rhyolite) is the likely source of silica needed for development of the geyser plumbing network.

Within the field (Map A, above), three separate zones of geysers exist, each with a different character. The three major geyser zones are: 1) The

Upper Geyser Basin (or Main Terrace) lies near the floor of a gently sloping valley and is characterized by relatively low water discharge but well–developed sinter terraces. Numerous large active and inactive geyser cones lie within the Upper Basin. The Upper Basin is the largest of the fields (spanning 5 km^2) and contains the greatest single number of erupting springs. A feature in this zone was the tallest observed geyser of the basin, erupting to 5 meters or more. While a majority of the erupting springs at El Tatio appears erratic, numerous geysers in the Upper Basin appear to have predictable intervals and durations. 2) The Middle Geyser Basin, a flat sinter plain, lies immediately to the south of the Upper Basin. A series of 3–meter deep pools have frothy, fountain–type eruptions. The intervals are short (near continuous) and the eruptions are erratic in duration and height. 3) The Lower Geyser Basin (or River Group) lies along the banks of the Río Salado, approximately 2 kilometers downstream from the Middle Basin. At least ten springs erupt in and near the river to heights of 1 to 3 meters. Some features in the Lower Basin erupt from within the flow channels of the river itself, including several underwater geysers whose eruptions eject sediment onto the riverbank. Very little sinter accumulation has occurred in this downstream river group.

Previous Work

Mentions of geysers in the altiplano were first included in descriptions of northern Chile by Bertrand [1885] and Sundt [1909]. In 1921, Italian engineer Ettore Tocchi [1923] began a study of the geology and geothermal manifestations to determine their suitability as a source for electricity production. The next attempt at a detailed study of El Tatio was by Brueggen [1943]; however, due to the isolation of the area and difficulty traveling to the geysers, only a few observations were made. In 1953 and 1960, Dr. Angelo Filipponi, a professor at the Universidad Técnica Federico Santa María, Chile, described the characteristics of the hydrothermal phenomena at El Tatio and made comparisons with the geothermal source and production facilities in Italy [Filipponi, 1953, 1960; Andres *et al*., 1998]. Zeil's 1956 and 1959 works were the first to provide a numerical count of features and a description of the springs' geochemistry.

The next detailed investigation began in 1968 with the joint work of the United Nations Development Program and the Government of Chile. These investigations included a detailed survey of the natural features of the basin by Trujillo *et al.* [1969], in which over 200 features were mapped. Continuing investigations were commissioned to assess the economic feasibility of geothermal electricity production and water desalinization. These studies included discussions of regional geology, structure, and geochemistry [Trujillo, 1969; Lahsen and Trujillo, 1976; Cusquicanqui *et al*., 1976]. Six exploration wells (at depths to 740 meters) and production wells (to 1,821 meters deep) were drilled between 1969 and 1974. The majority of these wells are 2 kilometers south of the Main Terrace. In 1974, a pilot desalinization plant was sited adjacent to the Main Terrace. In 1981, the Chilean Economic Development Agency (CORFO) conducted a study on the basin concluding that, with existing wells, El Tatio has electrical production potential of 15 to 30 megawatts [Andres *et al*., 1998]. In March 2002, no wells were discharging and no geothermal electric production facilities were in place at the field. The abandoned desalinization equipment still stands within 100 meters of El Tatio's tallest geyser (T25). Other recent scientific work has examined El Tatio's silica deposition, with an emphasis on geyser eggs and pearls around thermal pools and geyser cones [Jones and Renaut, 1997].

Purpose and Scope of This Study

The purpose of the investigation was to inventory and characterize the behavior of the geysers of El Tatio. The study is restricted to assessing the geysers themselves; within the limited time of only three days at the basin, many significant hydrothermal manifestations were not inventoried. While at least 30 perpetual spouters were noted, descriptive information was not collected for all of them. Based on previous investigations, our inventory includes approximately 25 percent of the thermal features in the field. Numerous perpetual spouters, mudpots, warm springs, solfataras, and fumaroles,

await future investigators. In addition, with our limited time, we were able to collect only basic, preliminary data for each cataloged feature.

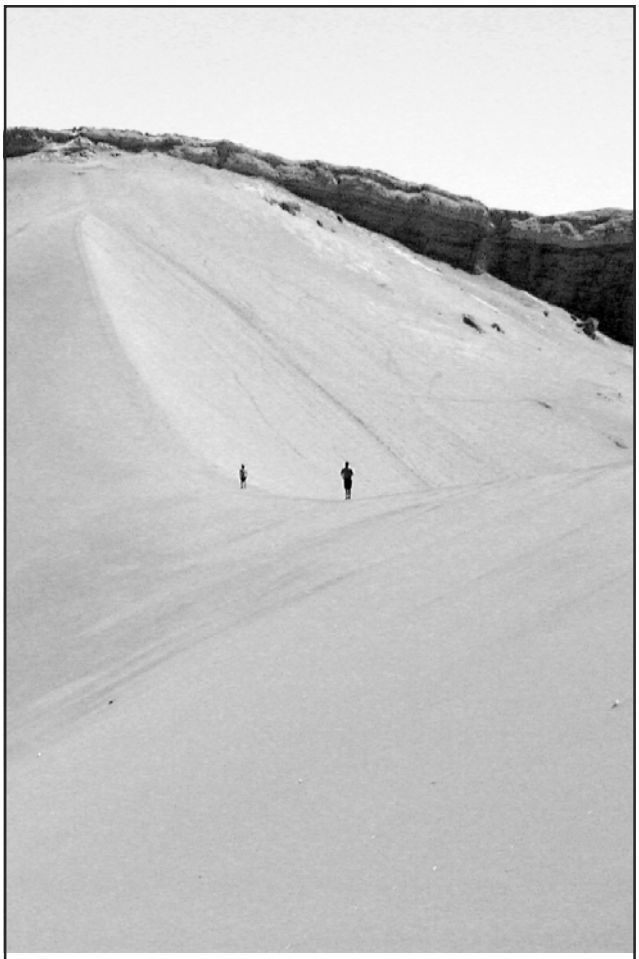
For most of the geysers, only one or two closed intervals were observed. Data presented reflect these short observation periods and should be evaluated accordingly by readers. In addition, the behavioral data represent a three–day snapshot of conditions at the basin. Seasonal climactic variations, seismic effects, and anthropogenic intervention are just a few of many factors that could greatly affect data presented in this report. During the study, we obtained only passive information from the basin and transcribed data to field notebooks; no water or rock samples were collected. During our visit to the geysers, no other people (guides, tourists, or workers) were at the basin. Thus, the cultural component of names and history of various features were not collected. According to local guides in San Pedro, the larger geysers and cones and several of the pools have been named. However, for this study, individual features are presented with a code assigned in the field. Where possible, we correlate these codes to the Trujillo *et al.* [1969] map numbers.

II. GEOGRAPHY

Regional Geography

The geysers of northern Chile are found in the Atacama Desert, a region of South America known for being one of the driest places on earth. The Andes Mountains bound the eastern side of Chile, with a high plain (altiplano) nestled between the mountain peaks. The Andes are tectonically active; volcanic eruptions and earthquakes are common. The mountains are forming as the Nazca oceanic plate subducts under the South American continental plate. Surface hydrothermal activity is present over a wide area of northern Chile and southern Bolivia, including several areas containing geysers or perpetual spouters. The known geyser fields of Chile include El Tatio, Polloquere, Puchultisa, and Tuja. Though unconfirmed, geysers and erupting springs also have been reported at San Andres de Quiguata near the village Lirima. The Sol de Mañana geothermal field lies across the international border from El Tatio in Bolivia.

The main cities of interest in the Antofagasta (or Region II) province of Chile, the zone in which El Tatio is located, include Antofagasta, Calama, and San Pedro de Atacama. The city of Antofagasta, with a population of 275,000, is the capital of the region. Antofagasta is a coastal harbor city that serves as a shipping center for the mineral resources produced in northern Chile and landlocked Bolivia. Calama lies about 300 kilometers northeast of Antofagasta at an altitude of 2,250 meters. Calama has the nearest commercial airport for travel to El Tatio. Calama, with a population of 150,000, is the service center and residential base for the Chuquicamata mine that is located 16 kilometers north of Calama. The mine is one of the largest copper mines in the world.



Shane Fryer and Weldon Hawkins atop a large sanddune at Valle de la Luna, near the village of San Pedro de Atacama. (Photo by Alan Glennon)

San Pedro de Atacama is about 100 kilometers southeast of Calama. San Pedro is a small village of about a thousand permanent residents settled around an oasis in the Atacama Desert. The village emerged as a rest on a cattle trail and a stop connecting the llama herders of the altiplano with the fishing communities on the Pacific [Graham *et al*., 1999]. San Pedro, at 2,440 meters in elevation, now serves as an eco–tourism mecca — a springboard for tours to the Atacama Desert, the Altiplano, and Andes Mountains. El Tatio, 86 kilometers northeast of San Pedro, is located at 4,200 to 4,300 meters above mean sea level.

The altiplano, or *puna*, is a stark region with unique wildlife. Several types of llama are found in this area, with vicuña most commonly seen around El Tatio. Small nocturnal animals, such as chinchillas and their relatives, *viscachas*, also live in this region. The desert, in many places, is void of vegetation. The rocky, reddish volcanic soils are exposed throughout, except where shrubby grasses and trees grow in wetter areas. Hydrothermally altered soils are widespread in the geyser basin and throughout the regional linear depression (graben) extending north and south of El Tatio. The thermal areas often feature rich, brightly colored algae and bacterial mats.

"El Tatio"

"El Tatio" comes from the Atacama word, *el tata*, meaning "the grandfather." Volcán El Tatio lies 10 kilometers southeast of the geyser field. According to local legend, the Grandfather, the volcanic mountain, protected the Atacama people and has provided the force of steam for hundreds of years [ENTEL Antofagasta, 2002].

Tourism at El Tatio Geysers

Our experiences at El Tatio were quite different from those of the typical visitor. We arrived later, stayed longer, had our own transportation, took notes, and saw more water than steam from the geysers. For the normal visitor, tours from San Pedro to El Tatio leave at 4 a.m. and return by noon, costing about US$20 per person. Regarding El Tatio, *Lonely Planet* stated that the "visual impact of its steaming fumaroles at sunrise…is unforgettable and strikingly beautiful" [Bernhardson, 2000, p. 287].

Another guidebook, *The Rough Guide*, said of the El Tatio tourist experience [Graham *et al.*, 1999]:

> First, you drag yourself out of bed in the dead of the night, with no electric lights to see by; you then stand shivering in the street while you wait for your tour company to come and pick you up at 4 a.m.; and finally, you embark on a three–hour journey across a rough, bumpy road. Add to this is the somewhat surreal experience of finding yourself in a pre–dawn rush hour.

These guidebooks recommended that the morning is the best time to see the geysers. Tourists typically watch the sun rise, eat breakfast, view the geysers, and take a soak in a warm pool before returning to San Pedro de Atacama. The tour agencies tell tourists that El Tatio is only active in the cool, early morning when there are tall, billowing steam plumes. As expected, we found that though the large steam clouds do diminish as daytime temperatures rise, geyser activity continues throughout the day unabated.

Tours also typically include breakfast at El Tatio, often consisting of eggs boiled in hot springs. Some tourists we spoke to at our hotel said that their guides served pieces of the hot spring bacterial mats and hot tea and milk warmed with thermal water. Several springs on the Main Terrace appeared altered for tourism. For instance, spring T60 had probably been used for cooking—its calm greenish–brown water had a thick film on its surface and had trash scattered around it. The pool's temperature was measured at 43.8°C, with an adjoining pool measured at 25°C. These temperatures were at least 30°C lower than other surrounding, non–erupting springs.

At El Tatio, there are no boardwalks or designated roads. Unfortunately, footprints and tire tracks are found all over the field. In fact, some sediment–filled spouters lie in the middle of tire ruts. Many springs had been vandalized with rocks jammed into their vents; one of the larger cones had a metal rod, trash, and rocks stuffed into its vent. We removed artificially placed rocks and pebbles from at least ten Main Terrace springs.

Many of these geysers erupted to greater heights after their obstructions were cleared. Given its generally unmanaged, unprotected status, it is probable that large amounts of geysersite and sinter pearls have been removed over the years. Overall, even though subjected to a great deal of abuse, the appearance and intensity of activity within the field is extraordinary.

Getting Around in the Basin

No roads from San Pedro to El Tatio or within El Tatio itself are paved. With its approximately 10 km^2 area, the main geyser areas are within 3 kilometers of one another. Tire tracks from other vehicles are visible throughout the basin and roads to drilled wells are obvious. The entire length of the Main Terrace is accessible by road, although we walked along the banks of the river to visit the springs downstream along the Río Salado (Lower Geyser Basin). Although no trail existed, it was a relatively easy walk. A manmade dam–like structure, possibly a weir, was located just upstream of the lowest spring group. The presence of the dam likely indicates the existence of a nearby road with easier access to the area; the road would likely be on the south side of the river. Some of the Río Salado could be waded, since it flows as a shallow (less than a 50 centimeters deep), braided river throughout much of the basin. Only a visit to the Lower Geyser Basin or to a thermal swamp above the wells required traveling more than 2 kilometers from the Main Terrace. A series of roads at the drilled wells lead upward to the thermal swamp and its perpetual spouter. The roads were built for geothermal drilling, and require a high–clearance vehicle; they also easily could be walked. Although El Tatio Geyser Basin poses the safety hazards of a typical major hydrothermal field, navigating within the basin is relatively straightforward.

III. HYDROGEOLOGIC SETTING

El Tatio Geyser Field is located in northern Chile on the western flank of the Andes at an altitude of 4,200–4,300 meters. The boiling point of water at the Upper Geyser Basin is 86.3°C. Though hydrothermal manifestations occur over a 30 km^2 area, the primary geyser field comprises only 10 km^2. Other smaller thermal areas have been noted southeast of the geyser area at altitudes greater than 4,600 meters.

El Tatio is situated in the Altiplano–Puna Volcanic Complex. Surface thermal manifestations are located on the upper levels of the sunken block called the Tatio graben, which is oriented north–south for approximately 20 kilometers. The graben is limited to the west by the horst of Serrania de Tucle–Loma Lucero and may be limited to the east by the modern volcanic chain that reaches altitudes above 5,500 meters [Lahsen and Trujillo, 1976; de Silva and Francis, 1991]. The horst and graben originated in a Pliocene extension that was largely responsible for the uplift of the Andes. El Tatio is set on ignimbrites and lavas of the upper Cenozoic overlying a basement of Mesozoic sediment. Silicic volcanism has occurred in the region for at least 10.4 million years [de Silva and Francis, 1991]. The hot water of the basin is mainly confined to two aquifers, which are overlain by relatively impermeable formations. The Puripica and Salado ignimbrites, forming the lower aquifer, are overlain by the impermeable Tucle tuffs. Another aquifer spanning the central, southern, and southeastern region of the basin is formed in the Tucle dacite, which is overlain by the impermeable Tatio ignimbrite [Cusicanqui *et al*., 1976].

Preliminary tritium data for thermal waters within El Tatio Geyser Basin yielded an age of 15 to 17 years at discharge [Cusicanqui *et al*., 1976]. In contrast, geochemical dating at Yellowstone indicates that the water ejected by Old Faithful Geyser today fell as precipitation approximately 1100 years ago [Rye and Truesdale, 1993]. The likely source basin for the Tatio water is an area 15 to 20 kilometers east and southeast of El Tatio, although the topography of the region may cause the water to travel twice that distance. The rate of water movement has been estimated at about 1 kilometer/year [Cusicanqui *et al*., 1976]. The Sol de Mañana thermal field is located 30 kilometers east, southeast of El Tatio Geyser Basin. It is likely that the El Tatio and Sol de Mañana hydrothermal fields are both fueled by the Pastos Grandes and Cerro

Guacha caldera systems, with Sol de Mañana being closer to the thermal source and El Tatio being a lower elevation distal discharge location [Healy and Hochstein, 1973; Lahsen and Trujillo, 1976].

Spring discharge from El Tatio Geyser Field coalesces to form the headwaters of the Río Salado. The river flows westerly out of the basin, through a narrow gorge penetrating the Serrania de Tucle Horst. Discharge of the Río Salado varies by season from 250 to 500 liters/second [Lahsen and Trujillo, 1976]. These measurements can roughly be compared to a range between the discharges of Yellowstone's Excelsior Geyser of the Midway Geyser Basin (223 liters/second) and the Upper Geyser Basin (518 liters/second) [Allen and Day, 1935; Rinehart, 1980]. Previous investigations at El Tatio have denoted an average thermal water pH of 7.2 [Lahsen and Trujillo, 1976], denoting an approximately neutral basin.

IV. METHODS

For this investigation, 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]. A *perpetual spouter* is a hot spring that ejects water out of its vent or pool with continuous eruptive activity.

In order to inventory and characterize the erupting springs of El Tatio, a combination of handwritten notes, Global Positioning System (GPS) locations, temperatures from a digital thermometer, still photographs, and video were collected during the three–day visit in March 2002. Working in the basin from the northeast to southwest, a two–person team took notes about each feature. For each feature exhibiting geyser–like behavior, the feature was assigned a code number. The feature's latitude and longitude, temperature, interval, duration, eruption height, and any other notes concerning unusual characteristics or behavior were then collected. GPS coordinates were obtained as close to the erupting vent as possible (within 1 meter horizontal and vertical) using a Garmin GPS III Plus handheld unit. Horizontal (degree, minute, decimal minute) and vertical (elevation in meters, with reference to mean sea level) locations were obtained in the WGS 1984 coordinate system; these data were recorded "raw," as non–differentially corrected. For the report's maps, initial positions were adjusted to reflect data from existing maps, satellite imagery, and relative feature locations in field sketches. For many of the features, vent and runoff channel temperature data were obtained, in degrees Celsius, using a digital thermometer. For most features, due to the prevalence of activity and time constraints, only two or three closed intervals were observed. It is likely that longer observations would show the geysers' behaviors to be more complex.

As two people inventoried and collected GPS locations, another person videotaped each feature, while the fourth individual conducted reconnaissance. Digital video was collected using a JVC GR–DVL815U mini–DV digital camcorder. In all, over six hours of video were taken at El Tatio, capturing the eruption of over 100 springs. Each of the four team members had a camera and several hundred still photographs were taken within the basin. With our team's limited time in the basin and the unexpectedly large number of true geysers, numerous perpetual spouters, mudpots, non–boiling springs, solfataras, and fumaroles were not inventoried.

Upon returning to the United States, field notes were transferred to a Microsoft Excel spreadsheet. Careful analyses of the field video and still photographs allowed the spreadsheet and notes to be verified and supplemented. In particular, the digital video provided the team with a method to develop detailed descriptions of both eruptive activity and feature appearance. Maps of the basin were created by importing name, location, and behavior data into the Environmental Systems Research Institute (ESRI) ArcInfo 8.3 Geographic Information System (GIS). A basemap of the basin was created by digitizing portions of topographic maps (Cerros de Tocorpuri and Toconce) from the Instituto Geográfico Militar [1985, 2001b] and further enhanced with NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. An Instituto Geográfico Militar [2001a] topographic map of Mauque, containing the

Puchultisa thermal area, was also digitized and added to the GIS. Given the close proximity of features compared to the resolution accuracy of sources, maps produced for this report are best suited for relative positioning and locating features in the field.

In the field at El Tatio, we used a map of thermal features by Trujillo *et al.* [1969]. Before the trip, Scott Bryan provided a list of feature numbers from the Trujillo *et al.* map that had been reported as geysers. Unfortunately, the density of springs made identification of individual features on the Trujillo *et al.* map difficult. Nonetheless, the map provided a reference to major spring groups and facilitated general navigation. Once the GIS was created, we attempted to reference our field numbers with the Trujillo *et al.* feature numbers. Using the ESRI ArcView Image Analysis extension, the Trujillo *et al.* map was georeferenced to the basemap. Overall, the density of thermal features decreased our ability to correlate specific numbered points from the Trujillo map. However, general spring groupings are apparent and consistent.

V. DISCUSSION AND FUTURE RESEARCH

Investigations at El Tatio Geyser Field have determined that it contains at least 100 erupting springs. With geothermal energy production and other exploitation impairing the major geysers fields throughout the world [Allis, 1981; Collar, 1990; Hroarsson and Jonsson, 1992; White, 1998; Sorey, 2000; Bryan, 2001], El Tatio stands as the third largest geyser field on earth and the largest geyser field in the southern hemisphere. The greatest number of geysers remains in the hydrothermal basins of Yellowstone, USA and Dolina Geizerov, Russia [Bryan, 2001]. With 80 or more, El Tatio's geysers account for approximately 8 percent of the world's active geysers. In addition, at least seven features previously reported [Trujillo *et al.*, 1969] as geysers were not visited. While many geysers and erupting springs were inventoried in this study, there are hundreds of other thermal manifestations at El Tatio to be documented, precisely mapped, and described. Additional mapping is necessary to gain greater detail, including observing more closed intervals, examining interrelationships among features, and updating behaviors that have changed since this and previous studies. Detailed maps of all features, not just the geysers, should be completed with higher–grade GPS units and applying differential correction or carrier–phase processing to the data. High–resolution satellite imagery can also provide an effective mapping tool for the area. A thermal feature inventory may be useful to evaluate the effects of previous and future hydrothermal drilling on the region.

Previous information reported that the geysers were only active in the morning. El Tatio tours typically arrive at the basin in the cool, early morning hours when tall steam plumes hide the geysers' relatively short eruption heights. We observed sustained geyser activity throughout our visit to El Tatio. There was no abatement in activity for any length of time within any part of the field. Although activity was consistent, geyser eruptions were observed to be relatively short in height. Of the erupting springs cataloged, the mean spouting height is 69 centimeters. Of the true geysers cataloged, the eruptions averaged 76 centimeters. A total of 31 geysers in the basin erupt to at least a meter; of these geysers, 13 have eruptions greater than a meter in height. Compared to Yellowstone and Dolina Geizerov, which both have a dozen or more geysers that erupt to 50 meters and greater, El Tatio geysers are small. The causes behind the short heights are unknown. More research is needed to determine if the heights at El Tatio are related to the plumbing system, the heat source, or other factors.

Many questions remain and numerous research avenues exist for the El Tatio geysers. Additional examination into the timeframe for the development and history of the activity of El Tatio, along with further tritium dating, are needed. The relationship between El Tatio and other Andean thermal areas, such as Sol de Mañana, should also be examined and quantified in future research. With its location in an active volcanic arc, opportunities exist to monitor relationships between seismic and volcanic activity and the field's hydrothermal behavior.

In addition, El Tatio's high altitude location within an exceptionally dry desert, create an extreme habitat for microorganisms. Microorganisms within other extreme environments, like the springs of Yellowstone, have been known to exhibit useful and financially marketable characteristics. Moreover, hydrothermal systems may be a "cradle" for early biosphere evolution, as thermophilic life may have the characteristics of the common ancestor of life on earth and other planets [Farmer, 2000; Walter and Des Marais, 1993; Farmer and Des Marais, 1994].

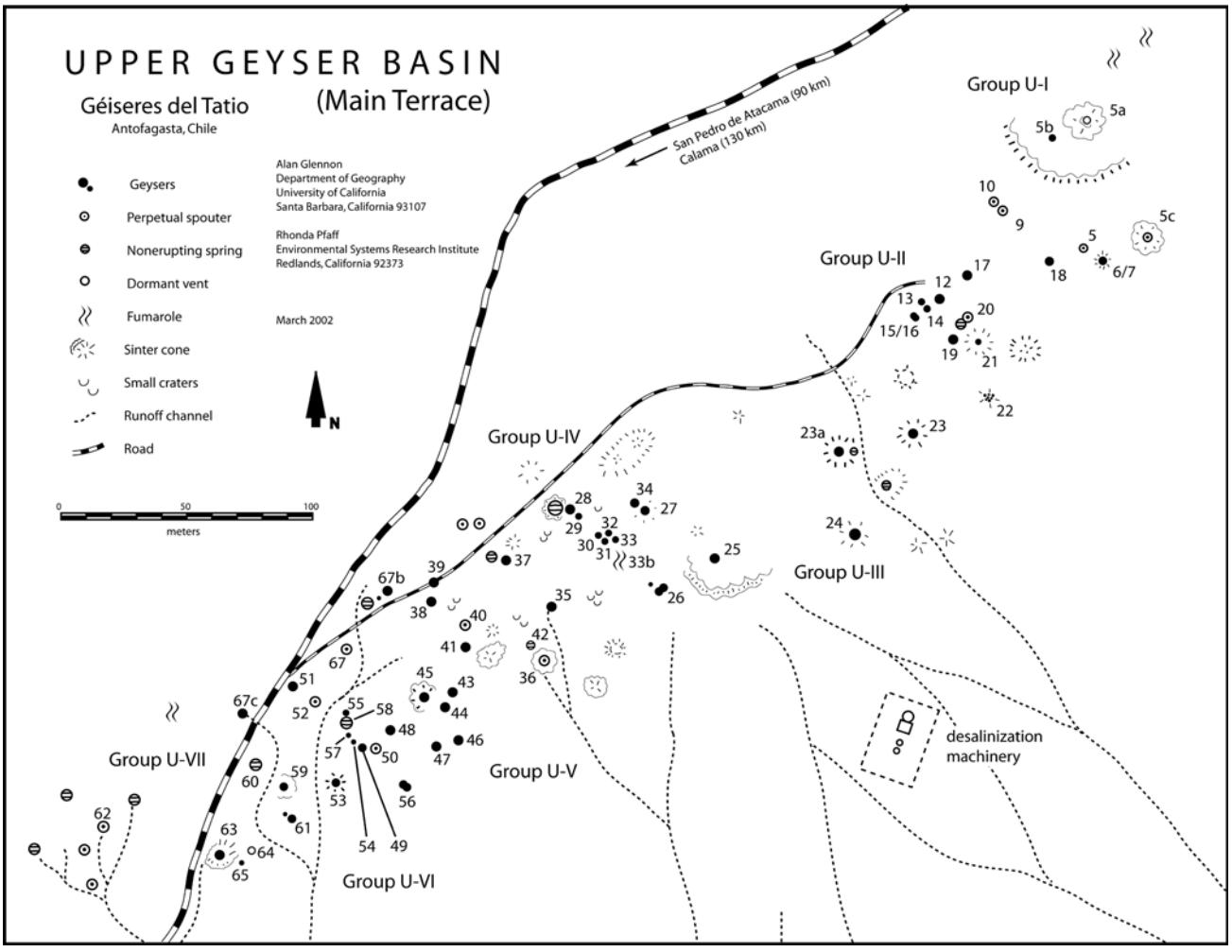
With its vigorous activity and rare display of geysers, El Tatio Hydrothermal Field is a unique, world–class natural resource. We hope this initial report will provide footing for researchers to develop a better understanding of this remarkable location.

PART II. SPRING DESCRIPTIONS

UPPER GEYSER BASIN OVERVIEW

The Upper Geyser Basin (or Main Terrace) lies near the floor of a gently sloping valley and is characterized by widespread, well–developed sinter terraces (Map B, below; see also Map A). The scene within the basin is stark. The broadly sloped flat of gray and white is punctuated by a handful of active and inactive geyser cones. During cold temperatures, steam is emitted from hundreds of crevices and vents. During warmer weather, viewing the area from a distance, it may appear that very little activity is occurring. However, a closer look reveals that the Main Terrace is always highly active. Numerous small spouters are in continuous eruption, several handsome pools bubble gently, and many of the largest geysers are usually nearing eruption.

Map B — Upper Geyser Basin (Main Terrace)



Within the Upper Geyser Basin of El Tatio, geysers surround the visitor.

Next to the broad flats of the geyser basin, the surrounding hills and mountains provide a contrast of color and scenery. To the west, north, and south, tall brown hills with scrubby grass line the basin. These steep hills are covered with reddish soils and have large boulders strewn along their slopes. The red soils are tempered by hints of green and yellow from grasses and stubby plant life. A wide, broad break in the hills to the southeast reveals the pass down out of the mountains. In the foreground of the pass, numerous steam plumes from the Middle Basin are visible low in the valley. Commanding the view to the east are the tall, snow–capped volcanoes of the Andes. The distant high–elevation mountains appear a shadowy blue.

The Upper Basin is the largest of the fields (spanning 5 km^2) and contains the greatest number of erupting springs. Though the Main Terrace extends into and down the valley to the Middle Basin, the primary zone of geysers stretches along a narrow band. The band follows a northeast–southwest lineament about 500 meters long and 100 meters wide. No less than 50 true geysers are in this small zone. Besides possessing the greatest number of geysers within El Tatio's three main basins, many geysers in the Upper Basin appear to have predictable intervals and durations.

Descriptions follow roughly from the northeast to southwest. With its small area and high concentration of springs, most Main Terrace features do not lend themselves to clear groupings. However, the springs' characters do change throughout the basin, with springs in close proximity often maintaining a similar character.

UPPER GEYSER BASIN, MAIN TERRACE

GROUP U–I

T5a (Suspect Geyser and Fumaroles)

In the far northeast zone of geyser activity, T5A is an elevated gray–white sinter terrace 3 meters high, spanning an area of 30–by–30 meters. Sitting atop the terrace is a large, steep–sided, highly weathered geyser cone. The cone is oblong–shaped and 1.5 meters high. With its crest approximately 3 meters above nearby features, within the eastern portion of the field, the terrace and cone are a dominating presence. Although we did not take detailed notes about the feature, Alan Glennon climbed to its top to assess its eruptive potential. Upon closer inspection, Alan found the feature not only highly weathered, but it also appeared to have been subject to explosive force. Large cracks had ripped open a portion of the cone, but its main vent was still intact. The feature's throat was approximately 15 centimeters in diameter. Unfortunately, several rocks had been lodged 50 centimeters down the vent. Regardless, below the rock jam, a loud belching churning sound could be heard. The vent itself was moist and hot with steam.

Approximately 20 meters to the northeast of the steep geyser cone, the sinter of the terrace meets the slope of the hill to the north. At the intersection, two deep, dangerous–looking, steep–sided rift craters are present.

T5b (Geyser)

Along the western base of the steep cone lies a small, round pool 20 centimeters deep and 50 centimeters wide. The pool occasionally sends radiating ripples along its surface as steam bubbles implode at depth. A deep thumping underground could be felt on the surface. Over a period of 10 minutes, the ripples increased. The pool began a slightly more vigorous overflow and weak splashing to 10 centimeters began. The splashing lasted about a minute before the pool level dropped approximately a centimeter and activity ceased.

T5c (Perpetual Spouter)

This is an attractive 1.5–meter high white sinter mound with a diameter of 2 meters. The mound gently slopes downward such that it is about twice as wide at ground level as at its vents. Water spurts nearly perpetually to 1 meter from at least two vents on its top. Three quarters of the mound is smooth and the other portion is rough and filled with jagged holes. Much of the mound is covered in orange and light brown–colored bacteria (or perhaps mineral deposition). Much of the runoff flows east. The

nearby ground is composed of smooth, white sinter surrounded by small gravels.

T5 (Perpetual Spouter)

T5 is a small perpetual spouter that splashes to 5 centimeters from a vent 20 centimeters wide.

T6 (Geyser)

T6 plays from a 1–meter tall, 2–meter in diameter, white mound with occasional spurts to 10 centimeters for 5 seconds. While no major activity was observed, it appears to have larger eruptive potential. Vigorous, agitated boiling can be seen 50 centimeters down in the cone. A hole in the cone's side has developed as a secondary vent. Water in the spring rises and falls, but only occasionally did it rise high enough to splash outside its cone. There is some chance that the secondary vent and nearby small perpetual spouters are robbing the geyser of energy, but not enough is known about the feature to develop informed conclusions.

T7 (Perpetual Spouter)

T7 is a cluster of 4 vents covered in green algae on a dry, white 40–centimeter tall mound. Activity is apparently perpetual, with spurts to 5 centimeters.

T18 (Geyser)

T18 is one of several vents located on a 3–meter long light gray sinter mound. Most of the vents gurgle and hiss as small frying pans. The smooth mound is only 10 centimeters tall and 10 centimeters wide at its largest. The area around the mound serves as a splash pool for T18. Beaded sinter deposits and other pebbles are scattered about the area.

T18 is a small geyser that splashes to 40 centimeters from a tiny vent along a rift line on the low sinter mound. The geyser erupts for 1+ minutes every 15 to 20 minutes. When not erupting, only a meter–wide zone of wetness hints at the geyser's existence. Otherwise, not even a puff of steam is emitted from its vent. Eruptions begin quickly and consist of splashing pulses, alternating between 20 and 40 centimeters tall.

T9 (Perpetual Spouter)

T9 is a small, typical El Tatio perpetual spouter. It perpetually splashes to 20 centimeters from a 20–centimeter deep, 25–centimeter in diameter pool. A brick–like rock, now covered in sinter, has fallen into the vent.

T10 (Perpetual Spouter)

T10 perpetually boils vigorously to 10 centimeters from a small pool. Both T9 and T10 are located in a small flat area just slightly higher in elevation than the geysers to the south. The flat area is covered with pebbles, gravel, and sand.

Rhonda Pfaff at **Spring T5c**. (Photo by Shane Fryer)

GROUP U–II

T12, T13, T14, T17, and possibly T15 and T16, are a complex of interrelated geysers. During our observations, activity within T13 and T14 were closely related. As T13 ended its eruption, T14 began steaming intensely and erupted 50 seconds after T13's end. We noticed that at the end of an eruption of either feature, both would commonly simultaneously

steam lightly. Their eruptions also appeared to affect the eruptions of the complex's major feature, T12, and vice versa. In addition, T17 and T12 also appeared to have sympathetic eruptions and steam phases. The features have relatively short intervals and durations and detailed observation may prove or disprove these hypotheses. In January 2003, Dr. Randall Marrett, Associate Professor of Geosciences at the University of Texas at Austin, conducted a multi–day investigation of this spring group. His findings have not yet been published.

A shallow, half–moon–shaped linear depression lies immediately south of the T12/13/14 complex. The feature was noted because of the suspicious zone of wetness around it. A couple of small fractures are vent possibilities. Further observation may show the feature to have eruptive potential.

T12 (Geyser)

T12 is a geyser that erupts from a sinter–rift complex. It appears to be the dominant geyser in a zone of several interrelated small geysers. The vent is located at the eastern base of the sinter mound. The current vent appears to be developed along the remnants of a geyser cone that has been cracked through its middle and is now heavily weathered. The geyser erupts up to 1.5 meters from a vent on the ground surface at the front of the rift crack. The play is vigorous, and during larger eruptions, a layer of water radiates to the northeast for approximately 3 to 4 meters. The discharge flows over a sinter apron and onto the sandy gravel beyond. Steam increases from the overlying rift and water weakly splashes from the primary vent in the pre–play. The eruption lasts less than 2 minutes and occurs on an interval of about 15 minutes.

T13 (Geyser)

T13 is a small geyser 4 meters northwest of T12 and is located on the sinter complex. It erupts from a gray crack and splashes to 20 centimeters for 2.5 minutes about every 15 minutes. Its play consists of continual splashes ejected as a wide, thin ribbon of water. It is likely to be closely related to the other geysers on the sinter complex, especially T14. At the conclusion of a T14 eruption, T13 typically begins steaming lightly.

T14 (Geyser)

Prior to eruption, steam billows out of a small crack (less than 10 centimeters wide) on a mound 2 meters from T12. Eruptions observed typically occurred within a few minutes of the conclusion of an eruption of T13. The crack and mound have a reddish–orange color. The eruption splashes clear water to 50 centimeters for 1.5 minutes. The play is at full volume and height after only a few seconds of thin spurting. The eruption ends over several seconds as volume, height, and splash intensity decrease. Quickly, water is no longer visible at the surface. The interval ranges from 3 to 15 minutes.

T15/T16 (Geyser)

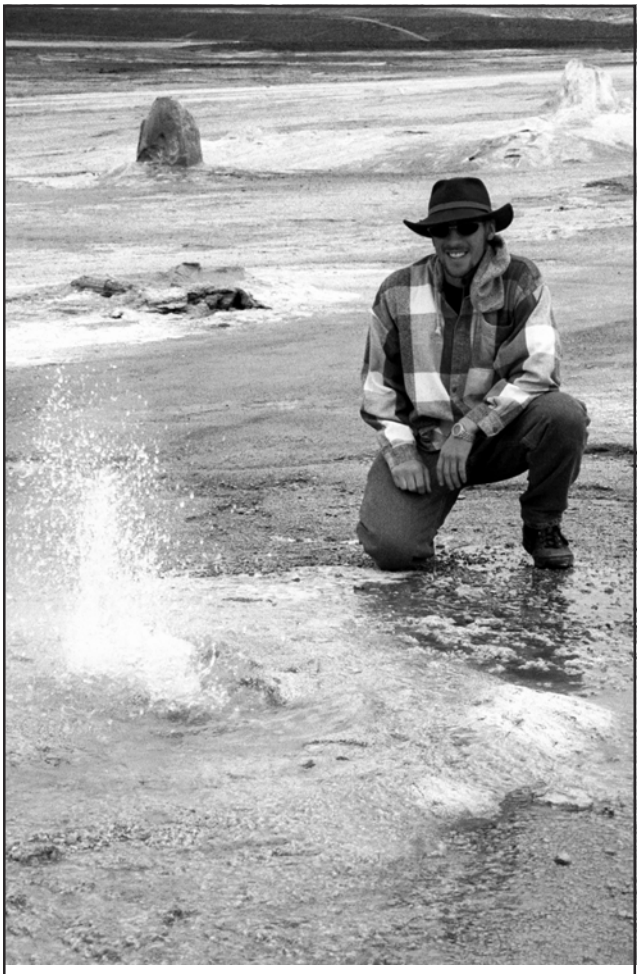
T15 and T16 are two adjoining fountain–type spouters that splash clear water to 10 centimeters nearly perpetually. The pools are located on top of a small sinter mound. The runoff channel has orange bacteria in it. The geyser plays for several minutes, with an interval of 4 minutes.

T17 (Geyser)

T17 is a small geyser that erupts from a gray sinter crater measuring 75 centimeters across and 30 centimeters deep. The vent at the bottom of the crater is about 5 centimeters in diameter. A light gray sinter crust lines the splashdown area around the crater. Clear water vigorously splashes to 50 centimeters for 9 minutes every 5+ minutes. Water rapidly fills the crater half–full and then gradually rises to overflowing during the eruption. When the eruption is finished, the pool's surface becomes still and the pool empties quietly. The pool is completely drained 30 seconds after the eruption's last splash.

T19 (Geyser)

T19 is a geyser that erupts from a shallow crater to heights of 1 to 1.5 meters. One of the more significant geysers of the Upper Basin, T19's eruptions consist of a surging, but sustained, fountain of frothy water. Its vent is located on a short, broad terrace. The vent is surrounded by a flat, platy sinter splashdown ring and its runoff flows south down the steeper side of its terrace. A black, softball–sized rock was located a meter east of the vent.



Weldon Hawkins at **Spring T19**. Springs **T23** and **T23a** are visible in the background. (Photo by Rhonda Pfaff)

The geyser erupts for 3 minutes every 20 to 23 minutes.

T20 (Perpetual Spouter)

T20 consists of a round, non–erupting pool and a ragged, splashing vent 25 centimeters away. The pool is about a meter across and 10 centimeters deep. The pool's rim is encrusted in white and tan sinter and has a silty, tan–colored bed. A softball–sized rock has been jammed into the pool's vent. The adjacent erupting vent perpetually splashes to 10 centimeters from a jagged hole. A wet, dark–brown–colored splash area extends 50 centimeters from the erupting vent. A 5–centimeter wide runoff channel carries its small discharge a meter before the flow disappears into sand and gravel.

T21 (Perpetual Spouter)

T21 is a 2–meter long white–gray mound with 10+ vents that sputter perpetually to 5 centimeters. The mound is banded gray and white with alternating wet and dry areas of sinter. A round non–erupting pool lies in sand and gravel about 3 meters north of the mound.

T22 (Geyser)

T22 is a very unusual, 50–centimeter tall, spiny sinter mound. It has at least 20 vents of pencil–sized diameter, out of which water sizzles for 2 minutes, every 5+ minutes. The eruption gains full strength within 30 seconds, with water spitting up to 30 centimeters vertically from several vents. Other vents shoot water short distances at many angles. The eruption slowly wanes over the next minute and a half. Eventually, only steam and a quiet sizzling sound can be heard. The steam persists for 30 seconds before leading to a 5–minute period of complete quiescence. There are two small runoff channels extending from opposite sizes of the mound. Intricate geyserite makes up the mound and

The unusual, multi-vented geyser, **Spring T22**. (Photo by Rhonda Pfaff)

immediate area. Strips of thin sinter radiate in a few places farther from the mound indicating splash areas of individual vents. The color of the sinter ranges from whites to grays and dark browns.

GROUP U–III

T23 (Geyser)

T23 is a very steep, 1.5–meter tall, dark brown and orange–brown cone that has a nearby dry, white–colored twin cone (T23A). T23 nearly perpetually splashes from a 30–centimeter wide vent at its top. Several periods of minutes had markedly less activity (for instance, splashing every several seconds to less than 10 centimeters). During most of our visit, splashes commonly reached 40 centimeters, with occasional droplets reaching a meter. The splashes often discharged enough water to send a bath of water down all sides of its cone. Along with the T5c, T23 is one of the only large continuously wet geyser cones observed in the basin. Photographs from February 2000 by Cyril Cavadore show the cone of T23 completely dry with no steam. Another tourist photograph showed a tourist seated atop its dry cone. Though its durations and interval are unknown, it appears that the duration, at least, is days. Given the photographic record, the geysers' intervals are likely to be days long, also.

The cones of **Spring T23a** (left) and **Spring T23**. (Photo by Cyril Cavadore)

T23a (Geyser)

Twenty meters west of T23, T23a possesses a cone of similar shape and height (1.5 meters tall and steep sided). However, unlike its twin, the cone is completely white and dry. Several rocks and a metal rod have been stuffed down its vent. A February 2000 photograph by Cyril Cavadore shows the cone wet and several small springs along its base overflowing. Randall Marrett reported T23a active in January 2003 (with T23 inactive). When active, the geyser splashes 0.5 meters over its rim several times per minute. The geyser's interval and duration is days. The twin features (T23 and T23a) display an apparent exchange of function. Observers, so far, have noted only one of the springs active at a given time.

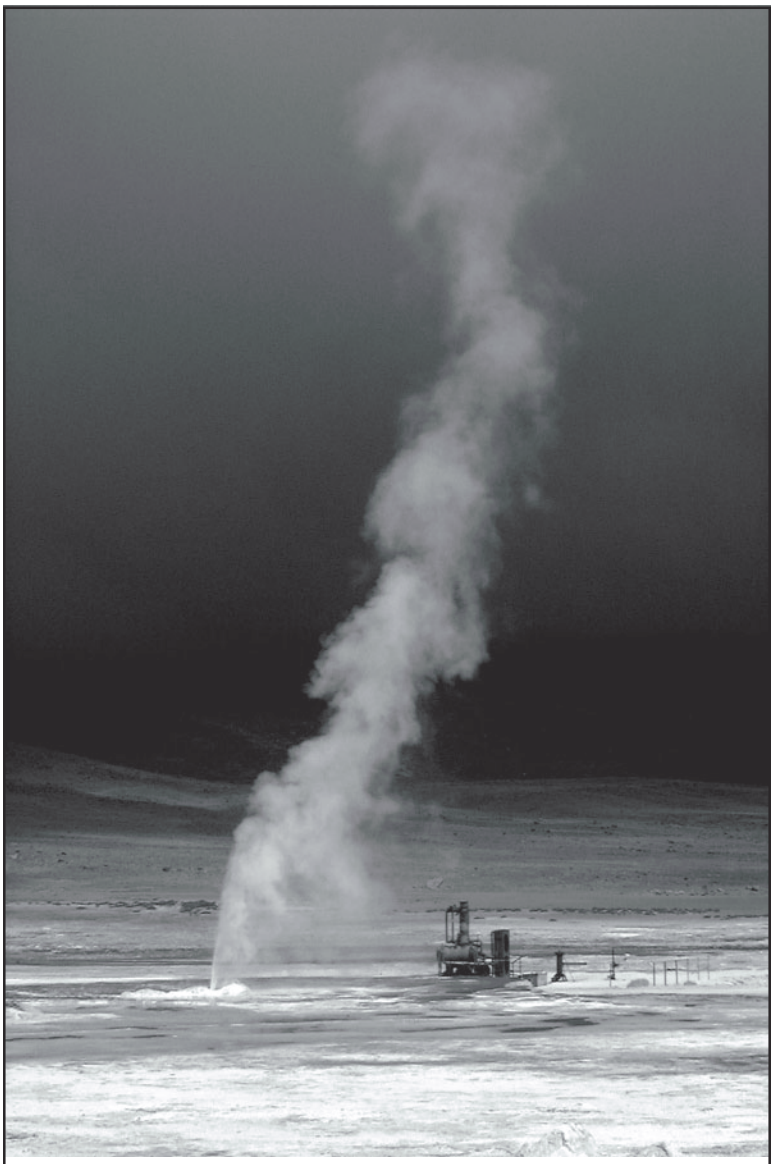
A small runoff stream flows between the two twin cones. Downstream, along its banks are several small boiling springs and perpetual spouters. Seven smaller, broad sinter mounds lie along the stream's downstream banks.

T24 (Geyser)

T24 is a geyser that erupts from a 2–meter wide cone with a 40–centimeter wide vent. The cone is light–to–medium gray–colored sinter and is 40 centimeters tall. The geyser splashes to a meter and forms a pool in the depression of its cone. Splashes infrequently reach 2 meters and land far beyond its elevated sinter mound. The duration of the splashing is less than 35 minutes, with an interval greater than 3 minutes. A series of rising and falling water levels were observed in the vent before the eruption, but future observation is necessary to characterize its exact behavior.

T25 (Geyser)

In terms of height and beauty, T25 is the star of El Tatio. The geyser, the tallest ob-



Storm clouds darken the sky behind **Geyser T25**. Machinery remains from an abandoned project to test steam-driven thermal water desalinization. (Photo by Alan Glennon)

served at El Tatio, can reach heights greater than 5 meters. The geyser is located on top of a wide, multi–tiered terrace 1.5 meters high. The southern portion of the terrace is a meter–high scarp covered with active columnar sinter. The runoff channel is composed of thousands of shallow microterraces. Beaded sinter and oncoids are located everywhere. The geyser exhibits lots of pre–play, consisting of slow building of water volume and height from its 30–centimeter tall mound.

The preplay builds for at least 30 minutes before the full eruption begins. The geyser plays for up to 15 minutes every 2 or more hours, although there was typically small splashes up to 30 centimeters at all times the geyser was observed. A short steam phase and several minutes of inactivity follow its major eruptions. During major eruptions, water is ejected nearly vertically to 5 meters, although a smaller amount of water is shot at a 45° angle to heights of 1.5 meters. During one eruption, the water phase appeared to taper into a longer steam phase. At the end of this type of eruption, the jet of water became increasingly narrow. The thin jet of water may reach heights exceeding 8 meters. Over several minutes, a narrow column of steam replaces the water. Of six eruptions seen, this higher type of eruption was observed only once. The geyser lies approximately 100 meters away from the abandoned desalinization well. A temperature of 62°C was taken from the surrounding splash pool that has orange bacteria growing in it.

Visitors in January and May 2003 reported hours to days of perpetual spouting from T25.

Shane Fryer and Rhonda Pfaff taking a temperature measurement at **Geyser T25**. (Photo by Alan Glennon)

GROUP U–IV

Below a 60–centimeter tall, 1–meter wide elevated hot spring pool, lies a series of small craters arranged linearly. Typically vertical perforations in the sinter, 40 centimeters in diameter and 30 centimeters deep, these craters are aligned primarily along three different trends. Each of the lineaments originates at the elevated hot spring pool and radiate outward. The first trend is approximately aligned toward the east. Only one or two craters exist along the trend, but they head toward a dilapidated, broad geyserite cone 20 meters away. Two geysers are located at the worn geyser cone. The second trend stretches southeast toward T25. Along this trend are numerous craters. Nearly all of the small craters emit steam and boil vigorously in the subsurface. Several of these craters periodically erupt to short heights as geysers. The third lineament trends to the southwest. Several steaming craters and small vents are present, but only one's boiling would periodically reach above the ground level. The trend continues outward toward a region of small vents. The vents trend roughly toward T36 and include numerous multi–colored warm springs with tiny vents (less than 5 centimeters in diameter), several steaming 20–centimeter deep craters, and tiny boiling springs.

T27 (Geyser)

T27 is a geyser that plays from a broad, heavily worn cone, 60 centimeters tall and a meter wide at its top. The top of the geyser cone funnels down 40 centimeters to a circular vent 15 centimeters wide. Most of the vent is clogged with pointy rocks and dry gravel, although a gap along one side of the vent provides an opening for eruptions. Eruptions play as angled surges splashing to 40 centimeters. The eruption rarely plays water outside of the cone's funnel and only a small area of the total geyser vent is wetted by the eruption. One eruptive duration lasted 5 minutes with a minute pause in activity. Other observations found the feature to be perpetual.

T34 (Geyser)

At the northwest base of T27's cone is a small geyser that typically plays to 10 centimeters, but occasionally splashes to six times that height. The geyser plays from a shallow, dark–colored funnel on the ground level amongst sinter gravel. The funnel itself appears worn and some of its sinter is broken. The play is nearly perpetual with momentary pauses. During a typical eruption, very little water flows away from the cone; however, during occasional 60–centimeter tall splashes, water often lands beyond its sinter funnel and onto the nearby gravel. The geyser's runoff channel is an area of moist gravel, but the wet area extends at least 6 meters from the little geyser. From its appearance, the feature occasionally sends significant but short–lived washes of overflow down its channel.

T28 (Geyser)

T28 lies along the southern base of the elevated cone of a 1.5–meter wide, non–erupting, steaming hot spring. The elongated vent creates a jagged cut laterally along the base of the cone. The vent is a meter long and 30 centimeters wide. A primary vent plays often and sends splashes up to a meter. Two satellite vents occasionally play in concert to 10 centimeters or more. The feature appears erratic but almost perpetual, with seconds to a minute of nearly continuous eruption followed by a pause of up to 20 seconds. The vent is angular and jagged, possibly indicating that the feature is relatively new, had a particularly explosive genesis, or has long periods of quiescence.

T29 (Geyser)

T29 lies along the lineament of craters toward T25 approximately three meters from southeast of the elevated hot spring. The steaming jagged crater, approximately 30 centimeters wide and deep, plays to 50 centimeters above ground level. Several observed closed intervals showed the play to last 30 seconds with an interval of approximately 2 minutes. The crater steams gently throughout its quiet period.

T30 (Geyser)

Six craters in a 3–by–3 meter area include several small, apparently erratic geysers (T30, T31, and T33). The largest of the group is T30. T30 possesses a 50–centimeter wide, 30–centimeter

deep crater. Similar to the other features in the immediate vicinity, the crater drops off at ground level with vertical walls and has an irregular shape. During three closed intervals, T30 played to 30 to 40 centimeters above ground level with a 5 second duration and an interval between 15 and 25 seconds. Very little water is discharged by the eruption.

T31 (Weak Geyser)

T31 is a very small and apparently erratic geyser playing from a narrow, 1–meter long vent. Though boiling can be heard constantly in the vent, an occasional splash to 20 centimeters may occur. During our observation of the area, a single weak splash would occur from the southern portion of the vent not more than once per minute. Overall, compared to the nearby activity, the eruption is very easy to miss. Normally, the geyser is a gently steaming crater.

T33 (Weak Geyser)

T33 is another very small and apparently erratic geyser. It plays from a 30–centimeter in diameter, erratically shaped vent along the lineament between T28 and T25. A single splash, lasting no more than a second occurs every 30 seconds or more. The weak splash commonly plays to 20 centimeters above ground level.

T33b (Fumarole)

Although not seen in eruption, this feature may be more important than the several other minor features in the area. T33B is an elongated vent sub–parallel with the T28/T25 lineament. The 20–centimeter deep crack has a tiny vent that hisses a 5–centimeter spray. The misty spray's height remains well below the ground surface. Although not as impressive as the other features in the immediate vicinity, T33B has a small, but distinct, runoff channel. A layer of small gravel lies ten centimeters from the vent in the upstream direction. It appears to be a high water mark for the feature. Though it may have eruptive potential, for now, it is classified as a small fumarole or dormant vent.

T32 (Geyser)

T32 is fan–shaped depression that slopes down to a point 30 centimeters below the ground surface. The vent is 20 centimeters wide at the bottom of the depression. Rocks have been jammed into the vent such that the small eruptions occur only through openings in the obstruction. The eruptions barely splash above the rock jam, with none observed to splash above ground level. Eruptions occurred during occasional rises in water level that reveal highly convective boiling leading to weak splashing to 10 centimeters. The activity appeared relatively erratic with rising and lowering of water to occur over several minutes and splashing to last only several seconds.

Small **Geyser T29** (middle left) plays in Spring Group U-IV. An afternoon storm hides the hills behind a weak, steamy eruption of **Geyser T25** (background). (Photo by Shane Fryer)

T26 (Geyser)

T26 is a fountain–type geyser that erupts from an L–shaped pool, 1.5 meters in length. The pool is 5 centimeters deep, with a gray mud bottom. The rim of the pool is lined with reddish–orange bacteria. Play

to 40 centimeters comes from two primary vents, which are 10 centimeters in diameter. The splashes are formed as the clear water rhythmically surges in and out of the vents every second. A third vent forming the bottom leg of the "L" is separated from the main area of the pool by a small natural bridge at the water level. Water in this 20–centimeter wide vent rhythmically surges. A tiny fourth vent lies 2 meters north of the pool and erupts in concert with the other vents (to heights of 20 centimeters). The eruption goes for a few minutes with periods of quiescence occurring in all vents lasting only a couple of seconds. In short, the spring is active nearly all the time.

GROUP U–V

T35 (Geyser)

T35 is one of the more significant geysers in the basin. It appears to be a consistent player with a well–developed, often–used runoff channel, consistent durations and predictable intervals. T35 erupts as a fountain from a vent flush to the ground 50 centimeters wide. The geyser reaches heights of 1.5 meters during its 1–minute eruption that occurs every 2 minutes. The eruption reaches full strength within 10 seconds with no pre–play. The eruption height overall is sustained in a series of splashy bursts throughout the eruption. After 50 seconds, the height of the eruption starts to decline and 10 seconds later the eruption has completely ended. It takes less than 10 more seconds for water to drain from the vent. The primary vent is located among a series of other smaller vents. The geyser erupts from only one vent, but it overflows and spills into several of the surrounding small holes.

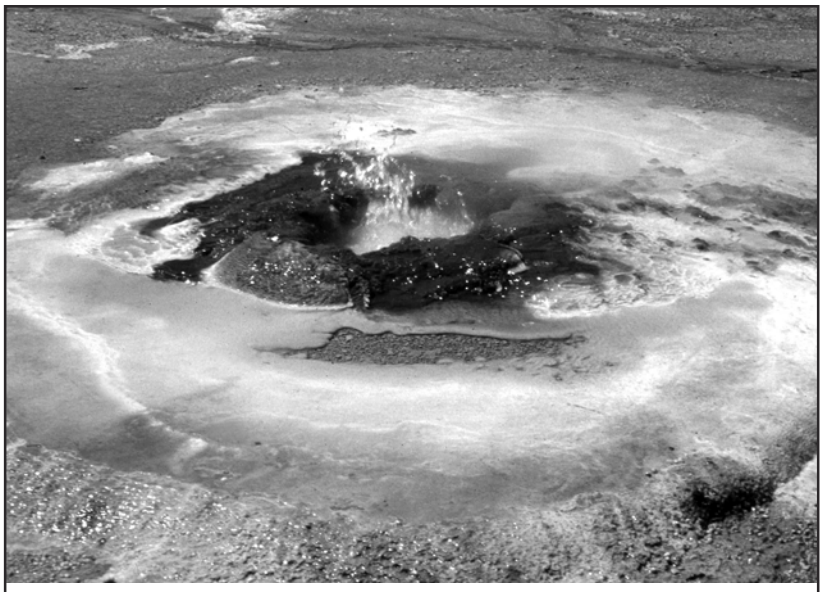
T36 (Perpetual Spouter)

T36 is an attractive spouter whose play (up to 50 centimeters) emerges from a 40–centimeter wide, dark brown–colored cone in the middle of a 10–centimeter high, white, flat sinter–mound. The lower mound, which is nearly circular, is approximately 1.5 meters in diameter. The lower mound is very wet from splashes. Orange and dark brown bacteria are growing in some areas of the lower mound, primarily around the outer rim of the flat mound. A small pool (30 centimeters in length and less than 2 centimeters deep) has formed over a portion of the lower mound. There are many geyser pearls and other small silica deposits in the pool.

Spring T35. (Photo by Shane Fryer)

T37 (Geyser)

T37 is located near the road along the northern side of the Main Terrace. Several small perpetual spouters are located in the vicinity, but only T37 was seen to have intermittent activity. The gurgling play is up to 10 centimeters high and is nearly perpetual. Quiet pauses last only



Spring T36. (Photo by Shane Fryer)

a few seconds. During the momentary pause, the water level in the feature drops before gurgling and splashing begins again.

T38 (Geyser)

T38 is a muddy, oval–shaped pool level to the ground. Four linear vents are present in the small pool. The pool measures less than a meter in length and is about 5 centimeters deep. T38 is near the main road that runs through the upper basin. All the vents splatter to 20 centimeters for about 30 seconds. When in eruption, the splashes of clear water occur from different vents while the pool is overflowing. At the conclusion of the eruption, the pool drains completely. Its interval is about 2 minutes.

T67 (Geyser)

T67 is a spring with a 10–centimeter deep pool at the vent. The vent was clogged with rocks that had probably been placed in the vent by tourists. The rock nearest the surface oscillated with the splashing of the water during the eruption. When two rocks were removed, the pool drained. After inventorying several other features, we noticed the vent had begun splashing to 40 centimeters. In addition, it had started to overflow and wet its small runoff channel. The eruption lasted for at least 10 minutes, but nothing is known about its interval. A ring of platy, rough gray sinter is present around the pool. Beyond that, the ground is composed of reddish–sandy deposits. A couple meters away, two tiny features spurt to a centimeter.

T67b (Geyser)

T67B plays from a 20–centimeter deep pool that is about a meter wide. A meter to the west, a 5–centimeter hole acts as a satellite vent. The geyser itself is located immediately north of the road that many tourist vans take into the basin. Only cursory observations of the geyser were made, but the activity was quite intriguing. The activity starts from a gently boiling pool and small splashes begin along the pool's northern side. The side of pool muffles the splashes and they reach only about 10 centimeters. After a minute of this activity, the splashing ends with a weak, but agitated, rocking of the pool. Over the next 30 seconds, boiling begins along the pool's southern side. The southern side of the pool has a ragged, overhanging sinter ledge that begins enduring most of the boiling. After several vigorous boils, a steeply angled splash begins jetting 30 to 40 centimeters from under the sinter ledge and tangent to the pool. The splashing increases in intensity for several seconds before the satellite vent begins a constant boil to 10 centimeters. The activity sends a thin overflow of water across the road. The eruption lasts around 4 minutes before returning to a somewhat agitated boiling along the pool's northern edge. Nothing is known about its interval other than the activity was not repeated within 5 minutes of observation.

T39 (Geyser)

T39 is a sediment–filled geyser that, unfortunately, lies in the middle of tire tracks on the main road through the upper terrace. The vent and pool together are 50 centimeters across and are completely choked with small gravels and pebbles. The small feature spouts to 10 centimeters for several seconds with an interval of less than a minute. When

in eruption, activity in a series of frying pans 50 centimeters away intensifies.

T40 (Perpetual Spouter)

T40 is a small spouter that splashes from a 20–centimeter wide vent. The pool splashes perpetually up to 10 centimeters.

T41 (Geyser)

T41 is a small geyser that spurts to 40 centimeters (at least 20 centimeters above ground level) from a hole that is 20 centimeters in diameter. There is a dry sinter–encrusted circular area reaching a meter from the vent, indicating that the geyser could possibly erupt higher than observed. The vent and splash ring are encrusted in beaded sinter. T41 splashes for approximately 2 minutes, with an interval of greater than 5 minutes. The vent dries in between eruptions, although the splash ring remains wet. The geyser is located 1 meter away from the crater of an old, large (1 meter in diameter, nearly 1 meter tall) dormant, reddish–colored cone.

T42 (Intermittent Spring)

T42 overflows and gurgles from a hole 25 centimeters across for 30 seconds. Another vent a meter away has similar behavior every 3 minutes.

T43 (Geyser)

T43 is a crater level to the ground coated in dark green and black algae. The coloration was unusual among the other spouters. Splashing reaches heights of a meter for several minutes with a very short (only seconds long) interval. The surrounding splash area extends a meter out from the vent, with similar dark–colored bacteria growing in all directions. There are no gravels or sediments located within the splash area, possibly indicating a high water mark. The outer rim of the splash area has some orange bacteria. A small, round hole located within the splash area occasionally spurts a few centimeters.

T44 (Geyser)

From above, T44 resembles a gray, open–faced seashell. The inner vent is nearly black. The top of the vent is flush to the ground, although the opening extends 20 centimeters beneath ground level. Frothy water surges once every few seconds from the 30–centimeter long sinter–covered vent with a sound that is reminiscent of rhythmic ocean waves breaking on the seashore. One side of the vent gently and smoothly slopes downward, while the opposite side is jagged like a half–conch shell. The bottom of the vent is full of fist–sized rocks and pebbles blocking the geyser's full eruption power. The surrounding splash area and reddish–colored sandy sediments are dry. The frothy eruption reaches to 10 centimeters and lasts more than a minute. The interval is greater than 5 minutes. A 10–centimeter in diameter hole—a satellite vent—adjacent to the main opening, occasionally splashes as well.

T45 (Geyser)

T45 is a geyser on a meter–tall, gently sloped, white sinter mound. Sinter beads are present on the mound. Several small rocks that were choking the 5–centimeter wide, round vent were removed, but several still remain. The eruption has an angled component and reaches laterally 70 centimeters. The east side of the geyser is wet, while the west side remains dry. A splash area at ground level has a coating of dark film. The geyser erupts for 1 minute at intervals of greater than 2 minutes.

GROUP U–VI

T46 (Geyser)

T46 is a geyser that produced a vigorous eruption after we removed ten rocks and pebbles that had been stuffed by vandals into its 10–centimeter in diameter vent. The vent and splash area were slightly damp and there was little activity (play to less than 10 centimeters). Cleared of blockage, the geyser plays to 1 meter, with an angled eruption emanating from an opening on the side of a low, gray sinter mound. Water from the geyser's eruption spills over into a lower splash area. Light and dark gray beaded sinter is present, with little or no coloration in either the vent or splash pools. The eruption lasts a minute or more with a 15+ minute interval.

T47 (Geyser)

T47 is a small geyser that erupts with weak splashing to 10 centimeters. Only one eruptive episode was observed. The duration was less than 10 seconds. Its small, wet splash cone implies that the interval is relatively short.

T48 (Geyser)

T48 has a smooth, 10–centimeter in diameter vent that extends 10 centimeters beneath the ground before being obstructed by several rocks. The rocks appear to have been artificially placed in the vent, so we attempted to clear them (most could not safely be removed). The geyser erupts up to 20 centimeters. There is a light gray sinter splash ring around the vent and a handful of pebbles scattered about it. The geyser has periods of quiescence minutes long. Eruptions observed consisted of a series of splashes every few seconds.

T49 (Geyser)

T49 is a somewhat–round pool 50 centimeters in diameter. The pool's western edge is bounded by a low, lumpy sinter accumulation that overhangs the pool and creates an irregularly shaped western shore. The pool's vent is located below the irregular side 10 centimeters underwater. Eruptive activity is typically weak and consists of small surges to 5 centimeters. Otherwise, during its quiet period, boiling at depth creates small ripples along the pool's surface. Orange bacteria line the eastern rim of the pool. A tiny runoff channel flows from T49 into T50.

T50 (Geyser)

T50 is a fountain–type geyser that splashes from two distinct vents. The vents share the same small pool. The shallow pool, which is oval–shaped and 1 meter across, has a dark green tint, with orange bacteria around the rim. Both vents commonly splash to 50 centimeters. Two frying pans splatter in T50's overflow channel. The intensity of boiling rises and falls and brief total pauses were observed. The duration is greater than 1 minute with an interval of seconds.

T51 (Geyser)

T51 is a geyser located immediately south of the road through the upper terrace. Its eruption consists of a continual gush of water, with heights up to 1 meter. Compared to the other small geysers of the basin, its eruption creates considerable discharge. Its pool and splash area, which is about 1 meter across, is full of small rocks. The pool is level to the ground. When the geyser is not in eruption, the pool is drained and its vent gently steams. The duration is less than 5 minutes and the interval is less than 15 minutes.

T53 (Geyser)

T53 is a small geyser that splashes to 15 centimeters from a 7–centimeter vent. The vent is covered in dark gray sinter. Adjacent to the geyser is a low, white sinter mound. Three small rocks were removed from the vent while it was not in eruption. The interval is approximately 10 minutes.

T54 (Weak Geyser)

T54 is an obscure vent on an area of flat sinter pavement. The 3–centimeter wide vent was noticed when it suddenly began splashing and bubbling water to 5 centimeters. The weak splashing only lasted a few seconds before ending. No runoff was produced. Further observation found the feature to erupt at intervals of less than a minute.

T55 (Two Geysers)

T55 is a geyser that intensely splashes to 10 centimeters from a crack vent 3 centimeters across. The crack, encircled by a smooth sinter splash zone, is ringed by an apparent high water mark radiating 20 centimeters from the vent. Another small, wet crack with an elongated sinter splash zone is located 20 centimeters east. Its duration is less than 10 seconds. The interval is unknown, but the feature was seen in eruption again within 15 minutes. With such a small geyser, any intervening eruptions could have easily gone unnoticed.

T56 (Geyser)

T56 is a fountain–type spouter whose pool is lightly scalloped around the edges. The pool is dark gray and 10 centimeters deep. Fifty–centimeter high

splashing occurs from a vent in the center of the pool. The geyser's duration is short with long quiet pauses of gentle boiling. The runoff channel has bright orange bacteria present.

T57 (Geyser)

T57 is a small spouter that splashes to 5 centimeters from a hole 5 centimeters across. Located in an area of flat sinter crust, its vent is obscure until it erupts. Eruptions only last a few seconds with an interval close to a minute.

T58 (Hot Spring)

T58 is a hot spring with a 1–meter long depression that is 20 centimeters deep. Two vents containing 72°C water were seen to be rising during 15 minutes of observation. The elongated depression has a thin coating of orange sinter.

GROUP U–VII

T59 (Geyser)

T59 was observed erupting up to 30 centimeters from its 30–centimeter tall, light–colored sinter cone. The round geyser vent is level with the ground, but is encircled by a short geyser cone. A wet area of dark gray deposits or bacteria encircles the geyser. Weak, brief splashes occur every 30 seconds. During 15 minutes of observation, occasional puffs of steam and intermittent rising and lowering of water levels in the crater were observed. From the size of the cone and nearby well–maintained sinter apron, the geyser may have a history of more vigorous activity. Given that two other large geysers exist nearby (T63 and T51) with relatively long intervals, perhaps this geyser also possesses a long interval between majors. In all, the observed activity of T59 was frustrating. Several times, when it appeared the water, steam, and activity rose enough to preface an eruption, the water level dropped, and the geyser became quiet.

T60 (Warm Spring)

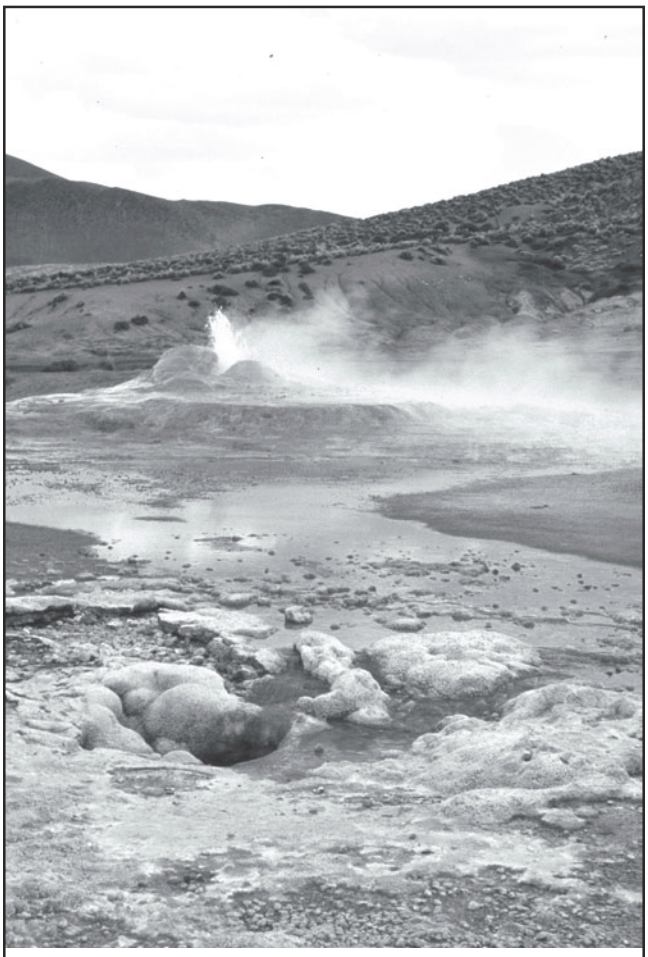
T60 is a spring that may have been used by guides to cook for tourists. T60's calm water was greenish–brown–colored with a heavy film on its surface and there was some trash scattered about the spring. The pool's temperature was measured at 43.8°C, with an adjoining smaller pool measured at 25° C. These temperatures are at least 30°C lower than other surrounding, non–erupting springs.

T61 (Geyser)

T61 is a rectangular pool that vigorously laps back and forth, eventually surging and splashing up to 60 centimeters from its orange–colored crater. The pool is sunk 10 centimeters from the surface. A smaller vent one meter away emits weak splashes to 10 centimeters. As the eruption ends, the intensity of the surging in the main vent decreases and the water level lowers. A relatively dry sinter–splash area encircles the vents. While always agitated, the spring definitely displayed minutes of stronger splashing and overflowing activity (and increased activity in its satellite vent). This activity is followed by minutes of weak rocking of water within its pool and small splashes to 5 centimeters.

T62 (Perpetual Spouters)

T62 erratically splashes to 10 centimeters. Quiescent periods several seconds long were noted, but not convincing enough to classify it as a geyser. The hill northwest of T63 creates a 60–meter wide alcove with several perpetual spouters, mudpots, and fumaroles. T62's irregularly shaped, 2–meter wide pool is scalloped and undercut around the sinter–encrusted rim. Its runoff temperature was measured at 84.6°C. The primary vent is obstructed by rocks, which likely reduces its eruption height to 30 centimeters. Two perpetual spouters that erupt to 10 to 30 centimeters are located within 20 meters to the north and west. T62 lies on the northern side of the main terrace primary road, opposite T63 and the majority of the main terrace geysers. About 10 meters up the slope east of T62, an interesting bright red–orange pool has several splashing frying pans along a slump on its uphill side. The pool's water shares the same red color. Above this pool and 50 meters farther to the east lies a lone, loud fumarole on a gentle slope. From the fumarole along the hillside, most of the main terrace can be seen.



Dormant **Vent T64** (foreground) and **Spring T63**. (Photo by Shane Fryer)

T63 (Geyser)

T63 is one of the major geysers of El Tatio Geyser Basin. It erupts to 3+ meters for 15 minutes with an interval greater than 2.5 hours. Steam increases from the vent and the cone begins to splash before an eruption begins. There are only about 10 seconds of splashing outside the cone before the water reaches its full height. The cone, which stands 60 centimeters tall, is dry at the beginning of the eruption. During the eruption, water gradually spills over the cone and into the surrounding splash pool. The runoff spills north, west, and east. Water also drains into a nearby hole at ground level (T64). Tourist postcards of T63 show what appear to be bacteria covering its cone and splash area. The bacteria range in color from tans and browns close to the orifice and deep reds, oranges, and near–blacks a meter or more from the vent. Although the play shown on the postcards is similar to what we observed, some type of change in activity or water chemistry has occurred.

T64 (Dormant Vent)

T64 is a dormant vent that is 2 meters east of T63. The vent is level to the ground, such that runoff from T63's eruption drains into it. A well–maintained sinter apron, a short splash cone rim, and intricate beading suggest that this feature may have eruptive episodes.

Looking west at **Spring T63** in eruption. (Photo by Shane Fryer)

T65 (Geyser)

T65 is a geyser that splashes to 15 centimeters from a series of three vents that lie in a 1.5–meter line. Rocks fill one of the vents.

T66 (Geyser)

T66 is a large pool, approximately 7 meters wide that has quick surges to 3 meters. The water is clear and there is a brown, sandy mound a meter tall on its northern side. The durations of the surges are only several seconds long with an ob-

served interval of more than an hour. During our visit, we noticed the pool constantly steaming. Occasionally the pool exhibits particularly intense, heavy steaming. During one of these periods, we noticed a low, white boiling surge in the pool. As we watched, the boiling surge rose to 3 meters. A few seconds of smaller surges were noted, as well as very heavy steam, before the pool went back to its normal boiling state. We walked to the pool in hopes of further activity, but no other similar surges occurred. The pool is located 100 meters south of T63.

T67c (Geyser)

T67c plays from a 1–meter wide, round, meter–deep pool. The pool has several different types of activity that appear erratic, but are nearly perpetual. The spring has momentary quiet modes. At those times, the pool is about a centimeter below overflow. These times of quiescence are short–lived. The typical eruption consists of either splashing with overflow, splashing without overflow, or overflow without splashing. Splashes occur from the center of the pool and typically reach 30 centimeters. Larger splashes reach a meter. Runoff from the spring spills down two runoff channels, but a lower runoff channel flows more often. The pool is located immediately north of the tourist road on the Main Terrace; its runoff channel crosses the road. Longer eruptive episodes can play uninterrupted up to a minute. The longest period of quiescence was only about 30 seconds. Most eruptions consist of a couple of splashes followed by a short 10 second pause.

UPPER GEYSER BASIN, OTHER PORTIONS

GROUP U–VIII (FAR UPPER GROUP)

Separated from main Upper Geyser Basin activity 500 meters up the valley to the northeast, the Far Upper Group features several kinds of landscapes. Rolling foothills surround the broad, flat area. A great deal of the thermal area is covered in green moss and scrub brush, much like a thermal marsh. Small, shallow, often bubbling, hot springs and runoff channels break up the patches of moss, although some areas of moss are brown and dying. Other areas of the Far Upper Group are characterized by a desolate landscape void of vegetation, with volcanic boulders the sizes of cars strewn about the area.

A few geysers exist in the Far Upper Group, although most of the play observed reached heights much less than a meter. There are, however, several intense mud volcanoes. Two of them are located on a hillside. The larger of the two continuously and vigorously boils watery, light brown mud up to 1 meter from a steaming crater 5 meters long, 3 meters wide, and 3.5 meters deep. The smaller mud volcano (about 1 meter in diameter and 1 meter deep) has formed in a hole downhill from the larger volcano. The vigorous splashing nearly reached the ground surface and had formed reddish–brown mud stalactites under the rim.

There were also several mudpots located within the area. An oblong–shaped, dark–gray 5–meter long mudpot was nearly dry; mud cracks were present throughout the depression. The only "plopping" was found in a watery spot in its center. Many of the hot springs and hot streams had patches of cream–colored, sudsy foam on their surfaces. The small springs of this area often had scalloped sinter encrustations around their pool rims. Very little bacteria mat growth was observed within the Far Upper Group, although a few pools did have runoff channels with red and orange bacteria present.

Inventorying the Far Upper Group in detail, due to the possibly unstable nature of the soggy moss and marsh, was dangerous. Therefore, only a portion of the area was visited up close on foot. Much of the basin was viewed at a distance from the hillsides.

T3 (Geyser)

T3 erupts up to 1 meter approximately every 4 minutes for 15 seconds from a series of three small, reddish–colored vents. The largest and primary vent is 20 centimeters across, with water splashing from a 10–centimeter tall, rough, white and dark gray sinter mound. The eruption begins with simultaneous splashes from the primary vent and a smaller adjacent vent on a shorter, although still connected,

mound. Water spills down the mound from the secondary vent. Splashing begins 15 seconds later from a third vent, which is an elongated rift tangent to the mound. The eruption creates an overflow stream about 1 meter in length. The geyser is located in an area several meters long comprised of rough, gravelly white and gray sinter. Two other mounds (one up to 50 centimeters tall) are present, although no eruptive activity was observed from these nearby features. The sinter area is surrounded by green moss and short, stubby grasses.

T4 (Geyser)

This geyser consists of a main vent and a secondary vent. From a distance, we saw a meter eruption from the main vent, possibly a major. Up close, we observed intense, 20–centimeter bursts from the main vent. The main vent is a rounded, crater–like pool that is 50– centimeters deep. The geyser has a well–developed, smooth–bottomed runoff channel, which, like the rim of the main pool, is encrusted with scalloped, gray sinter. There are also thin runoff lines radiating from the pool. One side of the pool has a 20–centimeter tall, overhanging sponge–like sinter deposit that is reddish–colored in locations where water splashes against it. The secondary vent alternates activity with the main vent. The pools undergo a series of filling and emptying in an 8–minute (possibly minor) eruption duration. The interval is greater than 14 minutes.

GROUP U–IX (MIDDLE VALLEY GROUP)

A spring cluster 700 meters east of the Main Terrace was not visited. At least twenty hydrothermal manifestations are represented on the Trujillo *et al.* [1969] map. At least a dozen more features are noted downstream of this group in the portion of the valley south of the Main Terrace. Both of these vicinities can be seen in the distance from the Main Terrace, but appreciable steam was not observed.

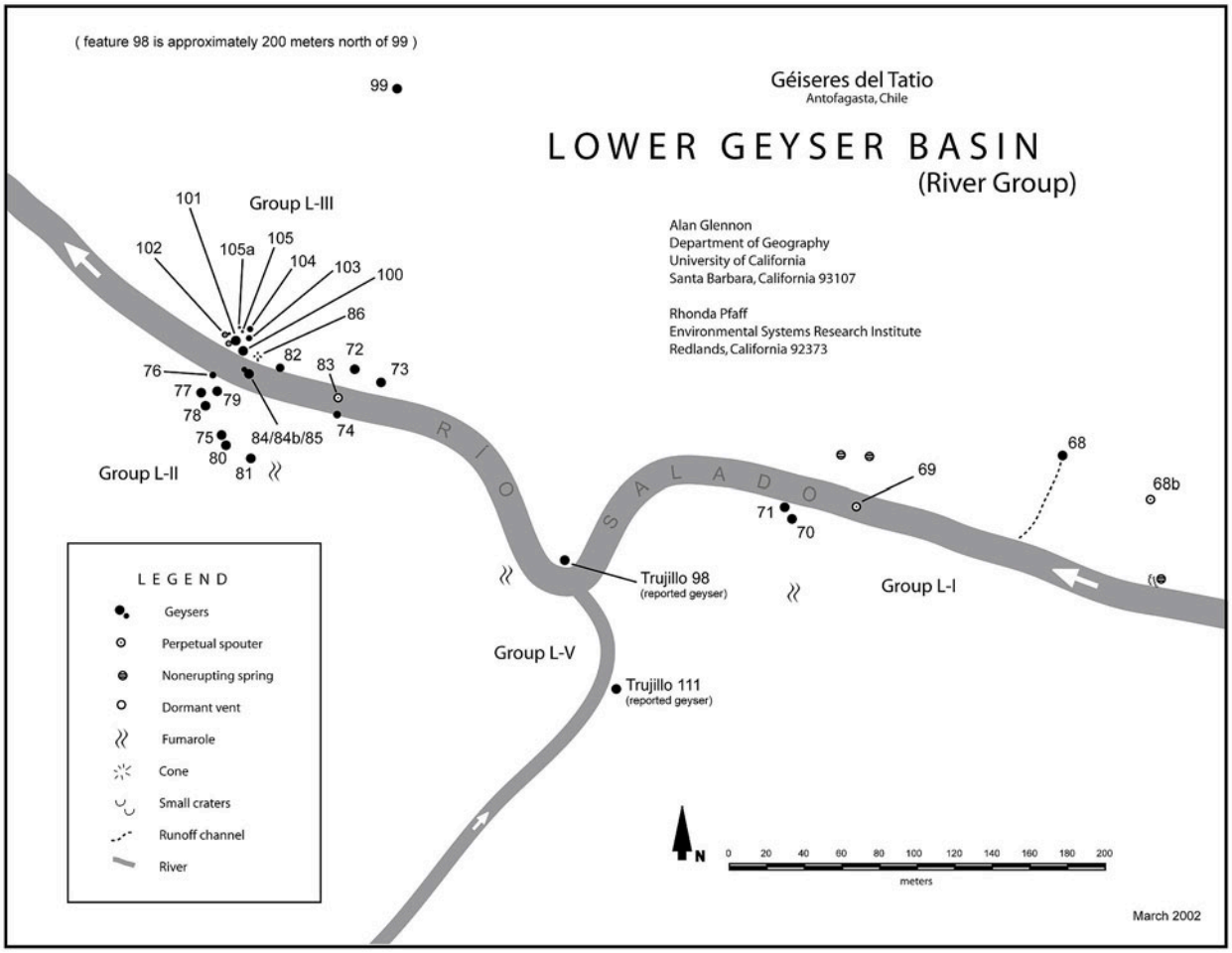
LOWER GEYSER BASIN OVERVIEW

The Lower Geyser Basin (or River Group) lies along the banks of the Río Salado, approximately 2 kilometers downstream from Middle Basin (Map C; see also Map A). In all, at least 20 true geysers are located in the area. Following downstream from the Middle Basin, the river becomes increasingly channelized between steep hills. The river throughout the group flows with a gray–colored bed. The river's color contrasts with the red soils of the hillsides, white and yellow hydrothermally altered ground, and many colors of the hot springs. At wide points, the river reflects the surrounding hills and sky.

For the first kilometer, the river remains a wide, braided stream. Only a half–dozen features exist in this zone, but they are of significant size (T68, T70, T71). An additional 500 meters downstream, the river takes a sharp southern meander loop. Along the banks of this southern loop, a spring group exists that we did not visit. Steam and fumaroles are visible in the distance. After the loop makes its northern curve, it flows northwest. As it flows northwest, a tightly packed grouping of spouting springs exists. The area of vigorous activity lies within a 100–by–100 meter area. Several springs erupt in and near the river to heights of 1 to 3 meters. Numerous springs in the Lower Basin flow or erupt from within the flow channels of the river itself, including several underwater geysers whose boiling deposits sediment on the riverbank. Two of the larger geysers (T72/73) erupt at steep angles. Very little sinter accumulation has occurred in this downstream river group; many of the geysers appear to be erupting from fractures and fissures in the bedrock itself. In this area, the Río Salado is a much narrower stream, but still maintains a braided character. Except when very close to a boiling spring, the sound of the river overwhelms many of the sounds of hissing, steaming, and splashing.

From the Lower Geyser Basin, the surrounding hills dominate the view to the south, west, and north. Their reddish–brown soil is dotted with low green and yellow scrub. Reddish boulders are strewn about along many of the slopes. Above similar low hills to the east, the same tall, dark snow–capped Andes stretch toward the north and south.

Map C — Lower Geyser Basin (River Group)



LOWER GEYSER BASIN, RIVER GROUP

GROUP L–I

T68 (Geyser)

T68 erupts from three ragged, red sinter–coated vents comprising a complex approximately 8 meters long and 5 meters wide. A nearby fourth vent is filled with cloudy hot water and did not respond to the geyser's eruption. The geyser is located at the intersection of a gulley draining from the north toward the Río Salado valley. Immediately above the vent complex, a contact between a conglomerate and white silicic rock exists. The white rock unit contains small flecks of garnets. Eruptions appear to occur in series at the geyser, with both minors (less than 1 meter) and majors (about 1 meter) noted. However, with only six eruptions observed, the geyser's true behavior is unknown. Eruptions consist of simultaneous splashing of frothy water from each of the three vents for approximately 1 minute. The interval during several closed intervals was timed at 3 minutes. The eruption ends with all three vents draining completely with only slight steam being emitted. Within 30 seconds, the steaming ends. Steaming begins again about a minute before an eruption.

T68b (Perpetual Spouter and Well–Developed Sinter Terrace)

Located 30 meters east of T68 near the bottom of the valley slope, a perpetual spouter (T68B) erupts frothy, but clear, water. The splashdown area surrounding the spouter is covered in dark green (nearly black) bacteria, with some bright oranges

along the outer rim and runoff channels. A grapefruit–sized rock covered in dark bacteria blocks part of the vent's opening. A small, bubbling vent lies within the dark green runoff channel 50 centimeters downstream of the main vent. Fifty meters south, a white and gray, 1–meter high, 2–meter wide silica terrace is located on the northern bank of the Río Salado.

T69 (Perpetual Spouter)

T69 is a perpetual spouter located just barely above water on a small island in the Río Salado. The vent is, at most, a few centimeters above river level, and would be submerged during wet periods. Activity occurs from a small vent at the level of the island. The spouter's activity can be most easily seen from the banks of the river on the path downstream from T68. Clear water fountains a consistent 30 centimeters.

T70/T71 (Two Geysers)

T70 and T71 geysers are located along the river bank on the south side of the Río Salado immediately before the river takes a southern bend. T71 is closest to the river and erupts as a surging fountain to a meter or more for a minute. Its height, interval, and duration are all greater than T70, which is located on a red–sinter bank about one meter to the southeast. While T71 remains quiescent between eruptions, minor activity seems to be occurring continuously at T70. Small splashes to 10 centimeters occur erratically, but eventually activity increases until the activity reaches a meter or more. The increase in activity at T70 appears to induce T71 to eruption. Although closely related, the geysers also exhibit independent activity. A small area of hydrothermally altered soil lies immediately to the south of the geysers. A large fumarole can be seen steaming from a red soil–lined crater that lies about 50 meters up the hill south of the two geysers.

GROUP L–II

T72 (Geyser)

T72 is a geyser located on the slope of the northern bank of the Río Salado about 10 meters north of the observed river flow. Water shoots from a ragged, red rocked vent. Outside the splash zone, the soil near the vent is white and light red. Continuous jetting, up to 2 to 3 meters, is angled (about 30° from vertical) east and south toward T73. T72 has a more defined spray than does T73. Dark bacteria cover the wet areas. T72 has a smaller pool than does T73, although its flow becomes channelized before it reaches the primary Río Salado flow (approximately 10 meters away during the observed flow conditions). Considering the long duration of eruptions, the geyser discharges a large volume of water.

Looking west toward **Group L–II**. (Photo by Shane Fryer)

T73 (Geyser and Several Perpetual Spouters)

Quick splash pulses from T73 gush at an angle 45° from the vertical southerly toward the Río Salado. These blasts of water splash from a 30–centimeter wide vent on the hill slope; the splashes commonly reach 2 meters. Several large rocks deflect some of the splash-

Geyser T73 (left foreground) and **Geyser T72** (right background).
(Photo by Shane Fryer)

ing, but the volume of water typically inundates them. The eruptions have formed a 3–meter wide splash pool that channelizes the flow 20 meters south into the Río Salado. A thin red sinter crust is around the geyser vent and all the way down its flow channel. The crust appears to be at least 10 centimeters thick in some areas. During some of the particularly powerful pulses, the geyser fans water from 90° from the vertical to the south to 30° to the north. As a result, these occasional splashes were observed to a meter or more outside the geyser's northern sinter lining. Several small perpetual spouters erupting to 10 centimeters were noted immediately southeast of T73.

T74 (Perpetual Spouter)

T74 erupts from a sinter–lined cauldron about 20 centimeters above the Río Salado's southern bank. A sinter crust creates a slight overhanging edge above its crater. One side of the rounded crater is open and flows into the Río Salado. Eruption heights approach the level of the ground surface, about 40 centimeters above the vent, with occasional droplets reaching a meter. The splashes mostly are vertical and slightly angled toward the center of the cauldron. The eruption appears to be perpetual.

T77 (Geyser)

T77 is a large fountain geyser that erupts to heights of greater than 1 meter. The pool is located on the edge of an exploded geyser cone. The eruption lasts 1 to 3 minutes, with an interval of 5 minutes.

T78 (Geyser)

T78 is a pool approximately 50 centimeters in diameter. The pool is at ground level, but debris piles 10 to 20 centimeters high are located near the pool. During its eruption, water surges and splashes to 40 centimeters. No closed intervals were carefully observed, but field video recorded the feature to have an interval of at least several minutes, with an eruption lasting more than 1 minute. The intervals and durations may, in fact, be erratic.

T79 (Geyser)

T79 is a small fountain geyser that plays from a pool that had dead frogs around it. The eruption reaches heights of 50 centimeters. The geyser continued playing while the nearby T77 underwent several closed intervals. T79's play continued for at least 15 minutes, and noticeably weakened through the duration. The geyser has a 10 minute quiet interval.

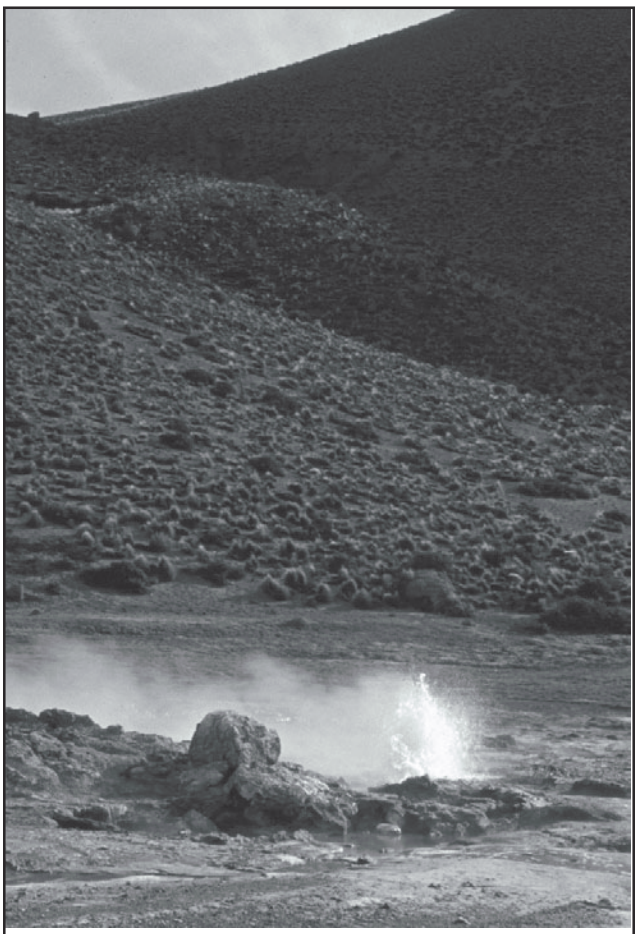
T76 (Four Perpetual Spouters)

Numerous apparent perpetual spouters lie near the southern shore of the Río Salado north of T79. At least four were noted splashing or causing surges into an elongated discharge pool from 10 and 50

centimeters high. Almost all of these features have unique, colorful sinter mounds or overhangs. Their close relationship to the river undeniably affects their development and eruptive activity. A careful inventory of these features would undoubtedly yield additional small perpetual spouters, and likely small geysers.

T80 (Geyser)

T80 is a geyser that sprays a thin stream of water up to 2 meters high. The activity quickly subsides into a steam phase lasting at least 20 minutes. Similar to its observed eruption, the geyser's steam phase consists of a thin column of steam being forcefully ejected for about 2 meters before dissipating into a less organized form. The geyser's vent, which is level to the ground, is surrounded by a circle of gray and red softball to basketball–sized rocks, with some much larger. These rocks possibly are the result of a hydrothermal explosion related to the geyser. The immediate ground is flat, barren, gray and red. Two meters from the vent, beyond the thermally altered ground, are patches of yellow–green moss.



Spring T78. (Photo by Shane Fryer)

T75 (Geyser)

Nearly adjacent to T80, a small splashing geyser erupts to 20 centimeters. It is immediately northwest of the T80 vent. Similar to T80, the area around the vent is strewn with softball–sized gray and red rocks. When this geyser was first noticed, it was vigorously splashing from a small pool. This was concurrent with the steam phase of T80. An inspection from a distance of 70 meters 30 minutes later noted no activity and no steam. Nothing further is known about its activity.

T81 (Fumarole and Perpetual Spouter)

Approximately 10 meters east of T80, a red soil slump area contains a gentle fumarole. At the base of the fumarole, a 50–centimeter high perpetual spouter was observed.

T82 (Geyser)

T82 is an underwater geyser that gently boils in a shallow, gray, murky pool next to the bank of the Río Salado. A few handfuls of black and cream–colored pebbles have been stirred up from the riverbed and deposited on the surrounding reddish–brown sinter crust. The main Río Salado flow has been cut off from this area. Boiling reaches up to 10 centimeters. When T82 is not in eruption, the water is still. The interval is at least 20 minutes and the duration is at least several minutes.

T83 (Perpetual Spouter)

T83 is located near the upstream tip of the island in the middle of the Río Salado. It is likely a perpetual spouter, with its eruption partially submerged in the river. The eruption gushes a mix of water, gravel, and sand to 15 centimeters. Though the spouter is in one of the two main channels of the river, the geyser is located on a sandbar. The water is only a couple of centimeters deep over its vent. The spouter is located very close to the location that T72's runoff channel enters the Río Salado.

T84 (Geyser)

T84 is a completely underwater geyser. Intense surging, which was observed as high as 1 meter over the river's water level, deposits pebbles from the riverbed onto the surrounding shore crust. The geyser is located near the northwestern corner of the island in the middle of the Río Salado. The pellet–sized sediments are typically black or cream–colored and form a 5–centimeter deep layer that extends on the bank up to 1 meter from the boiling pool. The geyser's water is typically murky, due to the pebbles and particles it is carrying. Two other adjacent underwater geysers (including T85) are located within several meters of T84 in the same deep pool.

T84b (Very Small Geyser)

One meter southeast of T84's splash area, a small geyser erupts with weak splashing to 10 centimeters for 10 seconds from two small vents. The geyser was not observed directly in the field, but noticed during examination of T84's videotape. In fact, during its quiet interval, we actually stepped right over the geyser without noticing it. T85b's vent is one of numerous unremarkable fractures and small holes spread throughout the island in this spring area. It is possible that other small geysers exist in the vicinity, but were not observed. The geyser's activity appears to be independent of T84. Only a single eruptive episode was observed; however, given the vigorous activity of the area, its interval is likely no more than several minutes.

T85 (Geyser)

T85 is a completely underwater geyser whose boiling picks up pebbles from the river bottom and deposits them on the bank. Located 2 meters northwest of T84 and within the same deep spot in the river, T85 periodically boils to 10 centimeters. One splash to 30 centimeters water was seen.

Group L–III

In the northwest portion of the Group II springs lies a concentration of features in a 20–by–20 meter area. The small area, part of the Río Salado's flood plain, is pockmarked with small craters and mudpots. These craters are typically 10 to 20 centimeters in diameter and about as deep. Two perpetual spouters and a number of geysers erupt from the craters.

T86 (Mud Volcano)

The most distinctive feature in the group is a 50–centimeter tall, 50–centimeter wide mud volcano along the northern shore of the Río Salado. Mud has been deposited forming a cylinder with walls about 10 centimeters thick. A small cauldron of mud boils 70 centimeters down inside the cylinder, occasionally splashing mud 10 centimeters or more out of the cone. A smaller mudpot adjoins the little volcano, but for some reason has not developed a cone of its own.

T100 (Geyser)

T100 is comprised of three small 10–centimeter deep craters. The craters coalesce to form an elongated feature that makes a highly distorted "T"–shape. The entire "T" is no more than a meter across. Each of the three craters contains a tiny pool of agitated water. The middle pool is the most active, with occasional erratic splashes to 10 centimeters. The middle pool occasionally offered larger eruptions. When this occurs, the erratic splashing increases its frequency and force until it is nearly constant. The angled play throws water laterally at least 50 centimeters. The vertical height reaches no more than 50 centimeters. The duration of the eruption was erratic, but commonly lasted over a minute.

T101 (Geyser and Perpetual Spouter)

T101 erupts from a small elongated crater no more than 80 centimeters long and 50 centimeters wide. Similar to other craters in the immediate vicinity, it is no more than 20 centimeters deep. The crater is slightly narrower in the middle and is somewhat shaped like a "Figure 8." The geyser was not approached too closely due to dangerous ground, but water appears to be relatively calm in its crater during its quiet period. The geyser begins eruption with an increase in boiling and water level in its crater. The activity builds for 10 seconds or more until the pulsing splashes reach a meter in height.

The play occurs from nearly the entire crater, so the splashes are typically 50 centimeters in diameter. A glaze of water is sent toward the nearby Río Salado. Several closed intervals were timed to between 100 to 220 seconds. Adjacent to T101, toward the river, a perpetual spouter erupts from a 10–centimeter wide crater. Its 30–centimeter high play looks like a smaller version of the T101 eruption. A few red–lined craters are present to the east of T101. Of these, the one closest to T101 appears to occasionally splash within its crater. However, no water rose above ground level. The next red–lined crater had a 4–centimeter layer of wet red mud downstream of its rim. During our observations, only steam was emitted from its crater.

T102 (Very Small Geyser and Perpetual Spouter)

Barely a geyser, a small feature exists in close proximity to a much more impressive perpetual spouter. The spouter maintains a frothy play to 10 centimeters. Of the two perpetual spouters in the L–III Spring Group, it is the farther downstream of the two. Mossy green material is located on a 10–centimeter mound on the spouter's southeast side. A tiny feature was noted 50 centimeters north of the spouter's main play. Every 10 to 15 seconds, a tiny vent throws a single, quick splash to 5 centimeters. The nearby ground is composed of light–colored sand and gravel.

T103 (Geyser)

T103 plays from a shallow meter–wide crater. It is effectively a twin feature with T104. Tilted bedrock is visible at the bottom of the crater at the geyser's vent. A thin coating of gray sinter gives the geyser a dark color. The geyser is nearly always erupting. Pauses were infrequent and lasted no more than 10 seconds. When not erupting, the crater is completely drained of water. The play consists of frothy, but clear water splashing 30 to 60 centimeters high. The activity of the geyser appears erratic.

T104 (Geyser)

T104 plays from a shallow meter–wide crater. The crater is similar in shape and appearance as T103, except that T104's sinter is red. Bedrock can also be seen near its vent at the bottom of the crater. The geyser plays almost continuously, but several complete stops were noted. When not erupting, its crater is completely drained, with steam coming from its vent. The play consists of erratic splashes of frothy, but clear water 60 centimeters to a meter high. Its duration lasted several minutes or more between pauses. Quiet periods usually only lasted several seconds, but a couple of 10 second pauses were also noted. Similar to its neighboring springs, the activity appears erratic.

T105 (Geyser)

T105 lies in an obscure area of craters west of T103. The crater could not be approached due to unstable ground, but appears to be about 30 centimeters across and about 10 to 20 centimeters deep. The play sends one or two splashes of water to 20 centimeters above the ground surface. Only about a liter of water is airborne during a single splash and very little discharge leaves the crater.

T105a (Geyser)

Dwarfed by its larger neighbors, T105a occasionally sends a single, weak splash of water to 10 centimeters above ground level. The small play occurs from an obscure crater 30 centimeters wide. The interval is less than a minute. Numerous similar craters lie within several meters of T105 and 105a.

LOWER GEYSER BASIN, OTHER SPRING GROUPS

Group L–IV

Another spring group lies north of the vigorous activity of main Lower River Group. From a quick trip to the group, Shane Fryer reported a geyser (T98), a suspected geyser (T99), and a pool complex.

T98 (Geyser)

T98 is a 20–meter wide complex of three springs, with at least one geyser that erupts from a 2–meter wide vent under a cliff face. Water shoots

1 meter before it hits a ledge. Momentary pauses were noted in the otherwise continuous play, otherwise nothing else is known about its duration and interval.

T99 (Hot Spring/Reported Geyser)

T99 is an 8–meter long pool that is about 1 meter deep. The spring has at least ten underwater vents. Vigorous boiling and fluctuating water levels were observed, but no eruptions seen. This feature has previously been reported as a geyser [Trujillo *et al.* (1969) feature 195]. Near T99, Shane also reported a deep, meter–wide shaft. During his quick visit to the area, the water level in the shaft dropped several meters. No other information is known about its activity.

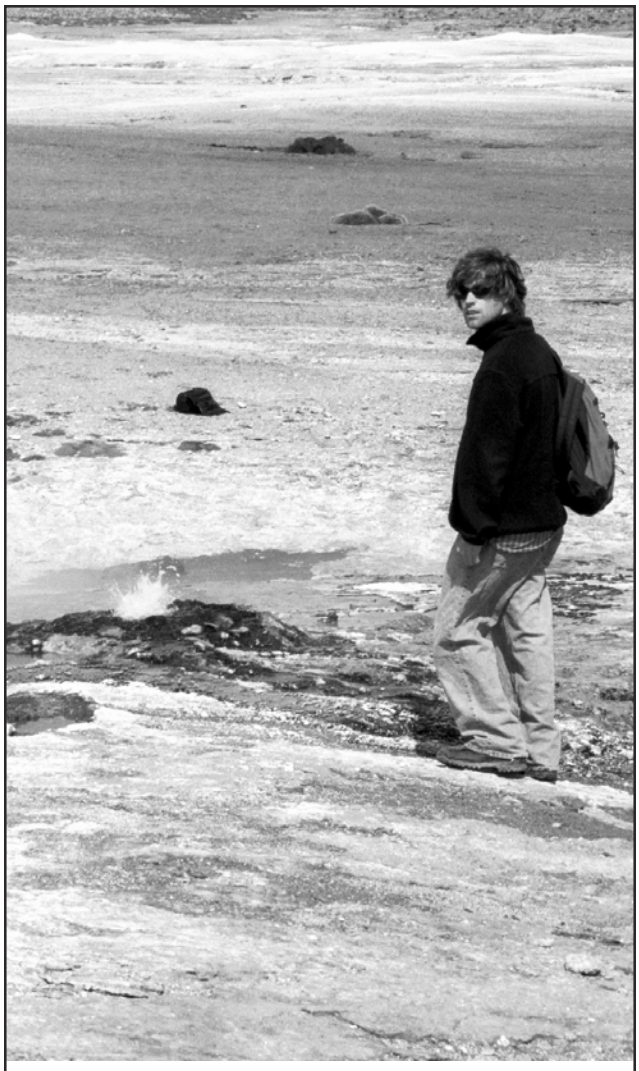
Group L–V (Two Reported Geysers)

A spring group reportedly containing geysers [Trujillo *et al.* features 98 and 111] is located on a southern bend of Río Salado, downstream of T70/71. From T70/71, fumaroles and intermittent steam were seen. The group was not visited due to time constraints. Since much of the activity appears to be south of the river, approach from the southern bank of the Río Salado may be the best strategy.

Feature 98 on the Trujillo *et al.* map was reported to be a geyser [Trujillo *et al*., 1969]. It is located downstream of T70/71 on the Río Salado. Approximately 50 meters south of Trujillo *et al.* feature 98, is another reported geyser. This spring is number 111 on the Trujillo *et al.* map. Both of these reported geysers were not visited on the March 2002 trip.

Group L–VI (Three Reported Geysers)

In the upstream areas of the Lower Basin lies another spring group that has been known to contain geysers. The group lies roughly between the Upper, Middle, and Lower geyser basins. Due to time constraints, we were able to visit only a small portion of the spring group. The group is located above a 10– to 20–meter high escarpment that prevented us from viewing the group from the Río Salado. Three features, numbered 168, 181, and 184 on the Trujillo *et al.* map, have been reported as geysers. The spring group extends southeast and down the short escarpment. This small portion of the group is along the road entering the geyser field.



Shane Fryer at **Spring T2**.
(Photo by Rhonda Pfaff)

T1 (Hot Spring Pool)

T1 is a 70–centimeter deep pool next to an upended rock 30 meters north of a branch of the Río Salado. The clear, shallow pool is 5.5 meters wide, scalloped and undercut with temperatures measured from the bubbling vent at 60.7°C. Several bubbles float on the surface of the pool. The pool has a tan–beige–colored bottom with a narrow band of red algae where the deeper pool meets its runoff channel. The runoff channel has dark brown and orange bacteria present, but the pool has relatively little discharge.

T2 (Perpetual Spouter)

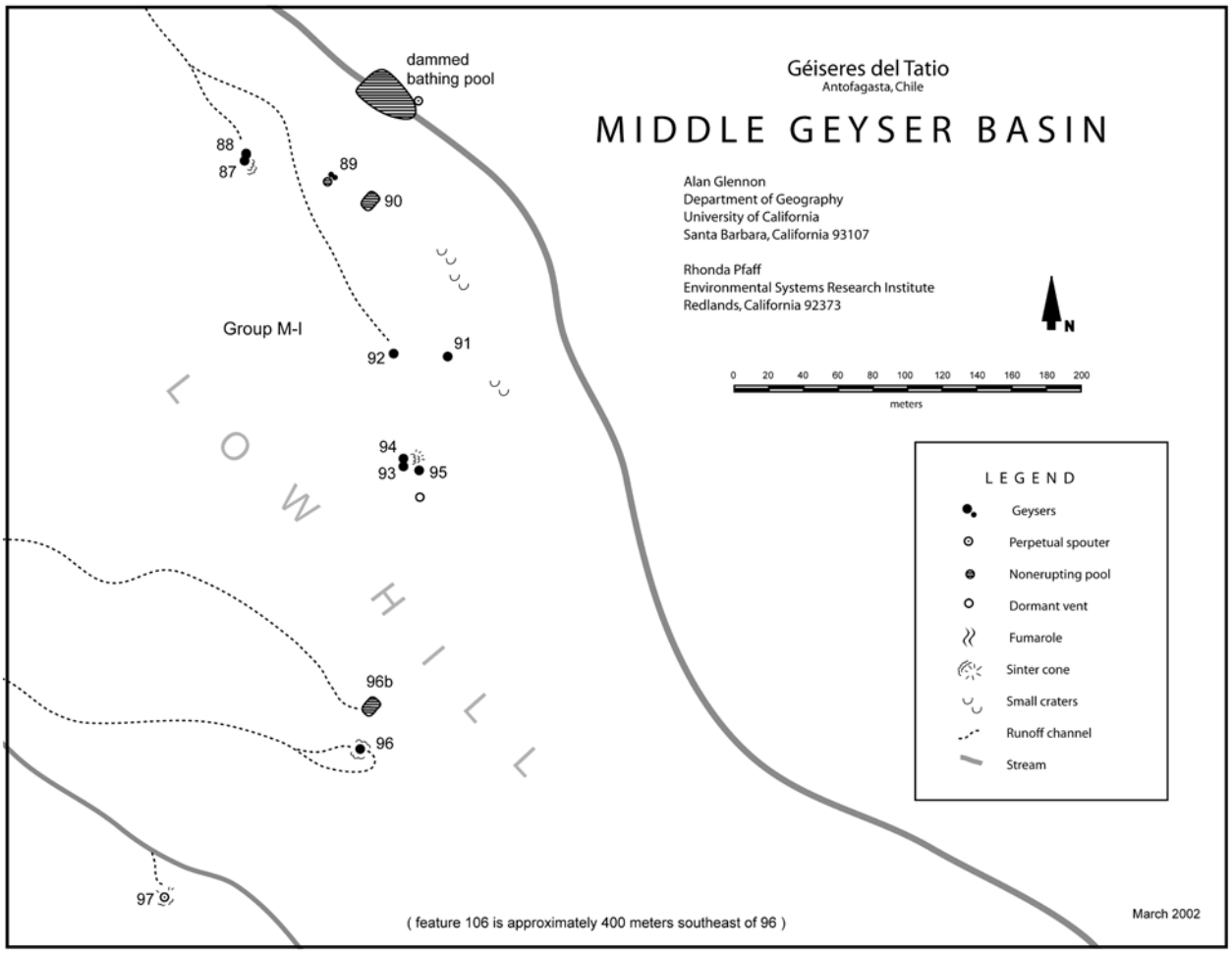
T2 plays perpetually to 50 centimeters from a 10–centimeter tall cone on a 1–meter high sinter mound. Orange bacteria are present on the sinter runoff apron. The apron stretches in a semicircle, with a radius of greater than 2 meters. The temperature at the orifice was measured at 80.5ºC. Two nearby vents on 8–centimeter high sinter mounds boil up to several centimeters in height. The discharge trickles down the mound and into a tributary of the Río Salado.

MIDDLE GEYSER BASIN OVERVIEW

The Middle Geyser Basin lies immediately to the south of Upper Basin and is a stark, flat sinter plane. The geyser activity of the Middle Basin lies in a zone 400 meters long and 100 meters wide (Map D; see also Map A). The basin contains at least ten true geysers. The area of geyser activity is bounded on the west by a low, flat–topped hill and a creek on the east; the creek is a major upstream branch of the Río Salado. Along the creek, a small dam has been created to form a soaking pool for tourists. The pool is approximately 30 meters long and 15 meters wide, with a few perpetual spouters erupting within a few meters of the pool.

The most prominent thermal features of the Middle Basin are six deep pools. Only one of these pools (T90) was not seen to erupt. The other pools average 3 meters deep and have frothy, fountain–type eruptions. The intervals and durations for the pools appear erratic. The area also contains numerous small examples of fumaroles, mudpots, and perpetual spouters between the pools and creek. Some of these features may be geysers. One of the features (T89) exhibited intermittent spouting as a true geyser. Numerous parallel shallow runoff channels flow to the north from the pools. A low, long hill follows to the west of the thermal flat.

Map D — Middle Geyser Basin



Besides the six pools, a widespread region of thermal activity lies upstream along the main creek and to the west (over the low hill, in a parallel creek). These other areas contain numerous hydrothermal features, but few geysers. The environs of these remaining geysers are described with their individual descriptions.

GROUP M–I

T87 (Geyser)

T87 is a frothy pool with a 1–meter tall exploded cone on its southern end. The eruptions occur from an overhung pool. The fountain, which measures 5 meters across, produces frothy, "Jacuzzi–like" surges up to 1 meter with an interval of less than a minute. Nearly the entire pool is frothy at some times in its eruption. The pool appears superheated and is rarely completely calm.

T88 (Geyser)

T88 is a pool adjacent to the north of T87 that is separated from T87 by a 1 meter bridge of overhanging crust. Its overflow flows northward in a wide runoff channel. Its surging is likely related to the activity of T87. Small splashing (up to 30 centimeters) that appears to be independent of activity within T87 occurs along the overhanging ledge on the pool's northern edge.

Spring T92. Despite its sudsy, frothy appearance, there is no evidence that Spring T92ís activity was induced. (Photo by Shane Fryer)

T89 (Geyser)

T89 is a group of small sputtering, boiling springs. A shallow pool 50 centimeters across vigorously boils and two vents a meter east erupt to 20 centimeters. During observation, the southernmost spouter erupted for at least 2 minutes with splashing to 20 centimeters before stopping. When it stopped, a vent 40 centimeters to the north began erupting to 20 centimeters. Play continued on the northern vent for more than a minute. Further information about its interval and duration are unknown.

T90 (Hot Spring Pool)

T90 is a handsome 2–by–2 meter pool that was not seen in eruption, although it is suspected to be a geyser because of its well developed, wide runoff channel. In addition, a sinter–lined splash area surrounds the pool and implies, if not eruptive activity, at least intermittent rises in water level. Continuous boiling occurs along the pool's southeast edge.

T91 (Geyser)

T91 is a pool 2 meters across with half of its perimeter encircled by white, bumpy sinter deposits that radiate out 1.5 meters from the pool's edge. The active vent is located on the eastern corner of the pool. The rim of the sinter next to the pool has orange and dark–brown bacteria growing along it. The pool had no distinct runoff channel. The geyser produces frothy surges up to 2 meters in height for a few seconds on an interval of about a minute.

T92 (Geyser)

T92 erratically produces frothy surges up to 2 meters from an elongated pool. The undercut pool is 2.5 meters across. Its abundant discharge flows north through a well–developed, meandering runoff channel. The area surrounding the pool is bright orange and wet to a distance of 1 meter. The temperature during quiescence was measured at 83.6°C.

Spring T91. (Photo by Cyril Cavadore)

T93/T94/T95 (Three Closely Related Geysers)

T93–95 is a group of three fountain geysers that surround an exploded cone at the base of the western hill. These geysers now act independently, although they may at one time have been one geyser. The remnant of the cone is about 1.5 meters in height and 3 meters in diameter. The cone is golden brown in color, with some white patches. T94 is the northern geyser, which splashes near perpetually to 1 meter from its bluish–colored pool. Its discharge is channeled northward. The runoff channel, with scalloped sinter encrustations along its borders, is about 50 centimeters wide and several meters in length. The channel has rusty orange deposits (possibly bacteria, although the colors do not vary along the channel), with some cream–colored patches along the upper rim. The entire pool occasionally appears to use a wide, wet overflow zone with brown, rusty orange and cream–colored deposits. T93 is the eastern geyser, which surges near almost perpetually to 2 meters. The overflow pool around T93 had a temperature of 83.5° C. T95 is the southernmost geyser, with near perpetual surges to 1 meter.

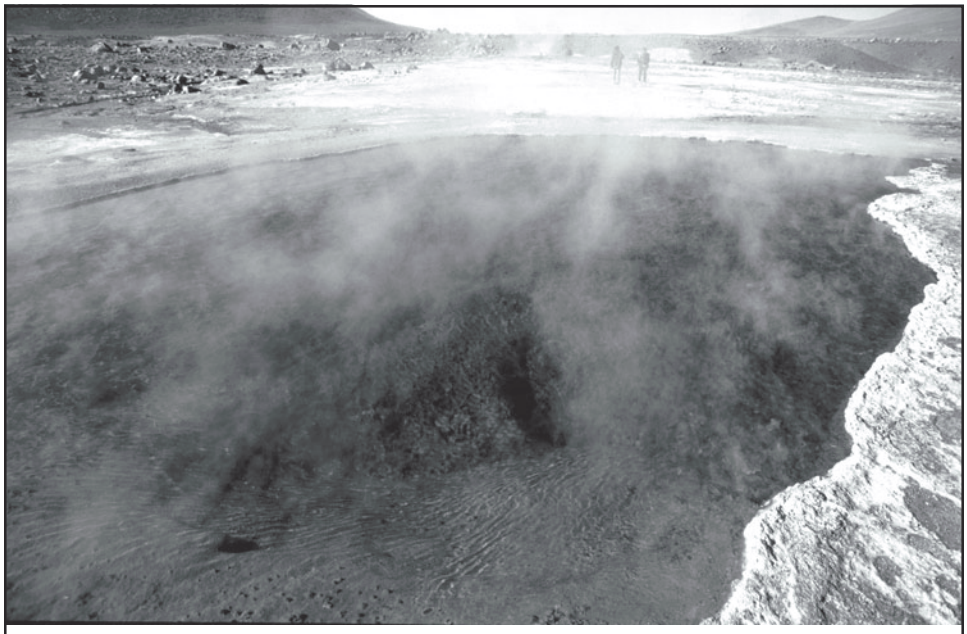
Immediately south of the geyser complex is a steaming rock–filled depression. Many of the rocks in the depression are concreted together by a fine layer of reddish–orange sinter. The sound of boiling water can be heard under the rocks. It is possible that the feature has eruptive behavior, but none was seen.

T96 (Geyser)

T96 is a 25–centimeter tall cone with an irregularly shaped meter–long cauldron. It is located near the top of the hill and its overflow is radial from the elevated cone. Water inside the cone appears to be 2 or more meters deep. This feature was not observed in eruption. However, a visitor's (Cyril Cavadore) February 2000 photograph shows a small eruption of the feature. The eruption appears to be a vigorous boiling overflow with a splash to 20 centimeters. During March 2002, a wide, wet zone surrounding the vent was noted, implying that the geyser is active. A combination of shallow water, mineral deposition, and bacteria create a colorful mosaic of dark reds and greens away from the elevated vent. Its interval is greater than 15 minutes. This region has dark ashy soils and volcanic rocks, ranging from baseball– to car–sized, spewed everywhere. Yellow scrub grasses are interspersed throughout the area.

T96b (Intermittent Spring Pool)

About 30 meters to the northeast of T96 is one of the largest pools in the basin. The 9–by–6 meter rectangular pool is filled with dark blue water on the edge of boiling. Parts of the spring have an overhanging geyserite crust, but otherwise, the bed of the pool descends as a cone to a meter–wide vent at the pool's bottom. At its deepest, the pool is at least 6 meters deep. We observed the pool to be approximately 1 centimeter below overflow. However, its shallow runoff channel was wet with scat-



The pool of intermittent **Spring T96b**. (Photo by Cyril Cavadore)

tered moisture and tiny pools. Whether the spring erupts is unknown, but the spring apparently has some type of intermittent discharge activity.

GROUP M–II

T97 (Perpetual Spouter, Hot Springs, and Sinter Terraces)

T97 is a red, iron–colored cone that is located on a mound. The feature is about 100 meters south of the Terrace Spring Group along a slope west of a small stream. This spouter erupts nearly perpetually to 30 centimeters with an erratic duration. Several similar boiling springs were noted on the same western slope; several are small perpetual spouters. This feature and one or two others are likely to be actual geysers.

Downstream of T97 lies an extensive area of short, white, brown, and orange terraces developed from non–boiling springs. Several of the taller terraces are composed of multiple 10–centimeter high tiers, combining to a height of no more than a meter. Though short, the terraces are widespread. The area follows down the small creek for at least 100 meters with a width exceeding 20 meters along the way. The terraces appear to be sinter.

GROUP M–III

A thermal marsh with two distinct mudpot areas and at least one perpetual spouter lies about 2 kilometers southeast of the Middle River Group. The marsh is approximately 100 meters long, 50 meters wide and situated in a ravine. Geothermal well drilling surrounds the area. Mudpots that consist of either entirely black mud or reddish orange mud are interspersed throughout the vicinity. In the upstream and northern portion of the swamp, an area of flooded mudpots is surrounded by tall grass and green moss. Along the southeast end of the thermal marsh lies a perpetual spouter that erupts clear water to a meter. It is located along the bank of a small stream flowing through the swamp. Its 30–centimeter deep crater–like vent is surrounded on one side by a leafy green moss. The other side is open to the nearby creek. Pebbles and gravel lie on its flat crater floor.

A large vigorous mudpot lies about 500 meters west of the thermal swamp. The feature is located south of the road in the same valley as the marsh. Numerous geothermal wells are visible from the

A view toward the mudpots near the thermal swamp of **Group M–III**. (Photo by Alan Glennon)

Mudpots within **Group M–III**. (Photo by Alan Glennon)

mudpot. The far southern end of the Middle Geyser Group can be seen from the mudpots. By far the most vigorous mudpot in the basin, the main area of activity occurs in a 3–by–3 meter cauldron. Watery red mud is splashed between 50 centimeters and 2 meters everywhere in the cauldron. A couple of meters to the north of the cauldron, an elongated pool 10 meters long and 4 meters wide boils gently with a less watery variety of the red mud. Fifty meters west of these mudpots, a fumarole belches steam from a 2–meter deep explosion crater.

T106 (Geyser and Reported Geyser)

A geyser (probably Trujillo *et al.* [1969] feature 35) is located 400 meters southeast of the primary Middle Group. Its vent is well–hidden within an area scattered with small ravines, small scrub brush, gravel, and boulders. The geyser erupts a stream of water 2 meters high at an angle about 30° from the vertical. The eruption lasts less than a minute. We originally saw this geyser while driving from the middle group to the thermal marsh area. Taking a well–drilling road, we noticed the geyser erupting, approximately 50 meters from our truck. By the time we stopped the truck and made it over to the geyser, the eruption had ended. In fact, when we arrived at the geyser, not even a trace of steam remained. Without using the eruption itself as a guide, the vent would be very difficult to find. The small vent looks like a small animal's burrow near a large rock. Similar rocks and small ravines make the location quite nondescript. Luckily, from the middle group, steam from the eruption is easily visible. From the middle group, having seen approximately three eruptions in the distance, the geyser's interval was estimated at 15 minutes or more.

The immediate vicinity of this geyser is intriguing, but we did not have the time to investigate. The area between the middle group and the thermal marsh has the appearance of a long–dormant geyser area. Several low, broad mounds appeared to be dilapidated spring terraces.

Spring number 36 on the Trujillo *et al.* [1969] map is a reported geyser. We did not visit the feature. The road into the basin from the south crosses a steep–sided ravine where several small springs can be seen from the road. The reported geyser is located upstream in the stream valley and access appears straightforward.

A perpetual spouter (unnumbered) in **Group M–III**. (Photo by Alan Glennon)

Appendix I
The Geysers and Springs of El Tatio
Observations of March 8–24, 2002

	Latitude	Longitude	Height	Duration	Interval	Description
GROUP U-I						
T5a	see map	see map		-	-	fumarole
T5b	see map	see map	0.10	1 minute	10 minutes	weak geyser
T5c	-22.32985000	-68.00951667	1.00	perpetual	perpetual	perpetual spouter
T5	-22.32988333	-68.00976667	0.05	perpetual	perpetual	perpetual spouter
T6	-22.32993333	-68.00970000	0.10	5 seconds	erratic	geyser
T7	-22.32993333	-68.00970000	0.05	perpetual	perpetual	perpetual spouter
T18	-22.32993333	-68.00988333	0.40	>1 minute	15-20 minutes	geyser
T9	-22.32975000	-68.01006667	0.20	perpetual	perpetual	perpetual spouter
T10	-22.32971667	-68.01010000	0.10	perpetual	perpetual	perpetual spouter
GROUP U-II						
T12	-22.33006667	-68.01030000	1.50	1.25 - 2 minutes	<15 minutes	geyser
T13	-22.33006667	-68.01030000	0.20	2.5 minutes	<14.75 minutes	geyser
T14	-22.33011667	-68.01033333	0.50	1.5 minutes	3 - 15 minutes	geyser
T15/16	-22.33015000	-68.01035000	0.10	minutes	4 minutes	geyser
T17	-22.33000000	-68.01020000	0.50	9 minutes	>5 minutes	geyser
T19	-22.33023333	-68.01023333	1.50	3 minutes	20-23 minutes	geyser
T20	-22.33016667	-68.01021667	0.10	perpetual	perpetual	perpetual spouter
T21	-22.33023333	-68.01016667	0.05	perpetual	perpetual	perpetual spouter
T22	-22.33045000	-68.01013333	0.30	2 minutes	5 minutes+	geyser
GROUP U-III						
T23	-22.33058333	-68.01040000	0.40	days	days	geyser
T23a	see map	see map	0.50	days	days	geyser
T24	-22.33095000	-68.01061667	1.00	35 minutes	>3 minutes	geyser
T25	-22.33105000	-68.01115000	5.00	15 minutes	2 hours +	geyser
GROUP U-IV						
T27	see map	see map	0.40	5 minutes	>1 minute	geyser
T34	see map	see map	0.10	seconds	seconds	geyser
T28	-22.33090000	-68.01168333	1.00	<1 minute	seconds	geyser
T29	-22.33090000	-68.01165000	0.50	30 seconds	2 minutes	geyser
T30	-22.33106667	-68.01163333	0.40	5 seconds	15-25 seconds	geyser
T31	-22.33093333	-68.01161667	0.20	seconds	> 1 minute	weak geyser
T33	-22.33003333	-68.00968333	0.20	seconds	30 seconds	weak geyser
T33b	-22.33033333	-68.00968333		-	-	fumarole
T32	-22.33093333	-68.01161667	0.10	seconds	> 2 minutes	weak geyser
T26	-22.33116667	-68.01133333	0.20	minutes	seconds	geyser
GROUP U-V						
T35	-22.33123333	-68.01176667	1.50	1 minute	2 minutes	geyser
T36	-22.33143333	-68.01180000	0.50	perpetual	perpetual	perpetual spouter
T37	-22.33106667	-68.01193333	0.10	seconds	seconds	geyser
T38	-22.33121667	-68.01221667	0.20	< 30 seconds	2 minutes	geyser
T67	-22.33140000	-68.01255000	0.30	10 minutes +	unknown	geyser
T67b	see map	see map	0.40	4 minutes	> 1 minute	geyser

T39	-22.33116667	-68.01223333	0.10	seconds	<1 minute	geyser
T40	-22.33130000	-68.01210000	0.10	perpetual	perpetual	perpetual spouter
T41	-22.33138333	-68.01210000	0.40	2 minutes	> 5 minutes	geyser
T42	-22.33140000	-68.01183333		30 seconds	3 minutes	intermittent overflow
T43	-22.33156667	-68.01215000	1.00	minutes	seconds	geyser
T44	-22.33160000	-68.01216667	0.10	> 1 minute	> 5 minutes	geyser
T45	-22.33158333	-68.01225000	0.70	1 minute	> 2 minutes	geyser
GROUP U-VI						
T46	-22.33173333	-68.01213333	1.00	>1 minute	>15 minutes	geyser
T47	-22.33176667	-68.01221667	0.10	seconds	unknown	geyser
T48	-22.33170000	-68.01238333	0.20	seconds	minutes	geyser
T49	-22.33175000	-68.01246667	0.05	seconds	seconds	geyser
T50	-22.33175000	-68.01243333	0.50	> 1 minute	seconds	geyser
T51	-22.33155000	-68.01276667	1.00	< 5 minutes	<15 minutes	geyser
T53	-22.33190000	-68.01256667	0.15	unknown	10 minutes	geyser
T54	-22.33175000	-68.01248333	0.05	seconds	seconds	weak geyser
T55	-22.33168333	-68.01251667	0.10	< 10 seconds	unknown	geyser
T56	-22.33191667	-68.01231667	0.50	seconds	> 1 minute	geyser
T57	-22.33171667	-68.01251667	0.05	seconds	1 minute	geyser
T58	-22.33171667	-68.01250000		-	-	hot spring
GROUP U-VII						
T59	-22.33195000	-68.01276667	0.30	1 second	< 30 seconds	geyser
T60	-22.33185000	-68.01288333		-	-	warm spring
T61	-22.33203333	-68.01275000	0.60	5+ minutes	seconds	geyser
T62	-22.33208333	-68.01345000	0.10	perpetual	perpetual	perpetual spouter
T63	-22.33216667	-68.01303333	3.00	15 minutes	2.5 hours+	geyser
T64	-22.33215000	-68.01290000		-	-	dormant vent
T65	-22.33220000	-68.01293333	0.15	seconds	seconds	geyser
T66	-22.33320000	-68.01300000	3.00	seconds	> 1 hour	geyser
T67c	see map	see map	1.00	1 minute	seconds	geyser
GROUP U-VIII						
T3	-22.32728333	-68.00568333	1.00	15 seconds	4 minutes	geyser
T4	-22.32813333	-68.00623333	0.20	8 minutes	14 minutes+	geyser
GROUP L-I						
T68	-22.34088333	-68.02275000	1.00	1 minute	3 minutes+	geyser
T68b	-22.34145000	-68.02235000	0.20	perpetual	perpetual	perpetual spouter
T69	-22.34106667	-68.02396667	0.30	perpetual	perpetual	perpetual spouter
T70	-22.34116667	-68.02421667	1.00	< 1 minute	~2 minutes	geyser
T71	-22.34108333	-68.02423333	1.00	~ 1 minute	~ 5 minutes	geyser
GROUP L-II						
T72	-22.34038333	-68.02635000	5.00	>30 minutes	minutes	geyser
T73	-22.34043333	-68.02621667	2.50	>30 minutes	seconds	geyser
T74	-22.34068333	-68.02655000	0.40	perpetual	perpetual	perpetual spouter
T77	-22.34050000	-68.02708333	1.00	3 minutes	5 minutes	geyser
T78	-22.34058333	-68.02710000	0.40	> 1 minute	minutes	geyser
T79	-22.34050000	-68.02705000	0.50	~15 minutes	10 minutes	geyser
T76	-22.34041667	-68.02705000	0.50	perpetual	perpetual	perpetual spouter
T80	-22.34075000	-68.02700000	2.00	25 minutes	unknown	geyser

T75	-22.34071667	-68.02700000	0.20	seconds	seconds	geyser
T81	-22.34081667	-68.02686667	0.50	perpetual	perpetual	perpetual spouter
T82	-22.34038333	-68.02673333	0.10	minutes	20+ minutes	geyser
T83	-22.34050000	-68.02650000	0.15	perpetual	perpetual	perpetual spouter
T84	-22.34038333	-68.02686667	1.00	minutes	seconds	geyser
T84b	see map	see map	0.10	10 seconds	minutes	weak geyser
T85	see map	see map	0.30	seconds	seconds	geyser
GROUP L-III						
T86	-22.34028333	-68.02690000	1.00	erratic	erratic	mud volcano
T100	see map	see map	0.50	1 minute	erratic	geyser
T101	see map	see map	1.00	1 minute	3 minutes	geyser
T102	see map	see map	0.05	1 second	10-15 seconds	weak geyser
T103	see map	see map	0.60	minutes	seconds	geyser
T104	see map	see map	0.60	minutes	seconds	geyser
T105	see map	see map	0.20	seconds	seconds	geyser
T105a	see map	see map	0.10	seconds	< 1 minute	geyser
GROUP L-IV						
T98	-22.33715000	-68.02640000	1.00	near perpetual	seconds	geyser
T99	-22.33898333	-68.02615000		-	-	hot spring pool
GROUP L-VI						
T1	-22.33955000	-68.01898333		-	-	hot spring pool
T2	-22.33958333	-68.01855000	0.50	perpetual	perpetual	perpetual spouter
GROUP M-I						
T87	-22.34241667	-68.01283333	1.00	near perpetual	< 1 minute	geyser
T88	-22.34240000	-68.01283333	0.30	seconds	> 1 minute	geyser
T89	-22.34255000	-68.01233333	0.20	2 minutes	1 minute	geyser
T90	-22.34265000	-68.01216667		-	-	hot spring pool
T91	-22.34348333	-68.01175000	2.00	seconds	~ 1 minute	geyser
T92	-22.34346667	-68.01203333	2.00	seconds	seconds	geyser
T93	-22.34408333	-68.01198333	2.00	near perpetual	seconds	geyser
T94	-22.34405000	-68.01198333	1.00	near perpetual	seconds	geyser
T95	-22.34410000	-68.01190000	1.00	near perpetual	seconds	geyser
T96	-22.34558333	-68.01221667	0.20	unknown	>15 minutes	geyser
T96b	see map	see map		-	-	hot spring pool
GROUP M-II						
T97	-22.34638333	-68.01326667	0.30	perpetual	perpetual	perpetual spouter
GROUP M-III						
T106	see map	see map	2.00	<1 minute	>15 minutes	geyser
Sol de Manana	-22.42545000	-67.76178333		-	-	Bolivian field

APPENDIX II: Expedition Log

Inception — Before the trip in March 2002, Alan Glennon had been talking about making a South American geyser trip for nearly a year. Along the way, his rambling about geysers high in the Andes Mountains piqued the interest of several friends. Rhonda Pfaff, a graduate student, had gained an interest in geysers while working at the Yellowstone Center for Resources at Yellowstone National Park during the summer of 2001. On one trip to visit her, Alan brought along geology student Weldon Hawkins. To show Weldon something different, Alan took him to Geyser Creek. After several hours in the backcountry thermal area, Weldon was hooked. Shane Fryer, a geography student and avid traveler, was our fourth participant.

Since, we were all associated with Western Kentucky University (WKU), we had the same spring break holiday. In addition, Shane's father works for an airline serving Santiago, Chile and was able to obtain discount passes. We left from Louisville, Kentucky, for Chile on March 13, 2002. We wanted to see the geyser field at El Tatio, and other thermal fields, too, if we could arrange the travel.

Flying standby from Louisville, we scheduled a "buffer day" in Santiago, Chile's capital and home of 5 million inhabitants, before our 2,000–kilometer domestic flight to Calama. We spent the day in Santiago walking around downtown, visiting the University of Chile, and obtaining maps at the Instituto Geográfico Militar (IGM). We purchased 1:50,000 scale topographic maps of the Chilean geyser fields of El Tatio and Puchultisa. The IGM employees spoke some English, although much of the conversation of selecting the particular map sheets occurred in Spanish. Rhonda and Weldon both speak Spanish. Their Spanish was particularly useful in obtaining food, lodging, and the rental car.

From Santiago to the Atacama Desert — From Santiago, we flew LanChile—Línea Aérea Nacional, the government airline of Chile—north to Calama, with a stop in Antofagasta. The Calama airport had roll–up steps for deplaning and a single baggage claim carousel inside. As we stepped off the airplane, we saw a vast, wide–open landscape voided of all vegetation and dotted with chunks of rock. At the Calama airport gift shop, we purchased a Spanish guidebook with road maps of northern Chile, published by the telecommunications company CTC Chile [Zúñiga, 2001].

A line of rental car agents from primarily American companies greeted the flight. We obtained our vehicle from the Chilean company Econorent without having confirmed reservations. We rented a Toyota Hilux (similar to a Tacoma), which was a double–cab, 4x4 sport utility truck with a 5–speed manual transmission, roll bar, and room for five people. We were sure to rent a truck that was tuned for driving off–road and at high altitudes. It came equipped with a flag on a 3–meter pole and a flashing blue light for driving in the large open pit copper mines near Calama. With unlimited kilometers, two drivers, and insurance, a week's rental was about US$500. An International Driver's Permit is required to drive in Chile.

Paved roads become dirt paths in San Pedro de Atacama, an oasis town of about a thousand permanent residents located about 60 kilometers southeast of Calama. San Pedro is a tourist town, with small hotels, quaint cafes and restaurants. The town has an outdoor market, archaeological museum, charming adobe church with a cactus–wood ceiling, and an interesting cemetery. There are also many Internet cafes, with an hour of access for as little as US$1.50. Most of the visitors we saw in San Pedro were German or Australian eco–tourists; Americans were scarce. The town has electricity from 8 or 9 a.m. to midnight and most hotels we found throughout northern Chile only have hot water when tourists request it.

We arrived in San Pedro after 10 p.m., which, without reservations, made it difficult to find a hotel. Since the first hotel we checked had a sign warning, "*Peligro! Cholera*," we took our search elsewhere (the sign was leftover from an outbreak several years ago). We ended up spending the week at the Hostal Sumaj–Jallpa, a hotel just outside of the "downtown." The small hotel had an inner courtyard and about five rooms. Our room cost about US$30 per night for four people. Weather during the day in San Pedro, at nearly half the el-

evation of El Tatio, was typically hot at around 27°C. However, temperatures decreased enough each night to make sleeping comfortable.

The majority of our meals in San Pedro were at Petro Pizza, a small restaurant run by a German–turned–Chilean hippy that, of course, served pizza. He also served empanadas and other traditional Chilean dishes. A pizza *marguerita* (cheese pizza) was about US$1.50 there. We found that only chain restaurants (like the Calama Domino's Pizza) served the typical American–style pizza. The local restaurants skipped the sauce and placed the cheese (often Roquefort) on wafer–like crusts. San Pedro grocery stores have water jugs, snacks, and beverages. Supplies had to be purchased in either San Pedro or Calama, since the area between San Pedro and the geysers is effectively wilderness.

As a general note, a Hepatitis A (and Hepatitis B) immunization is recommended for the trip. We visited travel doctors before the trip and received prescription medication for diarrhea, nausea, elevation sickness, and other travel–related unpleasantness. While some travelers said that much of Chile's water is potable, we drank only bottled water. Some villages near Calama have water supplies that have been contaminated by copper mine drainage. Alan became very sick on the trip (he left the United States with a terrible cold, which did not mix well with elevation), and almost had to cut his trip short. Because of lost time from his sickness, we were unable travel to Puchultisa, although we spent three days at El Tatio and one day in Bolivia.

San Pedro was our base for our El Tatio and Bolivia excursions. We spent two nights in San Pedro in order to acclimate to the high elevation (2,440 meters at San Pedro). Just a few kilometers outside of San Pedro is Valle de la Luna (Valley of the Moon) within the Reserva Nacional Los Flamencos (National Flamingo Reserve). Valle de la Luna has widespread salt deposits, caves, pits, heavily folded rocks, and sand dunes over 100 meters tall. However, in the area, we also passed several former land mine fields with signs warning visitors to remain on the road. Mines are a real danger in Chile; in 2001, a group visiting El Tatio found a mine along the main road [*La Estrella de Loa*, 2001].

To Bolivia — After a few days in San Pedro, everyone but Alan took a day–trip to Bolivia. The stops along the tour were Laguna Blanca, Salvador Dalí's Rocks, Aguas Termales (warm springs), Sol De Mañana thermal field, Laguna Colorada, and Laguna Verde. Tour companies in San Pedro primarily offered trips to Bolivia that lasted three days and concluded at Uyuni, Bolivia; Pamela Tours was the only company that we found that offered a single–day–long trip to Bolivia. Since a three–day trip to Uyuni is US$70 (plus an extra US$50 to return to San Pedro), our single–day excursion, with a minimum four people and a maximum of six people, was considered very expensive at US$50 per person. The tour left at 8:30 a.m. and dropped us off at our hotel at 8 p.m.

The trip began at the tour company's office, with the first stop at Chilean customs and immigration just a few kilometers outside San Pedro. An officer stamped us out of the country and collected our yellow landing slips from our arrival at the Santiago airport. The true border with Bolivia was approximately another hour away on a road that was paved for much of the way. At Bolivia, the van driver dropped us off as a new driver in a beaten–up Toyota Land Cruiser Sport Utility Vehicle (SUV) met us. At Bolivian customs and immigration, a shack with abandoned vehicles strewn about around the property, we each paid a US$5 entrance fee for the Reserva Nacional de Fauna Andina Eduardo Avaroa (a national wildlife refuge) and received a passport stamp valid for up to a 30–day stay.

The Bolivian dirt roads were very bumpy and heavily "wash–boarded." The first stop along the tour was a few kilometers from the border, at Laguna Blanca (White Lake). It is a clear, shallow, reflective lake surrounded by mountains. There were a few flamingos wading in the water. Laguna Blanca appeared to be a meeting point for several tours, since there were many backpackers sitting on the steps of a series of hostel rooms that faced the lake. There, our driver checked over the SUV; at one point, he was using a welder to repair something under the hood. This was also the last opportunity to use a flushing toilet, which cost 100 Chilean pesos (about US$0.15).

From Laguna Blanca, the next stop was Salvador Dalí's Rocks, a series of jagged outcrops that are reminiscent of a Dalí painting. Some tours drive up to the rocks, although ours remained a kilometer or so away. The 20 minutes of hiking out to the rocks spent time that could have instead been applied to the geysers.

About 20 minutes later, we reached Aguas Termales, a lake with a series of hot springs around the shore. At least five other tour groups were already at Aguas Termales. We measured the primary spring at 37°C. One of the other tour SUVs had a stereo and was blaring 1980s American dance music, as many of the youthful, European tourists bathed in the shallow waters or kicked a soccer ball amongst each other. We saw some tourists submerging themselves in the spring water, which we, as students of water quality, deemed an unhealthy decision.

At Aguas Termales, the tour company provided "lunch," which consisted of fresh cucumbers and tomatoes, and Bolivian bologna (we think) with pink and white fatty speckles. The "mystery meat" had been in a basket—not a cooler—in the back of the truck, in the sun, for several hours. Shane and Weldon ate the meat and became ill that day, while Rhonda, who brought a jar of peanut butter and made her own sandwich, remained healthy. Therefore, we suggest bringing your own lunch and gracefully declining the tour company meal. The tour operator also rinsed the dishes and knives from lunch in one of the thermal springs. During the dishwashing, we discovered that our vehicle had a flat tire, which the driver changed in about ten minutes. In all, about two hours was spent at Aguas Termales; a ten–minute stop is about all that is needed.

After another 45 minutes of driving, we reached Sol de Mañana thermal field (at elevations around 4,800–5,000 meters). At the field, there were already four tour SUVs. The air temperature was warm and the sun was bright, although a chilly wind blew across the altiplano. We drove across the hydrothermally altered ground and parked at an area of intense activity. As the driver stopped the truck, he turned around and said, "Diez minutos," which meant that we were leaving Sol de Mañana in ten minutes. Frustrated, we offered to pay him extra to skip the rest of the tour and remain longer at the thermal area. He repeated, "Diez minutos." Shane ran as far as he could from the truck to provide us with more time. In total, we spent about 25 minutes at the field; in the allotted time, we believe we saw only a quarter of the area.

The hydrothermally altered, barren soils ranged from reds and oranges to grays and whites. As we stepped out of the truck, the ground was whistling with steam and we felt thumps underfoot from intense subterranean activity. Faded, wooden, red signs warned us, "Peligro de muerte": danger of death. We saw tourists walking haphazardly through many risky areas. None of the tourists appeared to be in the field with their guides; indeed, our driver (as he did at all the stops), leaned his seat back, covered his eyes with his hat brim, and took a short nap.

Trying to see as much hydrothermal activity at Sol de Mañana as possible, we ran around the field (as quickly as we could at high elevations and in unstable terrain). The main area is about 10 km^2, although hydrothermal manifestations occur throughout a much larger region. In the short time that we were there, we saw one perpetual spouter sputtering a fine spray a meter high within its crater. Because other features in the area appeared to be watery, it is likely that there are other perpetual spouters and possibly geysers. The area we visited seemed to be part of the field's higher elevations; there is also a potential for eruptive features in the lower elevations of the basin. Nonetheless, Sol de Mañana has incredible mudpots that splash gray to deep–brown mud up to 2 meters. Many of the waterlogged pots splashed more than "plopped." Closely spaced depressions 3 meters deep and some nearly 7 meters wide dominated the field, with each splattering mud. Plumes of steam could be seen in the distance and on hills lining one side of the field. A strong fumarole vented steam 10 meters and higher. Angular, volcanic rocks, many larger than our truck, dotted the hillside and altiplano. Within 2 kilometers of the field, we noticed at least two geothermal wells.

The final two stops along the tour were Laguna Colorada and Laguna Verde. Laguna Colorada

is a pink–colored lake that had flamingos wading in it. Mountains and volcanoes surround the thermally fed lake. As we neared Laguna Verde, a brilliant, emerald green lake, the weather turned windy, cold, and rainy. At Laguna Verde, we stopped only long enough to snap a few photographs of the lake and a rainbow behind us. We soon arrived again at the Bolivian border, where we paid a "departure tax" of 1,500 Chilean pesos each (about US$2) and received exit stamps in our passports.

On the return trip to San Pedro, we passed through a storm that dropped more than a centimeter of snow. Every few minutes, the front seat passenger had to wipe the driver's continuously fogging windshield. As we descended to San Pedro, the storm passed. At Chilean customs and immigration on the outskirts of town, a narcotics dog sniffed the van and our personal items. Inside customs, we had to empty our bags and were hand–searched for drugs, fruits, and vegetables. Before long, we were back at our hotel and regaling Alan with stories about the tour. For the lakes, Andean views, and miscellaneous hot springs, seeing southern Bolivia is worthwhile, even with only 25 minutes at Sol de Mañana.

To El Tatio — After the day trip to Bolivia, we spent our next three days at El Tatio. We drove ourselves to and from El Tatio daily, again using San Pedro as our base. The 86–kilometer drive from San Pedro to El Tatio took between two and two–and–a–half hours. The route was along a rocky and heavily wash–boarded dirt road with occasional stream crossings and detours at washed–out bridges. The road to El Tatio is well–marked and easy to follow. Traversing unimproved roads, volcanic rocks, sand, and gravel proves hard on car tires. We were sure to bring the tools necessary to change a tire — including a good spare. In fact, the locals recommend having two spares. We also filled our gas tank daily, just in case weather or unexpected washouts forced us to return via the alternate route. The alternate road to El Tatio via Calama is about 130 kilometers long. Gas in Calama was reasonably priced, but was expensive in San Pedro. The single gas station in San Pedro is at Hostería San Pedro, where it cost as much as US$80 for a fill–up. We also took camping gear with us, in case we had major car troubles. It was reassuring that a load of tourist buses would be driving the road each morning.

Although the owner of our hotel in San Pedro questioned us for heading to El Tatio when there was supposedly no activity, we set out for El Tatio each day in the mid–morning. We passed tour vans returning to San Pedro, but we arrived at El Tatio after all the tourist buses had left. For the three days of our visit, we were alone in the basin.

At elevations close to 4,500 meters at the geysers, the decreased oxygen level slowed our physical activities. We spent the days recording the activity in a field notebook and collecting map coordinates using a handheld Global Positioning System unit. We took still photographs and used a video camera to document the activity. However, after two days, the camcorder malfunctioned. The combination of rough roads, dust, and steam proved too much for the camera.

The afternoon temperatures at El Tatio in March were chilly, primarily from mountain winds. As if preparing for a cool day in Yellowstone and at high elevations, we wore sunblock, sunglasses, blue jeans, floppy hats, jackets and fleece liners, and gloves. We also experienced a thunderstorm one day at the basin. Though the clouds made the sky dark, only a trace of rain fell.

We generally left El Tatio just before dark (at around 6 or 7 p.m.), so we would at least be on the road before night fell. We saw many chinchillas and other small nocturnal animals bounding across the road. By the time we arrived in San Pedro each night and took a quick shower, the town had already slowed down. By 10 p.m., most of the tourists had eaten and were wandering the streets returning to their hotels. We usually hit a restaurant as they closed and made a last supply run to one of the small general stores.

APPENDIX III: HAZARDS

Numerous hazards exist while traveling abroad in general. However, the following are some of the hazards and cautions specifically relating to travel to El Tatio Geyser Field.

The Thermal Area

Although the El Tatio Geysers have become increasingly accessible by tour and rented vehicle, visitors should be aware of numerous hazards involved in traveling to and within this thermal area. Guides in San Pedro told us that burn accidents are routine and several people have died by falling into boiling pools. Unconfirmed accounts have reported that a body was not recovered at El Tatio and that several bodies may remain in the mudpots of Sol de Mañana. In October 2002, a Spanish tourist to El Tatio stepped backward into a hot spring—with a temperature estimated at 90°C—and received burns to 80 percent of his body [*La Estrella de Loa*, 2002]. As a result, a $35,000 trail and parking project are underway to enhance visitor safety [*La Estrella de Loa*, 2003]. Regardless, as with all geyser areas, extreme care must be taken while walking throughout the basin. Thin crusts may conceal underlying pools of boiling water and mud. Unseen fragile rims may overhang deep boiling pools, while seemingly innocuous dry cones and rifts areas can violently eject boiling water with little or no notice. One remarkable characteristic of the El Tatio basin is that a number of thermal features are submerged in the Río Salado. These features look like deep spots in the otherwise shallow river, although these locations actually discharge boiling water. Visitors unaccustomed to the perils of backcountry geyser travel should be careful to stay with competent guides. Considerate travel through the basin not only is safer, but also helps protect the thermal features themselves.

Volcanoes

The geyser field is ringed by active volcanoes. On the drive to El Tatio, we noticed two volcanic vents. From San Pedro de Atacama we saw that Volcán Lascar, about 100 kilometers to the south, was having constant hydrothermal eruptions. These occurred throughout our seven–day visit. Volcán Lascar is one of the most active volcanoes in the central Andes. Violent eruptions in July 2000 sent ash streaming 4,000 to 5,000 meters above its summit. In addition, near Volcán Lascar, renewed activity has appeared at Volcán Chilique. The activity was first noted on NASA Aster satellite imagery in January 2002. During our last day at El Tatio, Volcán Putana, which is 25 kilometers southeast of the basin, began spewing 200–meter–high columns of steam from its crater. Visitors should be constantly aware of their surroundings and ask locals about ongoing volcanic activity.

Roads

The dirt roads to El Tatio from San Pedro and Calama are well marked, but there are several points to consider before traveling. First, make sure to have a vehicle tuned to high elevation travel. While El Tatio itself is at 4,200 meters, the road steadily climbs from these cities and traverses altitudes of greater than 4,700 meters. Elevation gain is accomplished through a series of occasionally sharp switchbacks. Numerous memorial crosses have been placed along the side of the road marking locations where vehicles have driven off the road and down the steep hillsides. On a return trip from the basin one evening, we encountered a truck that had taken a turn too fast and was now resting upside down with its windows shattered. We stopped to investigate since the overhead light in the truck was on, although there were no passengers inside when we found the vehicle. The wreck had occurred sometime while we were at El Tatio, since it was not there on our way to the basin. By our trip to the basin the next day, the vehicle had been towed to San Pedro.

Several large road washouts exist along the main route, too, but are not problematic with slow, attentive driving. The locals, possibly the tour companies, have created alternate winding routes around each washout. The road from San Pedro to the geysers also crosses a number of creeks that were up to sixty centimeters deep. The creeks could be dangerous if approached too quickly or if a recent rain had raised the water levels. Flash floods can create impassable muddy deluges during thunderstorms and sudden snow melts. During normal conditions, other than occasional streams and mud puddles, the route is dry. With a four–wheel drive vehicle, having a flat tire (since the dirt roads tend to be made of gravels and sharp volcanic basalts) is the most likely problem to occur along the road. Getting stuck at the geyser basin itself is possible,

though. Besides crossing the Río Salado, the road through the basin travels around and literally over numerous thermal features. Drivers should be extremely cautious. We originally planned to park at the edge of the basin and walk to the features. However, we found ourselves using our truck as a ferry to keep ourselves dry, since the Río Salado flows throughout much of the basin as a wide, braided stream requiring frequent fording.

Plans appear to be underway to create a paved road from San Pedro to the basin. Numerous government signs near San Pedro provide information about the road project, but probably also portend the beginning of geothermal electricity development. We noticed flagged survey stakes along the side of the road for a majority of the route.

Elevation Sickness

At elevations of 4,200 meters and greater, El Tatio Geyser Field is one of the highest geyser fields on earth. The road from San Pedro to the geyser basin often exceeds 4,700 meters. At the basin's altitude, elevation sickness is common. Allow time to acclimate slowly to the high elevations. Our team stayed in San Pedro de Atacama (2,440 meters) two nights before traveling to the higher elevations. When we arrived at the basin, we each felt at least some effect of the altitude. We found that the best way to cope with the high altitude was to walk slowly and minimize exertion (hiking and climbing was very slow as well). Fortunately, most of the geysers lie on gentle slopes or level ground. The kilometer or two walk to the Lower Basin (River Group) put everyone in our group out of breath; Alan and Rhonda both got headaches, but an ibuprofen solved the problem within an hour. Of course, being well–hydrated and getting plenty of sleep the night before lowers the risk of altitude problems. Tourist accounts of the basin seemed to come in two varieties: either the people loved the tour or they became sick. Since it is a good idea to consult a doctor about various immunizations before international travel anyway, ask about coping with high altitudes.

Landmines

Politically, Chile is a civilized, modern destination for travelers and scientists. Social and legal order are similar to Europe, Australia, and North America. Nevertheless, from 1974 to 1978, tensions between Chile and its neighbors Bolivia, Peru, and Argentina were the basis for a program of minefield creation. At least 293 separate minefields, between 250,000 and 1,000,000 landmines were laid in northern Chile. Although Chile now opposes the use of landmines and, in 2001, ratified an international treaty banning their use, minefields still exist in northern Chile. Particularly at Valle de Luna and along the road between Calama and San Pedro de Atacama, signs denote areas where minefields still pose a danger. Although there is no indication that mines were laid at the geysers themselves, tourists in January 2001 reported an antipersonnel mine on the way to El Tatio and notified local authorities. Mine clearance personnel from Calama were mobilized, but were unable to find any mines [*La Estrella de Loa*, 2001]. In 1999, the Chilean Government began an 11–year mine clearing program that will reduce the landmine threat.

Weather–related Hazards

With its location that spans the Andes Mountains and the Atacama Desert, the weather at the basin could be life–threatening for unprepared visitors. Be sure to carry plenty of water; the Atacama is known for being one of the driest places on earth. Water quality varies widely in the thermal basin; drinking the water is not recommended. Throughout the year, weather typically gets near or below freezing at night. Many tourist photos, which are generally taken at sunrise, show ice patches around the geyser cones. During the day, temperatures can be warm. However, snow above 4,000 meters is common. Although we did not encounter any dust storms, they are apparently quite dangerous in the area, particularly in the lower elevations at San Pedro and Calama. We were told that when dust storms occur, all travel, including tour operations, halts.

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Alan Glennon has visited several of the world's geyser areas. This photo, taken in 2003, shows a small geyser at **Hveravellir, Iceland**.