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Predicting the preservation of cultural artefacts and buried materials in soil

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HIGHLIGHTS

- The preservation in soils of different materials and of stratigraphic evidence is reviewed.
- A predictive framework for the preservation of materials in soil is proposed.
- Preservation of materials and stratigraphic evidence in soils of the EU is predicted.
- Soil performs an important cultural service by preserving anthropogenic artefacts.

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ABSTRACT

This study identifies factors affecting the fate of buried objects in soil and develops a method for assessing where preservation of different materials and stratigraphic evidence is more or less likely in the landscape. The results inform the extent of the cultural service that soil supports by preserving artefacts from and information about past societies. They are also relevant to predicting the state of existing and planned buried infrastructure and the persistence of materials spread on land. Soils are variable and preserve different materials and stratigraphic evidence differently. This study identifies the material and soil properties that affect preservation and relates these to soil types; it assesses their preservation capacities for bones, teeth and shells, organic materials, metals (Au, Ag, Cu, Fe, Pb and bronze), ceramics, glass and stratigraphic evidence. Preservation of Au, Pb and ceramics, glass and phytoliths is good in most soils but degradation rates of other materials (e.g. Fe and organic materials) is strongly influenced by soil type. A method is proposed for using data on the distribution of soil types to map the variable preservation capacities of soil for different materials. This is applied at a continental scale across the EU for bones, teeth and shells, organic materials, metals (Cu, bronze and Fe) and stratigraphic evidence. The maps produced demonstrate how soil provides an extensive but variable preservation of buried objects.

1. Introduction

1.1. Background

Soil contributes to a series of ecosystem services through its functions. Assessment and maintenance of these functions are central to the EU's thematic strategy for soil protection (European Commission, 2006a,b). Storage of buried heritage and providing a platform for the built environment are the main soil functions identified in the strategy and further assessments are required to characterise these and describe their spatial variability. A wide range of archaeological and cultural heritage and buried infrastructure is preserved in the soil environment and in landscape features that are formed from soil. Knowledge about which soils preserve which materials is valuable for the management of heritage and buried infrastructure and may also inform assessments of the longer-term impact on soil of spreading of wastes to land. The range of buried objects is wide and includes: artefacts made from a variety of materials e.g., stone, ceramics, bone, metals, wood and other plant materials, skins and hides, glass and plastics; burial mounds, cultivation terraces, and other earthworks; stratigraphic evidence of past environments (Harris, 1989), land management and human activities; and contemporary distribution and communication infrastructure. The spatial distribution of archaeological artefacts and landscape features reflects past occupation patterns and land uses and the actual presence of buried objects in soil and earthworks depends on many factors other than the soil type and its potential to preserve materials (Holden et al., 2006; Lillie and Smith, 2007). It is useful, however, to assess the preservation service that soils may or may not provide if objects are buried in them; such an assessment has potential to provide information for valuing the cultural and other

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ecosystem services provided by soils and to inform decisions about the management of buried resources. The survival and condition of buried objects and stratigraphic evidence depend both on the particular soil environment in which they are buried and the material from which they are formed (Cronyn, 1990) and, for anthropogenic artefacts, the nature of their manufacture. This study investigates the preservation of buried objects in soil, how this is affected by their material nature and soil type and how information about the distribution of soils can be used to assess preservation capacities spatially. It builds on existing guidance about which soil properties are important for the preservation of buried objects (Davidson and Wilson, 2006; Crow, 2008; English Heritage, 2008, 2011) and provides a commentary on the fate of different materials for different soil types defined according to standard taxonomic classification. It describes how soil mapping data can be used to systematically map the preservation of different materials by soil and applies this to predict this potential for soils across the European Union (EU).

1.2. Bones, teeth and shells

Human and animal bones and teeth are made of hydroxyapatite ($CaCO_3$) and smaller amounts of protein (collagen) fibres. Bones that still retain collagen have some elasticity but become more brittle with age as collagen degrades. The circumstances of burial and the immediate post-burial environment influence the longer-term fate of buried bones (Baxter, 2004; Jans et al., 2004). Relevant factors are the burial location, depth and any containment. In the early phases of bone burial, biological action affects the ageing process which may continue for decades. Colonisation is initially dominated by bacteria followed by fungi (Child, 1995; Jans, 2008). Biological degradation continues until nitrogen (N) derived from collagen is exhausted; in parallel and subsequently, physical degradation and chemical alteration and degradation occur. The solubility of hydroxyapatite rises with increasing acidity and the survival of bone and teeth correlates with the pH of soil and groundwater. Dissolution of bone results in a lower density material with more and larger pores and this progressively increases the bone area being actively dissolved and the rate of degradation. Alongside dissolution, ions in the soil solution can be incorporated into new minerals. Avian and mollusc shells are formed from calcite ($CaCO_3$) which dissolves more readily in moist acid conditions than hydroxyapatite in bones and their fate is similar but accelerated compared to bone and teeth.

The dry conditions present in soils in arid and semi-arid regions preserve bones and teeth and shells. Bones and teeth and shells are preserved better in alkaline soil, while their degradation and eventual destruction are quite rapid where the soil water is acidic and unsaturated, as in acid soils that are wet and free draining and formed on sands and acidic parent material in higher precipitation zones. Bones, teeth and shells are preserved better in soils that are permanently waterlogged by stagnant alkaline groundwater, as occurs in some lowland peat soils. Static pressures and surface loading to the soil e.g., during cultivation and by vehicles (Dain-Owens et al., 2013) may cause physical damage to buried bone material as may soil movement resulting from wetting and drying cycles in soils that contain expansive clay minerals.

1.3. Ceramics, glass and phytoliths

Many types of ceramics are preserved in soil, including tiles and bricks as well as figures, pots and other domestic items. Ceramic artefacts can survive in the buried environment for very long periods and a ceramic figurine dated to 16,000 years before present (Vandiver and Vasil'ev, 2002) has been found. This longevity reflects the resistance of ceramics to biological and chemical degradation processes. The material properties of ceramics vary depending on the clay and other materials used for their manufacture, e.g., carbonaceous or non-carbonaceous clay, with or without addition of calcite (Fabbri et al., 2014). Firing temperature affects robustness: higher firing temperatures produce stiffer objects that resist mechanical and other stresses better. Objects fired at lower temperature tend to have a more open pore structure allowing water to enter and cause degradation, including by subsequent frost-shattering.

Glass is a relatively durable material in the buried environment (Jackson et al., 2012) and the morphology of solid glass objects and fragments often remain intact. However, surface corrosion of glass occurs in moist and wet soils leading to a loss of transparency and the formation of a surface crust rich in silica and depleted of basic ions. This process weakens the glass and this may accelerate shattering of thinner objects (Huisman et al., 2008). The rate of surface degradation in soil is strongly affected by the glass composition and not easily predicted (Van Giffen, 2014). The alkali type and content is critical: Roman and other ancient glass is generally more resistant to chemical attack than glass from the mediaeval period when wood ash containing potassium (K) replaced soda ash in its manufacture. Under acidic conditions and moderately alkaline conditions ($pH < 9$) alkali ions are leached from the glass matrix, while under more alkaline conditions hydroxyl ions disrupt silicon–oxygen bonds within the silica structure (Melcher et al., 2010). At more alkaline pH, laminar surface layers are more likely to form (Roemich et al., 2003) which may be iridescent. In all but the driest soils, surface coatings and other decoration on glass are expected to degrade quite quickly (<100 y). The strong dependence of corrosion rates of glass objects on material composition and manufacture leads to uncertainty in any prediction of the relative rates of surface degradation in different soils: corrosion is expected to be least in very dry soils; rates of corrosion may be moderated in well-drained and neutral soils in drier regions; highly alkaline soils are anticipated to be the most corrosive.

While both ceramic and to a lesser extent glass materials are preserved well in soil, they tend to shatter and the resulting shards may then become dispersed. Physical damage to ceramics and glass buried in soil can arise from static and dynamic forces. Static forces increase with depth and dynamic forces from the treading action of animals and people and vehicle movements (Dain-Owens et al., 2013) may propagate in to subsoil. Where expansive clay minerals are present, these will create potentially destructive mechanical forces during wetting-drying cycles. Soil stiffness, which is a measure of resistance to deformation, will affect the likelihood that brittle objects will be fractured. For example, a dry clay soil will be more resistant to deformation and better protect objects from shattering than will a wet sandy soil. For most soils, however, the dominant factor determining shattering is likely to be land use and management rather than soil type.

Opaline silica is deposited as phytoliths in plants that vary in form between species and can provide evidence of past vegetative cover; they are highly resistant to degradation in soil and will be preserved in most soils, a possible exception being very wet and strongly alkaline soils.

1.4. Organic materials

Organic materials buried in soil include plant material (e.g., wood, fibres, fruits, seeds, and pollen), fungal spores, insects and their larvae, parasite eggs and the remains of animals and humans (e.g., skin, soft tissues). Immediately following their burial, organic materials may be recovered or at least disturbed by soil fauna, ranging from macrofauna including burrowing rodents to arthropods and their larvae. Subsequently, the main degradation process for organic material is biological oxidation by the soil ecosystem and this usually leads to its complete destruction where aerobic and moist soil conditions prevail, whereas soil conditions that are anaerobic are preserving, although not completely (Bjordal et al., 1999; Douterelo et al., 2010). In very dry soils microbial activity is restricted and this preserves organic materials. The least preserving hydrological conditions are expected to be those where soil is seasonally wet but dries in summer as this cycling of soil moisture levels encourages ‘flushes’ of more intense microbial activity as the soil wets up. Any activity that disturbs the soil and redistributes and releases soil organic matter, including tillage, is also likely to accelerate aerobic degradation. The rate of biological degradation of organic materials in soil is affected by their molecular structure