Aboriginal Use of Fire in a Landscape Context

Investigating Presence and Absence of Heat-Retainer Hearths in Western New South Wales, Australia

by Simon J. Holdaway, Benjamin Davies, and Patricia C. Fanning

A case study from western New South Wales, Australia, illustrates the age, preservation, and distribution of late Holocene heat-retainer hearths that are abundant in the semiarid archaeological record in the region. These hearths were constructed as underground ovens with stone heat retainers. They appear archaeologically as eroded concentrations of heat-fractured stone sometimes protecting charcoal deposits. We explore geomorphic processes influencing hearth temporal and spatial distributions using a neutral agent-based model. Parallels between model outcomes and the distribution of hearths in space and time suggest that processes of sediment erosion and deposition are having complex effects on hearth survivorship and therefore on patterns of hearth frequency. We consider the various processes that explain why hearths were made in the past and how they manifest in the present. Despite the relatively recent age of the hearths when compared with evidence for fire use in the Paleolithic record, the presence and absence of these fire features reflect the outcome of a large number of processes interacting together, not all of them related to human behavior. We use the results of the case study to comment on current behavioral models for the presence and absence of fire use in the distant past.

Human use of fire in the semiarid regions of Australia is visible archaeologically as abundant heat-retainer hearths that are found in eroded contexts along drainage lines. These hearths appear as concentrations of heat-fractured rocks clustered together with tens to thousands of heat-retainer fragments. In some hearths, these heat retainers protect charcoal deposits. However, as we discuss below, many of the hearths are eroding, and once exposed, the charcoal is also susceptible to erosion. The distribution of these hearths is of particular interest because they do not conform to a pattern consistent with occupation sites and they are not the remains of broadcast firing used to concentrate game or modify flora. Instead, these hearths were constructed in almost all parts of drainage lines. Such a distribution is not unique to semiarid Australia, being reported in some other parts of the world where surface exposure is favorable (e.g., Black and Thoms 2014; Brink and Dawe 2003; Milburn, Doan, and Huckabee 2009; Petraglia 2002; Schaefer et al. 2014; Sullivan et al. 2001; Thoms 2009). In common with the Australian example, the distribution of these fire features indicates an additional aspect of "on site" and "off site" fire use. Yet despite their ubiquity in different areas of the world, fire use in these settings has received relatively little attention. Here we outline the archaeological expression of this form of fire use in one part of semiarid Australia. In doing so, we emphasize how fire use can be understood as a set of interconnected relationships between people and environment in the way that human use of fire manifests, in the technology of fire use, and in the ways the outcomes of fire use are preserved in the archaeological record.

An older literature commented on changes in past Australian environments as a consequence of Aboriginal fire use (e.g., Flannery 1994; Kershaw et al. 2002; Singh, Kershaw, and Clark 1981). More recently, changes in the frequency of radiometric dates from archaeological fire features have been used as primary evidence for directional changes in past human population and occupation intensity (Johnson and Brook 2011; Smith et al. 2008; Williams et al. 2015). However, patterns in large-scale records of fire are not always principally determined by human activities even when human action may have contributed to their initial creation. For example, Mooney and colleagues (2011, 2012) have shown that when large numbers of charcoal records are

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compared from across the continent, climate-modulated changes in vegetation explain more of the variation in fire prevalence than do human activities over timescales measured in centuries to millennia, a finding that parallels the results of global studies (Bowman et al. 2009, 2011). If patterning in archaeological fire features is to be used to understand past human behavior, then behavioral contributions to those patterns need to be contextualized within the larger suite of formational processes operating on landscapes over time.

The reasons that hearths constructed in different places are found, the form that these hearths took, and the archaeological preservation of these hearths can be understood by considering fire use in relation to environmental and geomorphological history before behavioral inferences are drawn. While the history of fire use in semiarid Australia is of interest in itself, the case study reported here also has wider relevance for studying human use of fire. The types of archaeological signatures fire use produces will vary contextually, and inference about fire use needs to be assessed accordingly. The Australian case study illustrates that where consideration of the influence of these contexts on the formation of patterning associated with fire use is absent, behavioral inferences drawn from the presence or absence of fire features in the archaeological record may be misleading. This particularly applies to studies that rely on the absence of evidence for fire use (e.g., Roebroeks and Villa 2011; Sandgathe et al. 2011).

How fire manifests archaeologically is partly determined by the contexts in which people found fire useful, and these contexts in turn shape the archaeological record that preserves it. Fire functions are not self-evident in the sense that fire needs to be treated in relation to the ways people and objects interacted with past environments before its presence or absence can be understood. This relates to the way fire is employed by humans but also to how the material remains are preserved, itself the outcome of the interaction of the material remains of fire and a variety of environmental and geomorphological processes. Documenting such interactions from archaeological remains raises significant issues because at one level, we can only analyze what is preserved and what we can see. As is illustrated in the case study below, this issue is not confined to very ancient archaeological records.

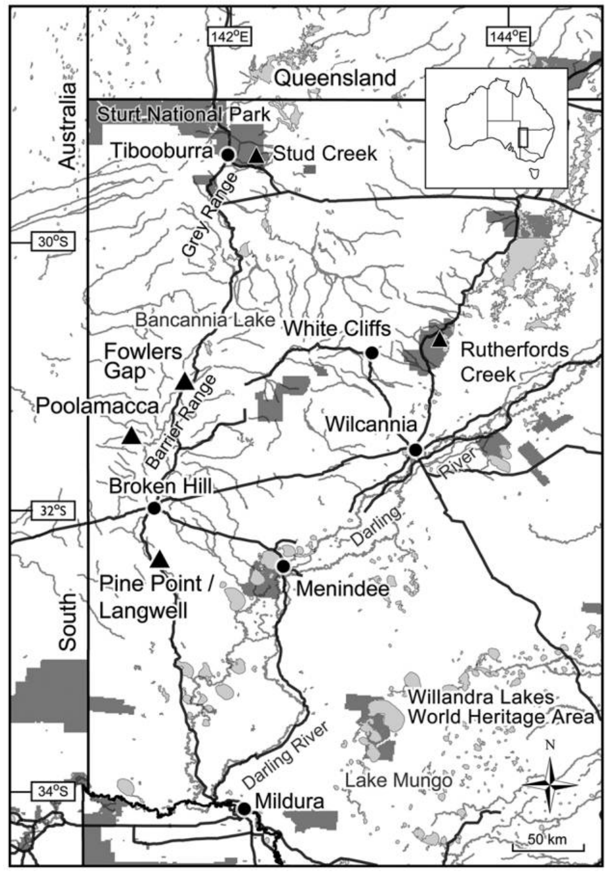

Figure 1. Western New South Wales study area. Source: Holdaway and Fanning (2014), pl. 1.

Case Study: Hearths in Western New South Wales, Australia

The Semiarid Environment

The Rutherfords Creek study area is located on the valley floor margins of an ephemeral stream draining a catchment of 37.8 km^2 in western New South Wales (NSW) on the southeastern margin of the central Australian arid zone (fig. 1). The climate today is semiarid, with mean annual rainfall less than 250 mm and pan evaporation exceeding 2,000 mm (Holdaway, Fanning, and Witter 2000). As a consequence, vegetation is sparse, with chenopod shrublands ubiquitous across the hillsides and trees confined to the larger watercourses. Both of these vegetation communities provided firewood. Extensive areas of stony ("gibber") and bare surfaces mantle the slopes and plains. Changes in vegetation cover and geomorphic processes occurred with the introduction of European-style pastoralism in the nineteenth century (Fanning 1994, 1999). Topsoil from hillsides was deposited on valley floors as laminated sandy sediments. Streams incised into the valley fills, and renewed erosion on the valley floors followed, leaving hard-setting, saline subsoils exposed at the surface on which archaeological materials, mostly stone artifacts but also heat-fractured stones from heat-retainer hearths, now rest (Fanning 1999).

Episodic flood events, resulting in erosion in some areas and deposition in others, are a feature of the study area (Fanning, Holdaway, and Rhodes 2007). Mean annual rainfall is low, but variability is high, and the bulk of the rain falls during short, intense rain depressions, especially in summer. Episodic events such as this affect the sedimentary record. Where the contemporary creek lines are cut into alluvial sequences, unconformities represent either substantial hiatuses in valley floor aggradation or, more likely, periods dominated by valley floor erosion. For example, at Stud Creek (fig. 1), gaps of several thousand years occur in the depositional record of Holocene and late Pleistocene deposits (Fanning and Holdaway 2001). The absence of buried paleosols in these deposits suggests the unconformities represent more than just stable periods in the evolution of the landscape when aggradation temporarily ceased. Instead, it is likely that an older record of occupation was destroyed by erosion represented by the unconformities in the stratigraphic sequence (Fanning and Holdaway 2001:99).

Surface visibility, and therefore the quantity of the surface archaeological record, is highest where there is an absence of vegetation and the surface is lagged, forming "scalds" where topsoils (more correctly, the uppermost sedimentary unit) are removed by a combination of wind and water erosion (Fanning and Holdaway 2004). Stone artifacts and hearth stones are exposed on scalds as the finer sediments are removed by unconcentrated overland water flow. On slopes greater than two degrees, this overland flow can also move small artifacts with a maximum clast dimension less than 20 mm. However, lateral movement is much less discernible among the larger stone artifacts and stone heat retainers (Fanning et al. 2009). In a sense, therefore, sediment erosion has "excavated" the archaeological record, offering an opportunity for investigation of large quantities of this record distributed across the landscape.

Archaeological Survey

From 2005 to 2008, archaeological and geomorphological surveys were conducted along a 13 km length of the main channel of Rutherfords Creek on the eroding valley floor margin. Artifact deposits are visible on eroded patches (the "scalds" discussed above) making up approximately 2 km^2 of the valley floor. The detailed archaeological surveys were confined to a randomly selected sample of the approximately 2,267 mapped scalds, amounting to approximately 4.5% of the eroded valley floor by area.

Hearths were constructed by Aboriginal people in the past by excavating a depression that formed the body of an oven into which stones and then food items could be placed for cooking (Holdaway et al. 2002). Europeans who observed Aboriginal people in the nineteenth and early twentieth centuries described the construction and use of these hearths (e.g., Eyre 1845 and Parker 1905, cited in Allen 1972:280–281). In one example, Daniel George Brock, who accompanied the explorer Charles Sturt (Peake-Jones 1988), recounts how hearths were constructed by scooping out a hollow, adding oven stones, then lighting a fire to heat them and burying plant and animal food in the scoop. The oven stones aided cooking by acting as heat retainers, helping to prolong the heat generated by the fire. Recent findings from the Mungo region show that the use of heat-retainer technology is present in Pleistocene deposits in Australia (Fitzsimmons et al. 2015).

As discussed below, heat-retainer technology dated to different periods is found elsewhere in the world and, in some places, is still in use today (Petraglia 2002). In western NSW, subsequent abandonment of the hearth led to depression infilling, burying, and preserving hearth remains. Once buried, hearths were probably difficult to identify even by the people who made them. Their presence on the surface today is a consequence of erosion processes that are both exposing them and at the same time causing their destruction and, for some, reburial (Fanning et al. 2009).

Heat-retainer hearths were identified during archaeological surveys of Rutherfords Creek as concentrations of heat-fractured stone sometimes protecting an underlying deposit of charcoal, with 979 recorded in eroding valley floor deposits in the Rutherfords Creek study area. Heat-fractured stone can be identified by the presence of small nonconchoidal flakes shed during heating (pot lids) and by cracking patterns as well as by irregular fracture. Identification was easiest when the heat-fractured stones were concentrated together but became progressively more difficult as erosion dispersed the fragments. Identification was also dependent on the nature of the land surface on which they rest. They were, for instance, much harder to identify on surfaces covered with a gravel lag. To some degree these problems were overcome by using a fluxgate gradiometer to measure both magnetic susceptibility and thermoremanent magnetism as a result of heating (Fanning, Holdaway, and Phillipps 2009; see also Gose 2000).

Because they are exposed by erosion, the condition of hearths differs depending on the extent of this erosion. Six categories are used to describe the degree of hearth preservation (fig. 2): buried, partially exposed, intact, disturbed, scattered, and remnant. "Buried hearths" describes those that remain largely buried with only the tips of the fire-cracked rock poking above the surface (fig. 2*A*). "Partially exposed hearths" describes hearths where a portion of the cluster of hearth stones is exposed along an erosion escarpment (fig. 2*B*) but the bulk of the hearth remains buried. "Intact hearths" are those where erosion has completely exposed the dense cluster of fire-cracked rock, but it has not been dispersed (fig. 2*C*). The next three categories—"disturbed," "scattered," and "remnant"—refer to hearths displaying increasing amounts of disturbance of the heat retainers (fig. 2*D*–2*F*).

All 2,267 scalds and gravel patches identified in Rutherfords Creek were searched to determine the presence of heat-retainer hearths. In addition, the areas between the sampling units were systematically surveyed. Hearths found on the scalds and gravel patches totaled 737 with an additional 242 hearths located between the sampling units (fig. 3). The overall distribution of hearths recorded per scald or gravel patch is clustered (Moran's $I = 0.131$, $z = 9.954$, $P < .001$). However, an Anselin Moran's *I* analysis indicates only two areas with substantial hearth clusters. The first is in the northeastern corner of the catchment, an area with concentrated sheet wash erosion, and a second area in the center of the catchment, where hearths are clustered in scalds that are particularly eroded. In addition, there are isolated examples where there are an unusually high number of hearths. Overall, while there are hearths visible in all parts of the catchment valley floor margins, these are not clustered in any one part of the valley.

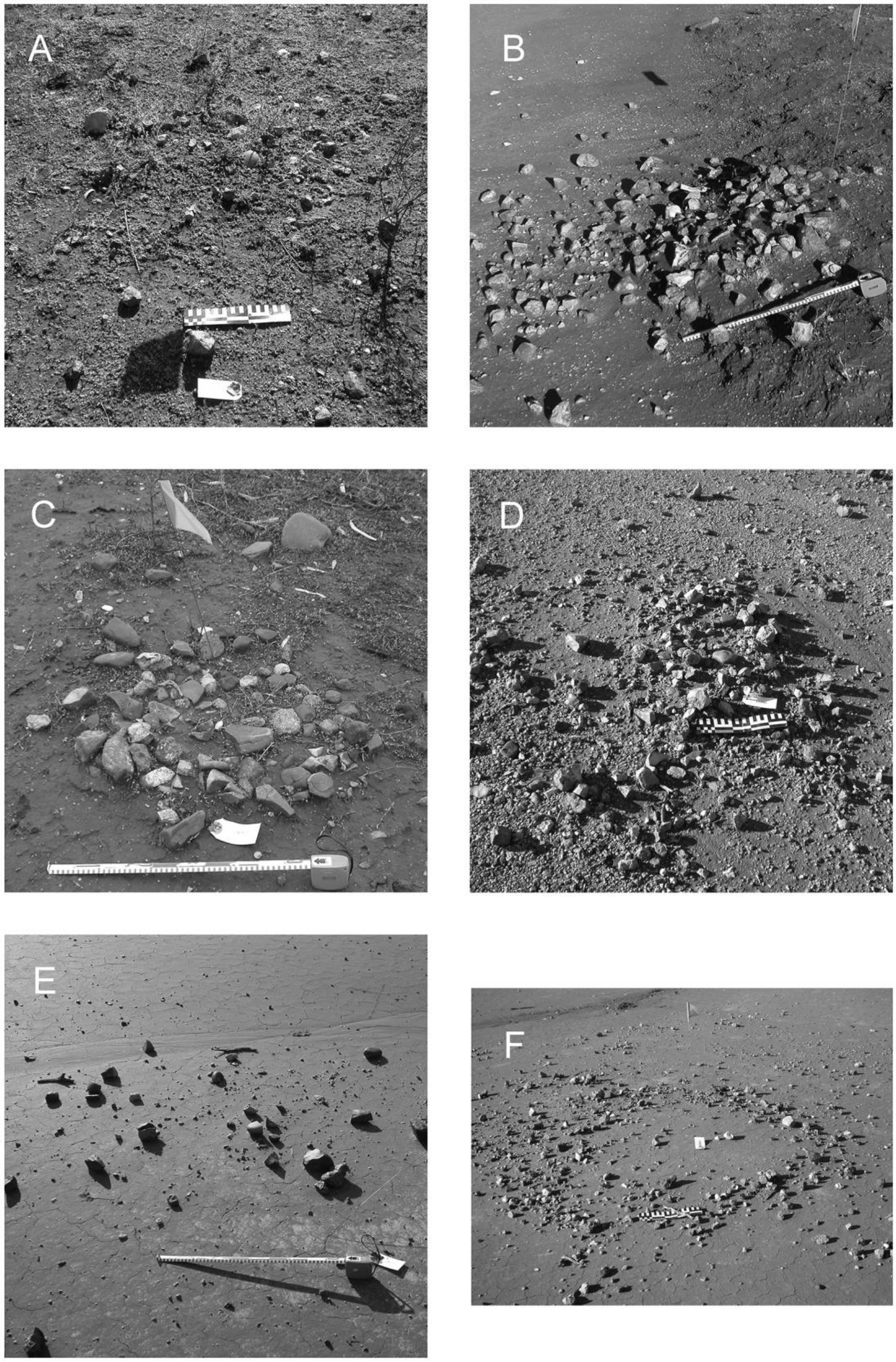

Figure 2. Hearth preservation categories: A = buried, B = partially exposed, C = intact, D = disturbed, E = scattered, F = remnant. Source: Fanning, Holdaway, and Phillipps (2009), fig. 3.

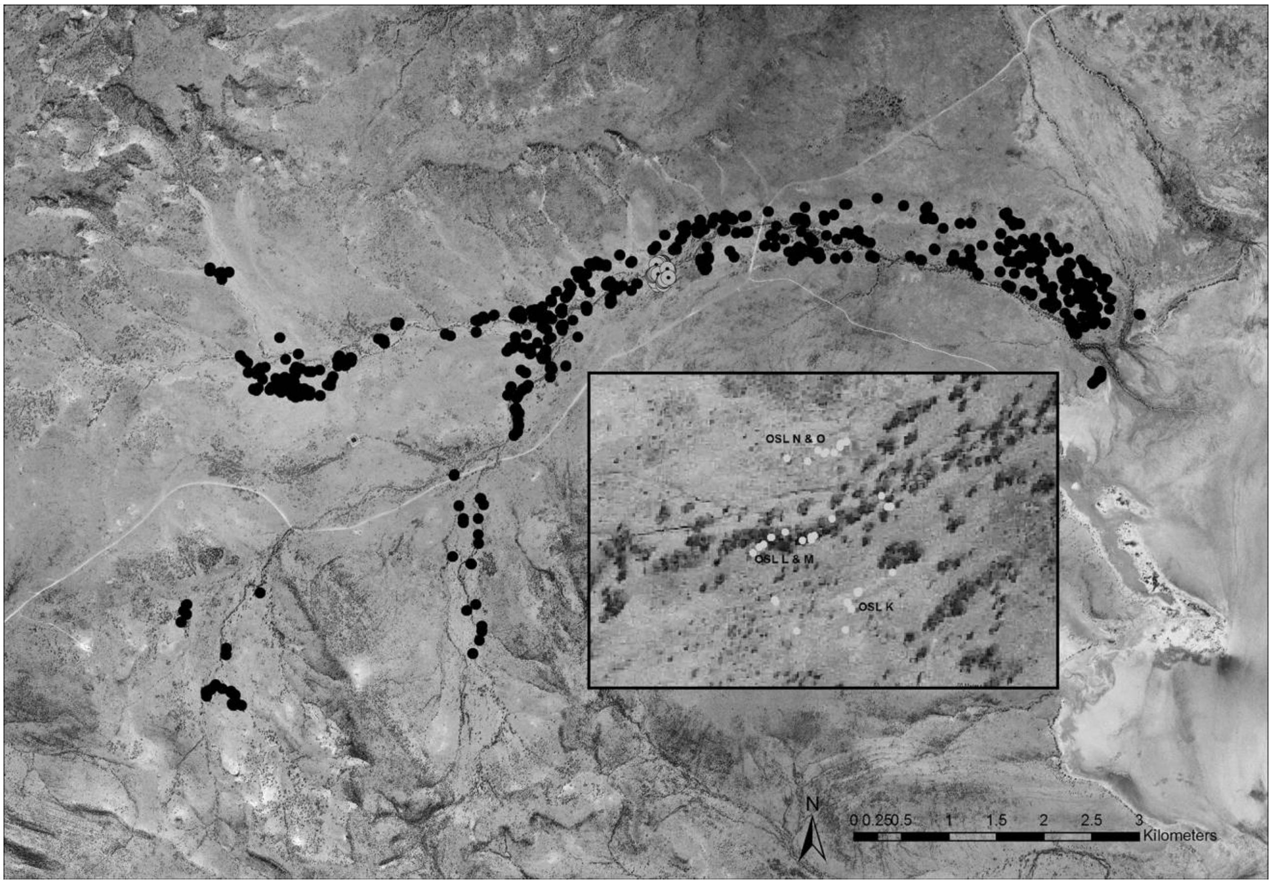

Figure 3. Hearths in Rutherfords Creek represented by black dots. Large gray circles represent Cluster 11 hearths. Inset shows Cluster 11 OSL sample locations (*letters*) and hearths (*gray dots*).

It is worth emphasizing that the total number of hearths identified reflects only those that were visible at the times when the survey was conducted. This total therefore reflects the outcome of processes of erosion and aggradation that initially exposed hearths and in some cases destroyed them while at other times reburying them. Thus, the total number of observed hearths is a sample of a much larger number of hearths that still exist or that once existed. The patterns that we see, both in the distribution of hearths and in their ages, need to be interpreted with these processes in mind. An agent-based simulation study of hearth exposure (Davies, Holdaway, and Fanning 2015) was developed and applied to illustrate these processes, as summarized below.

Hearth Dating

Two hundred and fifty-six hearths of the 979 identified were excavated to obtain dating samples, including hearthstones for optically stimulated luminescence (OSL) dating (Rhodes, Fanning, and Holdaway 2010; Rhodes et al. 2009). Only about one third of the hearths excavated contained enough charcoal for radiocarbon dating. Hearths were excavated in clusters to determine whether groups of hearths shared similar or different ages.

Hearth ages range from modern to ages in excess of 6000 cal BP, with the spatial patterning depending on their geomorphic setting (Holdaway, Fanning, and Rhodes 2008). To use Cluster 11 as an example (fig. 3), the youngest hearths in this cluster are found closest to the creek channel and to the north on the true left bank. OSL sediment ages suggest that in these regions, ancient sediments are deeply buried. At OSL sample locations L and M and N and O, Pleistocene-aged sediments occur but only at depths greater than 70 cm. Near-surface sediments are more recent than 2000 BP. In contrast, sediments at location K date to around 4000 BP at 35 cm depth. Here, hearths have ages that range from 2000 to 4000 BP together with some that are more recent. Thus, the distribution of hearth ages is likely to reflect surface preservation (Holdaway, Fanning, and Rhodes 2008). The northern hearths in Cluster 11 rest on sediments that are recent in age, probably because at times in the past the creek has avulsed and removed older hearths through erosion. Ancient sediments at this location are relatively deeply buried by more recent deposits. To the south of the creek, erosion is less prevalent, leaving relatively ancient hearths intact (as determined by OSL measurements on hearthstones).

Hearth ages therefore partly reflect the age of the sediment surfaces on which they rest. However, we also know that the hearths themselves are subject to change as indicated by the classification of forms discussed above. Of the hearths that we excavated, only a portion retained sufficient charcoal from which to obtain dating samples. These observations need to be considered when investigating the spatial and temporal patterns of the hearths that remain archaeologically. The current level of hearth exposure in parts of Rutherfords Creek, such as Cluster 11, is likely to be a reflection of the increased erosion since European pastoral practices were introduced. However, to some degree, semiarid regions of western NSW have always been subject to erosion, as illustrated by the stratigraphic disconformities in sedimentary deposits dating back to the Pleistocene (Fanning and Holdaway 2001). It is to be expected, therefore, that some hearths will be destroyed through erosion while others will be modified through exposure and, in some cases, reburial. Erosion affects the components of hearths in different ways, with charcoal deposits more susceptible to dispersal than stone heat retainers. As we demonstrate below using agent-based modeling, we need to understand the impact of erosional processes in order to make inferences about the spatial and temporal extent of hearth preservation.

Agent-Based Model of Hearth Visibility

As discussed above, patterning in the archaeological evidence for fire is often explained in behavioral terms based on inferences about hearth function derived from the contents of hearths and at times from ethnographic analogy and with limited consideration of the roles of visibility or formational processes. Frequencies of radiocarbon data obtained from hearths or other features are used to demonstrate diachronic changes in population or occupation intensity in a given location (e.g., Gamble et al. 2004; Johnson and Brook 2011; Mulrooney 2013; Rick 1987; Smith et al. 2008; Williams 2013; cf. Attenbrow and Hiscock 2015; Delgado, Aceituno, and Barrientos 2015). However, the strength of any explanation invoking behavioral change should be based on the ability to demonstrate a difference from instances when human behavior is not assumed (Brantingham 2003:490). It is therefore important to establish how different the pattern is when behavioral change is removed from the equation. Neutral models in which the formation of a given proxy is uniform are frequently used as mechanisms for developing expectations (e.g., Contreras and Meadows 2014; Rhode et al. 2014). If changes in human behavior were the primary driver in the generation of fire-related patterning in the archaeological record, then it is expected that such patterning would show little similarity to that produced by a model that assumed no variation in behavior (Brantingham 2003; Premo 2007). Similarities between the record and outcomes from a model with neutral assumptions can be used to evaluate the extent to which behavior needs to be considered as part of an explanatory framework or whether the resolution of the patterning is sufficient to distinguish it from a neutral record (Lake 2015:14).

To explore the effects of differential erosion and deposition on a uniform record of hearth manufacture that could be compared with the results obtained from the survey along Rutherfords Creek, an agent-based model was constructed using the NetLogo modeling platform (Davies, Holdaway, and Fanning 2015). The model consists of a grid world where each cell contains an ordered list of dated sedimentary layers. In the model, computational agents construct dated hearths at a constant rate over random points on the grid during the period from 2000 to 200 BP. Any hearth with an age younger than or equal to the age of the most recent layer of sediment of the cell on which it rests is considered visible, while any that are older are hidden as part of a subsurface deposit. At given time intervals, events occur that have the capacity to erode or deposit sediment in a grid cell. If erosion occurs, the uppermost layer of sediment is removed, and any hearths visible on the surface lose their datable charcoal. If deposition occurs, a layer of sediment is added to the cell, and any hearths currently visible on the surface are hidden. Hearths that are hidden can become reexposed through subsequent erosion events. In the model, two variables are initially explored: the probability of individual cells experiencing erosion versus deposition during a given event (modeled as Bernoulli process; Jaynes 2003:42) and the time interval between these events.

Results generated from 1,000 random samples of 100 hearth ages ordered from youngest to oldest are plotted in figure 4*A* with separate graphs for time intervals between events of 10 to 200 years and the probabilistic difference between erosion and deposition of sediment varied between 0.1 and 0.9 (to ensure some hearths are always present). If no deposition or erosion occurred, hearths would fall along a diagonal line from 200 years BP at bottom left to 2000 years BP at top right, depending on their age. When sampled ages of surface hearths from all simulations are compared, curves all fall to the left of this line and so are weighted toward the present. Increasing the frequency of events produces a record that is younger on average, while more mixed regimes feature a wider range of dates. As events become less frequent, the mean age of mixed-regime surface hearths tends to increase, but the variability decreases as the number of exposing events is fewer. However, in all cases, the upper quartile age of surface hearths falls within the last 400 years, showing that the modeled surface archaeological record is biased toward the present as a result of differential preservation.

Variants that have inverse erosion to deposition ratios (e.g., 0.3 and 0.7) feature more or less identical distributions. This is because under more erosional conditions, older hearths are less likely to survive destruction, and thus the record is mostly younger, while under more depositional conditions, older hearths will be hidden by layers of sediment, with only the most recent hearths being visible on the surface. Surfaces featuring similar distributions of hearth ages may have formed under highly divergent geomorphological regimes.

As the length of intervals between geomorphic events increases, chronological gaps appear. Because erosion or deposition events affect all grid cells in the model, all hearths sitting on the surface at those times (which includes all hearths

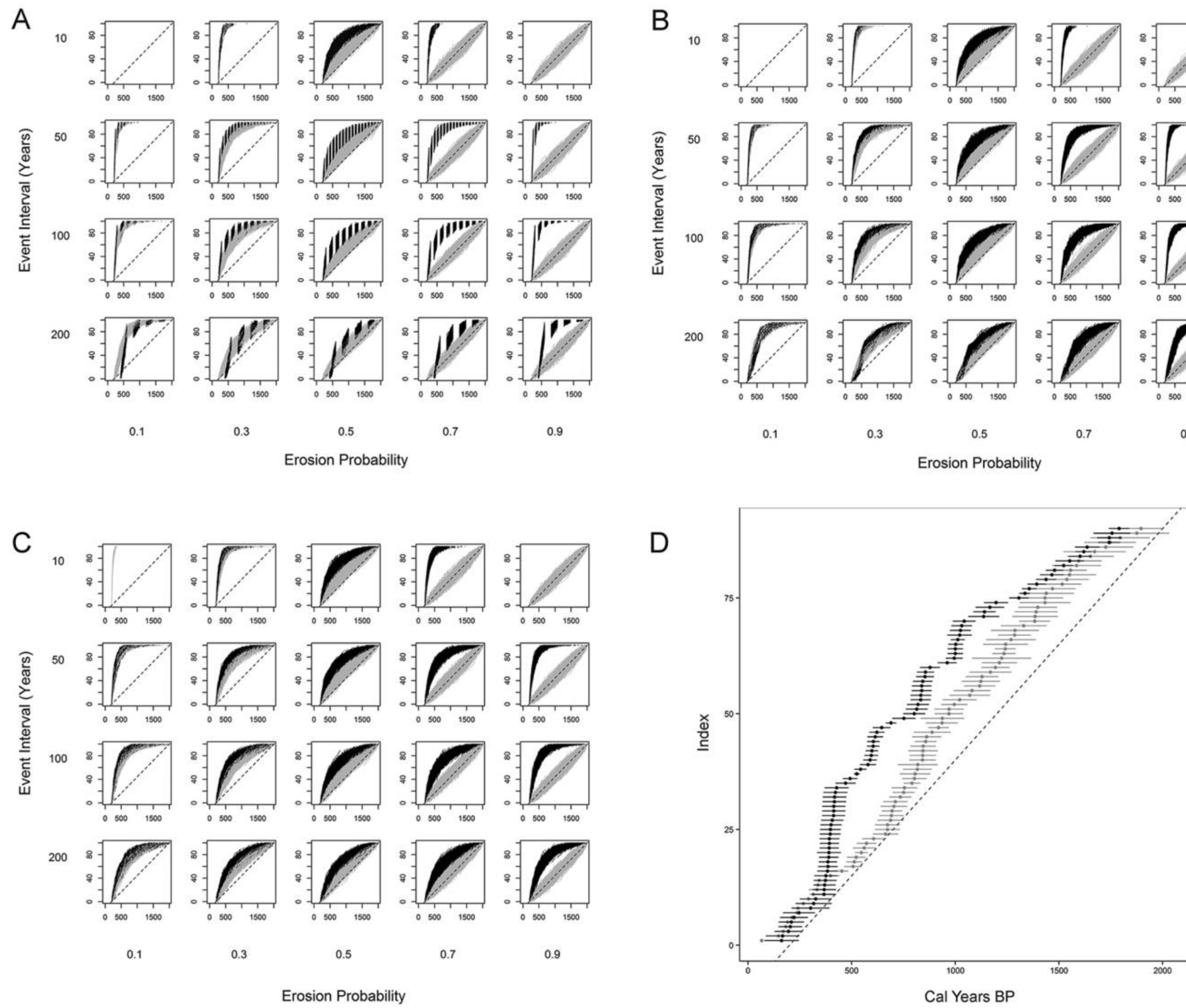

Figure 4. Distributions of radiocarbon (*black*) and OSL (*gray*) data from simulations (*A–C*) compared with data recorded from Rutherfords Creek (*D*). *A–C*, Individual graphs showing samples of 100 dates for each proxy taken from 1,000 separate simulation runs, ordered youngest to oldest, while each graph set shows different surface stability settings ($A = 0$, $B = 0.1$, $C = 0.5$). *D*, Dots showing mean ages for 93 radiocarbon determinations and a random sample of 93 OSL determinations less than 2000 BP (bars = 1 SD).

accumulated since the last event) will either be obscured by deposition or destroyed by erosion, leaving only hearths from previous intervals exposed on the surface to be joined by hearths from the upcoming interval. Repeating this process produces interdigitating sets of surfaces containing hearths grouped by alternating time periods, with older hearths within those groups becoming rarer through time. If ages were obtained from these surfaces at any given point in time, there would appear to be chronological gaps in the record, but these would be purely the result of geomorphic activity.

Figure 4*B* and 4*C* shows the results when surface stability is introduced, simulated as the probability of a cell's surface remaining stable through an erosion or depositional event. In this simulation, the erosion probability is set to 0.5 with the event interval set to 100 years, but the percentages of cells left stable (s) is varied. As the proportion of stable cells increases, the surfaces on which the hearths rest become less organized by the sedimentary process, and the gaps begin to aggrade ($s = 0.1$; fig. 4*B*). As surface stability approaches 50% ($s = 0.5$; fig. 4*C*), the gaps are completely extinguished, but a record of increasing frequency toward the present remains. When stability reaches 100% ($s = 1$, not shown in fig. 4), the record undergoes no geomorphic change and thus displays the uniform record of hearth generation.

The qualitative similarities between the modeled data and those obtained from the field are striking. The chronological gaps in the modeled data reflect the vulnerability of charcoal to dispersal through erosion and to sediment deposition that obscures the hearths themselves. However, hearth stones might be expected to show less dispersal than charcoal because they are much larger than charcoal fragments (Fanning and Holdaway 2001), and thus OSL dates obtained from hearth stones should show less evidence for the chronological gaps. We explored this in the hearth simulation model by taking another set of samples that included hearths that were visible but had lost their charcoal and thus were not included in the radiocarbon sample. We have shown that in the more depositional model environments, the radiocarbon and OSL dates track well together as fewer hearths are destroyed (Davies, Holdaway, and Fanning 2015). However, as conditions become more erosional, the curve of the radiocarbon data remains steeper than that obtained from the OSL dates. This is because hearths that have lost their charcoal in erosional events can still be sampled using the OSL method. Meanwhile, hearths that are obscured by overlying sediments are still effectively invisible to both dating techniques. When conditions become completely erosional, the radiocarbon distribution returns to the exponential curvature also seen under the highly depositional settings, but the OSL distribution straightens out, reflecting the actual record of hearth ages produced by the agents. Gaps that are clear in the simulated radiocarbon chronologies under settings with no surface stability are effectively absent from those in the simulated OSL record. A similar pattern is apparent when the actual radiocarbon ages obtained from hearths in Rutherfords Creek are compared to OSL ages obtained from the hearth stones (fig. 4*D*). Plotting the radiocarbon and OSL ages together shows variation in steepness similar to that predicted by the simulation indicating how erosion has a different effect on charcoal from hearths compared to the hearth stones. The chronological gaps that are visible in the radiocarbon sample are almost absent in the OSL sample.

Discussion

Hearths in Western New South Wales

To some degree the term "hearth" is evocative. In Western societies, we imagine people sitting around a fire as a center of domestic activity (e.g., Wrangham et al. 1999). This is unlikely to be the type of activity that occurred around the hearths we find in Rutherfords Creek. As heat-retainer ovens, they represent an aspect of food preparation but not one that acted as a focus for domestic activity. The ethnohistoric accounts cited above indicate that animals prepared and placed in an oven might be left for several hours while the people responsible undertook tasks elsewhere. In contrast, fires used in domestic locations for heat and light tended to be small and were made as needed (Gould 1971). The explorer Sturt, commenting about Aboriginal hearths on the central Darling River, stated, "Our fires were always so much larger than those made by themselves, that, they fancied, perhaps we were going to roast them" (Sturt 1834:150). A heat-retainer hearth might be in use for a considerable period, but it did not need to be tended. Therefore, the location where many daily tasks were carried out need not be the location where the hearth remains are found. While a great many hearths exist, and many more have likely been buried or destroyed, these do not cluster either spatially or temporally into groups that reflect prolonged occupations. Aboriginal people were able to construct hearths throughout the Rutherfords Creek valley, indicating that at different times, there was sufficient fuel and material for hearth stones readily available. From our observations (Fanning, Holdaway, and Phillipps 2009), stone was likely sourced from the immediate vicinity of the hearth location. In a small number of cases, termite mound clay was also used as a heat retainer. The locations selected for hearth construction also contained suitable sediments for the excavation of shallow depressions with the technology that they had available. Aboriginal people were also able to access fire in the different locations where the hearths were constructed. Gould (1971) describes the technique he observed for making fire during his time in the Western Desert in the 1960s involving friction when a wooden spear thrower or throwing stick was rubbed across another piece of wood. He cites other accounts where fire was produced by a stick drill and stone percussion, and he recounts how at times fire was carried using a substantial stick or bark (see also Hallam 1975:44). Whether or not these or other methods were employed in the past, the spatially extensive record of hearths that we observed in Rutherfords Creek attests to material availability as well as the technical ability to make and transport fire. Finally, that so many hearths are distributed so widely also indicates that suitable food items for cooking were available and that the impetus to cook them struck in a range of different locations at different times.

At some level, this wide distribution of hearths in time and space indicates mobility rather than repetitive place use. Our work on portable stone artifacts from Rutherfords Creek as well as other locations in western NSW similarly illustrates how Aboriginal people curated flakes, leaving behind concentrations of artifacts that are in a sense the antithesis of occupation sites (e.g., Douglass et al. 2008; Douglass et al. 2015; Holdaway, Douglass, and Phillipps 2015; Holdaway and Douglass 2015). The artifacts that remain for us to study are those that were not selected for transport because they were considered unsuitable (Holdaway and Douglass 2012). Thus, as Isaac (1983) long ago illustrated by way of a cartoon of an archaeologist imagining a group of hominins sitting around a fire, we have to be wary of deriving social or behavioral explanations from what appear to be self-evident features of the archaeological record.

At larger spatial scales, geomorphic processes affect the abundance of resources available for Aboriginal people to exploit (Holdaway et al. 2015). On the one hand, western NSW illustrates a lack of topographic complexity, with small areas of relatively high topographic roughness bounded by large areas where there is little or no change in relief. On the other hand, there is a high degree of local landscape heterogeneity, a product of modern vegetation cover plus regolith variation. To the degree that this heterogeneity can be used as a proxy for past environmental resource abundance, it suggests that at a local level, resources were likely to be highly variable. In western NSW, resource heterogeneity did not translate into the formation of regularly recurring resource patches largely as a consequence of low soil fertility combined with the rainfall variability (Holdaway, Douglass, and Fanning 2013).

Low fertility and intermittent rainfall produces a landscape that varies both spatially but also temporally in ways that would have been difficult to predict. For humans, this meant that a location rich in resources at one moment in time might become depleted at another, with little way of predicting when such a change might occur. Individual resource patch locations in western NSW were neither continuously nor cyclically attractive for occupation (Holdaway, Douglass, and Fanning 2013). If resources were episodic in their availability, both spatially and temporally, it might be expected that many places would see at least some use and therefore would see the creation of an archaeological record. Periods after episodic, abundant rainfall might lead to enhanced resource availability over large regions; however, at these times more than adequate resources might be available at more places than the available population could exploit at one time. In such a situation, no one place would be significantly better than another. Using a "dots on map" approach, the landscape would appear to be covered by a carpet of occupation debris just as we see in the distribution of hearths in Rutherfords Creek, as though all places were used at once. However, as the results of the analyses discussed above show, the opposite is the case: this carpet of dots is better explained by the high mobility of small numbers of people in a landscape where the ecology and topography leads to the wide dispersal of the archaeological material remains (Holdaway and Fanning 2014).

Taking all these factors into account, the distribution of hearths in western NSW makes sense. Hearths are distributed throughout the valley because at different times, different places might be attractive for hearth construction. At these times, places had sufficient fuel and stones to allow for hearth construction as well as suitable food stuffs to cook. However, while hearths were places where food was cooked, they might not be the places where other activities were concentrated. Because of the unpredictability of resource availability, people needed to be able to access different places at different times, something that we characterize as a low redundancy in place use (Holdaway and Fanning 2014). The same processes that explain the distribution of hearths also have an effect on their preservation and therefore the chronology that can be obtained from the datable materials found with the hearths. Patterns in the chronological distribution of hearth radiocarbon ages may be an outcome of differential dispersal of charcoal and the visibility of the hearths that retain these charcoal deposits. Visibility also has an effect on the hearth chronology obtained with OSL, although in a different way from that using charcoal; differential visibility and hearth erosion means that there are more hearths with recent ages than those that are older using both dating systems, but gaps in the chronological record are most apparent when only the radiocarbon record is viewed.

The simulation study results show how temporal hearth patterns can emerge when hearths are produced consistently and the frequency and likelihood of sediment erosion and deposition are varied. Erosion in Rutherfords Creek was at times spatially extensive. Using hearths dated to the last 2,000 years from all observed clusters, the distribution of radiocarbon ages shows a pattern of fluctuating hearth frequencies similar to that produced in the simulation when the level of surface stability is kept low and sedimentary events are infrequent (Davies, Holdaway, and Fanning 2015). This suggests that something like the alternating effects of erosion and deposition as modeled may be having an effect on hearth distribution, an inference further bolstered by additional patterns in the OSL data predicted by the model (fig. 4*D*). Modern-day rain events can result in erosion or burial of hearths (Fanning, Holdaway, and Rhodes 2007), and stratigraphic disconformities indicate that at times in the past, considerable volumes of sediment were eroded from valley floor fills (Fanning and Holdaway 2001). Correlations exist between the abundance of hearth ages and past continental scale environmental shifts (Holdaway et al. 2010). These studies indicate the likely mechanisms responsible for the exposure, erosion, reburial, and destruction of hearths in Rutherfords Creek. The hearths visible in the eroded valley floor sediments result from the intersection of all these processes. The interaction between Aboriginal people, the technological forms of fire control they utilized, and the environment explains why they made hearths in the way that they did, but their visibility in the archaeological record is not likely to be a direct outcome of this behavior. It is rather a consequence of the way the archaeological record is formed and transformed through time. These results suggest that Australian studies where the frequency of radiocarbon data obtained from hearths or other features are used to support proposed changes in population or occupation intensity (e.g., Johnson and Brook 2011; Smith et al. 2008; Williams 2013) require further consideration. That geomorphic process can determine the age and frequency of the archaeological record connected with fire even in very recent periods also has implications for understanding the Paleolithic fire record.

Implications for Understanding the Paleolithic Use of Fire

To determine when fire was used, we need to consider how it was encountered, made, and controlled and how often and where it was used, and all of these criteria are of course related to why fire was used, for what purposes, and in what contexts. Here the implications of the detailed case study presented above need to be considered. With some caveats, the case for the presence of human-controlled fire can be made if suitable features are present, but the case for its absence is much harder to demonstrate (Gowlett and Wrangham 2013). A great deal of research has concentrated on determining the makeup of the hearths themselves, involving ethnographic accounts (e.g., Black and Thoms 2014; Mallol et al. 2007; Thoms 2008), experimental studies (e.g., Brodard et al. 2015; Graesch et al. 2014; Homsey 2009; March et al. 2014), and micromorphological studies of likely hearth features (e.g., Aldeias et al. 2012; Berna and Goldberg 2007; Friesem, Zaidner, and Shahack-Goss 2014; Goldberg et al. 2012; Mentzer 2014). However, much less attention has been given to studying the distribution and visibility of hearth features at a landscape scale. Based on the NSW study, we could modify Gowlett and Wrangham's (2013:10) statement that "Hearths are the most valuable archaeological indicator of fire use, but may be a small part of a general picture in which fire was also exploited on landscapes" to read "fire use in occupation sites may be only a small part of a general picture of hearth use in landscapes." Those landscape studies that do exist often seek behavioral explanations for hearth distribution, frequency, and age and typically only consider geomorphic explanations to assess whether concentrations of heat-fractured rocks are anthropogenic in origin (e.g., Black and Thoms 2014; Schaefer et al. 2014; Sullivan et al. 2001).

The hearths studied in western NSW were probably not related to domestic activity as such. What we call heat-retainer hearths represent a cooking technology that, given their locations, the nature of the environment, and the types of stone artifacts with which they are spatially associated, signals something other than domestic camps. Thus, the hearths distributed throughout the valley floor do not fall easily into the categories of fire features that dominate the discussion of fire use within Paleolithic archaeological sites (e.g., Berna and Goldberg 2007; Sandgathe et al. 2011; Wadley 2012), nor do they fit within the gamut of broadcast fires used to modify the environment (Scherjon et al. 2015). Instead, they reflect an alternative way in which people in the past could use controlled fire (e.g., Milburn, Doan, and Huckabee 2009; Thoms 2008), apparent only if suitable locations in landscapes amenable to the use of this form of fire technology are investigated. Based on our studies of hearths and stone artifacts, the hearths in western NSW are consistent with people who practiced high levels of mobility. We therefore need to tread carefully when assuming that fire use will fall into the categories that we expect from our own experience or from simple archaeological divisions such as "on site" and "off site" that envisage movement to and from central places of occupation or indeed from limited readings of the ethnographic record involving only domestic fire features associated with these occupations. Absence of fire should not be concluded when consideration is limited to such a small number of categories within a small range of spatial locations. This observation has relevance to interpretations of sites in Europe during the period 0.8–0.5 Ma that preserve large quantities of bone, none of which are charred. For some, this reflects the absence of fire, but as Gowlett and Wrangham (2013) note, the absence of evidence may alternatively indicate that fire was used in places that almost never survive. They note, for example, how fire at Beeches Pit in eastern Britain was used near a water edge. Other similar locations exist in Africa (they note Florisbad), but in the main, evidence for fires in Europe comes from caves. In these contexts, fires are more extensive during the Middle Paleolithic, although not continuously so in some sites (Sandgathe et al. 2011). What may have changed was the locations where fires were created and therefore the probability of their survival in the archaeological record.

The Australian example also emphasizes the need to consider nonhuman, proxy-specific formation processes when considering evidence of absence. The fire record in western NSW is extensive, but it is probably patterned as a result of differential preservation and visibility. The erosion system that is likely responsible for preservation did not exist in all places and times during the Paleolithic or any other period and place (although of course we would not exclude the possibility that such a system operated at particular times and places). However, the example underlines how we should not assume that the archaeological record is patterned by human behavior alone. To test whether human behavior is indeed responsible for archaeological patterning, we need to employ approaches using a neutral model similar to that illustrated here. To better understand the mechanisms that lead to the presence and absence of hearths and also their apparent increase through time in the Australian record, the use of models needs to be combined with observations made from multiple locations so that the extent and nature of the processes involved in forming the archaeological record can be understood. This cannot be achieved by studying the record from one locality because absence at any one period from such a place could be due to the interaction of multiple processes operating at different scales, many of them natural rather than cultural. Indeed, as we demonstrate, "absence" can even vary depending on what dating system is used. That a neutral model of hearth construction can produce patterns homologous to the empirical archaeological record from a late Holocene context should be of concern to those analyzing records from the deep past where the accumulated effect of combined formation processes has the potential to be so much greater.

The early records of fire control seem to be very discontinuous through time, leading some to propose that fire use was either not required or intermittent (e.g., Roebroeks and Villa 2011; Sandgathe et al. 2011). From a formation perspective, such an intermittent record may speak of issues connected with preservation and visibility more than it does with the nature of human behavior. Petraglia (2002) reviews the use of what he terms "thermally altered stone," here referred to as heat retainers, providing case studies from mid-Atlantic Holocene sites in North America. All three of the sites he discusses are on terraces where plowing has revealed the thermally altered rock. Petraglia (2002) comments that western European Middle Paleolithic sites show limited evidence for heat retainers compared with those in the eastern United States, with much greater levels seen only from the Early Upper Paleolithic. He also comments on the lack of thermally altered stones in the earlier Paleolithic sites in open-air locations. This could represent an evolutionary change in the use of fire technology, but it could equally reflect changes in land-use strategies and ensuing changes in the availability of fuel and stone as well as food sources and shifts in the nature of contexts that preserve material from the past. It is the combination of such changes that needs to be considered when assessing the absence of evidence as well as the first appearance of fire use, for example, the appearance of fire use after 400 Ka in Europe discussed above. As the Australian example shows, all these aspects are interconnected, so we should not simply compare the presence and absence of fire features from different time periods and places as though they are equivalent. Comparisons need to acknowledge the potential complexity of hunter-gatherer behaviors no matter what the time period involved and recognize that what we see archaeologically are windows into settlement systems that were likely spatially extensive, as Binford (1983) long ago observed. However, how settlement systems are manifest also probably depends on the geomorphic processes, as the current study suggests. A great deal of attention in the literature is given to analyzing evidence that shows the presence of fire features. The results of this study suggest we should be giving equal attention to understanding, as Gowlett and Wrangham (2013) have recently argued, what the absence of such features might mean. This involves considering a wide range of evidence that, ironically, may seem unconnected (at least directly) to the human use of fire. It also means beginning with a model of formation that does not assume the primacy of human behavior. While this may seem contrary to the anthropological study of early human behavior, we will always run the risk of identifying false negatives without understanding the wider systems in which fire operated and that are involved in the preservation of the archaeological record of fire use. We await the result of such studies with interest.

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