Carbonate Tufa Columns as Exploration Guides for Geothermal Systems in the Great Basin

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ABSTRACT

Calcium carbonate tufa columns have formed around many subaqueous springs in terminal lakes in the Great Basin, western United States. These subaqueous springs can be either thermal or non-thermal, as long as the spring waters have sufficient calcium to react with atmospherically derived CO2 dissolved in lake water to precipitate calcium carbonate. In contrast to large calcium carbonate travertine deposits that form around subaerial springs, which are usually not associated with electricity grade geothermal systems, large tufa deposits in the Great Basin have formed around thermal springs whose fluid geothermometry suggests reservoir temperatures as high as 150-170°C (e.g. Needle Rocks and Pyramid Rock, Nevada), which is well within the temperature range necessary for electricity production. The reason that large subaerial calcium carbonate travertine deposits are usually not associated with electricity grade geothermal systems is that high temperature geothermal waters usually do not contain sufficient levels of dissolved CO2 to precipitate significant amounts of calcium carbonate around subaerial spring orifices. But if these same thermal springs form in lake waters saturated with atmospheric CO2, precipitation of calcium carbonate can still occur as long as the spring waters contain sufficient amounts of calcium.

Many springs that formed tufa columns in the Great Basin are currently dry because the associated lakes have dried up and groundwater tables have dropped significantly, making it unlikely for springs to form. Consequently, tufa columns can provide evidence of possible underlying geothermal activity where no hot springs are present. For this reason it becomes important to discriminate tufa columns that formed around thermal springs from tufa columns associated with non-thermal springs.

Trace element geochemistry is being evaluated for its ability to distinguish thermal from non-thermal tufa deposits. We report on the results of systematic sampling of spring-related tufa and chemical analysis using inductively coupled plasma mass spectroscopy (ICP-MS). Higher temperature geothermal waters tend to have different concentrations of some trace elements as compared to shallower cooler groundwaters. In a few cases, coprecipitated silica or possible sulfate minerals may also serve to distinguish thermal from non-thermal tufa. Carbon and oxygen isotopes are less likely to be useful, because the CO2 in tufa deposits is ultimately derived from the atmosphere.

Introduction

As evidenced by the recent identification of geothermal systems on the Pyramid Lake Paiute Reservation (Coolbaugh et al., 2006), the use of tufa columns as an geothermal exploration guide appears to be underdeveloped in the Great Basin. However, the use of tufa columns as an exploration guide is complicated by the fact that tufa columns can form around non-thermal, as well as thermal springs. At the University of Nevada, Reno Great Basin Center for Geothermal Energy, a research project funded by the National Renewable Energy Laboratory (NREL) is exploring ways to distinguish thermal from non-thermal tufa columns. This work includes shallow temperature measurements (Sladek et al., 2009), soil gas studies (Lechler et al., 2009), as well as geochemical studies of major and trace elements in tufas and travertines, whose preliminary results are discussed herein.

Descriptions: Travertines and Tufa Columns

Travertine terraces form on the land surface from spring waters saturated in calcium carbonate. The precipitation process is initiated by the effervescence of carbon dioxide, which can become oversaturated because of depressurization as spring waters reach the surface. The release of CO2 causes the pH of the remaining spring fluid to rise, under which conditions the solubility of calcium carbonate is reduced, leading to its precipitation in the form in calcium carbonate. Travertine tends to form large, gently sloping domes around central spring vents (Figure 1, overleaf), or as terraces in streams flowing away from those discharge vents (Figure 2, overleaf).
In contrast to travertine deposits, the formation of tufa columns in lacustrine lakes does not require saturation and effervescence of spring-derived CO₂. Instead, if subaqueous spring waters are sufficiently enriched in calcium, that calcium can react with lake waters saturated in atmospherically derived CO₂ to precipitate calcium carbonate (Benson, 1994). This leads to the formation of relatively steep-walled tufa columns that surround central spring vents (Figure 3). In comparison to travertine domes, tufa columns are often steep walled and in extreme cases can reach heights of 100 meters or more (Coolbaugh et al., 2006). Because of their large height-to-width ratios, these tufa columns sometimes collapse (Figure 3b); such collapse is probably facilitated by the withdrawal of supporting lake waters when lacustrine lakes dry up.

Tufa columns in the Great Basin are widespread in areas covered by former Lake Lahontan in northwestern Nevada. Lake Lahontan was in places saturated in calcium carbonate with the result that calcium carbonate deposition took place on the bottoms
and sides of the lakes regardless of proximity to springs. Such calcium carbonate deposits are thinnest on the former lake bottom, and thickest along shorelines and on projecting near-surface promontories where dissolved CO₂ concentrations were highest due to wave enhanced interaction of lake waters with the atmosphere (Figure 4). These non-spring-related calcium carbonate deposits, termed herein “wave tufa”, are easily distinguished from spring-related tufa columns because the wave tufa forms relatively thin and widely distributed crusts (Figure 4).

Because of the tendency of wave tufa to preferentially form on projecting surfaces in lakes, it can also conceptually form on the sides of earlier-formed, spring-related tufa columns. For this reason, if samples of tufa columns are to be analyzed, it becomes important to distinguish between multiple episodes of deposition. Benson (1994) provides excellent descriptions of tufa column morphologies and deposition histories from Pyramid Lake. As discussed by Benson (1994), exterior portions of tufa columns exhibit a wide variety of shapes and textures including outward facing palmate structures, pillows, dendrites, and pseudomorphs of formerly hydrated calcium carbonate mineral species. In the interest of identifying major and trace elements contributions from geothermal waters, we focused on sampling subvertical calcium carbonate tube structures that comprise the interior portions of tufa columns (Figure 3b). These tube structures appear to form around spring fluids as they rise buoyantly into the lake. Individual tubes are typically comprised of a centrally located marrow-like three-dimensional network of porous calcium carbonate, surrounded by a narrow but continuous inner tube wall, in turn surrounded by a more porous or intermittent outer tube periphery or border (Figure 5).

**Link between Surface Calcium Carbonate Deposition and Subsurface Geothermal Reservoir Temperatures**

Large calcium carbonate travertine deposits are not typically associated with electricity grade geothermal resources, because of the inverse solubility of CO₂ with temperature. Hot spring waters with high temperature subsurface histories have usually had most of their CO₂ removed long before they reach the surface to form springs. Lower temperature groundwaters, even non-thermal groundwaters, can hold higher concentrations of CO₂ in solution, and when these waters flow through limestones or other carbonate rocks at depth, they can dissolve large quantities of calcium carbonate, and in turn deposit large quantities of travertine when they reach the surface (Figures. 1, 2).

In contrast to travertine deposits, tufa columns can form from thermal fluids with relatively higher temperature subsurface histories (and corresponding lower CO₂ contents), because the CO₂ needed to induce calcium carbonate deposition can be supplied by lake waters (Benson, 1994). Evidence of this relationship can be seen in the comparative chemistries of thermal fluids associated with large tufa columns and travertine domes in the Great Basin (Figures. 6-8). Thermal fluids associated with large tufa towers

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**Figure 4.** Coatings of “wave form” tufa up to 10 cm thick along the shoreline of former Lake Lahontan south of Fallon, NV. This type of tufa deposit is not associated with springs.

**Figure 5.** Cross section of vertical tube from a tufa column from the southwestern Smoke Creek Desert, NV, illustrating central marrow texture (A), inner wall (B), and outer border (C). Sample is approximately 15 cm in width, left to right.

**Figure 6.** Bicarbonate and calcium contents of thermal waters associated with large travertine domes and large tufa columns in NV and eastern CA. These tufa waters have higher Ca contents and lower HCO₃⁻ contents compared to travertine waters. See Figure 8 for sample locations.
have average quartz and Mg-corrected Na-K-Ca geothermometer temperatures, respectively, of 132, 130, and 124°C. Conversely, tufa columns can form from non-thermal spring waters, provided calcium contents are high enough induce precipitation with CO2 dissolved in lake water. Cold springs at the Popcorn Rocks tufa columns on the southwest margin of Pyramid Lake are an example.

Exploration Potential: Tufas Columns and Dry Springs

Some of the few examples of where tufa columns and/or their associated springs are still forming or flowing today include hot springs at Needle Rocks and Pyramid Rock, Nevada (Garside and Schilling, 1979), cold springs at Popcorn Rocks at Pyramid Lake, tufa and springs at Mono Lake, and warm springs at Soda Lake, Nevada (Rosen et al., 2004). But most lakes of northwestern Nevada in which tufa columns have formed, including former Lake Lahontan, have dried up since the last glacial wet period. The springs associated with these tufa columns have also dried up in response to a lowering of the water table, leaving behind the tufa columns in many cases as the only evidence that geothermal groundwaters might be still present in the subsurface. Recent reconnaissance exploration on the Pyramid Lake Paiute Reservation (Coolbaugh et al., 2006) identified two localities (Astor Pass and the Southwestern Smoke Creek Desert) where thermal groundwaters underlie tufa columns without active springs and where lake waters are no longer present. At Astor Pass, temperature gradient drilling intersected near-boiling waters within 200 feet of the surface, and at the southwestern Smoke Creek Desert, geothermometry and mixing models of down-gradient artesian wells predict reservoir temperatures on the order of 165°C. The successes of these recent exploration efforts suggest that other tufa columns in the Great Basin may overlie as yet undiscovered geothermal resources.

Lithogeochemistry

The hypothesis behind lithogeochemical analyses of tufa columns is that hot spring fluids may have left a distinctive chemical signature of their presence behind during precipitation of the calcium carbonate in the lake waters. Geothermal waters have higher dissolved concentrations of many major and trace constituents compared to colder groundwaters. It is possible that when calcium from the spring waters was being precipitated to form calcium carbonate, other elements either co-precipitated with the calcium or precipitated to form other minerals under the influence of the rapid changes in fluid chemistry, temperatures, and pressures that were occurring.

Sampling and Analytical Procedure

This initial lithogeochemical survey consisted of 36 samples from northwestern Nevada and easternmost California: 27 samples come from tufas, 8 samples come from travertines, and one sample comes from a calcite-chalcedony vein. Samples were selected to enable distinctions between thermal and non-thermal tufa columns, high temperature versus low temperature travertines, distal versus proximally precipitated travertine, and tufa columns versus more regionally precipitated wave tufa. Most samples of tufa columns were taken from tube structures (Figures 3, 5), which
were further subdivided into tube centers, inner tube walls, and outer tube borders or peripheries (see “Descriptions: Travertines and Tufas” above).

The samples were analyzed at the Nevada Bureau of Mines and Geology. After crushing and grinding, 400 mg samples were dissolved in a mixture of 2 ml concentrated nitric acid, 6 ml concentrated hydrochloric acid, and 2 ml concentrated hydrofluoric acid, heated for one hour at 100°C, cooled, and brought to a total volume of 500 ml. Trace elements were determined with an ICP-MS (Micromass Platform) using USGS standards GXR-1, GXR-2 and GXR-5 for calibration. Calcium was determined using the ICP-OES (Varian Vista AX) using USGS standards GXR-1, GXR-5 and NIST-88a for calibration. The ICP-OES was used for Mg and Si determinations using GXR-1, GXR-2, GXR-5 standards for calibration. A table of the results will be provided upon request from the authors.

Results

An initial review of the results has not identified a clear, consistent lithogeochemical distinction between thermal and non-thermal tufas columns. Nevertheless, tufas and travertines do appear capable of retaining anomalous trace element signatures, as evidenced by two separate tufa samples from Lee-Allen Hot Springs which are higher in tungsten (3.7 and 38 ppm) than all other tufa samples analyzed, and two separate travertine samples from Fales Hot Springs, which are higher in arsenic (370 and 1,200 ppm) than all other tufas and travertines. It is possible that regional and local host rock lithological and geochemical variations are disguising underlying trends between thermal and non-thermal carbonates. In any case, a statistical assessment is still in progress, and additional constituents, including sulfate, will be analyzed in the near future.

The above discussion notwithstanding, silica concentrations have some potential for discriminating between higher temperature and lower temperature travertine systems (Figure 9). The trend in Figure 9 suggests that if fluid geochemical analyses are not available, lithogeochemical analyses of travertines could have value as a qualitative subsurface temperature indicator, because minor to moderate concentrations of fine-grained silica in a travertine can be difficult to discern in hand samples. When analyzing travertines for their silica content, the proximity to the spring vent may be important. During the field sampling for our study, silica concentrations in travertine at Jersey Valley, Nevada were observed visually to steadily decrease with increasing distance from the spring source, and similarly, at Fales Hot Springs, silica concentrations measured in travertines were lower at a distal stream travertine location (1.3%) than they were at the lip of the main travertine bowl (8.5%).

In the case of tufa columns, correlations between silica concentrations and temperatures of the underlying geothermal system are poorer than they are for the travertines. For example, silica concentrations in tufa columns at Bradys Hot Springs (2.0 to 2.8%) and Lee-Allen Hot Springs (4.4 to 5.3%) are relatively low in spite of the fact that these tufa columns are associated with high temperature geothermal systems and they immediately overlie opalized sands, muds, and gravels. Perhaps the tufas at Bradys Hot Springs and Lee-Allen Hot Springs formed from cold springs during lulls in geothermal activity. Alternatively, as some field relationships tend to suggest, perhaps in a lake environment there is a stronger segregation of co-precipitated silica and carbonate between overlying tufa columns and underlying silicified sediments; greater degrees of cooling in the unconsolidated sediment zone may promote precipitation of silica before waters enter the lake.

Although somewhat academic, it may be possible to geochemically distinguish tufas as a group from travertines, as illustrated by uranium and tungsten concentrations (Figure 10), which are relatively high in tufas and travertines, respectively. This is somewhat of academic interest, since it is usually easy to make this distinction in the field based on geologic context.

Conclusions

Carbonate tufa columns in the Great Basin are a useful and under-utilized exploration guide for locating geothermal ground-
waters even where no active hot springs or other surface indicators are present. Geothermal reservoirs associated with tufa columns could have the temperatures necessary for electricity production. The ability of major and trace element lithogeochemistry to distinguish tufa columns that have formed from thermal springs from those that have not formed from thermal springs is unclear, but research is at an early stage and analyses are continuing.

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References