Pengelly's legacy reconsidered: a GIS approach to spatial analysis of palaeontological and archaeological collections from Kents Cavern, England

Sorin Mihai a, Joyce Lundberg b,*, Donald A. McFarlane c, Barry Chandler d

a 1103-368 Eglinton Ave East, Toronto, ON, M4P 1L9, Canada
b Department of Geography and Environmental Studies, Carleton University, Ottawa, Ontario, K1S 5B6, Canada
c Joint Science Department, Scripps College, 925 North Mills Ave., Claremont, CA, 91711, USA
d Torquay Museum, 529 Babacombe Road, Torquay, TQ1 1HG, Devon, UK

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ABSTRACT

Tens of thousands of palaeontological and archaeological remains were collected by William Pengelly during 19th century excavations of Kents Cavern, but are now widely dispersed between museums. This has previously precluded spatial analysis. We have now assembled available museum records into a single database, and, using our previously-reconstructed Pengelly excavation map as a base, we have been able to exploit the unique Pengelly location code to set up a GIS mapping system. This allows, for the first time, the analysis of spatial patterns. In addition, the GIS serves to highlight potential problems of recording or curation in the original data. Here we report on the construction of the GIS system and its first use in the analysis of spatial distribution of bear remains. The maps demonstrate that Ursus deningeri entered the cave through a now-sealed High Level Chamber entrance at the back of the cave in the middle Pleistocene, whereas Ursus arctos accessed the cave in the late Pleistocene through the now-sealed Northeast Gallery entrance. The denning areas are reconstructed as Labyrinth/Bear’s Den for U. deningeri and Vestibule/Great Chamber for U. arctos. Considerable post-mortem re-distribution of the remains of both species is indicated.

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1. Introduction

Extensive excavations of Kents Cavern in the 19th century (McFarlane and Lundberg, 2005) yielded collections of tens of thousands of palaeontological and archaeological remains. The earliest excavations by MacEnery (1859) took place between 1825 and 1829. Later excavations undertaken between 1858 and 1880 by William Pengelly, with financial support from the British Association for the Advancement of Science, employed an innovative system that allows the specimens to be precisely related to their three dimensional location in the cave, a system that has since then been the basis for archaeological excavations world-wide (Warren and Rose, 1994).

Although the excavations were extensively documented in annual reports to the British Association for the Advancement of Science (e.g., Pengelly, 1884), Pengelly never completed a formal monograph on the results, and the finds were dispersed to various museums and in many cases lost. Moreover, although Pengelly’s field notes have survived, his accompanying field maps and sketches have not. This has discouraged subsequent workers from a proper analysis of one of the most important collections of British cave palaeontological and archaeological remains. Recent work on the reconstruction of the excavation map and the geochronology of Kents Cavern has re-affirmed the status of the site as perhaps Britain’s most important palaeontological cave site (McFarlane and Lundberg, 2005; Lundberg and McFarlane, 2007, 2008). This present work facilitates a comprehensive spatial analysis of the finds using a GIS-based approach.

In 1865 Pengelly began the excavation campaign that was to occupy a team of full-time workers for 15 years. Funded by the British Association for the Advancement of Science, the excavation was intended to address the then-controversial theory of the co-existence of human remains with extinct fauna. The cave yielded an extraordinarily rich collection from contexts that were laterally and vertically complex. Since the evidence for co-existence had been countered by arguments that human activity, such as grave-digging, had compromised the records, Pengelly was explicitly concerned with distinguishing between materials above and below a stratigraphically-continuous calcite flowstone layer that is now known to separate Holocene from Pleistocene materials.

* Corresponding author at: Department of Geography and Environmental Studies, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, K1S 5B6, Canada. Tel.: +1 613 520 2600x2571; fax: +1 613 520 4301.
E-mail addresses: sorin_mihai@yahoo.com (S. Mihai), joyce.lundberg@carleton.ca (J. Lundberg), dmcfarlane@jsd.claremont.edu (D.A. McFarlane), chandlerb1@ukonline.co.uk (B. Chandler).

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The flowstone layer sealed the lower materials from any possible historic-era human interference. Pengelly therefore had to devise a system that would enable him to keep track of the three dimensional origin of each find. Pengelly had already devised a prototype system for excavation on the historically critical excavation (under the joint supervision of the Royal and Geological Societies) of the Brixham Bone Cave in 1858 (Pengelly et al., 1873; McFarlane and Lundberg, 2005; Boylan, 2008; McFarlane et al., 2010a). His solution was to delineate the cave floor with a network of datum lines precisely located by compass orientation. Each passage was designated as a Series. Each series was divided along its length into one-foot-long Parallels. Each parallel then spawned a set of Yards at right angles to the main Datum line to the left and right, at various Levels each a foot deep. The entire excavation, which extended to almost a kilometre of cave passage, was thus divided into rectangular units measuring one foot wide by one yard long by one foot deep, which Pengelly called Prisms. (This system is described in detail in McFarlane and Lundberg, 2005.) The palaeontological and archaeological finds from each prism were stored in a box with a unique Pengelly number and indication of location.

As a basis for spatial analysis of the record, we have set up a database of all the available Pengelly materials, and a GIS system to facilitate mapping of the finds. This in turn allows spatial analysis. Here we report the first results from this project—the relationship of bears to cave entrance locations. We hypothesize that the distribution of bear remains should largely reflect the cave entrance that was open at the time of their sojourn and the extent of post-depositional repositioning of the remains by periglacial activity.

2. Methods

2.1. The database

The specimens themselves are dispersed amongst at least 19 museums where surviving material has been curated under different systems, and only some of the artifacts have been identified. Using the transcripts of Pengelly’s diaries, we produced a master list of all the Pengelly numbers, specimen identification, sediment type, and location. We assembled all the known records into a single database. In a few cases, errors in the curation records were checked against the original handwritten diaries (e.g., where the number and/or location and/or material type were not compatible).

2.1.1. Anomalous Pengelly numbers

Pengelly numbers were normally assigned in order as found. However, where extra materials were found after the main set of numbers had been assigned, Pengelly recorded these with the suffix ‘A’; e.g., 1856 and 1856A are from the same series but from different prisms. A potential source of confusion is in the Exeter Museum curatorial system where the suffix ‘a’, ‘b’, etc. (lower case) is used to designate individual specimens from within the same prism, whereas the Torquay Museum uses Pengelly’s original notation which would have been suffix ‘/1’, ‘/2’, etc. and the suffix ‘A’ refers to a separate prism.

Where the Pengelly number is recorded in the museum records with a question mark we checked the location and material type to see if the data are internally consistent. One example was encountered where the number was recorded with a forward slash that appeared to be mistaken for the number 1. The original Pengelly number recorded as 23/4149 potentially could mean the 4149th piece from prism #23 (unlikely) or the 23rd piece from prism #4149 (perhaps more sensible). The genus is Ursus. Prism #4149 is in the Black Mould, a Late Holocene deposit on the surface that, if it represents an in situ find, is very unlikely to harbour bear remains. Therefore, in this case, we interpret the notation that both the slash and the ‘1’ were mis-read, so the correct designation was most probably 2314/49 (49th piece from prism 2314—the other 48 may be unidentified items such as stones or shells). Prism 2314 is in Cave Earth, a sediment that yielded many bear remains, and other Ursus remains were recorded within two feet of this prism.

2.1.2. Taxonomy

Because the specimens are scattered amongst many museums, the degree of curation is inconsistent. Many Pengelly specimens have not yet been identified—these can be added to the database as they become available. Of those that have been identified, some are identified to species level, e.g., Cervus elaphus, others to genus, e.g., Cervus (equivalent to Cervus sp.), and others only to family, e.g., cervid. In most cases the species identified in the data bases are correct and needed no modification. In some cases, both for consistency within this project, and in order to assign the specimens according to the most recent taxonomy, we modified the names. For the most up-to-date designations we relied largely on Valden (1999). For example, ‘Elaphus’ is here ‘Palaeoloxodon’, ‘Rhinoceros’ (Diceros) ‘antiquitatis’ has been changed to ‘Coelodonta antiquitatis’, and ‘Meles taxus’ has been re-assigned to ‘Meles meles’. Cave bears are variously curated as Ursus deningeri or U. spelaeus, but are entered in the database as U. deningeri. This decision is based on Proctor et al. (2005) who establish the case for the correct taxonomic assignment being U. deningeri. The detailed technical assessment (McFarlane et al., 2006, 2010b) shows that the Kents Cavern cave bears, although a transitional form from U. deningeri to U. spelaeus, are fully attributable to U. deningeri.

We have included no sub-species identifications—partly to simplify the data and partly because such detailed identification is rarely trustworthy from fossil data. Probable, but uncertain, identifications are included as curated, but denoted with a question mark in the comments column of the database.

Some specimens are recorded that have no Pengelly number but do have identifications, e.g., BMNH M1029 is ‘U. deningeri fragment of humerus, head and 2 molars in matrix’. These may have intrinsic value but cannot be mapped and therefore are removed from this data base. Many specimens have Pengelly numbers but no identification.

2.1.3. Archaeology

Archaeological remains are classified by general type as well as detailed description. General mappable categories are: Midden (e.g., shell – food debris); Artifact (e.g., blade, shard); Charcoal; Bone (e.g., animal bones with human modifications); Human (e.g., human bones, teeth); and Other (e.g., pebble).

2.2. The GIS

The GIS was implemented in ArcGIS version 9.2 (ESRI, 2009). The cave survey is based on the original survey of Proctor and Smart (1989). The tabular data are stored in Shapefile and MS Access formats. GIS layer descriptions are shown in Table 1. The Shapefile data were generated in ArcGIS and contain the geometry and attribution of Pengelly’s reference system.

The accurate reconstruction of the Pengelly's excavation system, corrected to the modern survey (McFarlane and Lundberg, 2005—with two minor corrections), was converted to a vector map in ArcGIS. Datum line, Series, Parallel and Yard, were added to the Prism GIS layer as attributes, so they can be easily identified by using either the spatial or attribution queries. The Prism Centroids layer contains the same attribution. By merging the Series, Parallel and Yard information a new attribute, named CODE, was created and attached to the Prism polygon layer (Table 2). This represents a
unique identifier for each 2D location represented by a prism in the
Prism layer (there are more than 8000 prisms in this GIS layer
covering the excavation area). CODE3D adds the stratigraphic
information. Table 2 can be linked to the Prism GIS layer using
the prism CODE field and to any table containing Pengelly numbers.

2.3. Mapping

The maps use the prism location for spatial reference. In order
to simplify the creation of distribution maps the attribution of each
record in the GIS Prism layer (number and type of specimen) was
transferred to the GIS Prism Centroids layer which was used as the
main source for generating specimen distribution maps.

Two types of maps were produced: point location maps (which
show only the presence/absence of specimens in a prism irrespective of their frequency), and density maps (since one
prism may contain more than one specimen of the same type). The
density layers are created in ESRI Grid format with the Spatial
Analyst Density tool. Kernel density uses the number of finds per
prism. The values associated with each point are spread from the
point location to the specified radius. The parameters involved in
calculation are the search radius (which gave optimum results
when set to 2.5 m) and the cell size (optimum results at 0.2 m). The
first result is a float point grid that is consequently reclassified to
an integer value grid, which is used in the maps.

Material type was mapped as coloured prisms using the
material type information in the Pengelly records. However, only
the two main artifact-bearing materials, Breccia and Cave Earth,
are readily seen. Black Mould, Crystalline Stalagmite and Granular
Stalagmite cannot be mapped either because the numbers are so
small (e.g., Black Mould appears in only 3 prisms) or because the
record does not contain precise location information (e.g.,
Crystalline Stalagmite and Granular Stalagmite have only series
information). Two types of maps were produced: point location maps (which
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small (e.g., Black Mould appears in only 3 prisms) or because the
record does not contain precise location information (e.g.,
Crystalline Stalagmite and Granular Stalagmite have only series
data). Where a younger material overlies an older material the
older one will not be seen on a map that includes both material
types.

2.3.1. Proofing the maps

In all the output maps below, the cave wall is shown as a black
line and the excavation area a grey shade, the rectangles are the
prisms, the red dot is the centroid of the prism, the thick grey line is
the datum line of the series, and the thin grey line the lateral shifts
in the datum line. For the final output, all anomalous points on
the initial output were checked and modified if required. A separate
layer highlights problematic points for which we could find no
obvious solution. Examples of the kinds of error encountered are:

(1) Case 1: error in cataloguing

Unfortunately the history of identification and cataloguing
of the Pengelly specimens has been sporadic, by many different
parties, of many different abilities, and over about 100 years.
The result is a data base with potential cataloguing errors,
which are almost impossible to find by eye. This is where the
GIS mapping system comes into its own. An excellent attribute
of the GIS mapping system is that it graphically shows
problematic data points, which may include mis-catalogued
specimens. For example, Pengelly number 2428 is located in
the Northeast Gallery close to the North Entrance. This prism
included at least two pieces of bear remains. The first is located
in Torquay Museum and is identified as Ursus arctos. The

Fig. 1. Extract from South Sally Port illustrating some of the potential errors in data.
Black line = cave wall; grey area = excavation area as mapped in McFarlane and
Lundberg (2005); rectangles = prisms, red dot = centroid of prism, thick grey
line = datum, thin grey line = shift in datum; grey number = series number; red
ellipses indicate points discussed in text. (For interpretation of the references to
colour in this figure legend, the reader is referred to the web version of the article.)
second is housed in the British Museum of Natural History and is identified as *U. deningeri*. *U. deningeri* would not be expected in the Northeast Gallery where the record shows that the material is Cave Earth, a deposit laid down some 300,000 years after the extirpation of *U. deningeri* in Britain. Moreover, the BMNH specimen is only a metacarpal bone, which is not diagnostic for *arctos/deningeri*, and hence can be confidently assumed to have been mis-identified.

(2) Case 2: error in location data

In some cases the original data for prism locations proved to be erroneous. When locations as recorded in Pengelly’s diaries were mapped, several of the prisms fell outside of the original excavated area (in cases of dispute the original hand written manuscripts were consulted to eliminate potential errors of transcription – which proved rare – the errors were mainly in the original documents). So, either the record of the excavation is wrong or the location code of the Pengelly number is wrong.

If the prism lies by itself, and outside of all the other prisms, then it is likely that the location information is incorrect. For example, Pengelly #4281 is from South Sally Port, Series 13, Parallel, 31, Level 2 (2 feet below the surface), Yard 4R (4 yards to the right of the datum). This point plots outside of the excavation area. Since this record is isolated (highlighted by the red ellipse A in Fig. 1), it is not surrounded by other finds from the same prism, we cannot tell from the table of data (Table 3) if this record is correct. So, we move to the other consideration: the actual physical constraint of the cave passage. Clearly an excavation could not have occurred in the solid rock wall. This provides an obvious check on the veracity of a prism that appears to lie outside of the cave walls (but see below)—as is the case in this example So, here we re-assigned Pengelly number 4281 to 1R instead of 4R because the only other possibility to the right at that level is the very small partial prism 2R.

### Table 3

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</table>

Fig. 2. Typical sequence of excavation to left and right of datum line.

Fig. 3. Detail of the red ellipse B in Fig. 1 from Series 8, parallel 11, yard 3L. The black dots show all the finds from the series. The red dot plots outside of the excavation area and outside of the passage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

Fig. 4. The effect of non-vertical walls on pre-and post-excavation mapping.
Another consideration in trying to assess possible errors is the typical pattern of excavation that the diaries record: if a find appears to be out of the standard sequence of work, then it may be incorrect. For example, a typical series of Pengelly numbers follows the progression of the excavation, for each level, to the left of the datum line first and to the right second: e.g., Level 1: 1L, 2L, 3L, then 1R, 2R, 3R; Level 2: 1L, 2L, 3L, 1R, 2R, 3R, etc. (Fig. 2).

The case of Pengelly #3280 Series 8, Parallel 11, Level 1, 3L (highlighted in the red ellipse B in Fig. 1) plots outside of the excavated area and outside of the modern survey. The Pengelly numbers suggest that the sequence of left first and right second was followed here, but 2L appears to be out of place. When plotted in relationship to all the other finds of that series (Fig. 3), then it is obviously lying far outside of the rest of the deposits. However, if it is instead assigned to 1L or even 2L, then it fits into the passage.

(3) Case 3: error in excavation data

The example highlighted by red ellipse C in Fig. 1 plots outside of the excavation map but inside the cave survey. It is in a small alcove in the wall. There is no reason to suppose that the location is in error: it is likely that the alcove was added on after the details of the excavation were recorded.

In other cases, several Pengelly numbers plot side by side outside the excavation limit but inside the cave wall. Two examples are highlighted by the two red ellipses D and E in Fig. 1. There is nothing in the records to suggest that these are out of order. Here it is assumed that the records of finds are correct and that the problem must be in the recording of the excavation. In drawing the excavation map (McFarlane and Lundberg, 2005), where details were not given for every Parallel, then a straight line was drawn between two known points. Most commonly the diaries record that the limit for a parallel is the same as the last one; thus if a single change is not recorded then that error gets propagated.
In some cases it is quite clear that the excavation record must have been incorrect. The problem highlighted in red ellipse F in Fig. 1 is probably this. The extraordinary sudden inward spike of the edge of the excavation line was faithfully recorded in the mapping (and questioned at the time) but the Pengelly number location data place prisms right where the spike is.

In places that are physically very tight and tortuous, such the Tortuous Gallery, it is quite understandable that the record keeping was not quite as good as in the open passages.

(4) Case 4: apparent error, data correct

The effect of non-vertical walls can be seen in several cases where the excavation limit lies beyond the cave wall as shown on the modern map (e.g., ellipse G on Fig. 1). The cave wall is mapped as the position of the wall at survey height which, with vertical walls, is the same as the line of contact of the floor with the wall. However, if the floor had originally been several metres higher and the cave wall is at an angle to the vertical, then the edge of the excavation at the cave wall would have been outside the modern cave wall line (Fig. 4).

This principle may also explain some cases where the Pengelly location data plot outside of the excavation limits. If the wall were to widen with depth and the excavation information were recorded at the start of the dig, then the deeper layers will appear to extend beyond the excavation limit (Fig. 5). This may explain the red ellipse H in Fig. 1: all of these prisms are from levels 3 or 4; none are from levels 1 or 2.

(5) Case 5: ambiguity in stratigraphy

In the Pengelly records, the identification of the Breccia was always quite simple and clear cut. All examples of breccia are from the same, easily-identifiable sedimentary unit. However, the designation of “Cave Earth” is problematic because all sediments between the Crystalline Stalagmite and the Granular Stalagmite were designated as “Cave Earth”, regardless of their age or origin. The main deposit of Cave Earth entered the cave from the northeast, flowing southwest into Long Arcade and Southwest Gallery. Some of the deposits nominally listed as “Cave Earth”, such as that in the Great Oven Passage, are simply locally intruding infill and cannot be part of the main deposit. This compromises the relationship of specimens with sediment type.

3. Results and discussion

3.1. The data base

We have 2334 entries for palaeontological finds, from 8 different museums (listed in Appendix A). 7340 is the highest Pengelly number, but because some numbers were used more than once, there are actually 7412 Pengelly numbers. The archaeological finds are 1135 in number. The current database consists of 3469 of the original 7412 Pengelly finds. Subsequent updates will be done as curation progresses.

3.2. The bear maps

For this report, the distribution of bear remains was mapped. We hypothesize that the distribution of bear remains should largely reflect the cave entrance that was open at the time of their sojourn and the extent of post-depositional repositioning of the remains by periglacial activity.

Fig. 7. Map of Ursus locations and density in relation to material type.
Each Pengelly record represents a “Taxonomically-Identifiable Unit” or TIU, of which many may derive from the same individual animal. The total number of Ursus TIUs in the database is 462, of which 47 are not mappable, for various reasons such as missing identifiers. Thus 352 Ursus TIUs have been mapped, occupying 282 locations. Although one prism (in the Labyrinth sector) contained 26 TIUs, the majority contain just 1 TIU (222 out of 282) indicating a considerable dispersal of the remains. This is consistent with pervasive post-mortem re-distribution.

The Kernel density plots (Fig. 6) that were produced indicate that the two species have almost non-overlapping distributions. *U. deningeri* remains were largely confined to the breccia, in the western part of cave, while *U. arctos* remains were limited to the eastern part of the cave and were generally found in Cave Earth. When material type is added to the distribution map, then the association of *U. deningeri* with Breccia and *U. arctos* with Cave Earth is clear (Fig. 7).

Proctor et al. (2005) conjecture that *U. deningeri* entered through a hidden fissure in the roof of the Bear’s Den. However, the density plots do not show the expected greatest concentration of cave bear remains in the Bear’s Den area. Neither do the remains appear to spread out from the Bear’s Den area. The density map instead indicates an addition significant concentration in the Labyrinth and Hedges Boss areas. The implication is that the entrance was not in the roof of Bear’s Den as indicated in Proctor et al. (2005). The evidence of the spatial distribution of remains would be more consistent with access via the now-sealed entrance of High Level Chamber, which was also the entrance for the periglacial material that made up the Breccia deposit (Straw, 1997; Lundberg and McFarlane, 2007). Further, it suggests that denning may not have been confined to the Bear’s Den area—rather that denning may have extended along the passage from Hedges Boss through the Labyrinth to Bear’s Den. The single largest concentration (TIU = 26) against the south wall of the Labyrinth may represent remains from a single animal protected from periglacial movement in a wall nook. The most distally located specimens, in the Water Gallery-Southwest Chamber areas and Long Arcade, far from any potential entrances, were probably moved into these locations by periglacial action (the evidence for this was discussed in some detail in Lundberg and McFarlane, 2007). Two Ursid teeth and a thoracic vertebra recovered from Smerdon’s Passage – which is at a lower level underneath South Entrance – (RAMM 5323 and BMNH 5334) and nominally catalogued as *U. deningeri* are almost certainly mis-identified *U. arctos*, having been excavated from Cave Earth in juxta-position with Late Pleistocene *Hyena*.

The pattern displayed by the *U. arctos* remains suggests that the brown bears entered by a now-sealed entrance in the Northeast Gallery, and denned in the large chambers of the Vestibule and Great Chamber. The material in the tortuous and lower level North and South Sally Ports and Smerdon’s Passage is most likely the result of post-mortem re-distribution.

4. Conclusion

This study shows that the Pengelly system is sufficiently spatially explicit to be amenable to treatment in a GIS system. The GIS approach is a powerful tool when it is applied in the context of substantially dependable information; in this case diligent 19th century recording and a modern cave survey enable the errors and omissions in specimen curation to be examined critically and productively. Spatial plotting of species such as bears discriminates differences in taphonomies and life history of the animals. The spatial distribution of *U. deningeri* and *U. arctos* specimens suggests a new interpretation of the entrances used by the animals, the most likely denning areas, and post-mortem re-distribution of remains.

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Appendix A

Museums with Pengelly specimens included in the database:

- Torquay Museum
- British Museum of Natural History
- British Museum
- Royal Albert Memorial Museum, Exeter
- Ashmolean Museum, Cambridge, UK
- Bolton Museum, UK
- Brighton Museum, UK
- Liverpool Museum, UK

Note: the Smithsonian Institution Washington, USA has 29 bone/teeth specimens with Pengelly numbers but no identifications, 10 additional palaeontological specimens without Pengelly numbers, and 3 archaeological specimens also without Pengelly numbers, so none are included in our database.

References


Pengelly, W., 1884. The literature of Kent’s Cavern. Part V. Transactions of the Devonshire Association for the Advancement of Science, Literature and Art 14, 189–434.


