SITE DISTURBANCE AND ARCHAEOLOGICAL INTEGRITY: The Case of Bend Road, an Open Site in Melbourne Spanning Pre-LGM Pleistocene to Late Holocene Periods

Geoff Hewitt and Jim Allen*

Abstract

Bend Road is an open site covering c.12 hectares on a sand sheet formation in southeast Melbourne, now bisected by the new Mitcham-Frankston tollway. Results from earlier salvage archaeology suggesting this was a significant scientific site were subsequently questioned on geomorphological grounds that indicated post-depositional disturbance. In 2006 the authors carried out extensive and detailed excavations and analyses that indicated that while both large-scale aeolian deflation events and smaller-scale bioturbation could be demonstrated, paradoxically the archaeology retained a clear coherence. While the bulk of the archaeology relates to the backed artefact period – the site has now yielded hundreds of asymmetric points and geometric microlith forms from the late Holocene – an earlier sequence extends back to 30–35,000 BP, putting Bend Road amongst the oldest known sites in Victoria. This paper summarises the methodological procedures and results that reflect both the natural disturbances to the site and the data that demonstrate its archaeological integrity, and points to a growing imbalance between increasingly sophisticated dating techniques available to the archaeologist and the levels of scale and resolution that usually pertain in archaeological sites.

Context, Site Formation, Taphonomy and Bioturbation

Hiscock (2008:37) has recently re-emphasised the need to pay close attention to the depositional contexts from which archaeological data are excavated. Site formation processes are frequently ignored in site reporting while researchers rely ever more heavily on an array of sophisticated techniques, and especially radiometric dating of smaller and smaller samples, where context is increasingly crucial. Paradoxically, peer group reviews of archaeological claims most frequently attack contentious data by questioning site integrity (e.g. Allen and O’Connell 2003; Hiscock 1990; Roberts et al. 2001). Where interpretations depend on artefacts being in situ, it needs to be demonstrated rather than assumed that they have not been moved after deposition.

Earlier archaeologists (e.g. Binford 1964:424; Childe 1956:1 among many others) failed to recognise that artefact patterning in sites might not merely reflect human behaviour but also chemical, physical and biological post-depositional processes. Today such processes are well-known and widely documented (e.g. Armour-Chelu and Andrews 1994; Canti 2003; Dibble et al. 1997; Hole 1961; Nash and Petraglia 1987; Rick 1976; Schiffer 1972; Solomon et al. 1990; Wood and Johnson 1978). Hole (1961) defined nine forms of post-depositional disturbance: faunal turberation, floral turberation, cryoturbation, graviturbation, argilli turberation, acroturbation, aquaturberation, crystallturberation and seismiturbation. In Australia we are not greatly troubled by some of these, such as earthquakes or freezing and thawing, but others are common. While we do not have the range of burrowing animals seen elsewhere in the world, the introduced rabbit has damaged sites (e.g. Bird and Frankel 2001:51-52) and tree root intrusion is commonplace, even if rarely reported.

Direct discussions of taphonomic processes in Australian sites have been infrequent. Stockton (1973) investigated artefact displacement by scuffage and treadage at Shaw’s Creek rockshelter. Artefact redistribution by birds has been noted (Cane 1982; Solomon et al. 1986) and studies have been undertaken to distinguish bone deposits laid down by humans from those of owls (e.g. Cosgrove 1995a; Geering 1990) or scavengers such as dingo (e.g. Huchet 1990; Solomon and David 1990). Cameron et al. (1990) have studied the effects on surface sites of both matrix deflation and accumulation and more recently the effects of slope and rainfall flow on surface sites has been studied by Fanning and Holdaway (2001).

Much less attention has been paid in Australia to the effects of bioturbation, particularly by smaller organisms like worms, ants or beetles. Termites, some species of which can tunnel up to 50m below the surface and deposit up to one tonne of soil per hectare per year on the surface (Cahen and Moeyersons 1977; Coventry et al. 1988; Holt and Lepage 2000), have been recognised in tropical sites in Australia, but their impacts have not been closely investigated. Smith et al. (1997) recognised bioturbation by invertebrates at Puritjarra rockshelter in Central Australia but did not identify any immediate effects on the archaeological record there. Watson and Flood (1987) reported termites at Green Ant Shelter 1 and Echidna Shelter but dismissed serious bioturbation because they saw no signs of disturbance and no inversions in the radiocarbon dates. On the basis of Watson and Flood’s findings, Huchet (1990) dismissed significant disturbance by termites at Pleistocene-aged Yam Camp rockshelter on Cape York although ‘a large termite mound … presently stands about 2m away from the excavated area’ (1990:67; see also Morwood and Dagg 1995:Figures 9.3 and 9.4). Since this mound is c.2m high and comprises c.1 tonne of sand grains derived mostly from the archaeological deposit, the exactness of the site is questionable. One consequence of continuous deep soil churning by termites is that many natural stones sink to form ‘stone lines’ (e.g. Williams 1968, 1978). Stone artefacts can do the same thing and it is suggestive that at Yam Camp Morwood and Dagg (1995:114) identify artefact peaks at

Archaeology Program, School of Historical and European Studies, La Trobe University, Bundoora, VIC 3083, Australia g.hewitt@latrobe.edu.au, j allen@bigpond.net.au

* Corresponding author

Number 70, June 2010 Australian Archaeology
the base of the excavation in the two squares nearest this termite mound. More recently McNiven et al. (2009) attributed size sorting of stone artefacts in the lower levels of Kabadul Kula rockshelter in Torres Strait to either invertebrate bioturbation, rootlet penetration, rainwater percolation or treadage. Vectors of bioturbation present at the site include termites, ants and cicadas (McNiven et al. 2009:35). Lastly the possible site-disturbing effects of termite tunnelling in Nauwalabila has been canvassed by O’Connell and Allen (1998) and Allen and O’Connell (2003). Because termite activity may homogenise a deposit there may be no visual indication in the stratigraphy and termite bioturbation might only be detected through unusual artefact density peaks or other aberrant data such as artefact size sorting with depth, as with Kabadul Kula where stone artefacts in the lower strata of the site are significantly smaller than those above them.

Less is known about earthworms in Australia. Many species appear to feed on vegetation litter and thus may be confined to the upper levels of sites, unlike in Europe and the United States where their effects on soil profiles are well-known (e.g. Armour-Chelu and Andrews 1994; Canti 2003; Stein 1983). Since they appear to dislike extremes in acidity/alkalinity and temperature they may be of less importance in bioturbating Australian sites. On the other hand, archaeologists generally assume that any level of a site was once a surface, so worm bioturbation should not be readily dismissed. Surface ant nests indicate the degree to which ants can reorganise local landscapes and, from experience at Bend Road, burrowing black ants can create vertical tunnels to small nests up to 600mm below the ground (see below). Other species such as cicadas and dung beetles nest underground and can dig tunnels up to 300mm in length. We consider bioturbation at Bend Road later in the paper.

Bend Road

Here we report a case where excavation began with the expectation that a large sand sheet site in suburban Melbourne named ‘Bend Road’ was so disturbed that its only scientific interest was the chance to identify markers and vectors of site disturbance. While many were identified, we also found that the archaeology maintained a general stratigraphic coherence that provided an overall integrity to the conclusions that could be drawn from it. We contend that many Australian sites might be similar in this respect, but we are unaware of any that have been reported. Elsewhere there is a precedent in the Dry Creek site in Alaska (Thorson and Hamilton 1977, cited in Wood and Johnson 1978) where six of the nine turbative processes described by Hole (1961) have been recognised but where the site maintains sufficient contextual and stratigraphic integrity to provide meaningful interpretations of the archaeology and palaeoecology.

Excavations carried out at Bend Road are detailed in Hewitt and de Lange (2007) and Allen et al. (2008). This paper synthesises data relating to geomorphological processes, bioturbation, stratigraphies, artefact distributions, artefact conjoining and radiometric dating on the site. Many vectors of bioturbation including ants, worms, beetles, rabbits and humans were identified, but more dramatic were large-scale aeolian deflation and accumulation events creating and reorganising the sand deposit itself on an unknown number of occasions.

Deflation events in sand sheet deposits are at best of low archaeological visibility and frequently invisible. They are mostly identified by unusual dispositions of artefacts in the deposits and/or fine-grained radiometric dating programmes, together with soil particle analyses and other geomorphic assessments.

Here we contend that if post-depositional disturbance does not necessarily compromise the integrity of an archaeological deposit beyond measurable or predictable limits, then some archaeological sites will maintain scientific importance despite variable degrees of reworking. Bend Road is such a site.

If the Bend Road situation is not unusual then it has important implications. It is widely assumed that the demonstration of any stratigraphic disturbance in a site is sufficient to dismiss its archaeological relevance. For example, Roberts et al. (2001) base their criticism of Cuddie Springs on the fact that OSL dating samples contained younger and older sand grains. Single grain analysis identified ‘multiple discrete populations’ that implied that ‘some sediment mixing had occurred.’ Similar sediment mixing in some Bend Road OSL samples led the dating scientist involved (Matt Cupper, University of Melbourne, pers. comm., 2007) to draw similar conclusions about Bend Road.

However the Bend Road archaeology suggests that this should not be an either/or proposition. Here, multiple instances of ‘large-scale’ post-depositional disturbance and bioturbation can be demonstrated which do not undermine the coherence of the archaeological sequence.

The Site and its Archaeological History

Between January and August 2006 the authors carried out archaeological excavations at Bend Road on behalf of La Trobe University for contractors constructing a tollway from Mitcham...
to Frankston, in southeast Melbourne. At Keysborough, near Dandenong, the tollway passes directly through an open sand sheet site registered as AAV 7921-0735/6, but known as 'Bend Road' after the road that bisected the site prior to tollway construction (Figures 1-2).

The site is located on an undulating sand promontory jutting out into the northern end of Carrum Swamp, drained for farmland in the late nineteenth century. On the surface the site reflects extensive European alteration with house rubble, fences, drains and other structures evident. Until recently the northern end of the site was a large chicken farm. Carrum Swamp, extending c.20km from Dandenong to Frankston, formed a basin in the Port Phillip sunkland (Cupper et al. 2003:346). It comprised a ‘core’ swamp between sand barriers nearer to Port Phillip Bay that included marshland and permanent water bodies, and further inland a larger area of flood-prone alluvial flats. Near the site these flats may have dried out seasonally so that Aboriginal use of this resource was also likely to have been seasonal. Ethnographic accounts suggest that birds, eggs, fish, yabbies, shellfish, eels and edible swamp plants, together with the focus the swamp provided for foraging terrestrial marsupials, would have made the area an important resource for Aborigines, especially in spring. In summer people traditionally moved nearer to the coast (Long 2008).

Carrum Swamp was fed by Dandenong Creek, which debouched onto the basin floor adjacent to the Bend Road promontory. Thus the immediate location provided freshwater and swamp resources that indicate a preferred camping and foraging location.

Original surveys for the tollway (Vines 1997, 2003) identified the Bend Road sand sheet as a likely site location occupying an area c.600m x c.200m (Figure 3). In 2005 subsurface testing was undertaken by Tardis Enterprises Pty Ltd (2005). Tardis dug c.36 transects by backhoe, some in excess of 100m long, and sieved a proportion of the deposits through 7mm mesh mechanical sieves. Recovered stone artefacts, the only cultural data present, were briefly described and quantified in the field (Tardis 2005). Tardis concluded the area was of scientific significance and that deposits below the plough zone were generally in situ. The contractors commissioned a peer review of the Tardis report. Long and Hughes (2005) argued on the available geomorphic evidence and the assumed effects of wind deflation and bioturbation that interpretations of artefact distributions in the site were problematic.

Subsequently Hughes reopened some of the Tardis transects to gather further evidence. Hughes (2005, 2006) noted mottling in the sections that he interpreted as small-scale bioturbation possibly caused by rootlets. He also considered the depths and distributions of distinctive backed bladelets and geometric microliths, here referred to as backed artefacts, after Hiscock and Attenbrow (2005), a.k.a. ‘Bondaian’(see Attenbrow 2002, 2004). These artefacts are most common in southeast Australia in mid-to-late Holocene contexts (but see Hiscock and Attenbrow 1998; Slack et al. 2004 for older examples). According to Tardis (2005) these artefacts tended to concentrate at around 400mm below the surface in sand deposits 0.8m to 1.4m deep, but Hughes noted that Tardis reported that in 16 of their transects backed artefacts occurred at the base of the sand sheet in six cases and within 200mm of it in seven others.

Hughes concluded that if backed artefacts were in situ as argued by Tardis, then the whole sand sheet was of mid-to-late Holocene age. However Hughes could find no persuasive explanation for sand sheet development on such a scale at such a recent time and concluded that the sand sheet probably formed at or after the LGM. If the sand sheet was late Pleistocene in age, backed artefacts at its base could not be in situ.

Satisfactory resolution of this problem required further excavation.

Here we synthesise only the pertinent data from three areas of hand excavation (Pits) and three mechanically dug trenches (Trenches) that were dug by us.1

**Hand Excavated Pits**

Three pit areas were excavated by hand using either 25mm deep or 50mm deep arbitrary spits in the absence of stratigraphy that was not visible while excavating. All artefacts not disturbed by trowelling were recorded in three dimensions using an Electronic Distance Meter. All residues were wet-sieved through 3mm mesh sieves.

**Pit A** comprised a 3m x 4m rectangle excavated as 12 x 1m x 1m squares. No new spit in any square was begun until the previous spit had been removed from all 12 squares, thus affording good stratigraphic control between squares across the whole pit. A total of 1709 artefacts were recovered from this area.
Pit B grew as an irregular but contiguous excavation comprising 12 x 1m x 1m squares. It is 330m north of Pit A. Spits between squares in Pit B were correlated by spit depth measurements when required. A total of 2913 artefacts were recovered from this area.

Pit C is a cluster of three smaller excavations at the southern end of the site separate from each other but all adjacent to Trench 3 (see below). Pit C, is c.45m southeast of Pit A and comprised a 1m x 2m pit running north-south. Pit C, located 8.5m south of Pit C, was a 1m x 2m pit running north-south. Pit C, 5.5m south of Pit C,, comprised a 1m x 3m pit running north-south. A total of 728 artefacts were recovered from the Pit C area.

**Mechanically Excavated Trenches**

Three trenches, each with a different excavation history, provided relevant information.

**Trench 1** was dug as a toe drain by the road contractors. It is c.200m long, running roughly north-south in the northwestern part of the site. We recorded 11 x 1m wide stratigraphic sections at regular intervals along the western face and undertook a small excavation into sterile basal deposits of this trench near Pit B.

**Trench 2** was mechanically excavated and partly sieved by Tardis as their Transect A2. It is c.120m long and lies approximately east-west across the site. We recorded 16 x 1m wide stratigraphic sections at regular intervals on the northern face of this trench after reopening it.

**Trench 3** was dug by us at the request of the Traditional Owners. It lies north-south, intersecting at its northern end with Trench 2, c.5m east of Pit A and concluding at its southern end at the edge of the Holocene swamp (and beyond the sand sheet) a distance of 80m. The strategy was to remove spits 3m long, 1.5m wide (the width of the backhoe bucket) and 100mm deep down to the sterile coffee rock layer. Deposit was passed through mechanical sieves using a 7mm mesh. Wet-sieving was employed as required. We recovered 2865 artefacts from this trench. After each spit was dug the trench wall on both sides was cut back by hand to ensure that the backhoe bucket did not disturb the sections when re-entering the trench. We recorded 12 x 1m wide stratigraphic sections and one 3m wide section at regular intervals along this trench. Further stratigraphy in this location was recorded in the Pit C cluster of pits.

In all, the sample comprises data from 31m² of hand excavation and c.120m² of mechanical excavation and stratigraphic information from 60m of sections in the excavations and 40m of sections sampled from the 400m of exposed trench sections running both north-south and east-west across the site. This strategy provided an extended sample not normally available in Australian excavations. The excavations yielded 8215 artefacts; all of these were analysed, together with two collections preserved from the earlier Tardis work, one thought by Tardis to be a backed artefact ‘flaking floor’. These increased the sample by 421 artefacts. The site yielded 268 backed artefacts, the largest excavated collection of such tools in Victoria.

**Stratigraphy**

**Coffee Rock**

Coffee rock forms the basal substrate that underlies the archaeological sands everywhere but at the peripheries of the site. Coffee rock is formed within a sand body when iron leached from the non-quartz mineral component of the sand by water rich in organic acids is concentrated within a horizon causing sand grains at that level to become cemented and stained by iron oxides or iron/organic complexes. Either or both of two processes may be involved at Bend Road: the percolation of surface water down through the sand sheet and/or the prolonged contact of sand and groundwater at the level of the water table. The current sand sheet may not be thick enough to produce the coffee rock layer by the first method (Meredith Orr, Monash University, pers. comm., 2006), but it may have formed beneath a larger and earlier sand sheet, perhaps being sufficiently impervious to permit further coffee rock development on a ‘perched’ water table.

Coffee rock is present in two distinct forms at the site. In the north, in Pit B and in most of Trench 1 it comprises an unbroken layer, but one whose surface is uneven and pitted. In the south, in Trenches 2 and 3 and Pits A and C, the coffee rock occurs as rubble probably caused by exposure at the LGM (Figure 4). Stone artefacts, argued to be lagged, occur within the coffee rock rubble in the southern part of the site but are absent within the unweathered coffee rock in the northern part of the site. These artefact distributions offer support for our interpretation that the coffee rock in the south was exposed at the LGM and turned to rubble at that time. The sands and clays underlying the coffee rock are also archaeologically sterile.

Incidental exposures of coffee rock in Trenches 1 and 2 suggest that it varies in thickness between c.150mm and c.300mm. Beneath it cemented sands and clays are frequently mottled in colour from grey to brown, orange and red. In Trench 1 a hole was dug 500mm below the base of the coffee rock through these cemented sands. An OSL sample near the base of this hole (the first available level to allow extraction of a dating sample) returned a date of 126,500±7200 BP (KB15).
Overlying Sand Sheet

Bend Road sands form part of the larger Cranbourne Sands, an extensive belt of aeolian sands trending northwest/southeast northwards from the head of Westernport Bay (Cupper et al. 2003:354). Watchman (2006) concluded that the mineralogy and surface texture of the Bend Road sands indicated that they have been subject to polycyclic weathering that has removed all minerals other than quartz. The grains are highly rounded and frosted and have been recycled as wind-blown sand perhaps for hundreds of thousands of years (Hughes 2006).

Stratigraphic change within the sand sheet could not easily be detected while excavating but was visible in section. Figure 5 gives six examples of the stratigraphy from widely separated localities across the site. While specific differences between them are apparent, similarities and consistencies between them allow an overall stratigraphic sequence to be proposed.

Unit 1. Everywhere a sharply delineated grey sand unit normally 250–300mm deep was defined as a ‘plough zone’. European artefacts – glass, ceramics and metal – were common in this zone but rarely found below it. Occasional holes had been dug into the underlying sands from this unit. These included a horse burial in Pit A and a 2m deep drainage channel in Trench 2.

Unit 2. Occasionally separating Units 1 and 3 was a thin (<100mm) layer described in the field as dry sand, light grey sand or disturbed grey sand. This layer is of minor significance and perhaps should be included with the disturbed Unit 1.

Unit 3. This is a large unit frequently up to 500mm thick. In places such as Pit B the upper 100–150mm of this unit may be separated out as a distinct compact grey sand unit, but this may merely reflect a different late prehistoric use of this part of the site. Mostly Unit 3 comprises compact or undifferentiated brownish-grey sand. In places this sand is visibly mottled with lighter yellow blotches, considered by Hughes (2006) to reflect rootlet activity, but we believe that it reflects ant activity. As discussed below, ants at Bend Road are an important vector of small scale bioturbation.

Importantly Unit 3 can be subdivided into an upper Unit 3a and a lower Unit 3b, not on stratigraphic grounds, but by the presence of backed artefacts in the upper part of this unit and their absence below. This division is also marked by an important change in the soil particle size analyses (see below).

Unit 4. Over most of the site the sand underlying Unit 3 is light grey, almost ‘white’, while elsewhere it is mottled with incipient coffee rock, stained sand nodules that give the layer a darker, browner colour.

Unit 5. This unit occurs in discrete patches and pockets in the southern part of the site (Trench 2, Pit C2) where it is always located between Unit 4 and the coffee rock (Unit 7). It comprises clayey white sand that is moister than the overlying sands. Although labelled as Unit 5 we cannot determine its stratigraphic relationship with Unit 6 so we cannot determine which is earlier and which is later. On depth below surface this unit is deeper but depth is a poor indicator of temporal relationships on this site (see caption for Table 1).

Unit 6. This comprises moist dark brown sand that sits immediately above the intact coffee rock (Pit B, Trench 1). It is assumed that this is a causal relationship where this unit is either discoloured by the coffee rock and/or is in the process of becoming coffee rock. Stratigraphically its relationship with

Figure 5 Six examples of the Bend Road stratigraphy from widely separated areas in the site. Numbers are the stratigraphic units described in text. (a) Pit B, west baulk, square DN3; (b) Trench 1, section DSB; (c) Pit A, north baulk, square D4; (d) Trench 3, section S6; (e) Trench 2, section S7; (f) Pit C1, east baulk, square N.

Unit 5 is unclear because the two units nowhere intersect; each represents the immediate unit above the coffee rock. On the basis of the OSL dates (see below) Units 5 and 6 appear to be generally contemporaneous.

Unit 7. Coffee rock.

Unit 8. Underlying cemented sands and clays.

At the southern end of Pit C2 and throughout Pit C3 (both areas being beyond the extent of the coffee rock) Unit 3 overlies dark lacustrine clays and cemented sterile sands. Elsewhere cemented sands and clays beneath the coffee rock were exposed in Trenches 1 and 2.

Areal Distributions of the Stratigraphic Units

The three trenches exposed the lateral extent of the major stratigraphic units across the site. The southern ends of Trenches 1 and 3 and the eastern end of Trench 2 comprise the Holocene swamp margins. Unit 7, the coffee rock, terminates c.20m short of these margins. Unit 6, seen only in Trench 1 and Pit B, corresponds in distribution to the coffee rock. Units 4 and 5, considered to be Pleistocene sands, are further restricted, being 10–20m inside the coffee rock boundaries. In contrast, Units 1–3, Holocene sands, extend to the swamp margins.

Pit C2 was excavated to examine the termination of the coffee rock layer in Trench 3. Here the basal deposits reveal a stratigraphic succession with the coffee rock overlain by archaeologically sterile cemented sandy clay of unknown age and lastly with black lacustrine clay interpreted as swamp deposit. These deposits are directly overlain by artefact-bearing sand that yielded a date of 16,300±1900 BP (KB18), providing direct evidence of at least an intermittent swamp at Bend Road during the late Pleistocene. As with the late Holocene, swamp resources and available freshwater are likely to have provided the focus for Pleistocene human occupation.
Radiometric Dating

Twenty-four OSL dates and six 14C dates were obtained (Table 1). For OSL dates from Unit 3a (the backed artefact unit) this table lists a minimum OSL age as well as the central age. This was explained by Matt Cupper (University of Melbourne, pers. comm., 2006) as follows: the laboratory runs multiple aliquots for each sample to calculate its equivalent dose (De). Typically around 20–50 aliquots are run. Each aliquot gives an individual De, so a sample has a range of 20–50 De values. Statistical models are run on the results to determine the sample De. Generally an averaging model is used, which is the weighted mean of each individual De. This approach is most valid where there is only a small scatter in the distributions of the individual De values. Sometimes this central age may not be accurate, particularly in samples where the luminescence traps are inadequately reset at deposition. In these cases, some of the individual De values are probably too old, and a minimum age model may generate a more accurate result.

KB3, for example, has a number of older aliquots so that the weighted mean of the individual De values might give a central age that is too old. The minimum age model is based primarily on the youngest aliquots. Cupper advised that for KB3 and KB6 it would be more appropriate to use the minimum ages for these two samples. However, for the remainder Cupper saw no compelling reason to prefer the minimum ages over the central ages as the samples did not display notably asymmetrically young De distributions.

However the differences between minimum and central ages here are significant and indicate a wide range of younger and older De values. This implies sediment mixing in a range possibly explained by scuffage and treadage or ant bioturbation.

Even allowing for these technical difficulties, the OSL ages from Unit 3a are clearly older than the 14C determinations from the same levels. This is not a calibration problem (e.g. David et al. 1997) for while even late Holocene 14C dates are slightly younger than calendrical ages (e.g. Stuiver and Reimer 1993) the discrepancy with the OSL dates remains after calibration. This same phenomenon was noted throughout the closely dated sequence at Puritjarra rockshelter in Central Australia, again after calibration of the 14C dates. There, Smith et al. (1997:317-318, Figure 8) found that a similar situation existed in c.14 other sites where comparative data were available. At Puritjarra these authors discounted stratigraphic disturbance or technical problems with the dating methods and concluded that the sediments are apparently older than the charcoal and artefacts within them. They arrived at no conclusive explanation for this discrepancy but considered that the in situ disintegration of the shelter sandstone might be introducing ‘old’ material into the deposits. The equivalent at Bend Road would be the aeolian transport of older sand grains onto younger deposits in conditions that did not empty the radiation traps in the transported grains, such as transport at night or during storms. While feasible, we have no evidence for this and do not advocate it as the explanation of this discrepancy at Bend Road. But as with the artefacts at Puritjarra, the distribution of backed artefacts in Bend Road accords better with the 14C chronology than the OSL chronology. Several of the OSL dates (e.g. KB16, KB17) are beyond the expected backed artefact time range of c.4000 to 1000 BP and should not be taken as evidence of early backed artefacts at this site.

A separate issue concerns date inversions in Unit 3a. This is apparent in the series of 14C dates from Pit C, and shown in stratigraphic order in Table 2. Since there are no apparent problems with sample integrity this result indicates at least localised disturbance. The vertical distance between these samples is 153mm and we favour treadage and/or ant tunnels as the likely explanations for date inversions in this square. Whether or not Unit 3a is also disturbed in other parts of the site is further discussed in the next section. From Pit A, KB7 and KB6 are in stratigraphic order on the central dates, but not if the minimal date for KB6 is used; in Pit C, KB17 and KB16 are in stratigraphic order but are separated by a 14C date 2000 years younger than the central OSL dates; however this 14C date fits with the minimal OSL dates.

Despite these problems, the wider chronology is coherent. There is little overlap between the dates obtained from each of the stratigraphic units. Even with the mixing in Unit 3a, dates from this unit are distinctly different from those in Unit 3b, where the top spit of Unit 3b in Pit A, the Tardis pit and Pit C (c.45m from Pit A) each produced a similar age of c.6600 BP to c.6800 BP (KB2, KB5, KB21) and a calibrated 14C date of c.5000 BP. Below these dates Unit 3b extended to the terminal Pleistocene. Unit 4 dates mostly clustered around the LGM, with the stratigraphically lowest date (KB13) right on the boundary with Unit 6 in that square. We argue below that dates from Units 5 and 6 overlie stratigraphically secure artefacts, and that humans were present at the site by at least 30,000 years ago.

The second consistent difference is between the northern and southern parts of the site. Four dates (KB8, KB12, KB13, KB14) from the lower sands in Pit B (three different squares) have their central tendencies ranging between c.20,000 BP and c.35,000 BP where the coffee rock is intact. In Pits A and C and in Trench 3, all in the southern part of the site, the coffee rock has been eroded to rubble and the sands directly above them have provided four dates (KB1, KB4, KB18, KB20) that have their central tendencies ranging between c.15,000 BP and 19,000 BP. This supports the proposition that the coffee rock in the south of the site was exposed by deflation at the LGM, but remained covered in the northern part of the site at this time.

A single important exception to this north-south dichotomy came from Trench 2, where at the base of Section 7 (Figure 5e) a pocket of moist clayey sand was sitting in a small depression in the coffee rock, above an artefact at its base. This unit was predicted to be older than the basal sands elsewhere in the southern part of the site on stratigraphic grounds and was dated for this reason. KB24 returned a date of 29,100±2400 BP. This deposit appears to represent a pocket of older sand not stripped at the LGM.

Identifying Disturbance

Particle Size Distributions

Meredith Orr (Monash University) analysed multiple samples from one vertical face in each of the five pits to determine the particle size distributions of the 0.4 to 948μm component, the percent by weight of H2O2 oxidisable matter and percentage by weight of particles >1mm (Orr 2006; Orr and White 2007). Here as an example we reproduce Orr’s analysis of the strata in Pit B since this is the pit that produced the oldest site dates as the oldest site in the region.
Table 1 Radiometric dates from Bend Road sorted by stratigraphic unit. KB denotes OSL dates run at the University of Melbourne. Wk denotes 14C dates from the University of Waikato. *14C calibrations by CalPal 2007HULU (www.calpal-online.de; Weninger and Joris 2008). KB11 derives from a test pit otherwise not mentioned in this paper. a=check dates from same square and spit. Minimum OSL ages in bold may be preferred, see text. Within each stratigraphic unit dates from the same pit are also listed stratigraphically, but otherwise dates are listed in ascending age order for easy comparison. Given the large distances between pits, the undulating (and in places machine-damaged) site surface and variable depths of the sand deposit, depths below surface or site datum provide no sensible relationship between distant dates except at the most general level. Even so there is little depth overlap between stratigraphic units. As discussed in text the stratigraphic relationship between Units 5 and 6 is unknown and not implied in these numbered designations. KB15 derives from non-artefact bearing sands below cultural material (see text). The stratigraphic units provide the best comparative guide to depth/age relationships.

<table>
<thead>
<tr>
<th>SU</th>
<th>Original Site/Spit Designation</th>
<th>Area Designation in this Paper</th>
<th>Lab. No.</th>
<th>Depth Below Surface (mm)</th>
<th>Age BP</th>
<th>Calendrical Age (cal BP)</th>
<th>Minimum OSL Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>BR2/C/5 Pit B</td>
<td>KB10</td>
<td>400</td>
<td>3300±400</td>
<td>2100±100</td>
<td></td>
<td>2100±100</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/RTP/1 Tardis pit</td>
<td>KB3</td>
<td>350</td>
<td>3700±500</td>
<td>2000±100</td>
<td></td>
<td>2000±100</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/C/6 Pit A</td>
<td>KB7</td>
<td>400</td>
<td>3900±400</td>
<td>1700±200</td>
<td></td>
<td>1700±200</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/C/4/8-9 Pit A</td>
<td>KB6</td>
<td>550</td>
<td>4900±500</td>
<td>2700±300</td>
<td></td>
<td>2700±300</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/6 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Wk-23460</td>
<td>322</td>
<td>2277±32</td>
<td>2272±66</td>
<td></td>
<td>2272±66</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/8 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>KB22</td>
<td>379</td>
<td>3500±400&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2000±200</td>
<td></td>
<td>2000±200</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/8 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Wk-19710</td>
<td>379</td>
<td>2350±32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2389±40</td>
<td></td>
<td>2389±40</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/11 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Wk-23461</td>
<td>452</td>
<td>1828±36</td>
<td>1771±43</td>
<td></td>
<td>1771±43</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/12 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Wk-23462</td>
<td>475</td>
<td>1391±32</td>
<td>1314±18</td>
<td></td>
<td>1314±18</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/J/11 Pit C&lt;sub&gt;3&lt;/sub&gt;</td>
<td>KB17</td>
<td>367</td>
<td>5000±600</td>
<td>2000±200</td>
<td></td>
<td>2000±200</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/J/12 Pit C&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Wk-19709</td>
<td>346</td>
<td>2965±32</td>
<td>3147±56</td>
<td></td>
<td>3147±56</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/J/14 Pit C&lt;sub&gt;3&lt;/sub&gt;</td>
<td>KB16</td>
<td>455</td>
<td>5200±400</td>
<td>3200±200</td>
<td></td>
<td>3200±200</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/N/15 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Wk-23983</td>
<td>547</td>
<td>4485±30</td>
<td>5165±91</td>
<td></td>
<td>5165±91</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/P/13 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>KB21</td>
<td>531</td>
<td>6600±800</td>
<td>6600±800</td>
<td></td>
<td>6600±800</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/RTP/2 Tardis pit</td>
<td>KB2</td>
<td>650</td>
<td>6700±700</td>
<td>6700±700</td>
<td></td>
<td>6700±700</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/C/10-11 Pit A</td>
<td>KB5</td>
<td>680</td>
<td>6800±500</td>
<td>6800±500</td>
<td></td>
<td>6800±500</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/NS/S25-26 Trench 3</td>
<td>KB23</td>
<td>707</td>
<td>9700±800</td>
<td>9700±800</td>
<td></td>
<td>9700±800</td>
</tr>
<tr>
<td>3b</td>
<td>BR2/C12 Pit B</td>
<td>KB9</td>
<td>700</td>
<td>11,600±1200</td>
<td>11,600±1200</td>
<td></td>
<td>11,600±1200</td>
</tr>
<tr>
<td>3b</td>
<td>BR1/M/26 Pit C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>KB19</td>
<td>764</td>
<td>10,800±1000</td>
<td>10,800±1000</td>
<td></td>
<td>10,800±1000</td>
</tr>
<tr>
<td>3b</td>
<td>BR2/A/10 Not used this paper</td>
<td>KB11</td>
<td>650</td>
<td>12,300±1000</td>
<td>12,300±1000</td>
<td></td>
<td>12,300±1000</td>
</tr>
<tr>
<td>4</td>
<td>BR1/RTP/3 Tardis pit</td>
<td>KB1</td>
<td>950</td>
<td>15,100±1300</td>
<td>15,100±1300</td>
<td></td>
<td>15,100±1300</td>
</tr>
<tr>
<td>4</td>
<td>BR1/1/30 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>KB18</td>
<td>925</td>
<td>16,300±1900</td>
<td>16,300±1900</td>
<td></td>
<td>16,300±1900</td>
</tr>
<tr>
<td>4</td>
<td>BR1/C/15-16 Pit A</td>
<td>KB4</td>
<td>950</td>
<td>18,100±1400</td>
<td>18,100±1400</td>
<td></td>
<td>18,100±1400</td>
</tr>
<tr>
<td>4</td>
<td>BR1/P/27 Pit C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>KB20</td>
<td>957</td>
<td>19,200±1900</td>
<td>19,200±1900</td>
<td></td>
<td>19,200±1900</td>
</tr>
<tr>
<td>4</td>
<td>BR2/H/28-29 Pit B</td>
<td>KB14</td>
<td>920</td>
<td>20,700±1500</td>
<td>20,700±1500</td>
<td></td>
<td>20,700±1500</td>
</tr>
<tr>
<td>4</td>
<td>BR2/H/31 Pit B</td>
<td>KB13</td>
<td>1008</td>
<td>27,400±2400</td>
<td>27,400±2400</td>
<td></td>
<td>27,400±2400</td>
</tr>
<tr>
<td>5</td>
<td>BR1/EW/S7 Trench 2</td>
<td>KB24</td>
<td>1344</td>
<td>29,100±2400</td>
<td>29,100±2400</td>
<td></td>
<td>29,100±2400</td>
</tr>
<tr>
<td>6</td>
<td>BR2/G/31-32 Pit B</td>
<td>KB12</td>
<td>1050</td>
<td>28,200±2200</td>
<td>28,200±2200</td>
<td></td>
<td>28,200±2200</td>
</tr>
<tr>
<td>6</td>
<td>BR2/C/18 Pit B</td>
<td>KB8</td>
<td>1000</td>
<td>35,300±2600</td>
<td>35,300±2600</td>
<td></td>
<td>35,300±2600</td>
</tr>
<tr>
<td>8</td>
<td>BR2/toedrain/DS3 Trench 1</td>
<td>KB15</td>
<td>1550</td>
<td>126,500±7200</td>
<td>126,500±7200</td>
<td></td>
<td>126,500±7200</td>
</tr>
</tbody>
</table>

Table 2 14C age determinations from Bend Road Pit C<sub>1</sub>. Spits were nominally 25mm deep.

<table>
<thead>
<tr>
<th>SU</th>
<th>Original Site/Spit Designation</th>
<th>Depth Below Surface (mm)</th>
<th>Lab. No.</th>
<th>Age BP</th>
<th>Calendrical Age (cal BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>BR1/N/6</td>
<td>322</td>
<td>Wk-23460</td>
<td>2277±32</td>
<td>2272±66</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/8</td>
<td>379</td>
<td>Wk-19710</td>
<td>2350±32</td>
<td>2389±40</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/11</td>
<td>452</td>
<td>Wk-23461</td>
<td>1828±36</td>
<td>1771±43</td>
</tr>
<tr>
<td>3a</td>
<td>BR1/N/12</td>
<td>475</td>
<td>Wk-23462</td>
<td>1391±32</td>
<td>1314±18</td>
</tr>
</tbody>
</table>
Particle size distributions
Percent by volume

![Graphs of particle size distributions for different size classes.

Figure 6 Particle size distributions for Pit B, after Orr (2006). In this pit all samples down to 900mm show a unimodal distribution consistent with aeolian deposition and subsequent reworking by bioturbation and/or deflation. The bimodal distribution of the lowest set of samples indicates saltation or creep as the mode of transportation, without significant post-depositional modification. The oldest site dates came from this unit. See text for further discussion.

Table 3 shows the distribution of Orr’s bimodal and unimodal classes according to the stratigraphic units previously defined. Collectively there is variation across the site, with Unit 3b being the only unit to show disturbance in all samples.

The upper ‘plough zone’ shows expected disturbance in the soil particle analyses, attributed to European farming activities. Unit 3a, containing the backed artefacts, shows post-depositional disturbance only in Pit B. In this pit Orr notes that a change in particle size distributions differentiates the 300–600mm unit in the tested square from the 600–900mm unit. This change is at the approximate point of change from Unit 3a to Unit 3b, but is difficult to judge precisely in the tested square because of the absence of a clear backed artefact layer there. It is at the same depth as this transition in another Pit B square 3m away, where there are backed artefacts.

In several pits Orr (Orr and White 2007) reported increases in organic matter coinciding with a boundary between particle size distribution classes that might reflect buried surfaces. One of these coincides with the boundary between Units 3a and 3b and a break in the sequence at this point is independently confirmed by the relevant OSL dates, where the top spit of Unit 3b in three pits some 50m apart each produced a similar age of c.6600 BP to c.6800 BP (KB2, KB5, KB21). Here the soil particle analyses suggest widespread post-depositional disturbance of Unit 3b, stabilising with a surface comprising sands deposited around 6700 years ago. The subsequent deposition of a backed artefact layer can be argued on the data to be no older than 4000 years ago. This implies either a cessation of sediment accumulation or, more likely, an aeolian deflation event prior to the formation of Unit 3a. The alternative interpretation, that Unit 3a itself reflects a lagged deposit caused by such deflation, is not supported by the soil particle analyses, which suggest little or no post-depositional disturbance of this unit, nor is it supported by artefact distributions described below.

A final point of importance in these analyses is the lack of post-depositional disturbance at the base of Pit B (Unit 6), the unit that yielded three dates >27,000 BP from the northern part of the site (KB8, KB12 and KB13).
Table 4  Artefacts in Pit C, spits 28–35. Spits are 25mm in depth.

<table>
<thead>
<tr>
<th>Spit</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
<th>33</th>
<th>34</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>18</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Av. Wt. (g)</td>
<td>0.4</td>
<td>0.2</td>
<td>1.0</td>
<td>1.0</td>
<td>0.2</td>
<td>0.2</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Range (g)</td>
<td>-</td>
<td>0.1-0.2</td>
<td>0.1-3.3</td>
<td>0.1-8.6</td>
<td>0.1-0.2</td>
<td>-</td>
<td>-</td>
<td>0.4-1.5</td>
</tr>
</tbody>
</table>

Table 5  Artefacts in squares G and H of Pit B, spits 27–34. Spits are 25mm in depth. The aberrant data in Spits 33 is caused by the presence of a large silcrete core.

<table>
<thead>
<tr>
<th>Spit</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
<th>33</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>16</td>
<td>4</td>
<td>12</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Av. Wt. (g)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.1</td>
<td>27.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Range (g)</td>
<td>0.1</td>
<td>0.1-1.1</td>
<td>0.1-1.6</td>
<td>0.1-1.6</td>
<td>0.1-1.1</td>
<td>0.1-0.2</td>
<td>0.1-83.5</td>
<td></td>
</tr>
</tbody>
</table>
Deflation events are rarely discernible in archaeological deposits but can be reflected in the artefact distributions within them. For example, the break between layers containing backed artefact assemblages and earlier deposits just described was initially recognised in such distributions (Figure 7). The artefact distributions in Figure 7 suggest that the backed artefact layer is not a lagged deposit, but other lagged deposits can be recognised in the artefact data.

Artefact Conjoining

Conjoined artefacts from the same locations in sites do not necessarily demonstrate the post-depositional intactness of deposits, since separate pieces may move in tandem through a deposit. However, except in cases where artefacts are lagged by the removal of the soil matrix by wind or water, it is unusual for all conjoined pieces to remain together in a disturbed deposit (e.g. Richardson 1992). Thus vertically separated artefacts that can be rejoined may demonstrate post-depositional disturbance. To test this, conjoining was undertaken for selected parts of the Bend Road assemblage.

For Pit A, 24 conjoin sets comprised 56 artefacts and involved two to five artefacts in any single conjoin. All 24 sets came from the same or adjacent squares and 22 of these sets came from spits at most two spits apart. Of the two separated sets, one involves two pieces separated by 5 spits (250mm) and >1m laterally that might have been redeposited by the digging of a European pit used to bury a horse. The other involves five items from three adjacent squares that are also separated by 5 spits (one in spit 5, three in spit 8 and one in spit 10).

Only one of the 24 conjoin sets comes from outside the backed artefact unit, this being located in Unit 3b. This probably reflects both the higher artefact numbers in Unit 3a and the more ephemeral use of the site before this.

A second conjoin analysis was carried out on artefacts from Trench 3, where sieve mesh size was 7mm and spit depths were c.100mm. A further 24 conjoin sets involving 57 artefacts were recorded, but the search did not involve looking beyond the boundaries of each 3m trench segment, so these numbers were minimal. Here the analysis concentrated on vertical displacement; 21 of the 24 conjoin sets came from the same spits and the remaining three from adjacent spits. All conjoins came from spits containing backed artefacts.

Finally a brief analysis of the Tardis 'flaking floor' assemblage indicated at least 14 conjoin sets involving 32 pieces in a
collection of 332 artefacts. Vertical displacement could not be pursued because the bagged collection was undifferentiated stratigraphically and we held no information on the collection procedures beyond the collection coming from an area of trench c.3m long and 200mm deep. Again the collection is from the period of backed artefact production.

Overall, conjoining at Bend Road yielded evidence for 62 conjoin sets of which only two indicate significant vertical displacement. As noted, the vertical relationship between conjoined pieces can be maintained in disturbed deposits, but the possibility of maintaining close vertical associations between 145 conjoining artefacts across widely separated areas would appear to be remote, unless all these pieces are lagged (see discussion below). Instead, this test suggests that the backed artefact levels are generally in situ.

Summary
Artefact distributions in various parts of the site reflect deflation events, one in the pre-LGM layers being confirmed by radiometric dating. The most important of these occurred at the LGM when most of the southern part of the site was stripped and artefacts were lagged onto and into the decaying exposed coffee rock. In other parts of the site the archaeological record remains coherent and conjoining tests offer strong support for the stratigraphic intactness of the backed artefact levels. Other tests on artefact orientation and inclination, not reported here, did not demonstrate disturbance but could not exclude it.

The Distributions of Specific Archaeological Attributes at Bend Road
Figure 9 shows the distributions of artefacts by density, raw materials and diagnostic artefacts, including European artefacts, along 9m of Trench 3. This section is representative of such distributions right across the site and reflects a high degree of stratigraphic intactness. Figure 10 provides a comparison from one square from Pit B, more than 400m from the Trench 3 section shown in Figure 9.

Consistent distributional characteristics in these diagrams accurately reflect the wider site. European artefacts are confined to the top 200–300mm of deposit within the plough zone. Backed artefacts are always distributed between 300mm and 700mm below surface. This distribution correlates with both the highest artefact densities and those spits where fine-grained silcrete accounts for more than 75% of raw materials, except in Pit B where fewer backed artefacts occur; here quartz accounts for more artefacts than silcrete. Below the backed artefact assemblages fine-grained silcretes also occur but are mostly a minor component of a wider range of raw materials dominated by quartz and including more medium- or coarse-grained silcretes (or quartzites) and basalt. Artefacts in the lower units are mostly bigger than in the backed artefact assemblages.

Artefacts stratigraphically younger than backed artefacts are rare in the Bend Road site but do occur in places as concentrations of small, angular, amorphous quartz artefacts mixed with silcrete. Across the site backed artefacts frequently occur as discrete and dense horizontal distributions 3–4m in diameter. These occur in Pit B and at six locations in Trench 3. Pits C1 to C4, were all placed adjacent to these backed artefact ‘hot spots’ in Trench 3 but failed to yield densities equivalent to those in the adjacent trench segments, confirming that these dense aggregations were very localised. The Tardis ‘flaking floor’ is a further example where hand excavations only a few metres on either side of it also failed to find equivalent densities of backed artefacts and their production debris. These ‘hot spots’ show neither consistent raw material nor technological differences between them, nor do they cluster near to or away from the swamp edge or any other topological feature on the site. While such a distribution initially conveys the impression of temporary encampments or work stations rather than a base camp, if these ‘hot spots’ could be shown to be strictly contemporaneous the reverse would be true. The spatial pattern described here fits well with ethnographic descriptions of Alyawara residential base camps described by O’Connell (1987).

Two other aspects of the archaeological distributions require brief comment. Table 6 indicates the raw material distributions for the two spits containing backed artefacts from Trench 3 segment 36–37, a ‘hot spot’ location. In Spit 4 the two raw materials present are approximately half silcrete and half hornfels, but in spit 5 they are almost exclusively silcrete. This stratigraphic difference indicates at least two separate backed artefact occupations at this location. Here the backed artefact unit as a whole cannot be a lagged deposit. A similar situation is reflected in artefact distributions in Pit A where a deflation surface was identified pre-dating the backed artefact deposition there but where three-dimensionally plotted artefacts from the backed artefact spits are clearly not lagged (Figure 7).

The second piece of site data is a hearth in Pit C1 initiated from immediate post-backed artefact spits down through the backed artefact layers, apparently in a scooped pit. It extended from Spit 5 to Spit 15, a depth of 250mm. While this hearth could still have cut through previously disturbed backed artefact layers, its intactness demonstrates that deflation of this deposit did not occur after it was created. Given its depth it seems likely that this hearth was reused over a period of time. Because it is stratigraphically recent, dating this feature was rejected during

<table>
<thead>
<tr>
<th>Spit</th>
<th>Silcrete</th>
<th>Hornfels</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>49 (54.4%)</td>
<td>41 (45.6%)</td>
</tr>
<tr>
<td>5</td>
<td>189 (99.5%)</td>
<td>1 (0.5%)</td>
</tr>
</tbody>
</table>

Table 6 Bend Road Trench 3, segment 36-37, spits 4 and 5. Distributions and percentages of artefacts according to raw materials.
analysis because knowing its age did not help to clarify the aims of the overall excavation (Allen et al. 2008).

**Discussion**

**Site Formation**

Data from Pit B and Trench 1 show that the Bend Road coffee rock formed at the base of a sand dune that formed after 126,500±7200 BP. On the evidence of the younger sands now immediately overlying the coffee rock, this dune was deflated some unknown time before 35,000 BP and the coffee rock was briefly exposed as the stub of the older dune. This event probably occurred prior to humans occupying the site because there is no layer of lagged artefacts on the Pit B coffee rock surface. Above the coffee rock, artefact-bearing sands dating to 27–35,000 BP had their accumulation truncated between 27,000 BP and the LGM, resulting in a temporal gap in the sequence and a layer of lagged artefacts in the Pit B squares. Gardner et al. (2006) using data from Cape Liptrap, argue for a period of c.3000 years immediately prior to the LGM when extreme cold and aridity led to landscape instability and erosion in the region. This event probably explains the demonstrated Bend Road deflation as well as the prolonged stripping of the southern part of the site, where in Pits A, C1, and C2, and Trenches 2 and 3, the coffee rock broke down to rubble. However in Pit B and the adjacent part of Trench 1 the coffee rock was not exposed at this time and maintained a cover of pre-LGM Pleistocene sands that contain artefacts and exhibit particle size distributions suggesting no post-depositional disturbance.

Unlike the unexposed coffee rock in Pit B, elsewhere the coffee rock rubble contains numerous lagged artefacts dating to or before the LGM. At one location in Trench 2 a thick squarish quartzite artefact measuring 32.1 mm in maximum length was sealed in a depression in the coffee rock by wet clayey sand dated to 29,100±2400 BP. This indicates a localised area in the south of the site that was not completely stripped at the LGM, with the deposit overlying an artefact discarded at or before the OSL date (see below).

The available post-LGM dates show a general age-depth concordance through the terminal Pleistocene and early Holocene, but the particle size distributions suggest deposition at rates low enough to allow synchronous near-surface reworking and deflation. The low levels of artefact deposition at this time indicate people at the site at least intermittently.

During the mid-Holocene a deflation event was detected in Pits A and C1, and in the Tardis pit, where the exposed surface dated to c.6700 BP with OSL (KB2, KB5, KB21) and 5165±91 cal BP with \(^{14}C\) (Wk-23983) (www.calpal-online.de; Weninger and Joris 2008). Backed artefacts sit directly above this surface in all three instances, occupying a unit 200–300mm thick at these locations. Artefact distributions, the conjoining results and the soil particle size distributions all indicate minimal post-depositional disturbance in this unit, but inverted \(^{14}C\) dates in Pit C1 suggest at least localised disturbance. Above this unit the disturbed plough zone indicates European farming activity.

One remaining question is why the backed artefacts are located so far below the surface. Hughes (2006) asked where so much sand might have come from in the last 4000 years to bury them, and speculated that this might reflect increased human activity in the region that reduced the plant cover and exposed the sand to greater mobilisation, a process exacerbated in the last 150 years by farming.

**Ant Bioturbation**

Ant tunnels up to 5mm in diameter and small nests to c.60mm in diameter are prevalent in some parts of the Bend Road site and one active nest was noted 600mm below the surface. These ants, unidentified to species, are small and black, up to 5mm long. Mottling seen in section and in plan and initially identified by Hughes as rootlet turbation is now recognised as old nests (Figures 11-12). While commonly seen in section in parts of Pits A, B and C they are not present everywhere and do not occur in the Pleistocene layers except in the post-LGM layers of Pit B. The proposition that the Pleistocene sands are homogenised, thus disguising ant bioturbation, is rejected on the evidence of the particle size analyses. These indicate no post-depositional bioturbation of the lowest sands anywhere on the site.

While tunnelling and nesting might have caused minor artefact relocation downwards through slumping, the evidence from this site (e.g. Figure 12) suggests that the tunnels were too small to allow the downward passage of stone artefacts and that
nests and tunnels were infilled by sand grains from the surface rather than slumping by the deposit. This idea is supported by the artefact conjoin data.

Thus there is no evidence of ant bioturbation or other post-depositional disturbance affecting the lower deposits in Pit B that produced the earliest dates from the site.

When Did Humans First Occupy Bend Road?

In Pit B three dated samples – 35,300±2600 BP (KB8), 28,200±2200 BP (KB12) and 27,400±2400 BP (KB13) – derive from three adjacent squares. On heights relative to datum, KB8, the oldest date, is c.2mm below KB13 but c.1mm above KB12 (Hewitt and de Lange 2007:127-129, Figure 58), the small inversion being explained by the uneven coffee rock surface trapping older and younger sands at slightly different levels. All dated spits have artefact-bearing spits beneath them; KB8 has two deeper spits containing two artefacts, KB12 one further spit containing one artefact and KB13 four deeper spits containing 14 artefacts below it. As stated, this area reflects no evidence for artefact lagging, bioturbation or other post-depositional soil disturbance. Additionally, 330m distant, a remnant deposit in Trench 2 dated to 29,100±2400 BP (KB24) overlies one artefact (discussed above). Even if these artefacts are lagged, for which there is no evidence, all four dates represent minimum ages for the artefacts beneath them, unless these artefacts have subsequently migrated down the profile. However, KB8 actually older than the other three dates of c.27–29,000 BP, given the wide error margins?

In order to examine OSL dates at the 95% probability level one does not merely double the standard deviation as with radiocarbon dates (see Roberts et al. 1990:126 for explanation). Instead Matt Cupper (University of Melbourne, pers. comm., 2007) advises that following the procedures advocated by Furetta (2003) the total 2σ uncertainties are 4150 years (KB8), 3510 years (KB12), 4170 years (KB13) and 4170 years (KB24). Using these data, the ages of all four dates correspond at the 2σ confidence level (Figure 13). However the overlap between KB12 and KB13 on the one hand and KB8 on the other is slight, representing only a few hundred years around 31,000 BP. These dates suggest that humans were present at Bend Road by 30,000 BP and possibly by 35,000 BP.

Lagging and Artefact Migration

Integrating the dating studies, particle size analyses, stratigraphy and artefact distributions has isolated three major and several minor deflation episodes that resulted in artefact lagging in at least two and probably three demonstrated instances. This approach allowed us to establish areas in the site where the lack of such evidence does not immediately disqualify the integrity of the archaeology. Both the backed artefact and pre-LGM Pleistocene assemblages fit this latter category.

Artefact migration through the existing matrix, as opposed to lagging, is well-attested in sandy deposits in Australia and elsewhere, where it is normally demonstrated by artefact conjoining (e.g. Richardson 1992, 1996). However demonstrating that artefacts have not moved down a profile after deposition is always difficult and frequently ignored. Apart from subjective impressions, appeals are mostly made by looking at the numerical distributions of artefacts together with their size and raw material distributions (e.g. Bird et al. 2002).

Examining Pit B data shows there is no patterning suggesting that the lowest artefacts have migrated down from higher levels and none of the artefacts is resting on the basal coffee rock, the first ‘impervious’ stratum they would have encountered. The lowest artefacts are spread laterally across Pit B and we have not merely dated the ‘lowest artefact’ (e.g. Roberts et al. 1994; Turney et al. 2001). Even so, none of these facts demonstrates that artefacts have not migrated downwards.

While we are unaware of experimental studies that have demonstrated that smaller artefacts are more likely to move down a profile than larger ones where small vectors of bioturbation (ants, termites, small beetles) are involved, this is a reasonable assumption since a larger artefact requires a larger area beneath it to be undermined for it to descend within a deposit than for a smaller one to descend. This is the assumption that underlies the claim by McNiven et al. (2009) for disturbance in the lower levels of Kabadul Kula, where they argue that turbation has resulted in the size sorting of stone artefacts, with only small artefacts descending into the lower levels.

While most artefacts in Pit B at Bend Road are <10mm in length, the artefact in the lowest spit of one square (G/33) is a silcrete core with a maximum dimension of 55.7mm and a weight of 83.5g. Equally the artefact from S7 in Trench 2 beneath a date of c.29,000 BP is 32.1mm in maximum dimension. Artefacts of this size are unlikely to move far under the forces of minor bioturbation. The raw materials and their proportions (quartz 66%, silcrete 33%, sample =18) accord with what is encountered elsewhere in the earliest levels in the site.

There is also no evidence of downward movement elsewhere in the site. As already discussed, while a close vertical relationship between conjoined pieces can be maintained in disturbed deposits and obviously in lagged deposits, the possibility of maintaining such a relationship in 60 of 62 conjoin sets involving 145 conjoining artefacts is remote if the backed artefact assemblages are not lagged, as argued.

Regional Evidence

Dates for first human presence at Bend Road at 30–35,000 BP are unexceptional. People were in Tasmania by c.40,000 cal BP at Parmerpar Meethaner (Cosgrove 1995b) and Warreen Cave (Allen 1996), indicating that people were also in southern Victoria at this date in order to access the Bassian bridge into Tasmania. The claimed antiquity for Bend Road is not contentious even though it ranks among the oldest known Victorian sites. Site 7921-0510/0511 on the Koo Wee Rup floodplain near Pakenham
(Rhodes 2004) has a basal date of 24,168±268 BP (Wk-15090). Keilor, on the western side of the Melbourne CBD, has most recently been dated by Cupper et al. (2003) at or about the LGM (24,000–18,000 BP). Further afield, Richards et al. (2007) report human occupation at c.32,000 BP on a lunette on the edge of Lake Tyrrell in northwest Victoria, but do not emphasise a calibrated radiocarbon date of c.44,000 BP associated with a single stone flake from deeper in the lunette. Other older sites in Victoria, Drual Rockshelter in the Grampians-Gariwerd region (Bird et al. 1998) and New Guinea II Cave in the mountainous northeast of the state (Ossa et al. 1995) were both occupied around 30,000 cal BP.

Are the Backed Artefact Deposits at Bend Road Lagged?

In Pit B, while the backed artefact phase was present in much the same stratigraphic relationship seen right across the site, it occurred in sands reflecting a unimodal distribution of particle sizes indicative of reworking through time. Elsewhere the deposits containing backed artefacts were thought to be undisturbed on the particle size data.

At three locations in the site the earliest backed artefact deposits were shown to be sitting on a deflated surface pre-dating c.5000 BP, well before the time such artefacts most frequently occur in southeast Australia. In these immediate localities backed artefacts occupy a stratum c.200–300 mm thick, suggesting they are not lagged. In Trench 3 segment 36–37, two distinct layers of backed artefacts reflecting obvious raw material differences and are not a conflated deposit. Despite inverted radiocarbon dates on loose charcoal in Pit C, that possibly reflect local mixing of the backed artefact layers, perhaps as a result of human activities, we can propose no mechanism for reworking of the deposits in a manner that might produce the distinctive small horizontal patches of backed artefact production recorded right across the site.

Radiometric Dating and Archaeology

Questioning the validity of archaeological sites on perceived mixing of sand grains in single grain or small aliquot OSL samples – for example at Cuddie Springs (Roberts et al. 2001) and now Bend Road (Matt Cupper, University of Melbourne, pers. comm., 2007) – requires fuller attention elsewhere. At Bend Road the widespread evidence for ant nests and shafts provides a ready mechanism for the intermingling of sand grains (and charcoal fragments) down a profile. Intuitively it seems improbable that this activity also caused any widespread downward movement of much larger stone artefacts in ways that would not be recognised in the artefact distributions and conjoining exercises. If we add the scuffage and treadage factor of human activity on sandy surfaces, it is reasonable to ask whether the levels of resolution available in many archaeological sites are compatible with the implied precision of single grain OSL samples. A comparable problem in microscopy is known as ‘empty magnification’; where enlargement of the image may not enhance and may even obscure the detail being sought.

Conclusion

Disturbance at Bend Road consists predominantly of aeolian deflation and accumulation events before and during human occupation of the site and subsequent bioturbation by ants. By identifying these events we have been able to assess the integrity and coherence of the archaeological record at the site, which we find to be quite high. Bend Road has maintained identifiable coherence stratigraphically, chronologically and archaeologically and thus has maintained its general scientific importance. However this coherence needs to be understood in terms of the scales of comparison we can apply to different parts of the site and the levels of resolution available to us (Cosgrove and Allen 1996:23). In different areas we can distinguish earlier and later Pleistocene and earlier and later Holocene phases, but where present, these may differ in time spans that make any comparative behavioural interpretations between them problematic. Equally, while we can define backed artefact and Pleistocene phases across most of the site stratigraphically, it is clear that these horizons are neither continuous nor undisturbed within their own stratigraphic boundaries. Additionally, while these phases might be contained stratigraphically we cannot demonstrate contemporaneity of individual events within them. The discontinuous ‘hotspots’ of backed artefact disposal are a good example. While there is no evidence to suggest that any of these were deposited outside a general backed artefact range of c.4000 BP to c.1000 BP, the site data do not allow explicit contemporaneity between these discrete locations to be demonstrated chronologically or typologically.

On balance there is no obvious reason to doubt that people were at this site by 30,000 years ago and that small, restricted but intense concentrations of mid-to-late Holocene backed artefacts and associateddebitage reflect a real, if unusual, settlement pattern. At the same time, if Bend Road were to be subjected to the same ferocious and subjective scrutiny that has descended on Cuddie Springs (e.g. David 2002; Gillespie 2008; Gillespie and Brook 2006; Roberts et al. 2001; but see Hiscock 2008) critics might well deny its integrity.

Acknowledgements

We thank the Wurundjeri Tribe Land Compensation and Cultural Heritage Council Inc., the Victorian Boonerwring Elders Land Council Aboriginal Corporation and the Bunurong Land Council Aboriginal Corporation for their interest and assistance. The work was financed and assisted by Thiess John Holland and La Trobe University. Among many individuals we particularly thank Josara de Lange who carried out the lithic analyses, Matt Cupper for OSL advice, and Andrew Long, Philip Hughes, Meredith Orr, Megan Goulding, John Mckechnie, Rudy Frank, Tim Murray and Ming Wei for discussions and assistance. Philip Hughes, Jim O’Connell, Peter Hiscock and Judith Field and referees commented on drafts of the paper. We thank the very large field crew that comprised both members of the Aboriginal community and La Trobe students.

Endnotes

1 Originally the site was differentiated north and south of Bend Road with the area south called BR1 and that to the north BR2. BR2 was excavated and analysed by Hewitt and de Lange (2007) and BR1 by Allen et al. (2008). Pit A was originally reported as BR1 Phase 1. Pit B was originally reported as BR2 Phase 1 Pit C, plus Phases 2–4 which incorporated squares D, E, F, CN1, CN2, CN3, DN1, DN2, DN3, G and H. Pit C was reported as BR1...
Phase 3, where the present C1=Trench NP, C2=Trench LM and C3=Trench JKS. The present Trench 1 was reported as BR2 toe drain, Trench 2 as BR1 east-west trench (Tardis trench A2) and Trench 3 as BR1 Phase 2 Trench.

References
Cameron, D., P. White, R. Lampert and S. Florek 1990 Site destruction and factors of soil formation in relation to isotropism and anisotropism. Antiquity 266:812-815.
Cane, S. 1982 Buddist gastrointestinal in the archaeological record. Australian Archaeology 14:25-34.
Coggrove, R.1995b Late Pleistocene behavioural variation and time trends: The case from Tasmania. Archaeology in Oceania 30(2):83-104.
Coventry, R.I.1990 Radiocarbon dates from Ngarrabullgan Cave, a Pleistocene archaeological site in Australia: Implications for the comparability of time clocks and for the human colonization of Australia. Antiquity 71:183-188.
Hiscock, P. 1990 How old are the artefacts at Malakunanja II? Archaeology in Oceania 25(3):122-124.


O’Connell, J.E. and J. Allen 1998 When did humans first arrive in Greater Australia, and why is it important to know? *EvolutionaryAnthropology* 6:132-146.

Orr, M. 2006. Particle Size Analysis Report, Bend Road 1 and Bend Road 2 Pit C. Unpublished report to School of Geography and Environmental Science, Monash University.


