APPENDIX A: OVERVIEW, DESIGN CONCEPTS, AND DETAILS FOR HMODEL

The following description of the simulation follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006, Grimm et al. 2010). The original simulation was programmed using the NetLogo platform (Wilensky 1999).

1. Purpose

The purpose of the model is to:

1. Explore surface archaeological formation dynamics by modelling the interaction of individual hearth features within a shifting sedimentary environment.
2. Evaluate the combined influence of preservation and visibility on the chronological distribution of surface archaeological features based on the concept of episodic disequilibrium discussed in Fanning et al. 2007.

Additional configurations are used to examine the effects of periodic absence, population growth, and taphonomic decay on the simulated data, as well as the impact of these forces on the surface visibility of stone artefacts.

2. Entities, state variables, and scales

To model the effects of episodic changes in landsurfaces on surface archaeology, two primary entities are used: *hearths* and *patches*. A hearth is an archaeological feature from which chronometric data might be obtained. In the model, hearths are modelled as agents that contain a date, given as the variable `age`, which is the number of time steps that have occurred at the time of its construction subtracted from the total number of time steps over which the model is run ($T - t$). Hearths can exist in one of four states: hidden and intact hidden and dispersed, visible and intact, and visible and dispersed. Hidden hearths are not considered part of the surface record and are thus cannot be sampled in an archaeological survey. Dispersed hearths cannot be sampled using the radiocarbon method.

A patch is a discrete unit of space within a gridded toroidal space (referred to using the more generic term ‘cells’ in the text but using the NetLogo-specific term ‘patches’ here). Hearths contain an ordered list of sedimentary layers called `sediment_ages`. Each sediment layer is associated with the date it was deposited. The visibility of any hearths within the patch is determined by their age in relation to the most recent sedimentary later on the patch (i.e. only hearths younger than the youngest sedimentary layer are visible).

A third group of entities, *humans*, are modelled as behaviourally neutral actors that move between random points on the landscape, building hearths at a constant rate of one per year. The use of behaviourally-neutral humans is part of a strategy of model-building aimed at determining the degree of human agency or social complexity required to explain a given phenomenon.

Three parameters are used to control the sedimentary process within the model: the `event_interval` parameter determines the frequency of geomorphic events; the `stability` parameter controls the probability that a patch will undergo some kind of change during an event; and the `erosion_proportion` parameter determines the relative probabilities of a patch undergoing geomorphic change.

The passage of time in the model occurs at yearly intervals, which are tracked forward from a number of years before present using a state variable called `years_bp`. While the simulation is ostensibly meant to model processes at the scale of the 'landscape', the spatial relationships are abstract and not reflective of any particular scale.

3. Process overview and scheduling

During each year, each of the humans moves to a random point within the world and generates a hearth which is visible on the surface and contains an `age` value equal to the current value of `years_BP`. At given intervals, determined by the `event_interval` parameter, an event occurs which affects a subset of all patches. Membership in the subset is determined for patches individually using the `stability` parameter as the probability of change occurring. Patches undergoing geomorphic change determine whether that change is erosion or deposition from a Bernoulli probability draw based on the `erosion_proportion` parameter (see section 6), and this will affect whether hearths on the surface become buried or dispersed, or whether any hearths lying directly beneath the uppermost layer of sediment in the patch become visible. Finally, the `years_BP` value is decreased by one.

4. Design concepts

4.1 Basic Principles

The simulation is based on idealised geological and archaeological concepts of stratigraphy and palimpsests. In the model, archaeological deposits exist within stratigraphic layers of sediment. Sediment is transported into and out of a given location by geomorphic processes (e.g. water or wind action). These forces have the capacity to obscure or disperse different elements of surface archaeological deposits.

4.2 Emergence

Regularities in the chronometric distribution of sampled data emerge through the individual-level interactions between patches and hearths. These include super- or sub-linear changes in the frequency of hearth ages, as well as the presence or absence of chronological gaps.

4.3 Interaction

Human agents within the model interact with their environment by adding cultural residues (hearths, artefacts). Patches interact with hearths and artefacts by making them visible or invisible through changes in the sedimentary layers of the patches. Patches also interact with surface hearths by dispersing them in the event of erosion.

4.4 Stochasticity

The movement of agents was modelled as completely random under the neutral assumption of no behavioural bias in the formation of the record. Other elements, such as the probabilities of patches undergoing geomorphic change and the probability of that change being erosional or depositional, are based on Bernoulli distributions, and random number draws are to establish whether these probabilities have been met.

4.5 Collectives

Humans do not form any collective beyond all following the same behavioural rules. Hearths can be grouped based on their visibility and dispersal status.

4.6 Observation

Data was primarily collected at the end of a simulation run. The ages of intact hearths on the surface were recorded to simulate sampling of a radiocarbon record based on charcoal. The ages of all hearths on the surface were recorded to simulate sampling of an OSL record based on hearth stones. For instances where artefacts were included, the mean numbers of artefacts for each patch were recorded. Other data used for debugging purposes included the ages of intact and dispersed hearths that are hidden, spatial distribution of hearths and the number of sedimentary layers in patches.

5. Initialization

When the model begins, all patches contain `sediment_ages` lists with a single value for the start of the modelled time period, equal to the initial value of `years_BP`. The humans within the model are distributed randomly within the modelled space.

Table 1 Parameter settings used in the simulation

Parameter	Setting
world_size	32 × 32
years_BP	2000
starting_population	5
event_interval	10, 50, 100, 200 years
erosion_proportion	0 – 1 (0.1 intervals)
stability	0 – 1 (0.1 intervals)

6. Submodels

6.1 Geomorphic event model

During an event, affected patches will either undergo erosion or deposition, determined individually using a Bernoulli draw:

$$P(n_j) = \begin{cases} 1-p, & \text{for } n_j = 0 \\ p, & \text{for } n_j = 1 \end{cases}$$

where p is the value of the erosion_proportion parameter. Patches undergoing erosion will lose the youngest member of their sediment_ages list. Visible hearths situated on patches experiencing erosion will become dispersed (dispersed? = true), while any hidden hearths situated on an eroding patch that are younger than the youngest member of the patch's updated sediment_ages list will become visible (hidden? = false). Patches undergoing deposition will add a new value to their sediment_ages list, equal to the current value of years_BP. Any visible hearths (hidden? = false) situated on a patch experiencing deposition become hidden (hidden? = true).

7. Alternative configurations

7.1 Stone artefacts

While the original configuration of the model is aimed at understanding these effects of these geomorphic processes on the formation of chronometric processes, the model can be naturally extended to examine how they affect the visibility of stone artefacts on the surface. To do this, patches were given an additional list variable, called artefacts. At each time step, after an

agent builds a hearth, it adds a value to the `artefacts` list equal to the current value of the `years_BP`. The number of visible artefacts on the surface of a patch at any given time in the model can be calculated as the number of values in the `artefacts` list that are younger than the youngest value in the `sediment_ages` list.