Burning Questions: Interactions of naturally occurring surface fires and archaeological site conditions

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Abstract: During the summer 2007, archaeological surveys were conducted in the Absaroka Mountain range, northwestern Wyoming. Wildland fires from 2006 had altered the landscape leaving behind traces that, in some cases, emulated those left by humans. Instead of ubiquitous burning across the surface of the landscape, naturally occurring fires created discrete patches of oxidized sediments using the fuel provided by root systems of shrubs and trees while thermally altering the soil, rock, and cultural material within the burn areas. Further, lithic artifacts and naturally occurring stones exposed to high levels of heat during these fires went through the same physical changes of thermal alteration by fracturing and spalling that would be expected to occur in humanly produce hearths. The data collected from these are used to test the hypothesis that individual burnt remains within archeological sites could be naturally produced. Before human controlled use of fire on archaeological sites can be ascertained it is crucial to measure the taphonomic processes associated with naturally occurring fires. Understanding these processes aids in analyzing how fire effects the formations and alterations of archaeological sites and ultimately in refining our ability to identify hearths in a wide variety of settings.

Introduction:

Understanding when habitual, controlled use of fire came to be ubiquitous in the behavioral repertoire of hominids opens a window to look into the emergence of crucial aspects of human adaptability. Fire gave early humans protection, it gave them a source of mobile, extrasomatic warmth allowing them to migrate into colder niches, and it gave them a center point at which to gather. Evidence of controlled use of fire is suggested to date back further than 1 mya (Weiner et al. 1998:251). However, distinguishing naturally occurring fires from hearths is proving to be an archaeological enigma. Deciphering the formation processes in natural burn areas can assist in evaluating evidence of fire from archaeological sites. This poster examines patterns of thermal alteration and explores the physical processes behind their creation.

Figure 1:

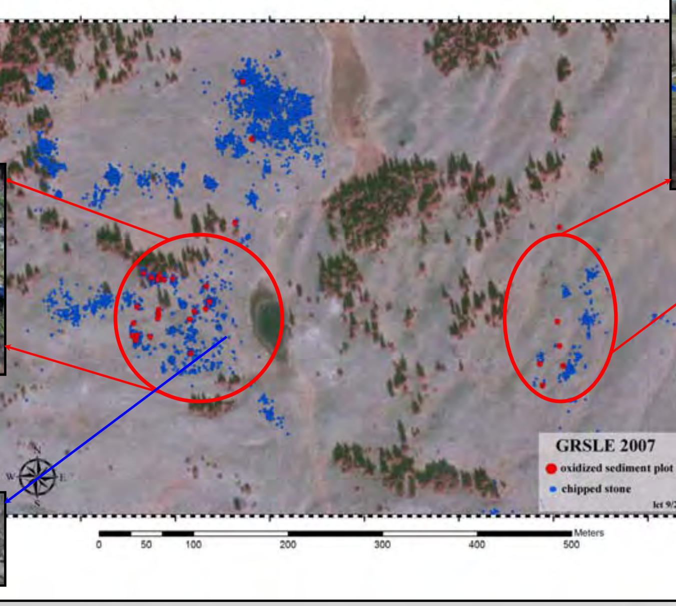

Figure 1.a: Image of oxidized sediment patch on site 48PA2772.

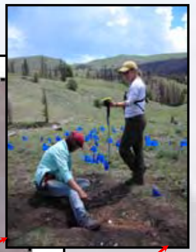

Figure 1.b: Students gathering GPS data on lithic material surrounding an oxidized sediment patch on site 48PA2776.

Figure 1.c: Thermally altered projectile point

Spatial Patterning:

Figure 1 above displays oxidized sediment patches and associated chipped stone on sites 48PA2772 and 48PA2776. When comparing this to spatial patterning of other archaeological sites, they appear to be similar. After time these features will go through the same depositional processes as hearths (Johnson 2003). Further discussion of oxidized sediment patches in relation to phantom hearths is also investigated in greater detail in Koepsell 2007. Given the close, discrete nature of these patches and the burned material within them they could be interpreted as evidence of either a reoccupation site, or multiple unit camp site.

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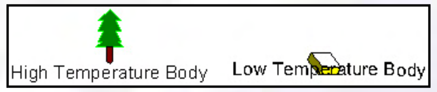
How does energy get into the stone?

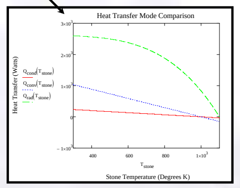
By the Zeroth Law of Thermodynamics, heat will transfer from a warmer body to a cooler body until the temperature of the warmer body and the temperature of the cooler body are equal. The Zeroth Law of Thermodynamics is what accounts for energy into the stone and energy out of the stone. The energy source and sink terms deal with chemical reactions which transform chemical energy into thermal energy. The energy accumulated is determined via the energy in and energy out differences, and the energy accumulation will give an idea of the change in temperature of the stone being heated. From the change in temperature, and the thermal conductivity of the stone, a temperature gradient can be determined. From the temperature gradient, the thermal stress and strain in the stone can be determined and a reasonable conclusion about whether the stone should explode or not will be determinable.

$$\mathrm{Energy}_{\mathrm{in}} - \mathrm{Energy}_{\mathrm{out}} + \mathrm{Energy}_{\mathrm{source}} - \mathrm{Energy}_{\mathrm{sink}} = \mathrm{Energy}_{\mathrm{accumulated}}$$



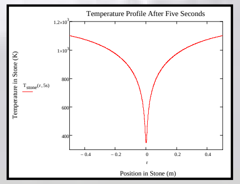
As suspected, the heat transfer into the stone is dominated by radiation.

$$Q_{rad}(T_{stone}) := \sigma \cdot A_{stone} \cdot \left(T_{fire}^{4} - T_{stone}^{4}\right)$$

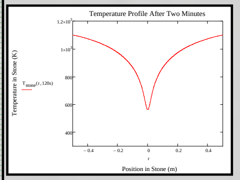


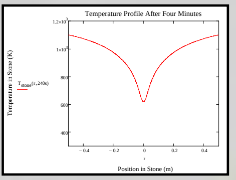
$$T_{stone}(r,t) := T_{fire} + \left(T_{fire} - T_{ambient}\right) \cdot \sum_{n=1}^{80} \left(\frac{1}{5r} \frac{R_{stone}}{n^2 \cdot \pi} \cdot \sin\left(\frac{n \pi r}{R_{stone}}\right) \cdot \frac{-1}{\exp\left(\frac{n^2 \pi^2}{4R_{stone}^2} \cdot \alpha \cdot t\right)} \right)$$

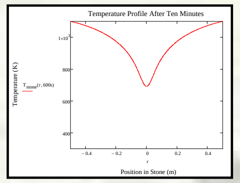
In order to determine an internal temperature gradient, it was assumed that the temperature of the surface was constant and equal to the value of the fire. This was done in order to obtain suitable boundary conditions.



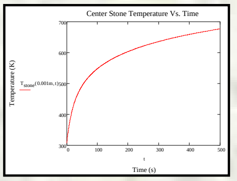
Since these functions have been thoroughly defined, they have been compared graphically to see if there are any dominant terms in the heat transfer as the stone heats from warm day temperature (25ºC, 298 K) to the temperature of the fire. This has been done assuming a stone of diameter of one tenth of one meter (0.1 meters).







After the rock is exposed to the hot forest fire, it has been assumed that the temperature of the surface quickly achieves a temperature close to that of the fire via radiation.



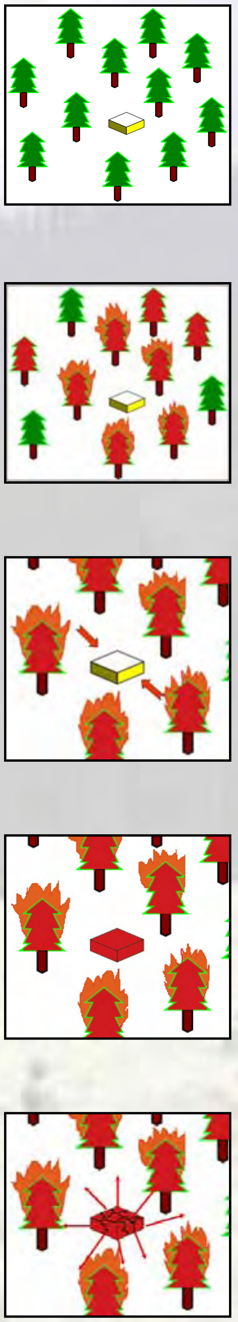
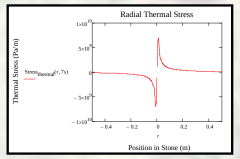


Figure 2

The ultimate stress, the stress at which failure occurs, of quartzite has been measured to be up to 280 megaPascals (Incropera & Dewitt 2002). A possible value of thermally induced stress of 500 megaPascals has been found during this investigation. In conclusion, it is possible for fracture of quartzite to occur if quartzite stone roughly spherical in shape, and one meter in diameter, is caught in a hot forest fire.

$$G_{rad}(r,t) := \left(T_{fire} - T_{ambient}\right) \cdot \sum_{n=1}^{50} \left(\frac{1}{5 \cdot r^2} \cdot \frac{R_{stone}}{n^2 \pi} \frac{\sin\left(\frac{n \cdot \pi \cdot r}{R_{stone}}\right)}{\exp\left(\frac{n^2 \pi^2}{4 \cdot R_{stone}^2} \cdot \alpha \cdot t\right)} - \frac{1}{5 \cdot r \cdot n} \cdot \frac{\cos\left(\frac{n \cdot \pi \cdot r}{R_{stone}}\right)}{\exp\left(\frac{n^2 \pi^2}{4 \cdot R_{stone}^2} \cdot \alpha \cdot t\right)} \right)$$

$$E_{quartz} := 70 \cdot 10^{9}\,\mathrm{Pa}$$



From Strain function and Hooke's Law for elastic materials, the thermal stress has been estimated. A typical value for the elastic modulus, E, for quartz has been used. Elastic modulus of quartz (Gere 2004).

Thermal Spalling:

Figure 3: Examples of thermally spalled stone.

Intense heat causes spalling on naturally occurring materials as well as artifacts. The size, distance, shape, and degree of spalling depend on many factors some of which are: flaws in the material, cryptocrystalline structure, moisture content, intensity of heat, and prolonged exposure. Sadd 2007 and Niswanger 2007 perform more in-depth analyses of thermally spalled material.

Discussion:

Controlled use of fire was a huge technological innovation for humans (Bellomo 1993) and separating natural process from controlled habitual use is crucial to investigating the impacts of this technology. Holistically researching the history of the environment aids in reconstructing interactions between archaeological material and naturally occurring fires. Analysis of materials that have undergone thermal alteration are not always the products of human activity (Buenger 2003). Spatial patterning between oxidized sediment patches show that they can leave discrete patches across the landscape. Thermal spalling and other alterations of material provide data on the frequency of naturally occurring fires and can aid in constructing a fire history of the landscape.

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