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Research paper

Chronometry of pedogenic and stratigraphic events from calcite produced by earthworms

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ABSTRACT

Dating phases of pedogenesis, soil carbonate deposition or even the burial of whole soil profiles using ^{14}C is a valuable goal in archaeology and pedology, but one that has been consistently hampered by the presence of old carbon skewing the measurements to produce apparent dates older than the true formation date. Calcite produced by earthworms could be a useful alternative source of datable carbon. Since earthworms both inhabit and ingest soils with an old carbon content, however, the granules could yield a ^{14}C date older than the date of their formation. In this study, by examining granules from two sites of known-age stratigraphy, we show that the radiocarbon date derived from the granules' calcite closely reflects their true formation date, opening up the possibility of using the granules either individually or as distributions of dates to understand soil processes and date sealed archaeological layers.

1. Introduction

Direct carbon dating of the organic matter in soils and archaeological stratigraphy can only give a mean residence time because of the old carbon retained in soil (Stout et al., 1981) and it is unlikely that we will ever be able to use these types of ^{14}C results for any form of chronometry. The possibility of dating soil carbonates has offered a greater chance of success, in so far as they are likely to be individual events rather than mixtures. Nevertheless, most soil carbonates still ultimately derive their carbon from the soil air, and the published measurements of soil $^{14}CO_2$ (Dörr and Münnich, 1980, 1986; Haas et al., 1983; Thorstenson et al., 1983; Trumbore, 1993; Wang et al., 1994) show a general trend of unresolved complexity, primarily due to the carbon being derived either from root respiration or from organic matter decay, each giving very different values (Amundson et al., 1998). The resulting carbonate ^{14}C dates can, therefore, vary significantly from the true date, depending on factors such as the season and the depth in the soil at which the carbonate has been deposited. No clear methodology has emerged to resolve this problem.

Earthworms produce calcium carbonate from specialised oesophageal glands (Leo, 1820; Lankester, 1864). Many species additionally concentrate the product into calcite granules up to 2.5 mm in size (Darwin, 1881) which are then expelled with the casts and may build up to very large numbers in neutral or alkaline soils (Meijer, 1985). The granules have undergone considerable research scrutiny in the last 20 years, so we now have a reasonable understanding of the producing species (Canti and Piearce, 2003), as well as many aspects of the ecological, taphonomic and preservation characteristics (Canti, 2003, 2007a; Lambkin et al., 2011a, 2011b). It is likely that the granules (Fig. 1) are produced from the contemporary carbon in fresh organic matter and, in the case of species dwelling near the soil surface, atmospheric rather than soil CO_2. Preliminary investigation of carbon pathways in earthworm metabolism using the stable isotope ^{13}C indicated that little or no ingested soil carbonate was involved in the formation of earthworm calcite, and it appears that the carbon comes chiefly from the diet or directly from the atmosphere (Canti, 2009; Briones et al., 2008) both of which would tend towards true ^{14}C dates.

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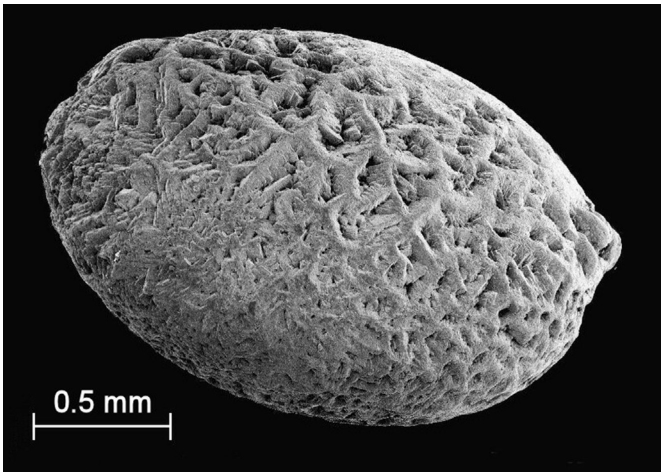

Fig. 1. Granule of calcite produced by *Lumbricus terrestris* (SEM image).

The δ^{13}C results led us to try out a series of ^{14}C dates on individual earthworm granules recovered from independently-dated stratigraphy. This had to be an old soil which had been capable of supporting a population of the larger *Lumbricus* species, since these are the ones that can produce granules with enough mass for ^{14}C dating. It also had to be isolated (e.g. by burial) from intrusion by modern worms, and have an independent date for that isolation. Since, by definition, the granules must be preserved in order to be dated, the expectation, on dating a number of them, was to find a distribution of dates reflecting the whole period during which earthworms had inhabited the soil, and terminated at the moment of burial (Canti, 2007a).

2. Westward Ho! – sampling and results

The first site meeting all the conditions needed to test the model of the granules' date distribution was the Mesolithic sequence at Westward Ho!, Devon, U.K. (Churchill, 1965; Balaam et al., 1987). Here, midden sediment rich in shell, charred plant remains and flint was sandwiched between datable layers of peat (above) and blue clay (below), with the whole stratigraphy being under the sea at all but the lowest tide, thus preventing any intrusion by modern earthworms (Fig. 2). Although the midden has now disappeared (Riley, 2002), dried material had fortuitously been saved in the archive. It was found to contain earthworm calcite granules >0.5 mm, in a concentration of about 25 per 100 g of dried sediment. A number of ^{14}C dates already existed for the peat and blue clay layers at different parts of the Westward Ho! site, and a further 3 from plant remains in the midden sample were obtained. 20 earthworm granules were dated at ANSTO using the laboratory methodology outlined below. The dates of these granules and of the other layers found within 25 m of the midden site are shown in Fig. 2 and Table 1.

3. Silbury Hill – sampling and results

The second site was Silbury Hill, Wiltshire, UK. This is the largest prehistoric mound in Europe, constructed of a central core containing whole blocks of turf (the Organic Mound), capped by chalk to a height of more than 30 m from the old ground surface (Fig. 3). Dried turf from the Organic Mound recovered during the 1968 excavations contained moderate quantities of earthworm calcite granules >0.5 mm. Various plant materials collected from the Organic Mound during the 2007 excavations provided secure independent dating on the primary construction (Marshall et al., 2013) The huge bulk of the hill was a safeguard against penetration by the larger earthworm species, thus preventing deposition of later granules.

Twenty-five granules from the turf samples were dated at Oxford RLAHA and ANSTO using the methods outlined below. Their dates and the independent dates of the plant materials are shown in Fig. 3 and Table 2. One granule had anomalously high δ^{13}C (2.4‰) and gave very old date (32,300 years, uncalibrated; see OxA-X-2208-14), suggesting, a chalk microfossil or other contaminant. The remaining 24 show a distinctive distribution ranging from ca. 6310 cal BP to ca. 4100 cal BP, and skewed towards the younger ages.

4. Discussion

It is clear from the results at these two sites that earthworm calcite gives a radiocarbon date corresponding to the secretion date. At Westward Ho!, the age span of earthworm calcite samples is 6530–7280 cal BP which is in agreement with that of terrestrial organic samples (ranging from 6490 to 7940 cal BP). In addition, the calcite age range is older than that of the upper peat layer (5660–6780 cal BP), and younger than the lower "blue clay" layer which is 6880–7850 cal BP. At Silbury, although one of the organic material dates (OxA-X-2352-53) has rather broad error margins, the majority indicate a burial date of 4100–4500 cal BP; all of the earthworm calcite dates (6310–4100 cal BP) are either contemporary with this date or older.

At both sites, the nature of the date distributions gives us additional information about the history of the stratigraphy. At Westward Ho!, the twenty dates are uniformly distributed through time, probably as a result of continuous human deposition of calcareous sediment onto the midden surface, which would act to prevent decalcification, thus leaving the same numbers of granules in each age category. By contrast, at Silbury Hill, the majority of the granules are close to the date of burial and a tail of older ones is still present. This is exactly what would be expected from the topsoil at a land surface undergoing very slow decalcification before being cut at about 4300 cal BP and built into a mound, then covered with chalk, after which decalcification ceased.

Knowing that earthworm calcite ^{14}C gives a true date for the calcite deposition opens up a number of chronometric possibilities. Due to the fact that earthworms can deposit the granules throughout their soil environment, calcite dating could only involve individual granule dates in rather unusual circumstances of tightly constrained stratigraphy isolated from both later and earlier granule deposition. The greater potential would come from analysing distributions of dates in situations where the stratigraphy is sealed from later worm burrowing, such as an old land surface deeply buried beneath an earthwork. Here, the distribution curve should show a sharp drop to zero at the date of burial.

5. Conclusion

There may be potential for dating the primary pedogenesis where calcareous sediments have been deposited onto rock (or other granule-free substrates), by looking for the oldest earthworm calcite in a distribution of dates. Confidence in this approach would rely on proving that there had been no decalcification tending to remove the older dates. Earthworm calcite dating also makes possible a radiocarbon-based age determination for oxygen isotope palaeothermometry (Versteegh et al., 2013). Finally, the physical distribution of earthworm granules in modern soils mostly shows a