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Long-term effects of hydrated lime and quicklime on the decay of human remains using pig cadavers as human body analogues: Field experiments

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ABSTRACT

An increased number of police enquiries involving human remains buried with lime have demonstrated the need for more research into the effect of different types of lime on cadaver decomposition and its micro-environment. This study follows previous studies by the authors who have investigated the effects of lime on the decay of human remains in laboratory conditions and 6 months of field experiments. Six pig carcasses *(Sus scrofa)*, used as human body analogues, were buried without lime with hydrated lime ($Ca(OH)_2$) and quicklime (CaO) in shallow graves in sandy-loam soil in Belgium and recovered after 17 and 42 months of burial. Analysis of the soil, lime and carcasses included entomology, pH, moisture content, microbial activity, histology and lime carbonation. The results of this study demonstrate that despite conflicting evidence in the literature, the extent of decomposition is slowed down by burial with both hydrated lime and quicklime. The more advanced the decay process, the more similar the degree of liquefaction between the limed and unlimed remains. The end result for each mode of burial will ultimately result in skeletonisation. This study has implications for the investigation of clandestine burials, for a better understanding of archaeological plaster burials and potentially for the interpretation of mass graves and management of mass disasters by humanitarian organisation and DVI teams.

1. Introduction

An understanding of specific taphonomic processes is important for the search, detection, recovery, analysis and interpretation of buried human remains. The continued emphasis on taphonomic research has led to a growing understanding of the taphonomic processes that occur within the immediate buried body environment and their effect on the rate and extent of decomposition in different dispositional conditions. Certain conditions have an impact on the rate of change and bring about conditions which differ from the usual decay process. There is still a paucity of scientific information on the effects of specific chemicals on decay. An increased number of enquiries by police forces and archaeologists have demonstrated the need for more research regarding the effects of lime on cadaver decomposition and on the grave micro-environment.

Since the Greek and Roman period, it is a commonly held belief that lime can be used to enhance the speed of decay, to reduce the likelihood of detecting a body, to destroy evidence and that ultimately lime will lead to the rapid and total destruction of human remains [1]. For this reason, lime is often observed in clandestine burials [2–9]. Besides the association with criminality, there are specific traditions of archaeological burial incorporating materials such as lime, chalk gypsum or a generic class, commonly referred to as plaster burials. These customs are interpreted as preservation rites or linked to disposal practices associated with safeguarding against epidemics and contagion. A cremation rite involving crushed rock carbonate was common in the iron age of the Balearic Islands [10]. Lime has been evidenced in Roman and early Christian burials [11–21], medieval burials [22–25], post-medieval burials [26–30] and during modern times in mass graves associated with conflict, including the First and Second World War, Rwanda and former Yugoslavia [31–37] or mass burials with victims of natural disasters such as tsunamis or earthquakes [38].

Lime, derived from limestone, is a generic term used to cover calcium oxide (CaO variously known as quicklime, unslaked lime

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or burnt lime), calcium hydroxide ($Ca(OH)_2$ variously known as hydrated lime or slaked lime) and non pure derivatives such as hydraulic lime.

When limestone or calcium carbonate ($CaCO_3$) is calcined at a temperature in excess of 800 °C, carbon dioxide (CO_2) evolves, resulting in a white residue of calcium oxide or quicklime (CaO). Calcium oxide is hygroscopic. It can absorb atmospheric moisture rapidly or reacts with water in a process of hydration. When water is added to quicklime, an exothermic reaction takes place to form calcium hydroxide ($Ca(OH)_2$) (Fig. 1). This can yield a dry, powdery product or, when lime slaking occurs with an excess of water, it produces a slurry of hydrated lime. Calcium hydroxide has the property to harden in reaction with carbon dioxide, a process called carbonation. On exposure to air, re-absorption of carbon dioxide by hydrated lime occurs and water is driven off, resulting in the formation once again of calcium carbonate (Fig. 1).

Lime is an alkaline product. When calcium oxide reacts with water to form calcium hydroxide, heat is released while the pH immediately reaches 12–13 and further increases over the next 30 min to pH 14.4. Therefore, contact with lime can cause several types of skin reactions from mild irritation to full thickness burns [39]. Lime is used in leather tanning processes where the depilatory effect of alkaline solutions is caused by the instability of keratin to alkalis [40]. Furthermore, lime is applied in agriculture to raise the pH and thereby reduce the acidity of soils. The addition of lime to soils will optimise the bacterial breakdown of organic matter because bacteria operate best within an optimal pH range [41]. This supports the common belief that covering a body with lime will lead to its rapid decomposition. However, the pH range tolerated by soil bacteria is generally between pH 4 and pH 10. If the soil is too alkaline, bacteria will not flourish and for this reason lime has traditionally been used in carcass disposal and during mass disasters as a disinfectant. Nevertheless, the World Health Organisation specifically advises against the use of lime as disinfectant because of its limited effect on infectious pathogens. Instead they recommend the use of chlorine solutions or other medical disinfectants [38,42,43]. Besides disinfection, various sources suggest the use of lime to reduce putrefactive odours and discourage scavenging by predators. The only published study on odours and lime suggests that lime is only effective at reducing an initial odour within the first few weeks of post-mortem [44].

The effects of lime on the decay of human remains are poorly understood, with the available information rather limited and often conflicting. The earliest experiments go back to 1932 based on a case study in Chicago [2]. Experiments with quicklime on a dead owl and pieces of beef were conducted over 4 weeks. Despite the short time frame of the experiments and the rather small subjects, Laudermilk was the first researcher who proved that lime neither destroys bodies nor accelerates decay. More than half a century later, Thew [45] studied the effect of hydrated lime on 6 buried pigs on a farm in north western Indiana (USA). Two pigs were interred for 30 months and four pigs were buried for 6 months. The results showed that hydrated lime retards the rate of decay significantly. Forbes et al. [46] investigated the effect of the burial environment on adipocere. Pig adipose tissue from the abdominal region, containing muscle and skin was studied in different burial environments over a 12 month time interval in an attempt to form adipocere. The study demonstrated that a burial environment containing lime significantly inhibits decomposition and that adipocere formation was not evident. The lime had formed a shell encasing the tissue sample and a large quantity of the original tissue remained. Finally, Schotsmans et al. [47,48] studied the effects of quicklime and hydrated lime on pig cadavers buried for 6 months and in laboratory conditions. The results suggested that quicklime initially accelerates the decay process but that general decomposition is slowed down by both quicklime and hydrated lime over a time period of 6 months [47,48].

The study presented here is complementary to the analyses of Schotsmans et al. [47,48]. The major focus of this study was modelling lime burials in field experiments over a period of 17 and 42 months. The macroscopic and microscopic effects were investigated in conjunction with the microbiological and taphonomic changes. The results were compared to the former 6 months field study [47] and to further laboratory experiments with complete limed and unlimed carcasses [48].

2. Materials and methods

2.1. Field site

The field experiments were started in 2008 on land owned by the Belgian Military in Meerdaal wood, near the city of Leuven in

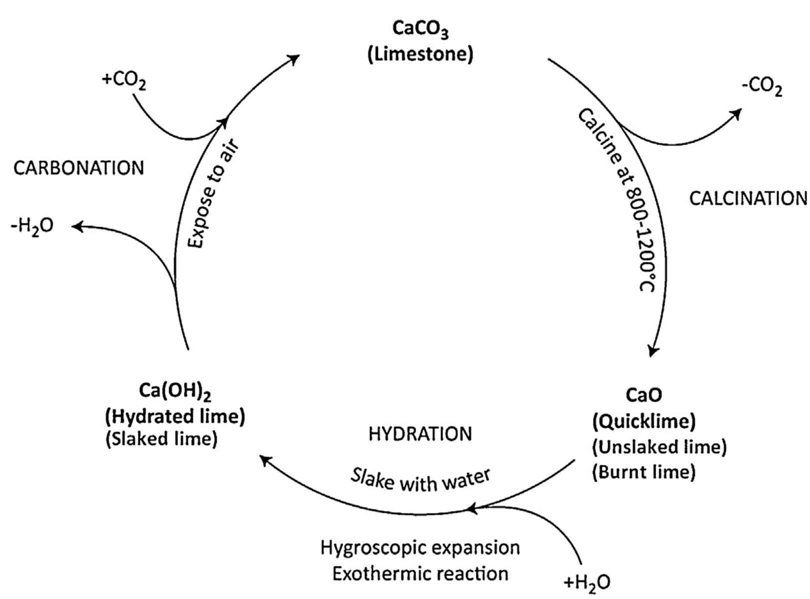

Fig. 1. The lime cycle.