Digital Mapping of Structurally Controlled Geothermal Features with GPS Units and Pocket Computers

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Keywords
Geothermal, GIS, GPS, digital, mapping, structure

ABSTRACT

Hand-held global positioning system (GPS) units and pocket personal computers (PCs) were used to map surface geothermal features at the Bradys Hot Springs and Salt Wells geothermal systems, Churchill County, Nevada, in less time and with greater accuracy than would have been possible with conventional mapping methods. Geothermal features that were mapped include fumaroles, mud pots, warm ground, sinter, and a variety of silicified rocks. In both areas, the digital mapping was able to resolve structural patterns and details not shown on pre-existing maps. The cost of digital mapping technology can be relatively inexpensive, yet it can greatly speed the process of gathering data in the field and converting it into digital GIS-compatible formats.

Introduction

Geological mapping activities and other field data-gathering processes are rapidly becoming digital. Inexpensive hand-held units are now available with GPS technology that enables the user's field location to be displayed on screen in real-time, superimposed on a variety of maps and remote sensing images. Software interfaces have been developed to allow geological and other types of information to be entered and displayed in the field using user-defined patterns and symbols. These devices are particularly useful in arid terrain such as the Great Basin, where a lack of vegetation allows clear reception of satellite signals, yielding an accurate positional fix with a minimum of equipment. Locational accuracies with these hand-held GPS receivers range from 15 meters down to < 5 meters with a Wide Area Augmentation System (WAAS) correction. The amount of office labor required to convert field data into digital information is being minimized. Consequently, digital GIS-compatible geological maps can now be produced more accurately, and in less time, than has been possible in the past.

When the field acquisition process is accelerated, some types of data can be gathered that otherwise would have been ignored because of the time and expense involved. Monitoring of the evolution of geothermal features over time becomes more practical. Two examples are described here, where GPS units and pocket PCs were used to map surface geothermal features at the Bradys Hot Springs and Salt Wells geothermal systems, Churchill County, west-central Nevada. In both of these areas, previous maps did not contain the accuracy or detail necessary to identify all of the structural trends resolved in the digital versions.

One incentive for mapping surface geothermal features with digital equipment is the fact that structural controls on some geothermal systems are incompletely understood. If extensive surface expressions of geothermal activity are present, they can provide additional information and clues to the locations, orientations, and possible intersections, of structure.

Equipment

A Garmin etrex Venture® hand-held GPS unit (Figure 1), purchased for ~US$200 at a sporting goods store, was used to map approximately 300 thermal features in 3 days at Bradys Hot Springs, in northwest Churchill County, Nevada, using both "waypoint" format (for individual GPS points) and "track" format (for polygon features). A total of ~1,400 data points were downloaded onto an office computer using a serial interface cable and then converted into ArcView GIS®-compatible shapefiles using freeware available over the internet.

A Hewlett-Packard iPAQ® model 5550 pocket PC (Figure 1, overleaf), purchased for ~US$1300 including extra battery packs, chargers, memory cards, and a GPS unit, was used to map geothermal features at the Salt Wells geothermal area in southern Churchill County, Nevada over a 5-day period. The iPAQ® is equipped with a 400 MHz processor, 128 Mb of RAM, and a 128 Mb storage card. A GIS-functional software environment on the pocket PC was provided with ArcPad®, a

Figure 1. The HP hand-held iPAQ 5550® pocket PC (on left) and Garmin etrex Venture® (right) used for mapping surface geothermal features.

spatial data capture tool for ArcView® andArcGIS®. A custom geological mapping software interface (applet), complete with geological symbols and related pick-lists, was provided by Gary Edmondo (MinGIS, Inc., Reno, NV), who developed the program in conjunction with Placer Dome Exploration (Edmondo, 2002). This applet was modified at the Great Basin Center for Geothermal Energy to include symbols for surface geothermal features.

The iPAQ is a more fully integrated field-mapping device than the hand-held GPS unit. The memory and display capabilities of the iPAQ allow geo-registered images of shaded topography, orthophotographs, and remote sensing images to be displayed on the screen as background information, while the current GPS location is displayed with a point symbol. Spatial information can be input to the pocket PC by either tracing features on the screen that are visible on the displayed images, or by "walking out" the features using the active GPS function. The geological mapping applet, with its pick lists and data entry forms, actually builds the GIS database in the field by allowing user input of attributes such as rock type, strike and dip, descriptions, etc. These attributes are displayed on the field screen with unique symbols for better visualization of the map as it is being built. Finally, at the end of a field day, the fully attributed data can be directly downloaded into ArcView without the need to hand-enter field notes and other descriptions.

Surface Geothermal Features

Bradys Hot Springs

Any type of geologic, cultural, geographic, or environmental feature can be digitally mapped, but geothermal features were the focus of this study. At Bradys Hot Springs, active thermal features were mapped; these included mud pots, loud steam vents, areas of warm ground, steaming ground, and linear features such as open cracks, linear vents, and veins. Evidence of warm ground included vegetation anomalies, wet soil in the sub-surface, and accumulation of salt minerals. When necessary, verification of warm ground was obtained by digging below the surface and feeling the temperature or measuring it with a thermocouple probe.

Other types of geothermal features present at Bradys Hot Springs include sinter, silicified roots and algal matter, silicified bedrock, and silcrete. Silcrete consists of variably silicified surficial colluvium, sands, and gravels. These siliceous rocks have a more extensive distribution than do the active thermal features, suggesting that hot-spring activity was more widespread in the past than in historic times. In fact, some hot springs discharged into Lake Lahontan prior to it's recession, based on the fact that siliceous rock is locally capped with tufa, a calcium carbonate-rich rock that formed along shorelines and from sub-aqueous springs in Lake Lahontan (Russell, 1885).

Siliceous rocks at Bradys Hot Springs were mapped in detail using hyperspectral infrared remote sensing methods as part of another study (Kratt et al., 2003), and consequently were not mapped in detail with field GPS methods. The active thermal features were also mapped using remote sensing methods, with the help of nighttime ASTER and Landsat thermal infrared imagery (Coolbaugh, 2003), but the 60-90 meter ground cell resolution limited the ability to discern details. The GPS mapping provided field verification of the thermal infrared imagery and substantially increased the resolvable detail.

Salt Wells

At the Salt Wells geothermal system, active thermal features at the present time appear limited to a couple of small areas of warm ground adjacent to former hot springs that were active in the late 19th or early 20th centuries, including Borax Springs (Garside and Schilling, 1979, p. 17). Much more extensive are a large variety of surface and near-surface silicified rocks, sinter, and silcrete. Silcrete in the form of silicified sand is the most extensive surface geothermal feature at Salt Wells and was recognized as having formed from hot spring fluids by Morrison (1964, p. 35-36), who nevertheless did not map their distribution. Most of the silicified sand belongs to the Sehoo Formation, deposited in a lacustrine environment in Lake Lahontan (Morrison, 1964). Tufa overlies the siliceous rocks in places. Veins of opal and chalcedony crosscut the silcrete and underlying volcanic bedrock.

In some locations it is not obvious that the lithified sands and gravels at Salt Wells have been cemented by opaline silica. In fact, in some cases, lithification by calcium carbonate has occurred instead. An acid bottle (~10 wt% HCl) proved useful for distinguishing calcium carbonate-cemented sands from silica-cemented sands, although in places both cementing agents are present. In any case, most silicified sands at Salt Wells are overlain by thin to moderately thick (5 cm to 2 meters), discontinuous lenses of sinter.

Sinter at Salt Wells consists of three main varieties: 1) relatively massive opaline material, 2) siliceous oolites, and 3) silicified roots, mud, and algal matter. The predominant form of silica, based on a few x-ray diffraction (XRD) analyses, is opal-A. Relatively massive opaline material often contains abundant casts or petrified remnants of woody material (Figure 2). Siliceous oolites are up to 0.5 mm diameter and occur in poorly bedded sequences up to 6 cm in thickness (Figure 3). Silicified roots, mud, and algal matter are widespread and distinctive in appearance (Figure 4), occurring in highly irregular worm-like, "droopy-mud", and coral-like shapes. Much of this silicified material appears to have formed around irregular sinuous voids believed formerly occupied by roots, but the outer silicified surfaces, with their smooth, droopy forms, have a morphology similar to algal mats and overgrowths on plant materials seen in modern Great Basin hot spring pools. Framboidal pyrite and casts of diatoms have been observed in thin section and with a scanning electron microscope (SEM). In places, silicified filiform algae are present on rock surfaces, and, as with modern hot springs, their growth direction is believed to indicate the direction of water flow.

The textures of materials classified here as "sinter" at Salt Wells are quite different from sinter textures observed at Steamboat Springs, NV., Dixie Valley, NV. (Lutz et al., 2003), Yellowstone National Park, and New Zealand (Jones and Renaut, 2003), but are similar to siliceous depositional textures observed in several nearby geothermal areas, including Bradys Hot Springs, Desert Peak, and Allen Springs, Nevada. It is thought that the unusual textures may in part be the result of relatively low silica depositional rates in a variably subaerial to sublacustrine environment associated with former Lake Lahontan. The observation of tufa directly overlying sinter and silcrete at Salt Wells and Bradys Hot Springs provides clear evidence that some siliceous deposition occurred prior to complete evaporation of the lake. Interestingly, Bradys Hot Springs, Desert Peak, Allen Springs, and Salt Wells all fall within the former extent of Lake Lahontan. The siliceous "sinter" deposits at Salt Wells might not be classified by all workers as "sinter", but the presence of siliceous oolites (evidence of wave action), linearly oriented filiform algae on boulders and rocks, and selective growths and replacements around roots and stems, all point to formation on or very near the surface.

Figure 2. Relatively massive sinter from Salt Wells with abundant casts of twigs or roots.

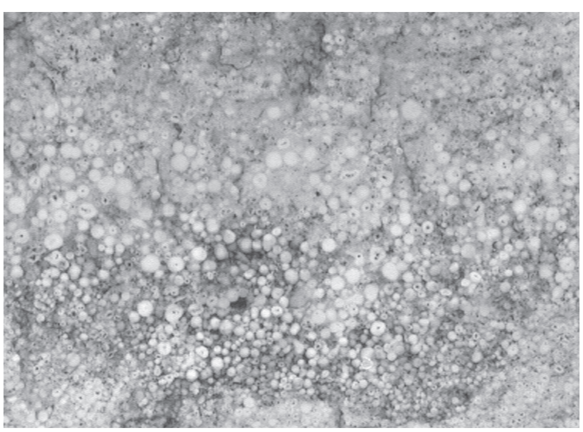

Figure 3. Siliceous oolites, viewed perpendicular to bedding. These oolites are closely associated with more massive sinter (Figure 2) and silicified roots and stems (Figure 4). Opal and calcite fill the interstices between oolites. The horizontal field of view is approximately 1.5 cm.

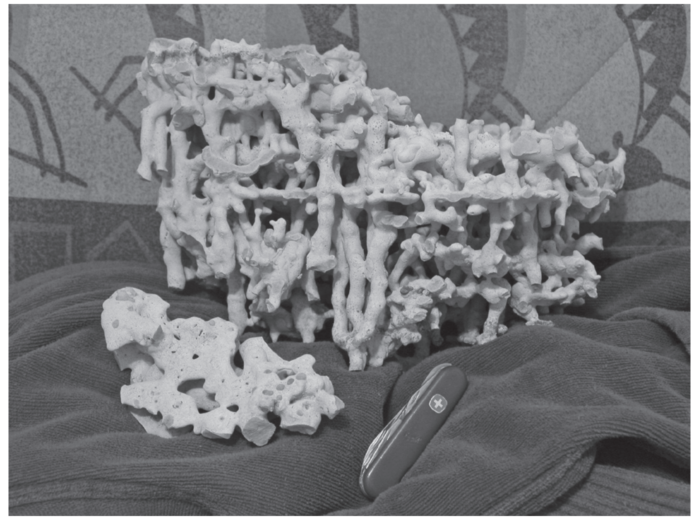

Figure 4. Unusual worm or coral-like opaline rocks. These rocks are typically found with sinter, and usually overlie silicified sands and gravels. The worm-like tubular shapes contain narrow, sinuous 1-2 mm diameter hollow tubes in their centers, thought to represent the leached casts of roots and twigs. Exterior forms resemble algal mats seen forming around roots and twigs in some modern Great Basin hot springs. Fragments of these rocks are distinctively shaped and colored, somewhat resistant to erosion, and consequently are good visual guides to the presence of fossil hot-spring activity in the Salt Wells and Bradys geothermal areas.

Results

Bradys Hot Springs

Active thermal features at Bradys Hot Springs were mapped along a 4-km length of the Bradys Fault Zone (Figure 5). Two dominant trends of surface features were observed: one trending ~N45°E, the other trending nearly north-south. The N45°E trends are more continuous and consist of several sub-parallel strands. The north-south trending features are shorter, but contain most of the mud pots. Both trends link together in an apparent en echelon or cymoid-loop-type manner, and the most intense and centrally located area of thermal activity occurs along a north-south-trending left-stepover in an otherwise N45°E-trending fault system. A similar left-stepover in northeast-trending faults has recently been mapped by Faulds et al. (2003) near the center of the Desert Peak geothermal system, approximately 7 km to the southeast, suggesting similar structural controls for both systems. As described by Faulds et al. (2003), the structurally complex nature of fault stepovers may make it easier to maintain open pathways for fluids at the depths necessary for high-temperature heating. Possible left-lateral motion along the Humboldt structural zone, which includes the Bradys and Desert Peak systems, may accentuate rates of opening along these faults (Faulds et al., 2003).

Salt Wells

At Salt Wells, extensive sinter and near-surface zones of silicification were mapped over several square kilometers, a much larger area than previously mapped (Figure 6). The presence of this silicification lends support to the relatively high geothermometer temperatures calculated for geothermal fluids at Salt Wells (~175°C based on internal company reports), which is noticeably higher than the actual fluid temperatures measured in sub-surface permeable zones encountered by drilling. This reinforces the hypothesis that a higher-temperature reservoir exists at depth. The fact that some silicified zones and sinter at Salt Wells and Bradys Hot Springs are capped by tufa indicates that hot springs were active prior to the recession of Lake Lahonton. Hot springs may have been more active in the past than they are today because water tables were probably higher at that time than they are now.

Most opal veins at Salt Wells have north to northeast strikes, but the best-developed and thickest accumulations of silicification define a broad northwest-trending zone that follows the southwest margin of Salt Wells basin. At the north and south ends of this northwest-trending zone, silicification is controlled by conspicuous north to northeast-trending structures. Thus, similar to Bradys

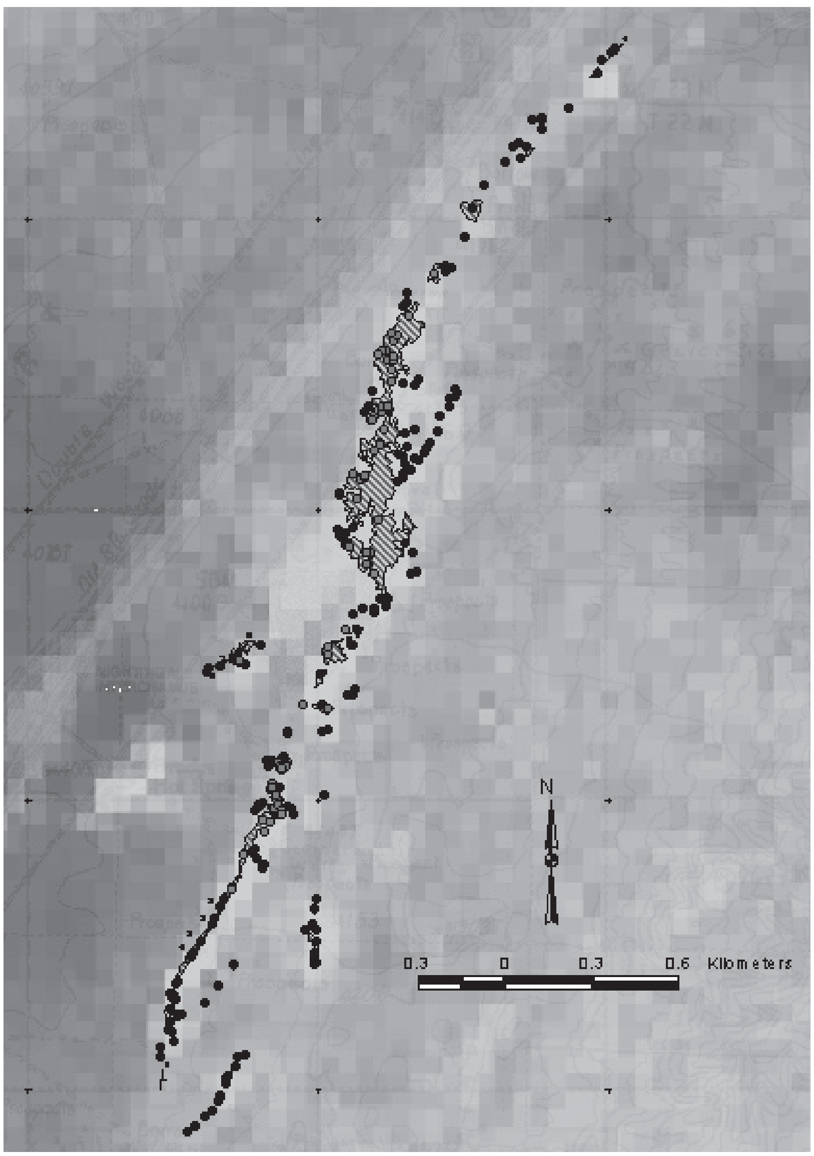

Figure 5. Thermal features at Bradys Hot Springs, Churchill County, Nevada, mapped with a hand-held GPS unit. Black dots are warm ground, gray dots are mud pots and loud steam vents, and striped polygons are larger areas of warm ground. Lighter-colored background areas represent temperature anomalies detected with nighttime Landsat and ASTER thermal infrared imagery.

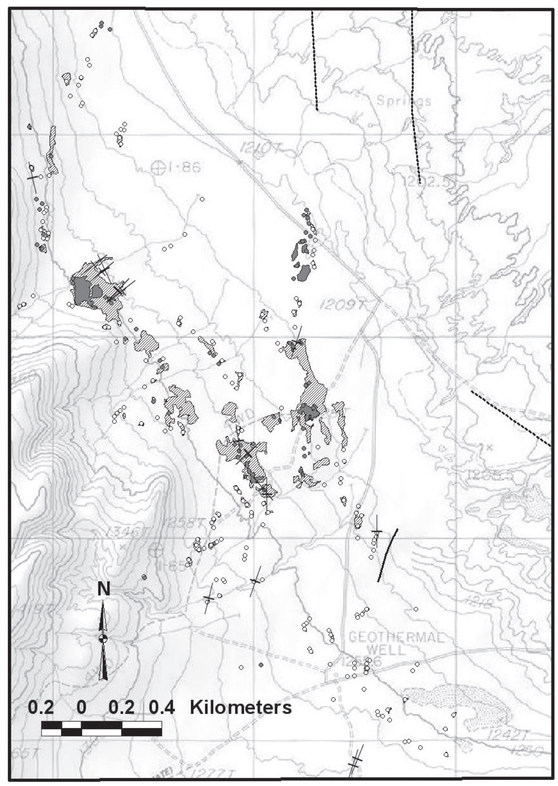

Figure 6. Distribution of sinter and opaline-rich silicified rocks in the central portion of the Salt Wells geothermal system, Churchill County, Nevada, mapped with an iPAQ pocket PC. Silicified rocks are represented with white circles and light-gray ruled polygons; sinter (Figures 2, 3, and 4) is represented with gray circles and dark-gray polygons. The strike and location of opal-bearing veins are denoted by the straight-line symbols with short cross-hatches. The largest exposed zones of silicification follow north to northwest-trends and lie between two regional sub-parallel zones of north-northeast trending structures. Dashed lines are Quaternary and late Tertiary faults mapped by Dohrenwend et al. (1996).

and Desert Peak, geothermal activity at Salt Wells may be controlled by cross faults or stepover faults between two sub-parallel zones of north-northeast striking fault zones.

Conclusions

The digital mapping of geothermal features has provided additional insight into the structural complexities at both the Bradys Hot Springs and Salt Wells geothermal systems and improved our understanding of how these systems may have formed. Geothermal activity in both areas may have been localized by north to northwest-trending, left-stepping cross faults that connect en echelon segments of north-northeast trending fault zones.

New structural information about these geothermal systems was gained in just a few days of mapping. The examples illustrate the value of gathering information rapidly and accurately with digital mapping devices. By bringing digital methods to the field, the process of gathering field data and integrating it into digital databases is greatly accelerated, while at the same time maintaining a higher level of accuracy. In this study, hand-held GPS units provided an accurate and rapid means of mapping geothermal features as long as the complexity was not too great. The iPAQ hardware and software package offers significant additional advantages with its capability to record geological attributes, display them in real time, and directly download them into a fully functional GIS on an office computer.

Acknowledgments

We express our appreciation to Ormat Nevada Inc., Gilroy Foods, and Nevada Geothermal Specialists, LLC, for access to their properties for geologic mapping. This work was made possible by the support of Dr. Lisa Shevenell, associate director, and Dr. Jane Long, director, of the Great Basin Center for Geothermal Energy, and their interest in furthering research into digital technologies. This research is supported by the U.S. Department of Energy under instrument number DE-FG07-02ID14311.

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