Ground-based thermal infrared imaging survey of the Salton Buttes

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ABSTRACT: Using a thermal infrared camera and temperature probes, we obtained imagery of all five Salton Buttes. In addition to five warm vents discovered earlier, we found a number of regions that were warmer than might be easily explained unless geothermal activity was present. The warmest was near the summit and western flank of Red Hill North. Cooling times were calculated for magma dykes of various diameters and their relation to the buttes in terms of recent volcanism is discussed.

Introduction

The Salon Buttes are five rhyolitic domes (volcanic necks) in the Salton Trough of Southern California.[1] From south to north they are Obsidian Butte, Rock Hill, Red Hill South, Red Hill North and Mullet Island (Figure 1). They fall along a roughly NNE trending arc, indicating a probable fault. The trough itself is the result of a large pull apart basin between the North American and Pacific plates and much of it is below sea level.[2] Within the trough lies the Salton Sea Geothermal Field (SSGF) where the geothermal gradient is large enough to support a number of geothermal electricity generating plants.[3] The large geothermal gradient originates from a shallow magma body underlying the SSGF and the buttes.

The age of the buttes were initially measured at ~16,000 BP[4] but more recent work has suggested that they may be much younger[5,6], perhaps as recent as ~2000 BP. With evidence that they are Holocene features, the USGS has raised the eruption threat potential to high.[1]

At the present time, there are five areas within the SSGF showing geothermal activity on the surface,[7,8] only one of which is on a butte.

1. F1 fumarole
2. F2 fumarole
3. F3 fumarole
4. DS—Davis-Schrimpf mud pots[9]
5. Red Hill North hot vents (“Red Island”)

The first four above and Mullet Island fall along a straight line that suggests a fault, named earlier as the Calipatria fault.[7] The fifth region lies near the summit of Red Hill North on its southern flank.[8]

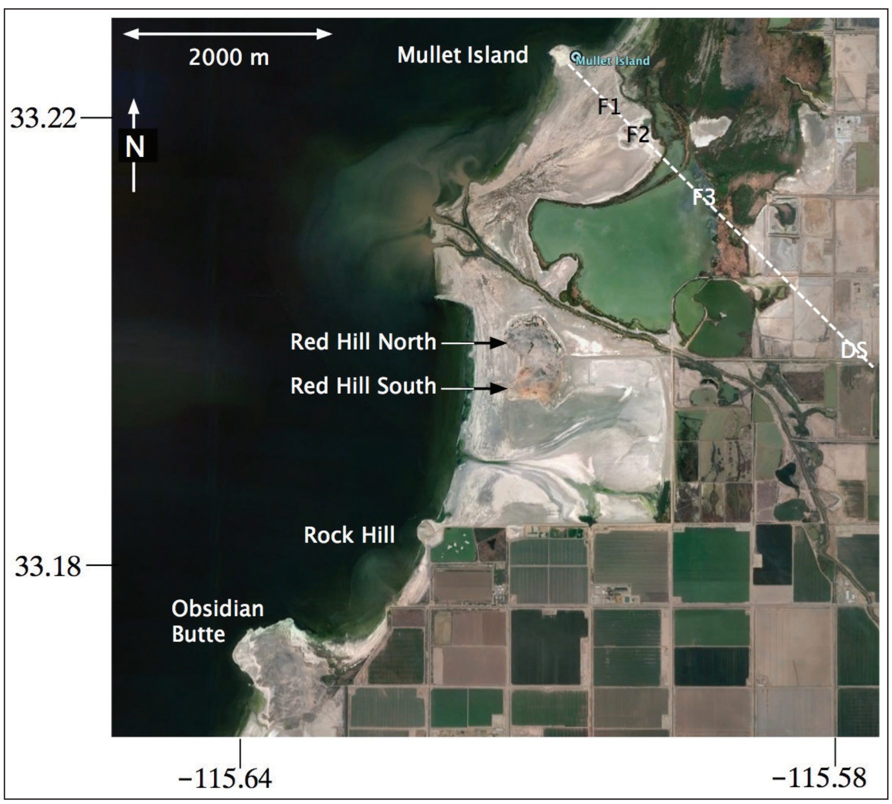

Figure 1. Annotated Google Earth image of the Salton Buttes area. Note that Mullet Island, fumaroles F1, F2, F3 and the Davis-Schrimpf mud volcanoes DS are in a straight line, presumably marking the putative Calipatria fault. Imagery date 20 March 2015.

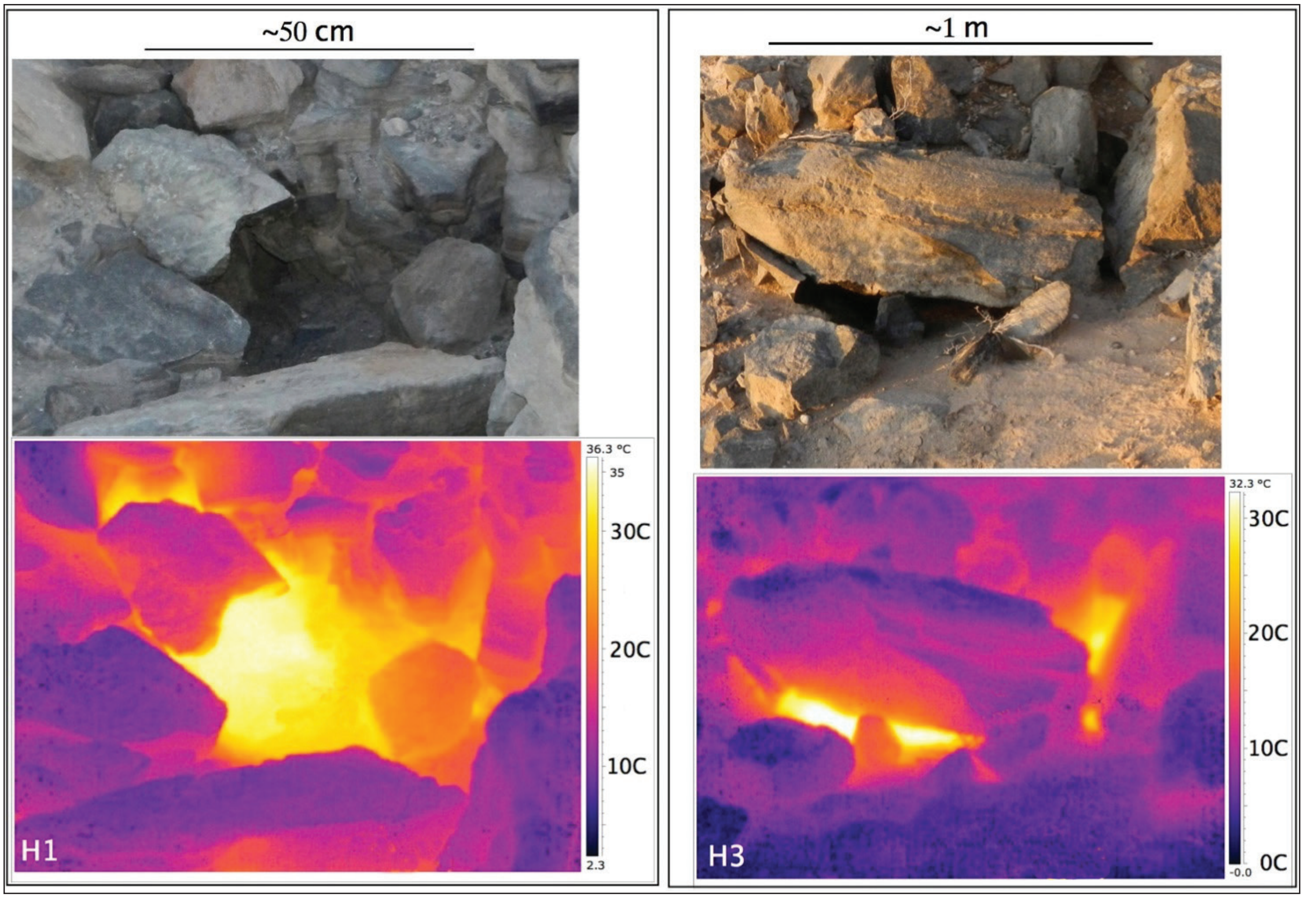

Figure 2. Visible (top) and thermal IR (bottom) images of two hot vents near the summit of Red Hill North.[8]

In view of the potential for volcanic activity and known geothermal features, we undertook an infrared (IR) imaging survey of the buttes. The preliminary results are reported here.

2. Methods

On November 6, 7 & 29, 2013, we surveyed the buttes on foot and by truck with an Agema ThermoVision 570 infrared camera (wavelengths ~8-13 micrometers) and a hand held Martin P. Jones & Associates, Inc., Model 9910 TE Infrared Thermometer equipped with a laser pointer. Relative accuracy for both is about ±0.1°C. During the day, the sunlit surface rocks were the hottest features and overwhelmed geothermal affects so we worked at night in order to maximize the contrast between any hot spots with their surroundings. The approach was to search for "warmer than normal" areas and investigate these. When they were found, we inserted a type K thermocouple (with an Omega HH-52 digital thermocouple reader) to measure the air temperature directly. The nights were cold (~4 C) and clear.

3. Survey results

Five hot spots were found on the south flank of Red Hill North and approximately thirty warm regions were found on the buttes that remain to be investigated. Figure 2 shows two of the hot spots. Figures 3 and 4 are two wide-angle mosaic IR survey images showing some areas of localized thermal emission (yellow).

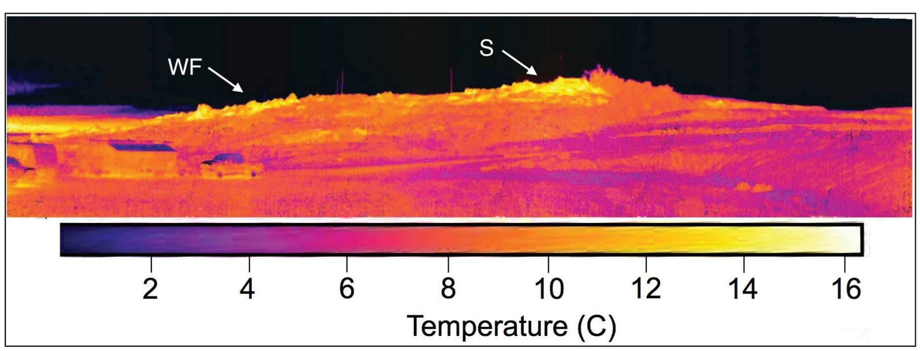

Figure 3. Red Hill North looking north. Warm regions are in yellow, cooler areas are in red and purple. Regions near the summit (S) and west flank (WF) are anomalously warm.

The hot spots reported earlier[8] are near the summit at the middle right of Figure 3. While our panorama is not sensitive enough to show the individual vents, the area is warmer than average. We believe this is a real geothermal feature, because the images were taken at night when the summit would be expected to be colder than the flanks The warm region to the left is also probably real for the same reason. In both places we found a number of sites that were distinctly warmer than the surroundings.

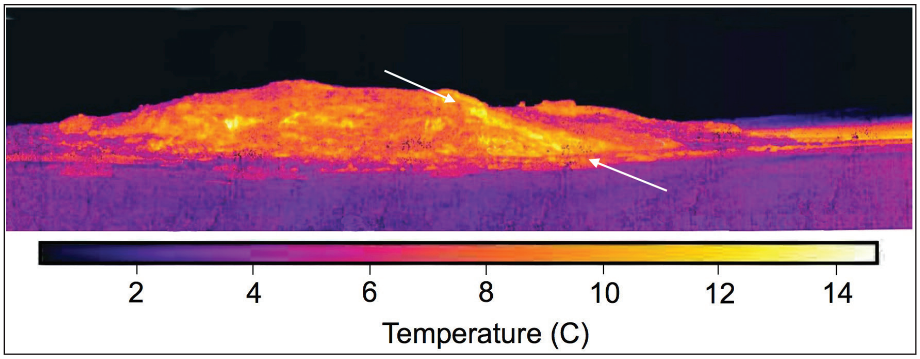

Figure 4. Red Hill South looking south. The warm region in yellow in the middle may be geothermal.

Thermal surveys were also conducted at Obsidian Butte, Rock Hill, and Mullet Island, but few if any thermal anomalies were observed. We note that Obsidian Butte has been quarried and the surface is highly disturbed, which would probably mask any subtle natural thermal features.

4. Remote retrieval of temperatures.

Many of the warm regions were probably not of geothermal origin because ordinary mechanisms can produce apparent and/or real temperature maxima in the landscape: shadowing and emissivity variations.

The temperature of a rock surface is determined by the rate at which it gains and losses heat. Rocks gain heat by three mechanisms: thermal radiation, diffusion, and convection. They loose heat by the same mechanisms, so the equilibrium temperature is a classic rate problem. Broadly speaking, rock surface temperatures follow a diurnal pattern of warming up during the day when sunlight hits them, and then cooling off at night as they emit thermal radiation to the sky. For shaded rocks that are not exposed to sunlight or the sky, their temperature excursions are similarly diurnal but more muted, with thermal diffusion and air convection playing a dominant role.

Radiance $I(\lambda)$ from a surface is a product of two terms: emissivity $\varepsilon(\lambda)$ and the Planck function $B_\lambda(T)$. Radiance measured remotely by an instrument is converted to temperature T by assuming that the emissivity $\varepsilon(\lambda)$ has some fixed value near unity at a given wavelength λ.

$$I(\lambda) = \varepsilon(\lambda)\, B_\lambda(T) \quad (1)$$

$$B_\lambda(T) = 2hc^2\lambda^{-5}/(e^{hc/\lambda kT} - 1) \quad (2)$$

The Planck constant, Boltzmann constant and speed of light are given by h, k and c, respectively. The assumption that $\varepsilon(\lambda) = 1.0$ is a good approximation for most opaque dielectric surfaces, but is not always correct. Since $\varepsilon(\lambda)$ is a component of the measured radiance $I(\lambda)$, variations in emissivity can masquerade as temperature variations. Thus an isothermal surface will show false temperature structure if $\varepsilon(\lambda)$ varies spatially across it. There was significant variation in surface color, texture and composition among the rocks on the buttes. It is possible that such variations also represented emissivity variations.

A more significant complication involves surface geometry (Figure 5). Under normal circumstances, there are always warmer-than-average regions in any natural scene, but they are not of geothermal origin,

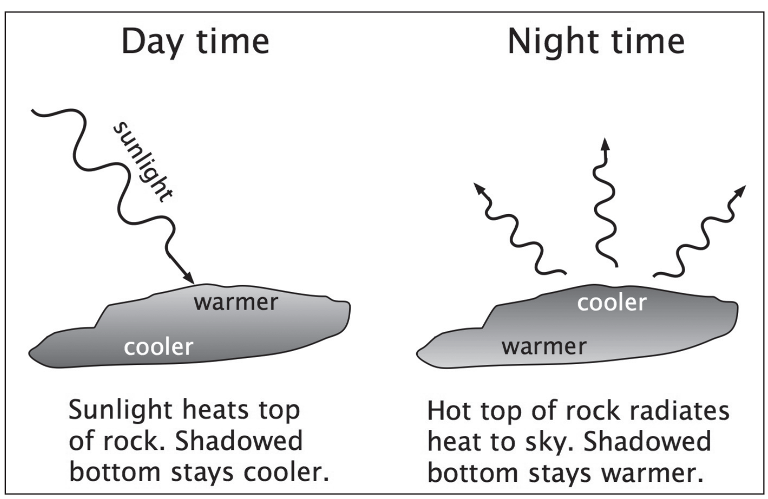

Figure 5. Left: During the day, visible sunlight heats the top of the rock. The bottom and shaded parts remain cooler. Right: At night the top of the rock radiates infrared energy into space and cools the rock. The bottom remains relatively warm because it cannot radiate heat to space.

for example the top of a sunlit rock. The lower surface of a rock is shaded and may never see the sun, so it will remain cooler than its upper (sunlit) surface. At night, however, the situation is reversed. The upper surfaces cools by emitting thermal infrared radiation to the sky in the 8–13 μm window. The lower surface cannot radiate heat to the sky and in fact is bathed in thermal radiation from the ground. As such, it will remain warmer at night than its upper surface.

A good example of the effect is shown in Figure 6. The view is north at the south side of Red Hill South where a number of shallow recesses are found. At night they were significantly warmer than the surface rock.

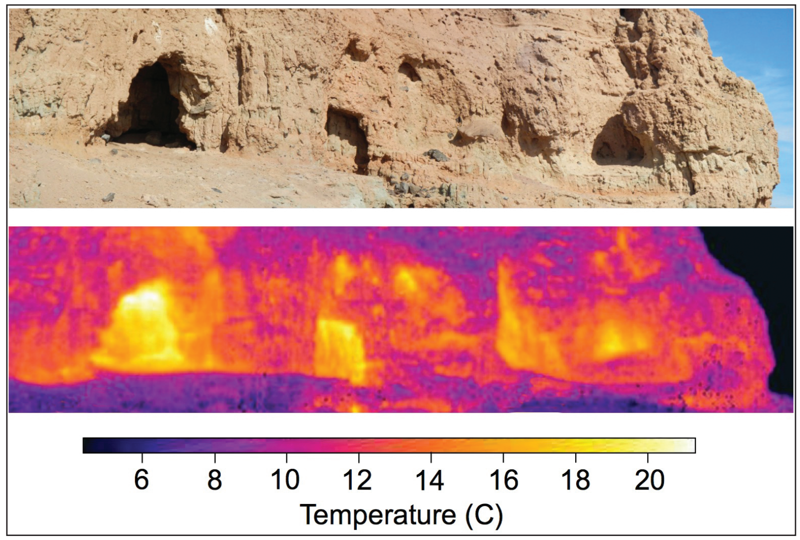

Figure 6. Red Hill South looking north. Top: Daytime visible image. Bottom: Nighttime thermal IR image. Shaded areas in the recesses remain cool during the day and stay warmer at night.

5. Cooling time of magma dykes

Are the geothermal hot spots found on Red Hill North the result of remnant heat from the original volcanism or from recent intrusions of magma that have not yet reached the surface? To help answer this question, known solutions of the heat conduction equation[10,11] for a vertical cylindrical magma dyke were evaluated for a range of time scales and dike diameters (Figure 7). Temperature as a function of time was calculated for dyke diameters 0.1 – 1 km with an initial temperature of 1200 K and an assumed final temperature of 273K (0°C). A thermal diffusivity of 10^{-6} m^2/s was used, typical for igneous rocks. A similar calculation for basalt[12] is consistent with our computations. In concert with Figure 7, Figure 8 is a guide to relative dyke diameter in three possible scenarios.

Can we say whether the heat seen in the thermal images of Red Hill North are remnants of the original extrusive volcanism that produced it or is due to a more recent intrusion of magma? Consider the following arguments.

Red Hill North and Red Hill South have merged, yet they have very different lithologies. The former is grey to black rhyolite and flow banded obsidian, while the latter consists primarily of tan volcanoclastic deposits. Their summits are ~500 m meters apart, so they were formed from two different dykes. Therefore the dyke diameters must be less than 500 m, and significantly so.

If the age of the butte is 2000–3000 years,[6] Figure 7 shows that the dyke that produced it must be 300–1000 m in diameter. Were it smaller, it would have cooled off by now. The butte itself is only about 400 m across, or in the 300–1000 m range. This scenario suggests that the butte diameter and dyke diameter are about the same, corresponding to Case B in Figure 8. This geometry, however, seems unlikely because it is such a special case.

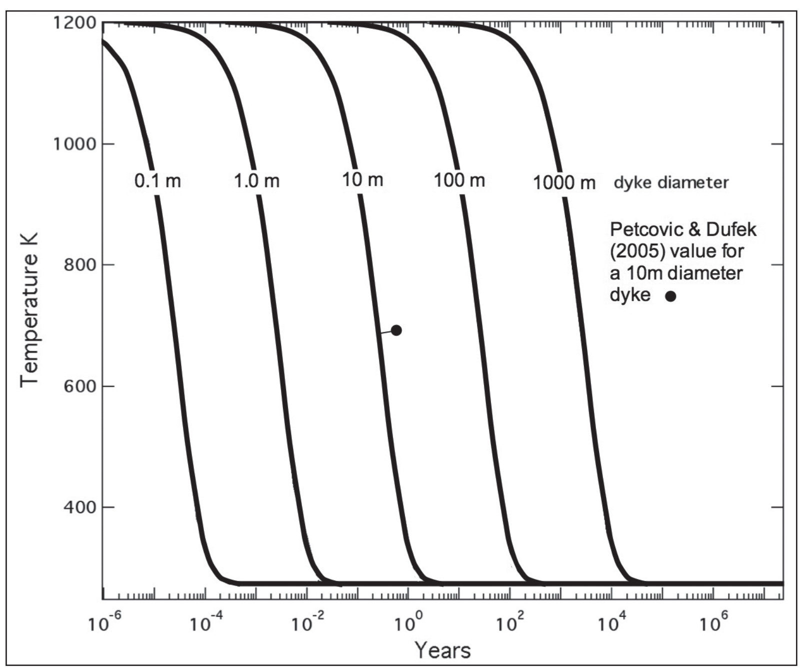

Figure 7. Cooling curves of magma dykes as a function of time. These curves are approximate. The black dot is from a similar calculation for basalt for a 10m diameter dyke.

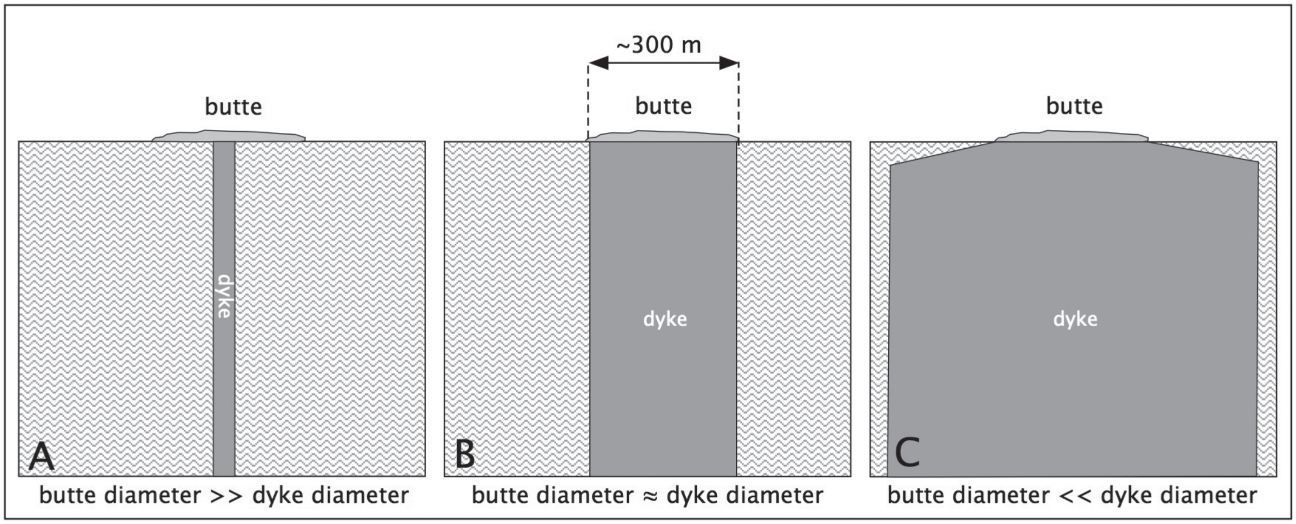

Figure 8. Relative diameters of dykes and buttes.

Having a magma intrusion that reaches the surface and then stops without spreading out is improbable. The more likely scenario is Case A in Figure 8. Here the dyke diameter is much smaller than the butte. Taking 100 m as an example, we see from Figure 7 that such a dyke would cool off in something like a few hundred years. Since this is more likely than a 300–1000 m dyke, we suggest that the heat we currently see on Red Hill North is due to a relatively recent magma intrusion that is not part of the volcanism that originally produced the butte.

6. Summary and conclusions

A thermal infrared survey of the Salton Buttes has revealed a number of hot vents (~35° C) on Red Hill North and dozens of warm areas whose elevated temperatures may represent geothermal heat. Arguments are presented that the geothermal heat from the buttes may be recent and not remnants of the original volcanism. If Red Hill North's dyke diameter is less than ~100 m, then the heat we see today is probably from a relatively recent subsurface magma intrusion that is not associated with the original extrusive volcanism.

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