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Human–environment interactions at regional scales: the complex topography hypothesis applied to surface archaeological records in Australia and North America

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ABSTRACT

We match stone artefact distributions and assemblage compositions at the local geographical scale to measures of both complex topography and environmental history, as suggested by the work of Bailey and King. By comparing two study regions that have different topographic complexity measures, one in western New South Wales, Australia, and the other in Oglala National Grassland, North American Great Plains, we show that people created distinct long-term landscape use histories in both regions. While stone artefact manufacture and use, and indeed the transport of stone artefacts over great distances, feature in both areas, the accumulation of stone artefacts in different places leads to a quite different site use history in each of the case study regions.

Keywords: stone artefacts, topographic complexity, mobility.

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In 1988, David Frankel wrote an influential paper on the issues around the units archaeologists use to characterise change (Frankel 1988). Change can always be detected in the archaeological record at some level, which raises the problem of how to evaluate different forms of change. Frequently, this is done by interpreting change as the result of human behaviour in relation to ecological resource availability. However, as Bailey (2005) remarked, short-term ecologically based environmental changes may not be the best means with which to evaluate the types of changes associated with human evolution. Bailey and King (2011) instead suggest topographic complexity as a measure that operates at the type of temporal scale suitable for answering evolutionary questions.

The complex topography hypothesis as applied to human evolution (Bailey & King 2011; King & Bailey 2006) suggests that active tectonics produced landscapes that provided opportunities for hominins to monitor animal resources in ways that allowed them to outcompete other predators while also finding protection from carnivores. This adaptation created a powerful selection pressure in human evolution. Here, we consider the implications of this hypothesis by investigating landscapes characterised by the opposite of topographic complexity where, at least in principle, humans could exploit places where variation in topography was relatively low. Two study areas – semi-arid Australia and the Great Plains of North America – were chosen because they allowed an initial investigation into how the hypothesis might operate in regions of minimal topographic complexity, occupied by modern rather than archaic hominins, and where the surface archaeological record had been recorded and analysed in similar ways. The significance of both case studies is the relationships that they help illustrate between the long-term interaction of people and the environment in comparison to variations in the archaeological record that reflect the accumulation of behaviours that occur over shorter time periods. As Frankel (1988) commented, to understand change we need to consider the time periods over which it occurred and how different time periods impact on the types of changes we can see. Here, we extend Frankel's discussion to include variable geographical as well as temporal scales.

THE COMPLEX TOPOGRAPHY HYPOTHESIS

Some general trends in hominin evolution are widely accepted. For example, our ancestors were ground-dwelling bipeds who ate a diverse range of food types, including quantities of meat. Hominin fossils show an increase in both body and brain size, while archaeological sites demonstrate the manufacture of stone artefacts. Hominins were able to deal with heat stress, foraged over long distances and were characterised by a relatively long period of childhood and learning. The consequences of these adaptations were that hominins required regular access to water, had increased their level of animal protein intake compared to ancestral forms, needed access to stone for artefact manufacture and had a social organisation capable of providing increased levels of parental care (King & Bailey 2006). The combination of these behaviours would be facilitated by a meat-eating niche inaccessible to other carnivores, where hominins accessed animal protein through hunting and/or scavenging, or exploited such resources at times when competition from other species was less severe. However, such behaviour would also potentially expose hominins to greater predation dangers. In the words of King and Bailey (2006: 268),

> Feedback between different elements of this package is commonly emphasised, for example between daytime hunting, upright stance and physiological adaptation to heat stress, between stone tools, meat-eating and increased brain size, between increased brain size and cognitive skills in communication and problem-solving, and between cognitive skills, spatial memory and the use of larger and more environmentally diverse home-ranges.

A number of conditions might favour these adaptations: an environment with varied plant and animal resources, accessible water, locations giving protection from carnivores and the potential to trap animals. Bailey and King consider that the African Rift fulfils all these criteria because it comprises an area of localised topographic complexity that results from active tectonics. It was the complex topography of places such as the Rift, they argue, that allowed hominins to access the large animal biomass from the neighbouring savannah plains (Bailey & King 2011).

A key aspect of the topographic complexity hypothesis is that tectonic activity occurs in time frames that correlate well with the scales at which species evolve and at which ecological interactions can be observed. In some parts of the world, continued tectonic activity helps to maintain topographical, hydrological and environmental conditions that differ considerably from neighbouring landscapes that are tectonically inactive (Bailey *et al*. 2011). In landscapes with little tectonic relief, features such as waterholes and associated vegetation occur when the water table reaches the surface. These conditions make the availability of water and food resources in these areas more susceptible to environmental oscillations such as desiccations and local aridity. Following the complex topography hypothesis, such landscapes should show variation in human adaptation compared to those places with more complex topography. It might also be expected that humans reacted in similar ways to less complex topography.

As the discussion above illustrates, consideration of the ramification of the complex topography hypothesis has focused on the earliest periods of hominin evolution, when the behaviours that differentiate ancestral hominins from earlier species are thought to have evolved (e.g. Winder *et al*. 2013). However, another way to investigate the hypothesis is to consider examples where humans successfully negotiated living in less complex topographies – in simple terms, the plains – rather than the dissected, tectonically complex regions considered in previous applications of the hypothesis so far. Bailey and King (2011) cite studies by Marean (1997) and Dewar *et al*. (2006), as well as the results of the Kilithi project (Bailey *et al*. 1993), that illustrate how peoples from late Pleistocene and Holocene contexts used local and regional topographic complexity to access food and water, and to monitor the movement of, as well as to capture, mobile prey. It is useful to consider how these activities were managed in places that lacked the types of complex topography that have been identified in the African and Mediterranean examples. In the case studies described below, the archaeological records from semi-arid Australia (specifically, western New South Wales), where the regional topographic complexity is low and local resource availability is spatially and regionally variable, are compared with the archaeological record from a study area in the Great Plains of North America, where the regional topographic complexity is more varied and local resources availability is more predictable. In both studies, the data we use are the spatial patterning of stone artefacts distributed across the landscape. We demonstrate that the archaeological record patterns in distinctly different ways when, as Frankel (1988) suggested, it is considered at a variety of temporal and spatial scales.

APPLYING THE COMPLEX TOPOGRAPHY HYPOTHESIS

Proxy measures of the topography of the earth's surface that help indicate likely locations of tectonic complexity have been developed by tectonic geomorphologists. To generate a measure of topographic complexity, filter functions are used to convert elevation data into a measure of topographic roughness (the mathematical basis for roughness calculation is provided in Bailey *et al*. 2011, appendix 1). However, rough terrain is not dependent simply on elevation – it can occur at high and low elevations, and on both steeper and flatter areas. For archaeologists, understanding complex topography is important because past peoples moved and, in some instances, they moved considerable distances. However, archaeologists have encountered difficulties in characterising environments at sufficiently large scales to capture such movement, given the comparatively small spatial scales at which archaeological research is undertaken. An alternative is to work down from the large scale to the local level, and then to focus on parts of a landscape that give more specific examples of how a region was used (Bailey & King 2011). Satellite imagery and digital elevation data together with GPS provide the ability to combine large-scale mapping with local observation. These technologies, which have informed studies that relate continental-scale tectonic deformation to surface processes, can also be applied, as described here, to archaeological problems (Hubert-Ferrari *et al*. 2002; Tapponnier *et al*. 2001). Through the use of a variety of image processing and GIS technologies, it is now relatively easy to visualise a location projected on a whole series of scales. Here, we combine our characterisation of regional topographic complexity with the localised scale of our case study areas, where the specific consequences of the more general processes can be observed.

SEMI-ARID WESTERN NEW SOUTH WALES, AUSTRALIA

Our first study area is located on the valley floor margins of an ephemeral stream (Rutherfords Creek), draining a catchment of 6500 ha in western New South Wales (NSW) (Figure 1). The climate today is semi-arid and vegetation cover is sparse and patchy. Extensive areas of stony ("gibber") and bare surfaces mantle the slopes and plains. 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 (or winnowed), forming scalds[1] (Holdaway *et al*. 2008). Stone artefacts and heat retainer hearths are exposed on scalds as the finer sediments are removed by unconcentrated overland flow (Fanning *et al*. 2009). Scald formation thus leads to the exposure of artefacts but not their lateral movement. Artefacts are deflated on to a common surface but otherwise remain where they were discarded. In a sense, therefore, sediment erosion has "excavated" the archaeological record, offering a unique opportunity for investigation of large quantities of this record distributed across the landscape. We begin by describing analyses of this archaeological record and then provide a context for interpreting the results by considering these in relation to the regional topographic complexity. As discussed above, this approach provides an alternative to interpreting the results in relation to short-term ecologically based environmental changes (Bailey 2005), developing the ideas that Frankel (1988) proposed.

The archaeological record

Heat retainer hearths – the remains of what were once shallow subterranean ovens – are a ubiquitous archaeological feature in western NSW, and are identified archaeologically by clusters of heat-fractured hearth stones. In Rutherfords Creek, the oldest hearths are found in locations at some distance from modern channels, where surfaces are relatively ancient (i.e. several thousand years) and were preserved from subsequent erosion episodes. In places closer to the modern channels, hearths are more recent, because older hearths that once existed in these locations have been eroded away, along with the sediments into which they were excavated. In each of the areas investigated, a range of ages was found for hearths that are located within a few tens of metres from each other (Holdaway *et al*. 2008).

Elsewhere in western NSW (Holdaway & Fanning 2014), we have characterised this form of occupation as reflecting a low redundancy in place use; that is, where there is a largely uniform degree of variability in place use such that one place looks more or less similar to another. While people used places more than once, no one place in the Rutherfords Creek valley was used more often than anywhere else. This is reflected in the distribution of the hearths themselves. Those that are visible as a result of exposure are distributed up and down the valley, with no obvious concentration either near the creek mouth, where it discharges into an ephemeral lake, nor at points in the mid-section of the valley, nor indeed at its headwaters. Along the 15 km or so length of the drainage, Aboriginal people found the need to create hearths at many different places and did so, as far as we can determine, at many different points in time over the past 2500 years (Holdaway *et al*. 2008).

The low redundancy in place use indicated by the heat retainer hearths is matched by similarities in the composition of stone artefact assemblages. The scalds discussed above provided ready-made sampling units. We surveyed the location of approximately 2500 scalds and sampled 5% of these by area. The three-dimensional location coordinates of all artefacts with a maximum clast dimension > 20 mm were recorded on the resulting 96 sampling units. Features that might restrict visibility or indicate disturbance, such as soil islands or rills, were also mapped. A variety of technological and typological attributes of the stone artefacts were recorded.

Sources of knappable stone are distributed widely in the study area, with silcrete and quartz the dominant lithologies used for artefact production. Silcrete occurs in outcrops of duricrust and associated boulder mantles that form the residual capping of mesas and plateaux that border the catchment, as cobbles and gibbers forming desert pavements on the hillslopes, and in the channel beds of dry creeks. Quartz is not local to the Rutherfords Creek Catchment, but was instead brought in from elsewhere. A smooth, rounded cortex covers the exterior of both silcrete and quartz nodules (Douglass & Holdaway 2011). Analysis of around 25000 stone artefacts recorded in the sampling units shows little variation in assemblage composition for scalds located in different parts of the catchment. All assemblages are dominated by flakes and cores, with few retouched tools. Silcrete cobbles were selected for knapping in much larger numbers than quartz and quartzite, and show low variability in size and shape.

An analytical methodology known as the cortex ratio (Dibble *et al*. 2005; Douglass 2010; Douglass & Holdaway 2011; Douglass *et al*. 2008; Holdaway *et al*. 2008; Lin *et al*. 2010) provides a measure of the effects of artefact transport on to the formation of the archaeological record. This approach is based on a comparison between the amount of artefact cortical surface area in an assemblage and that which should be present given the volume of

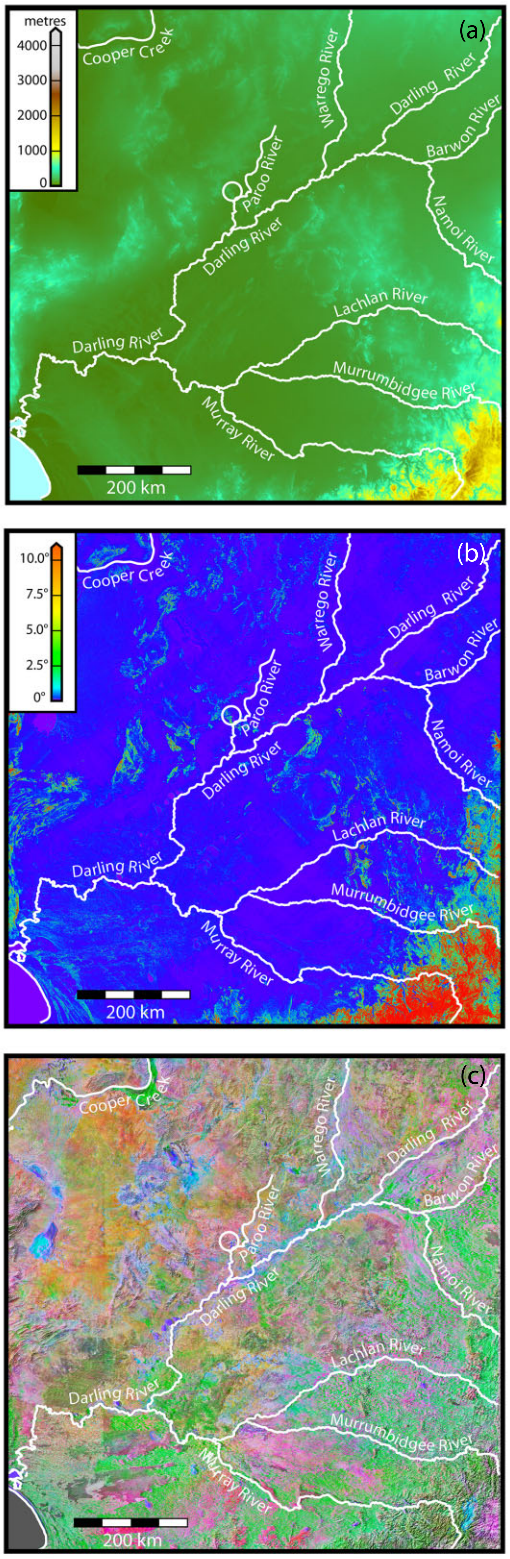


Figure 1. The topographic complexity of the Murray–Darling region in south-eastern Australia. The Rutherfords Creek study area is indicated with a white circle on all three maps. (a) An elevation map, based on SRTM3 data, with major rivers superimposed (the key shows the altitude above mean sea level). (b) A slope map as a proxy for topographic roughness. (c) A map of landscape complexity, based on Landsat ETM data.

stone worked and the approximate size and shape of the cobbles that were knapped. Results for artefacts made on two different types of silcrete (Table 1) indicate that cortical surface area is under-represented within the sampling units at Rutherfords Creek, an outcome that strongly suggests that a significant number of the artefacts produced from the raw material there were transported elsewhere and are thus absent from archaeological record within the catchment. In this process of artefact removal, it is inferred that a deficit in expected cortex proportions is most likely the result of the selective removal of flakes for use elsewhere.

The cortex ratio value needs to be assessed in relation to levels of core reduction. If cores are only lightly reduced, they will retain large quantities of cortex and will also comprise the bulk of the mass in an assemblage. Even if the majority of flakes produced from these cores are removed, the cortex ratio will dip only slightly below one. This can be assessed by calculating three separate cortex ratio values, one related to the volume and surface area of the cores, one to the volume and surface area of the flakes and one for the combined assemblage. For the cortex ratio of the entire assemblage to deviate substantially below one, cores must be reduced beyond light flaking. This in a sense "frees up" the volume from the cobbles and enables selection of large numbers of flakes for removal (Holdaway & Douglass in press).

The cortex ratio results suggest that artefacts, specifically flakes, were removed and not replaced, since there is insufficient flake surface area present to account for the number of cobbles that were worked. If flakes had either not been removed, or had been removed and others deposited in their place, then the cortex ratios would tend towards one. It is therefore parsimonious to suggest that flakes were moved outside the valley and not returned. In all of the areas that we have studied in western NSW, low cortex ratio values suggesting a high degree of flake movement are nearly always indicated, implying that movement was over distances greater than those between one catchment and the next (Douglass 2010; Holdaway & Fanning 2014). The inability to find places with a cortex ratio value of one suggests larger-scale regional patterns in the movement of people, as seen through the transportation of flakes that occurred over long periods of time.

Topographic complexity

To help understand what might potentially correlate with such large-scale land use, we created low-level filter maps of topographic roughness for the lower Murray–Darling Basin, in which our study area is located. The elevation map derived from Shuttle Radar Topography Mission (SRTM) data (Figure 1a) shows that the region is characterised by low elevation surfaces. The topographic roughness map derived from slope data (Figure 1b) illustrates the lack of topographic complexity across the region. Small areas of relatively high topographic roughness in the south-east are bounded by large areas where there is little or no change in relief. Landsat

Table 1. Cortex ratio values for the Rutherfords Creek sampling units. Separate ratio values are calculated for cores, flakes and the total assemblage, following the method discussed in Douglass (2010). Ratio values were calculated using a single estimate of original cobble size for all sampling units. Cases with missing values, where flakes or cores were either not present or present in too small a number to permit calculation of the ratio, are not reported.

Sampling unit	**Clast silcrete**			**Matrix silcrete**			**Sampling unit**	**Clast silcrete**			**Matrix silcrete**		
	Core	Flake	Total	Core	Flake	Total		Core	Flake	Total	Core	Flake	Total
9999	0.63	0.46	0.55	0.81	0.47	0.45	17122	0.64	0.57	0.66	0.78	0.48	0.48
10136	0.4	0.63	0.65	0.87	0.65	0.63	17147	0.56	0.45	0.02	0.55	0.38	0.36
10141	0.42	0.87	0.85	0.55	0.81	0.66	17286	0.66	0.62	0.72	0.69	0.46	0.49
10145	0.35	0.67	0.57	0.46	0.64	0.51	17354	0.43	0.48	0.52	0.93	0.77	0.53
10166	2.09	1.42	2.08	0.4	0.42	0.35	17424	0.34	0.58	0.49	0.68	0.37	0.33
10193	1	0.85	1.03	0.71	0.68	0.57	17582	0.35	0.56	0.54	0.52	0.61	0.48
10227	0.18	0.65	0.46	1.61	0.57	0.73	17762	0.49	0.65	0.65	0.95	0.73	0.68
10249	0.82	0.57	0.72	0.68	0.68	0.57	17792	0.38	0.28	0.35	0.56	0.48	0.42
10270	0.88	0.76	0.92	1.13	0.74	0.77	17847	0.36	0.68	0.71	1.01	0.56	0.53
10306	0.25	0.61	0.54	1.3	0.4	0.4	17897	0.5	0.71	0.69	0.86	0.66	0.59
10327	0.54	0.41	0.53	0.52	0.44	0.4	17926	0.41	0.3	0.38	0.46	0.47	0.4
10333	0.63	0.52	0.65	0.36	0.66	0.47	17928	0.15	0.96	0.55	0.31	0.45	0.33
10338	0.47	0.51	0.54	0.93	1.1	0.9	17954	0.41	0.61	0.6	0.47	0.56	0.47
10397	0.3	0.61	0.55	1.13	0.59	0.58	23496	0.83	0.33	0.63	0.33	0.52	0.39
10448	0.34	0.53	0.54	0.61	0.5	0.43	24340	0.3	0.37	0.39	0.41	0.41	0.34
10610	0.36	0.6	0.58	0.96	0.89	0.75	24358	1.07	0.49	1.02	0.92	0.69	0.74
10623	0.51	0.58	0.62	1.15	0.63	0.68	24392	0.38	0.35	0.4	1.05	0.38	0.41
10633	0.5	0.6	0.63	0.87	0.57	0.55	24488	0.32	0.32	0.37	0.43	0.62	0.5
10662	0.63	0.72	0.77	0.19	0.55	0.28	24609	1.04	0.69	0.97	0.87	0.46	0.49
10680	0.37	0.32	0.4	1.44	0.55	0.7	27109	0.57	0.66	0.69	0.97	0.82	0.74
10702	0.39	0.55	0.58	0.65	0.71	0.58	27149	0.7	0.53	0.74	0.38	0.58	0.43
10726	0.8	0.86	0.98	0.99	0.89	0.78	38268	0.87	0.47	0.73	0.62	0.73	0.6
10734	0.9	0.44	0.52	0.74	0.9	0.72	38297	0.56	0.61	0.66	0.45	0.46	0.39
14010	0.28	0.44	0.45	0.74	0.55	0.51	41533	0.8	0.37	0.58	0.26	0.61	0.4
17020	0.25	0.44	0.45	1.46	0.53	0.54	43302	0.69	0.96	0.89	0.7	0.95	0.74
17028	0.21	0.71	0.69	0.45	0.48	0.4	43321	0.85	0.81	0.94	0.66	0.79	0.65
17051	0.69	0.34	0.58	0.28	0.46	0.37	43383	0.41	0.59	0.62	0.37	0.53	0.41
17076	0.61	0.48	0.58	1.85	0.4	0.45	44945	0.6	0.38	0.49	0.6	0.5	0.44

Enhanced Thematic Mapper (ETM) data for the same region (Figure 1c) indicates, on the other hand, a high degree of local heterogeneity of the landscape, most likely 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. However, this inference needs to be interpreted in relation to environmental processes that have an impact on resource abundance. 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 climatic variability (Holdaway *et al*. 2013). In general, Australia is characterised as having an "infertile, well sorted landscape" (Stafford Smith & Morton 1990: 261). Long periods with little or no rain are separated by short periods of very abrupt rainfall. At the same time, Australian soils are depleted in nitrogen and phosphorous, largely as a result of the continent's tectonic history (Morton *et al*. 2011: 317). Average soil fertility, however, masks considerable local variation in nutrients over a variety of different spatial scales from 10^1 to 10^4 m^2, an observation that is reflected graphically in the colour variation shown in Figure 1c.

Lack of fertility and intermittent rainfall thus combine to produce a landscape that varies both spatially but also temporally in ways that were not easy to predict. This is opposite to the Great Plains case study discussed below, where Kornfeld and Osborn (2003) note that there is a tendency for Great Plains environments to display relatively high spatial and temporal autocorrelation in resource availability. For humans, lack of predictability in environmental resource heterogeneity 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, an observation that makes sense of the variable ethnohistorical accounts described below. Iterated across space and through time, this suggests that, in contrast with the Great Plains case study, individual resource patch locations in the western NSW study area were neither continuously or cyclically attractive for occupation (Holdaway *et al*. 2013).

Ethnohistorical sources describe Aboriginal people living along the Darling and Murray Rivers at European contact. However, the accounts describe variability in group size, only some of which can be accounted for by seasonal differences in resource abundance (Allen 1971). Movements away from the rivers allowed for the exploitation of game and grass seeds, and a range of small animals were collected, larger animals being hunted with nets and clubs rather than with spears. While Allen talks about seasonal differences in mobility, he also notes how the ethnohistorical accounts document marked differences in population numbers recorded on return visits during the same season. Thus the productivity of particular sources at particular places through time, even within the same season, is difficult to gauge based on the ethnohistorical accounts alone.

Allen recorded people moving from areas west of the Darling River to the Darling River or to the Bulloo Overflow to access riverine resources. This movement was two-way, in the sense that people who inhabited the riverine areas would sometimes move out into the ranges. It is possible that these kinds of movements are similar to those we have recorded from the Rutherfords Creek study area, as well as from the other locations in western NSW that we have studied (Holdaway & Fanning 2014). Accounts suggest that prolonged drought reduced the mobility options for groups as water sources became more dispersed and the availability of plant foods declined. Drought therefore probably reduced the landscape heterogeneity discussed above, but not in a way that improved resource predictability.

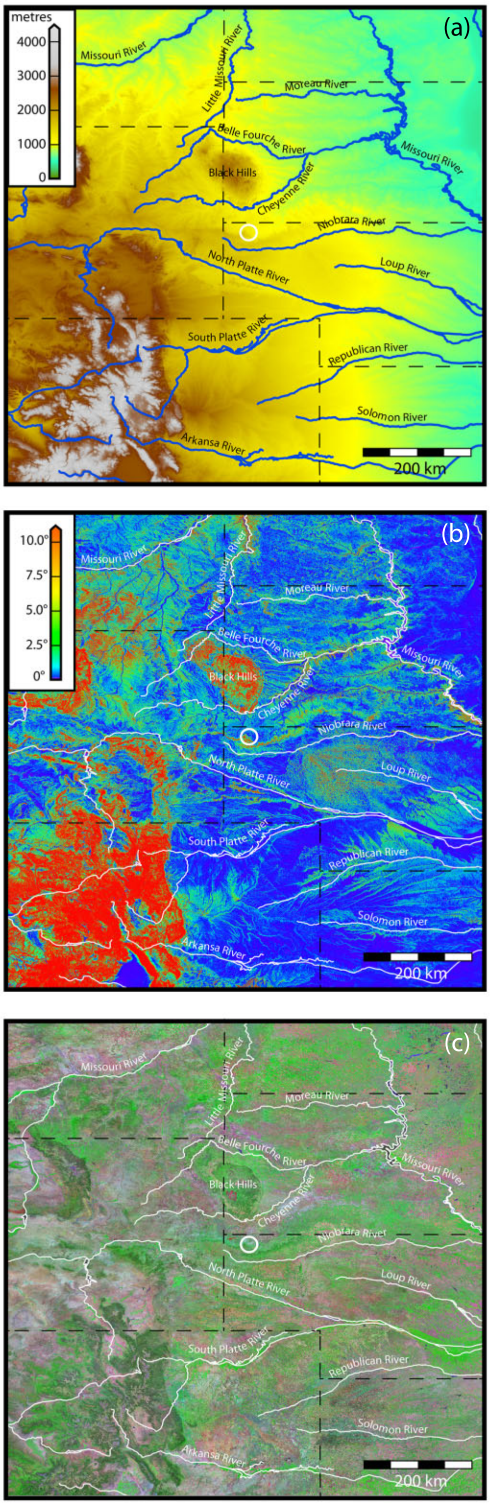
If resources were episodic in their availability, both spatially and temporally, it might be expected that many places would see at least some use and therefore would see the creation of an archaeological record. Using a "dots on maps" approach, the landscape would appear to be covered by a carpet of occupation debris, as though all places were used at once. In fact, the opposite is the case; absolute dating of hearth remains and land surfaces on which the artefacts rest (Holdaway & Fanning 2014; Holdaway *et al*. 2002, 2005) demonstrates that this carpet of dots is instead a signature of high mobility by small numbers of people in a landscape where the ecology and topography leads to the wide dispersal of the material remains of occupation.

Image analysis of the region in which it is situated gives landscape context to the archaeological record from Rutherfords Creek. The low redundancy in place use, as evidenced by the variety of ages and the wide distribution of hearths, indicates how multiple places saw use, but none at levels significantly higher than its neighbours. Low redundancy in place use is also indicated by similarities in assemblage composition. Analysis of the stone artefacts indicates movement, suggesting high mobility consistent with the need to move often and far to find the resources that became available through time, rather than residential occupation sites.

THE NORTH AMERICAN GREAT PLAINS: THE OGLALA NATIONAL GRASSLAND

The Oglala National Grassland (ONG) comprises 38235 ha in north-west Nebraska (Figure 2). The topography varies from flat and low rolling prairies, through deeply eroded badlands, to stream valley systems. The most

Figure 2. The topographic complexity of the western Great Plains region of North America. The Oglala National Grasslands study area is indicated with a white circle on all three maps. (a) An elevation map based on SRTM3 data, with major rivers and state boundaries superimposed (the key shows the altitude above mean sea level). (b) A slope map as a proxy for topographic roughness. (c) A landscape complexity map based on Landsat ETM data.



prominent feature is the Pine Ridge Escarpment, positioned along the southern edge of the grassland. These upland areas in the Plains are likened by Kornfeld and Osborn (2003) to habitat patches.

A 10–13 km wide piedmont zone bordering the Pine Ridge Escarpment of the grasslands is dissected by numerous incised streams. Extensive erosion has created badland exposures. A region of low-relief, rolling hills developed on Pierre Shales is located north of this zone. Springs originating at the Miocene/Oligocene geological contact create permanent and intermittent streams that are a primary water source (Meston 1976). These feed into the White River basin locally and the Cheyenne River further to the north (Figure 2). The modern environment is semi-arid, with broad seasonal changes reflecting a continental climate. On average, 400–500 mm of precipitation falls annually in these areas, with high variability. Rain falls predominantly in the months of May to July; January temperatures range from an average of −13° to +2°C; July temperatures range from an average 14° to 33°C (Wandsnider *et al*. 2008).

The archaeological record

Archaeological surveys of eroded areas and deflated hills and ridgelines were conducted along the Sand Creek drainage, a lagged cobble bed below a hillslope locally known as Pete Smith Hill, badland exposures within the vicinity of Toadstool Geologic Park, and deflated hillslopes exposed by grass fires near the Hudson–Meng Bison bone bed and north of Roundtop Butte. The chronology of human occupation in the region is based on projectile point typologies and these individual study areas each display considerable temporal depth.

Unlike Australia, sources of flakable stone in the Great Plains are limited, which had an impact on how people made artefacts, and how these were distributed. Raw materials belonging to the locally available Chamberlain Pass Formation are the most common in all of the sampling areas, but there is also evidence for the use of material from more distant sources. These include White River Silicates, which outcrop throughout the broader region (Hoard *et al*. 1993) as well as locally, and are also found as water-worn cobbles within the Chamberlain Pass Formation, Flattop Chalcedony (Colorado), Hartville Uplift chert (Wyoming), and a variety of non-local quartzites, mostly from Wyoming and South Dakota.

The relative abundance of these non-local materials varies between the study locations (Figure 3). While the Sand Creek and Toadstool locations show only small portions of this non-local material, a greater material diversity, including more materials transported in from some distance (Hartville and Flattop), is found in the North of Roundtop and North-west of Hudson–Meng study locations. Artefacts from these non-local sources tend to be smaller and more likely to have retouch than their local Chamberlain Pass counterparts. This size difference not only reflects a reduction in artefact size with distance from the source, but also reflects the discard of smaller flakes that result from edge maintenance on retouched tools and bifaces, as evidenced by increased frequencies of bifacial and crushed platforms.

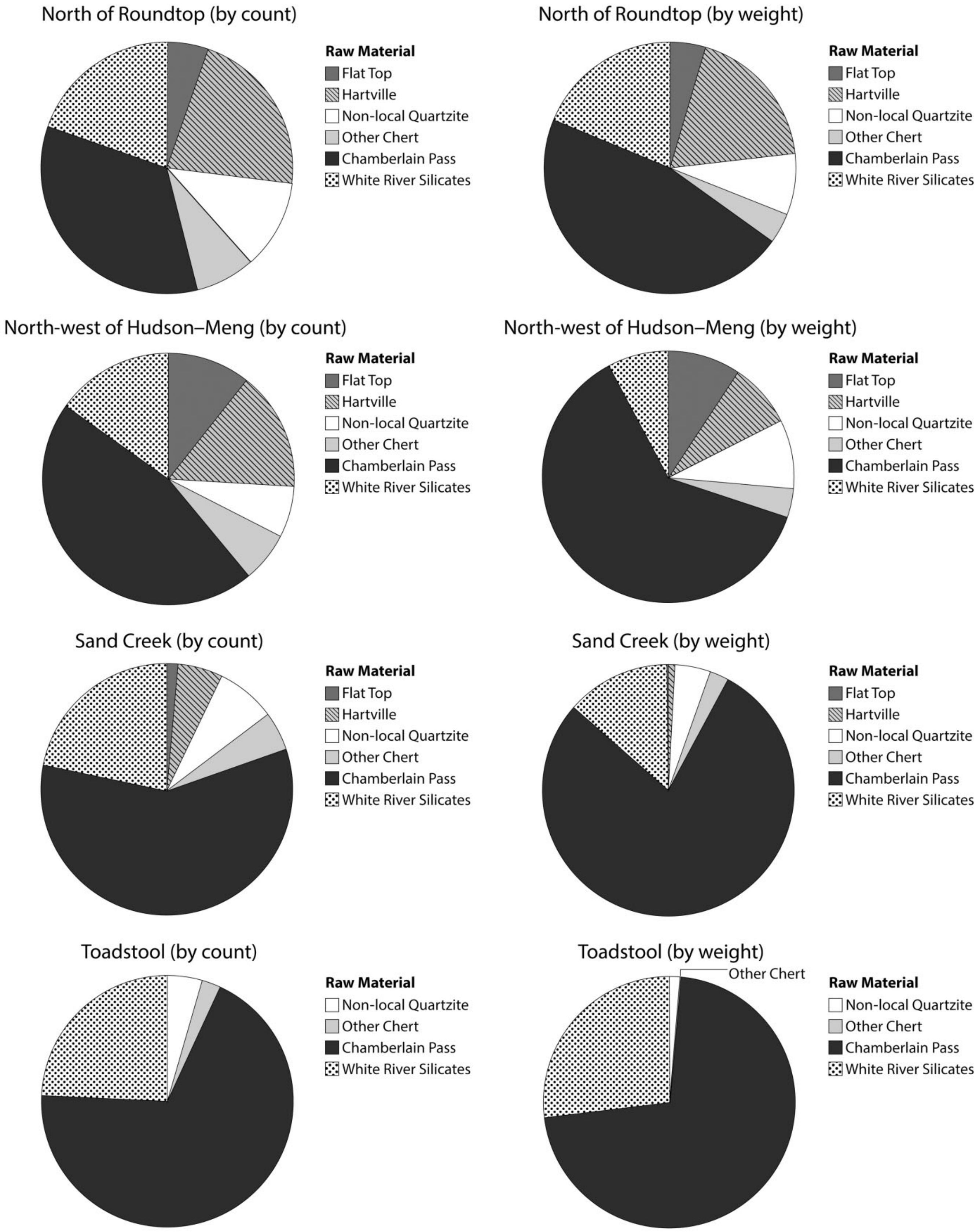
Nodular cores are abundant at Pete Smith, the sampling location adjacent to a raw material source (Table 2), but rare throughout the rest of the study area. This trend is indicated by the high flake to core ratios in these off-source locations. Where non-local raw material cores are present, these are smaller in size than those from Pete Smith.

Measures of core cortex proportions and other indices of core reduction intensity (Braun 2006; Douglass 2010) indicate that cores at Pete Smith averaged a 36% loss of core mass. Pete Smith cobbles include quartz, quartzite, silicified sandstone, chert and silicified wood. Some materials, such as quartz, quartzite and silicified sediments, can be hard to knap and require considerable force for flake propagation, whereas finer materials, such as the cherts, with a high silica content, are more easily flaked. Cobbles of all materials are also occasionally found with flaws that make knapping difficult. Core working at the Pete Smith location was therefore influenced by a process of extensive cobble testing and generally low reduction intensity. However, as indicated above, many artefacts were also removed and are found distributed across the other sampling locations.

Table 3 shows cortex ratios for Pete Smith Hill for the cores and flakes and for the total assemblage. Since the Pete Smith Hill sample is directly on top of a material source, a small deficit in cortical surface area (cortex ratios below one) suggests the removal of artefacts and thus transport for use over the broader landscape. Further exploration of differences between these values helps to shed further light on the process of export from Pete Smith. If cores are only lightly reduced, they will retain large quantities of cortex and will also comprise the bulk of the mass in an assemblage. As exemplified by the cores at Pete Smith Hill, with a cortex ratio of 0.94, even if the majority of flakes produced from these cores are removed from the location, the cortex ratio will dip only slightly below one. However, the cortex ratio value for the flakes is 0.68, suggesting that the cortical surface area on flakes is lower than would be expected given their volume. Since initial flake removals will have greater cortical surface area than later removals, it is likely that a substantial portion of the flakes produced at Pete Smith Hill were removed from the location.

The other assemblages analysed show considerable diversity, although all show cortex under-representation (Table 3). The lowest cortex ratio is for North-west of Hudson–Meng, an assemblage with only 46 artefacts in total, and with 21 of these produced from the local Chamberlain Pass cobbles. The study location with the highest value for the cortex ratio is Sand Creek, a drainage that trends in the direction of Pete Smith Hill and thus the known locations of Chamberlain Pass Formation cobbles. While this location is not appreciably closer to a raw material source than the other areas, it is not surprising

Figure 3. Raw material proportions for each of the study areas (right) by weight and (left) by artefact count.



that local stone occurs here in the greatest proportion and that the cortex ratio (0.91, Table 3) is comparable to that for Pete Smith Hill. However, within the Sand Creek valley in general, cores are rare ($n = 6$) and flakes relatively common (the flake to core ratio is 17; Table 2).

The cortex ratio for flakes at Sand Creek is > 1, indicating the addition of cortical flakes along with some cores, a pattern that, while close to that seen at Pete Smith Hill, reverses the relative order of the values for cores and flakes. At Pete Smith Hill, cores are overly cortical and flakes are under cortical; at Sand Creek, flakes are overly cortical, while cores have lower cortex proportions. If bigger, and therefore on average overly cortical, flakes are removed from source locations such as Pete Smith Hill, the cortex ratio values are greater than one at the locations where they are discarded.

This pattern becomes clearer if a division of the assemblages within Sand Creek is considered (Table 3).

Table 2. Flake to core ratios for the sampling units for all raw materials (A) and for Chamberlain Pass Formation materials (B).

A: Flake-to-core ratios, all raw materials				
Raw material	*N*	MNI flakes	Cores	F/C ratio
NRTP	208	76	0	N/A
NWHM	46	20	0	N/A
PS	238	101	69	1.46
SC	287	164	9	18.22
TS	116	70	4	17.5
B: Flake-to-core ratios, Chamberlain Pass Formation				
Raw material	*N*	MNI flakes	Cores	F/C ratio
NRTP	71	26	0	N/A
NWHM	21	9	0	N/A
SC	166	102	6	17
TS	80	47	3	15.67

Table 3. Cortex ratios for the Oglala National Grassland sampling areas. Separate ratio values are calculated for cores, flakes and the total assemblage, following the method discussed in Douglass (2010). Ratio values were calculated using a single estimate of original cobble size for all sampling units. Missing values indicate cases where flakes or cores were either not present or present in too small a number to permit calculation of the ratio.

Survey location	**Core assemblage**	**Flake assemblage**	**Total assemblage**
Pete Smith Hill	0.94	0.68	0.87
North of Roundtop		0.75	0.79
North-west of Hudson–Meng		0.23	0.23
SC	0.63	1.09	0.91
SC2011	0.74	1.22	1.11
SC2012	0.56	0.55	0.53
Toadstool	0.66	0.77	0.73

The 2011 artefacts were collected from along the creekline, as well as a larger quantity of artefacts sampled from an arroyo system running perpendicular to the valley and up to its margins. In contrast, the survey in 2012 concentrated on the floodplain scalds further to the west, and thus upstream, of the assemblages from 2011. Assemblage-wide values for the 2011 data have a cortex ratio of 1.11, while the assemblage-wide cortex ratio for 2012 has a cortex ratio of 0.55. The cortex ratio for the 2011 flakes is 1.22, while that for the 2012 flakes is 0.53 (Table 3).

Based on cortex ratio values, North of Roundtop and Toadstool are similar to each other, while the North-west of Hudson–Meng assemblage is similar to Sand Creek 2012. For complete flake mass, Toadstool (17.5 g) is similar to Sand Creek 2011 (16.1 g), but with less cortical surface area per artefact. This is also shown by the flake to core ratio. Complete flake mass at North-west of Hudson–Meng (2.9 g) and North of Roundtop (1.0 g) resemble that at Sand Creek 2012 (2.8 g), but the cortex ratio value for North-west of Hudson–Meng is considerably lower, while for North of Roundtop it is considerably higher, than Sand Creek 2012.

In sum, this small sample of locations shows considerable variation in raw material use. Projectile point typologies suggest a considerable antiquity for the region in general, and points spanning thousands of years are found together in individual study assemblages. Thus, the diversity seen in the lithics from these areas is not a reflection of differences in activities in a few individual occupations but, instead, reflects broad trends in use of these individual study locations through time. Combining all study locations shows a pattern of local raw material use with material working its way out from local sources, mostly in the form of larger, overly cortical flakes. While some locations show places where large, cortical flakes were abandoned, it remains unclear how large a spatial scale is required to account for the overall pattern of flake removal. Other locations, however, do not show the deposition of large, cortical flakes. Instead, these assemblages with smaller flakes may indicate either the continued removal of larger flake products (as implied by the platform data at Sand Creek 2012) or else the conversion of these transported flake forms into retouched tools, either through use or manufacture. This is particularly clear from the small yet rather cortical flakes at the North of Round top location, where the size range of flakes is constrained and rates of retouch are relatively high.

In locations with smaller artefacts, implying a different pattern of material use with an emphasis on refurbishment and economical stone utilisation, higher rates of non-local material artefact deposition are also seen. These locations have a different relationship to raw material economy and provisioning, and demonstrate a process where lithic raw material use is more reflective of the broader use of space within a context of material poverty. These sampling areas are removed from drainages in the study area, instead being positioned along prairie/upland margins associated with the transition from the Pine Ridge to the expansive flat Plains in the north of the study area. Thus, different locations in the ONG are variably sensitive to the two-way processes of raw material moving out from a local source and coming to rest over the broader landscape, and materials from other more distant sources working their way into the study area.

Topographic complexity

As the complex topography analysis confirms (Figure 2), topographic differences throughout the ONG study region are more pronounced than for the Australian case study. The Pine Ridge Escarpment and associated upland features, together with an array of drainages that radiate off them and into the flatter grasslands to the north, create a patchwork of habitats within the immediate study area. Extending outwards, the location of the study areas is noteworthy for its position between the topographic diversity of the Pine Ridge and the Black Hills, both of which create landmarks that dominate the visible landscape. At a regional scale, the spring-fed creeklines of the immediate study area connect to large stream systems, and ultimately to a series of west-to-east flowing, incised rivers that to some degree create corridors for movement that are much more complex than that of the Murray–Darling region in Australia.

The landscape complexity map (Figure 2c) suggests that, overall, this landscape is much more homogeneous at a local level, but more heterogeneous at a broader level, than is the case in the Australian study area. In the plains, the diversity in terrain creates a greater mixture of resource availability, and thus lends a degree of ecological diversity and complexity to the broader study area. The combined effect is a greater array of opportunities for resource exploitation through the temporal and spatial autocorrelation of flora and faunal species within these unique topographic and physiographic contexts. This serves to increase the predictability of resource availability over the long term in a way that is very different from the long-term homogeneity and resource unpredictability that is seen in the Australian case study. When coupled with raw material access that is limited to a few distributed locations, the result is a high redundancy in place use, reflected in the marked differences in assemblage composition in different landscape contexts that have a long history. Similar observations have been made for other parts of the Great Plains region. In a series of case studies, the concept of ecological islands is used to explore a diverse array of habitats and features that punctuate the broader Great Plains grassland environment (Kornfeld & Osborn 2003). The scale of these studies ranges from a consideration of large topographical and ecological zones, such as the Black Hills and Nebraska Sand Hills, to smaller patterns related to individual hydrological features (e.g. playa lakes and lake systems), to even smaller redundancies in the occurrence of species of plant and faunal resources (e.g. sego lilies and ungulates). This resource island concept, and its general relationship to the structure imposed by changes in topography within the broader Plains setting, makes sense with the patterning observed in the ONG. The topographic features of the Pine Ridge within the study area and the Black Hills to the north, both visible from several of the locations analysed in this study, served as fixtures of relative ecological diversity in the landscape. At a more local scale, the positioning of the Pine Ridge and associated uplands creates unique ecological contexts within which different species of plains and upland flora and fauna can be found. Localized springs and rainwater run-off create intermittent yet relatively predictable water sources, which in turn lead to drainage features that connect the local landscape to a larger system of creeks and rivers. Thus, unlike the Australian case study, the conditions of marginal yet important topographical complexity in the ONG study area, and the ecological feedbacks that result, provide a degree of resource and thus land-use continuity that breaks from the broader flat seas of grass that characterize the region in general. This landscape is still topographically mundane at a large scale, and as attested by the movement of stone artefacts between sources separated by hundreds of kilometres, required the use of extensive mobility and extended home ranges as a key feature of Great Plains human adaptation. Yet within this process of large-scale human mobility, the constellations of ecological and topographical islands imposed a degree of spatial and temporal resource predictability that served to guide broader regional patterns of land use that, through time, resulted in the distinct diversity of place-use histories implied by the lithic patterning observed in the ONG study locations.

DISCUSSION

As outlined in the Australian case study, Aboriginal people faced environmental challenges in the past. Resource abundance was unpredictable owing to the combination of a highly variable rainfall and low nutrient levels, itself a product of the topographic history of the continent. It is the ecological consequences of both variable rainfall and low nutrients that help us to understand how Aboriginal people interacted with the environment in the way they did. Archaeological sites from a variety of locations in the semi-arid region of Australia show evidence for high levels of movement (Holdaway *et al*. 2013). This in turn suggests a response to a flora and fauna that evolved to deal with marked and unpredictable changes, one that operated at a variety of temporal and spatial scales in a topographically undifferentiated landscape that was characterised by high local heterogeneity but little systematic, regionally predictable pattern through time. Faced with such unpredictability, people moved frequently and over long distances.

In contrast, the ONG study area represents a region of "islands" within a grassland "sea" (Kornfeld & Osborn 2003). The study area also has distinct raw material sources that contrast with a general material poverty in the wider region. Similar to the Australian example, people transported flakes. However, in the ONG case study, artefact transport indicates a pattern of land use that is in marked contrast to patterns shown in the Australian example.

In Australia, assemblage diversity is present only at the smallest, local level, seen in the variability in stone artefact assemblages amongst the sampling units studied. But expanded to the scale of an entire drainage system, this variability does not scale up into different patterns of use related to landform. On the contrary, assemblage composition shows an almost random variation across the study area. In contrast, within a relatively circumscribed area of the ONG, differences in raw materials, in artefact size and in indications of retouch are apparent. It really does appear that there are distinct, highly redundant, histories of landscape use in the broader grasslands, where similar types of behaviour are generated on unique topographic and ecological contexts. To put it simply, in the ONG example certain places appear to have been used in similar ways throughout history but differently to other places, whereas, in the Australian example, different places right across the study area appear to have been used in largely similar ways. There is continuity in the means by which different elements of the broader ONG study area attracted human use through time, whereas in Rutherfords Creek there is a lack of fixity in landscape elements, and the overarching patterns suggest low redundancy of land use over large tracks of geographical territory. Thus, the place-use histories of the ONG study area and that of Rutherfords Creek are distinctly different, a difference that can be related to their differing landscape complexities, illustrated here using analyses of satellite data (Figures 1 & 2).

CONCLUSION

In this study, we have matched stone artefact distribution and assemblage composition at the local geographical scale to measures of both complex topography and environmental history at the regional scale, illustrating the issues that Frankel discussed in his 1988 paper. Bailey and King (2011) suggest topographic complexity as a measure that operates at the type of temporal and spatial scales suitable for answering evolutionary questions. To test this proposition requires that measures of topographic complexity be related to observations of the archaeological record. By comparing two study regions that have different topographic complexity measures, we show that people created distinct long-term landscape-use histories in both regions. While stone artefact manufacture and use, and indeed the transport of stone artefacts over great distances, feature in both areas, the accumulation of stone artefacts in different places leads to a quite different site-use history, one characterised by low redundancy in place use in the Australian example and one with high place-use redundancy in the ONG study. We set out to study regions that had a different topographic complexity to the examples of the complex topography hypothesis in previous studies. What we discovered was that, while both the regions selected might be described as plains, their topography is quite different. The fact that this difference is matched by differences in their respective archaeological records suggests that the method has sensitivity to the way in which people used past landscapes.

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NOTE

1. “Scald” is a local term describing unvegetated patches of ground where topsoils or surface sediments have been eroded by wind and/or water, exposing saline subsoils or subsurface sediments. They may occur naturally, or as a result of overgrazing (Charman & Murphy 2000: 62).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest for this article.

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