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The effect of soil type on adipocere formation

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Abstract

Adipocere refers to a postmortem product which forms from body fat in the later stages of decomposition. Factors present in the surrounding decomposition environment will influence adipocere formation and may accelerate or retard the process of conversion. One such factor important in burial environments is the type of grave soil in which the burial has taken place. This study was conducted to investigate the influence of various soil types on the formation of adipocere in grave soils. X-ray diffraction and particle size analysis were used to characterise the soils which were essentially chosen on the basis of grain size. Infrared spectroscopy, inductively coupled plasma-mass spectrometry, and gas chromatography–mass spectrometry were used to investigate the lipid profile and chemical composition of adipocere developed from decomposing tissue. The results suggest that adipocere is able to form in various soil types and that particular soil environments may accelerate its formation.
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1. Introduction

Adipocere is the soap-like substance that can form from the neutral fats of decomposing bodies and is well known as a later postmortem change. Adipocere formation has the ability to slow or inhibit decomposition; as such an understanding of the mechanism of its formation in grave soils is of interest to forensic scientists. Several investigations have been carried out previously in an attempt to determine the factors that affect adipocere formation [1,2], however all of these investigations involved the formation of adipocere in water. To date, only minimal research has been conducted involving adipocere formation in grave soils [3,4]. The purpose of the current study was to investigate the effect of grave soil type on adipocere formation.

Adipocere formation is characterised by the hydrolysis and hydrogenation of fatty tissue into a mixture of predominantly saturated fatty acids (mostly myristic, palmitic and stearic acids). In addition, unsaturated fatty acids (oleic and palmitoleic acid), calcium salts of fatty acids, hydroxy and oxo fatty acids have all been identified as constituents of adipocere [5–7]. However, their presence appears to be dependent on the factors present in the decomposition environment. The optimum conditions for the formation of adipocere have been suggested to be a damp, warm, anaerobic environment [3]. It was once thought that adipocere required immersion in water or waterlogged burial conditions for its development, however, more recent studies have shown that the water required for hydrolysis can be derived mainly from the body's tissues [8,9]. Hence, the

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body contains sufficient water to induce adipocere formation, even in a dry soil environment.

In 2000, Stuart et al. [10] used infrared spectroscopy to analyse soil samples that were known to contain adipocere. This qualitative technique allowed for the identification of the presence of adipocere as well as the determination of its general composition. Infrared spectroscopy was also found to be useful for the identification of calcium salts of fatty acids that occur concomitantly. A more recent paper on adipocere published by this research group utilised GC–MS to identify adipocere in grave soils and characterise its chemical composition [11]. X-ray diffraction was also used to characterise the mineral nature of the soil.

Five main techniques were used for the analysis of samples as part of this study. X-ray diffraction (XRD) was employed to determine the mineral composition of the individual soil samples. Particle size analysis was utilised on representative soil samples to provide an identification of soil type. Infrared spectroscopy was used to provide a preliminary lipid profile of the adipocere samples as well as identifying the fatty acid salts. Inductively coupled plasma-mass spectrometry (ICP-MS) further confirmed the presence of salts of fatty acids within the adipocere by identifying the major cations. Finally, gas chromatography–mass spectrometry (GC–MS) was employed as the confirmatory test for the identification of adipocere in grave soils.

2. Materials and methods

2.1. Adipocere formation

In order to determine the effect of soil type on adipocere formation, experiments were conducted in a laboratory environment so that the individual variables could be adequately controlled. The formation of adipocere was critical for this study and the experiments required the addition of those factors known to enhance adipocere formation (e.g. sufficient adipose tissue, moisture, bacteria, and an anaerobic environment). The study utilised large decomposition containers which included a tap for draining purposes and an airlock seal for the release of gases present within the container. The airlock seal was designed so that external air could not enter the container, thus ensuring the internal environment became anaerobic.

Ethical restrictions in Australia prevent the use of human tissue in decomposition trials and current considerations are that decomposing pigs are the next most reliable model [12,13]. Samples of tissue were obtained from domestic pigs which were reared on a pig farm for commercial use. A sample of pig adipose tissue collected from the abdominal region and still containing some muscle and skin was used for each experiment. A control sample was initially prepared utilising common soil with a loamy sand composition. The experiments were prepared using various soil types, namely sand, silty sand, clay and sterilised soil in place of the soil type used in the control. The sterilised soil utilised the same type of soil as the control soil but was heated to 200 °C for 12 h to destroy most of the soil bacteria.

Each soil type was placed within a container and the fatty tissue completely covered with soil until sufficiently buried. Although studies have shown that sufficient moisture is present within adipose tissue to form adipocere, the soil was kept damp to ensure adipocere formation occurred. The containers were held at room temperature which averaged approximately 22 °C for the 12 month duration. Three replicates of the control and each soil type were prepared to enable interpretation of the results.

2.2. Sample collection

The experiments were conducted for a period of 12 months. During this time, the containers were regularly monitored to ensure the internal environment remained anaerobic and the soil remained damp. Upon completion of the study, the containers were opened and the adipocere formation documented in situ. Samples of adipocere were collected from each replicate soil environment and placed in a specimen container for analysis.

2.3. X-ray diffraction

X-ray diffraction of finely ground soil samples was performed using a Siemens D5000 θ–θ diffractometer. A Cu target X-ray tube ($\lambda = 1.5406$ Å) was used to focus radiation onto the sample through a 2 mm divergence slit. The radiation was diffracted by the sample through a 0.2 mm receiving slit and recorded by the detector. The diffractometer contained a 2 mm anti-scatter slit to reduce background noise. Nine hundred Watts of power was used resulting in a 5% efficiency rate to the detector.

2.4. Particle size analysis

The oven-dried (105 °C) soil samples were initially split using a sample splitter so as to obtain a representative sample. Approximately 150 g of split coarse material was placed into a 250 μm sieve and shaken through successively smaller sieves until the entire sample had fallen through. The exact particle size of the coarse material was able to be determined from the size of the sieve used and the percentage of material retained. The fine material (<0.5 μm) was analysed using a particle size analyser. The machine was calibrated using a 66 μm standard. Following the calibration, the background was measured to subtract any excess noise from the sample results. Several milligrams of sample were placed into distilled water in an ultrasonic bath and stirred. The sample was analysed by the flow of the suspended material through a laser beam and the particle size identified. The analysis utilised a Malvern S2600 Particle Size Analyser with a size range of 0.5–564 μm. The laser transmitter contained a 2 mW He–Ne laser with 633 nm

wavelength, 9 mm beam expansion and spatial filtering. A Fourier transform lens with 100 mm focal length was used as the receiver.

2.5. Infrared spectroscopy

Approximately 2 mg of adipocere was ground together with approximately 10 mg of powdered potassium bromide (KBr) using a mortar and pestle. The background spectra were run using approximately 20 mg of powdered KBr. All spectra were referenced to KBr. The samples were investigated using a Nicolet Magna-IR 760 Fourier transform spectrometer equipped with a DTGS detector. Each sample was diluted with KBr and placed in a Spectra-Tech microsampling cup for analysis. Reflectance spectra were obtained using a Nicolet diffuse reflectance infrared sampling accessory and the spectra were scanned over the frequency range 4000–500 cm^{-1}. For each sample, 64 scans were recorded with a resolution of 4 cm^{-1}. All spectra were collected using Omnic software.

2.6. Inductively coupled plasma-mass spectrometry

Five milligrams of adipocere was accurately weighed into a plastic screw-top tube and 300 μl each of concentrated HNO_3 (BDH Laboratory Supplies, UK), concentrated HCl (Riedel-de Haen, Germany) and H_2O_2 (BDH) added. The sample was heated for 30 s and allowed to cool. Upon cooling, the sample was diluted to 10 ml using distilled water. The analysis was carried out using a Perkin-Elmer SCIEX ELAN 5100 inductively coupled plasma-mass spectrometer featuring a Plasmalok plasma-mass spectrometer interface and Perkin-Elmer FIAS-400 flow injection system. All samples were injected using a Perkin-Elmer AS-90 autosampler and the data analysed using ELAN software.

2.7. Gas chromatography–mass spectrometry

Two milligrams of adipocere sample was accurately weighed into a sterilised reacti-vial. One millilitre of chloroform (BDH Laboratory Supplies, UK) was added and the mixture sonicated for 15 min. The chloroform layer was drawn off and placed in a sterilised screw top tube. Approximately 250 μl of hexamethyldisilazane (HMDS) (Sigma–Aldrich, Australia) was added to form the trimethylsilyl esters of fatty acids and the tube heated at 70 °C for 15 min. Upon cooling, an aliquot was removed and placed in a vial for analysis by GC–MS.

All analyses were performed on a Hewlett Packard 5890 Series II Gas Chromatograph coupled with a Hewlett Packard 5970B Series Mass Selective Detector. A 1 μl aliquot of the sample was injected into a DB5-MS (J&W Scientific, USA) fused-silica capillary column (30 m × 250 mm × 0.25 μm, 5% phenylmethylpolysiloxane). The carrier gas was helium at a column pressure of 100 kPa. The initial column temperature was 100 °C and the initial time was 1 min. The temperature was then increased at 7 °C min^{-1} to 275 °C where it was held for 5 min. All injections were in the splitless mode using a HP 7673 autosampler injector. The analysis was conducted in selected ion monitoring mode, and identified those fatty acids known to comprise adipocere. The saturated fatty acids considered were myristic, palmitic, stearic, and 10-hydroxy stearic acid. The unsaturated fatty acids, palmitoleic and oleic acid were also considered because of their occasional presence in low concentrations. Peaks relating to the trimethylsilyl esters of the fatty acids were identified by comparison of their retention time and mass spectra against the NIST98 Mass Spectral Library.

3. Results

3.1. Adipocere formation

All of the soil types investigated were able to form adipocere to varying degrees. The control soil environment converted the entire adipose tissue sample to adipocere. Similarly, the silty sand environment produced adipocere with a mass almost identical to that of the original adipose tissue. The sandy environment produced adipocere with a slightly reduced mass when compared to the original tissue. Both the clay and sterilised soil environments also formed adipocere with a reduced mass.

3.2. Soil characterisation

X-ray diffraction was employed to analyse the mineral content of the soil matrices. A representative sample of the soil matrix was collected for analysis prior to the commencement of the experiment.

The principal soil used for the control and sterilised soil was a manufactured product purchased from a landscape supplier and was described as a 'loamy sand soil'. The X-ray diffraction analysis identified mainly quartz with some anorthite, and small amounts of the secondary clay mineral, illite. The presence of illite in the soil allows for cation exchange between the soil and adipocere, with a concomitant effect on the calcium and magnesium salts of fatty acids often identified in adipocere. The sand was described commercially as 'Sydney River washed sand' and the silty sand, another manufactured product, described as 'yellow brick sand'. X-ray diffraction analysis identified quartz as essentially the only mineral present in both soil types, however it is possible that very minor quantities of iron oxides and/or kaolinite could have been present as coatings. Analysis of the commercially prepared 'clay' soil samples identified quartz as the predominant mineral however significant quantities of the secondary clay minerals were also identified. These minerals included illite, kaolinite and montmorillonite.

The particle size analysis was used to describe the various soils and classify their type in a general sense. Particle sizes

in natural sediments and manufactured soils are likely to be best referenced to the Wentworth Scale of particle sizes [14]. Although the control and sterilised soil was described as a 'loamy sand soil', the particle size analysis identified different attributes. The soil contained high proportions of both medium and coarse sand as well as a moderate proportion of silt. Using the Wentworth Scale [14], the soil was more correctly classed as silty medium-coarse sand. The soil sample had a relatively non-uniform composition and a large range of particle sizes. For the purpose of this paper, the silty medium-coarse sand will simply be called 'soil' because of its representative nature.

The nature of the 'sand' sample matrix was confirmed by particle size analysis to contain fine to medium size sand particles. The sample had a uniform composition and a very narrow particle size range. The sample was classed as a fine-medium sand using the Wentworth Scale.

The silty sand matrix was used to represent another instance of commonly occurring particle size distribution and was found to be comprised of large proportions of fine-medium sand and smaller proportions of silt. The silty sand was more correctly classed as silty fine-medium sand, but is referred to as a 'silty sand' for the purpose of this paper.

The clay did not contain enough small particles to class it strictly as a true clay. It was determined to be a clayey fine-very fine silt but herein will be referred to as 'clay'. The clay matrix represents a material consistent in particle size at the very fine end of the natural soil particle size spectrum.

The description of soils by predominant reference to particle size is inexact. The variability of soil sizes and textural systems in use worldwide, and the variable nature of the mineral matrix of soils because of oxide aggregates, precipitated deposits and particle coatings accounts for this situation. The initial approach taken by this research group was the use of the Wentworth Scale [14] to describe the soil type. However, it is considered that *natural* soils—with a particular focus in the forensic context, may be more usefully described by an alternate, internationally recognised standard. The United States Department of Agriculture (USDA) texture class scheme could provide an alternative system; these matters are further discussed by Murray and Tedrow [15]. The USDA scheme can also be used for natural transported materials (sediments, colluvium, talus), but probably not for 'fill'.

3.3. Infrared spectroscopy

An infrared spectroscopic analysis was conducted on the adipocere samples collected from each soil environment and a characteristic spectrum used to demonstrate a preliminary lipid profile. Fig. 1 illustrates the infrared spectrum characteristic of the adipocere identified in the control soil environment. A high concentration of saturated fatty acids was indicated by a band at 1700 cm^{-1}. A broad band representative of hydroxy fatty acids was observed at 2673 cm^{-1} whilst small amounts of salts of fatty acids were present in the region 1576–1540 cm^{-1}. A small shoulder attributable to =C–H stretching of unsaturated fatty acids was noted at 3017 cm^{-1}. The lipid profile, as determined by the infrared spectrum, suggested that substantial adipocere formation had occurred in the control soil environment.

Fig. 2 illustrates the infrared spectrum characteristic of the adipocere identified in the sandy environment. The spectrum contains strong C–H stretching bands in the region 2950–2800 cm^{-1} and strong bands attributable to salts of fatty acids in the region 1576–1540 cm^{-1}. A small band at

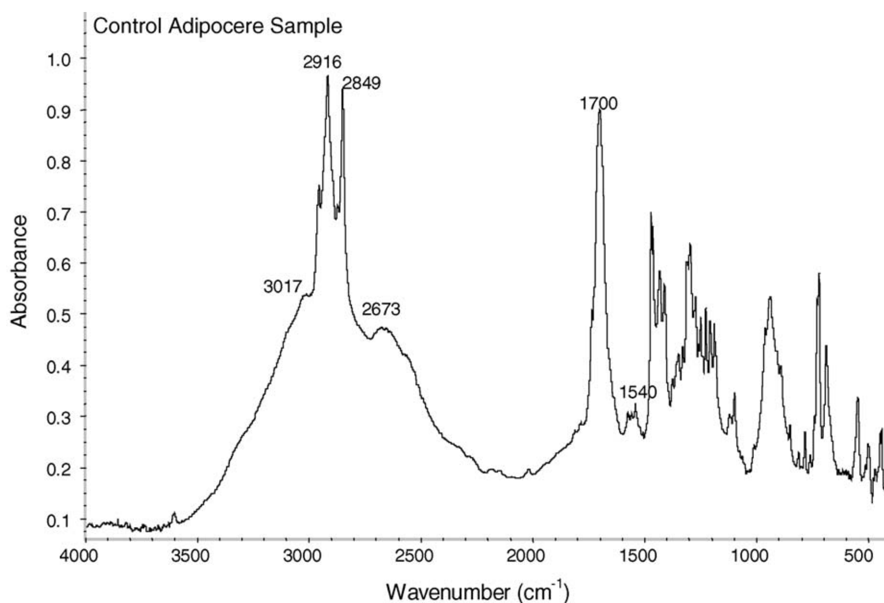

Fig. 1. Characteristic infrared spectrum of adipocere formed in a control soil environment.

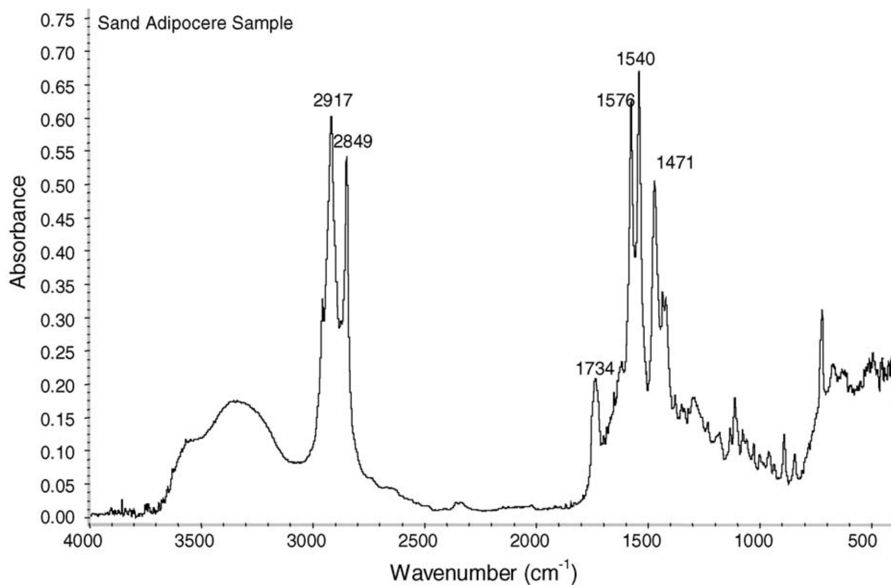

Fig. 2. Characteristic infrared spectrum of adipocere formed in a sand environment.

1734 cm^{-1} is evidence of triglycerides still remaining in the sample and may account for the reduced mass which formed. Fewer bands are observed in the region 1450–600 cm^{-1} as the sand matrix is inorganic in nature and contains only one component. The lipid profile established the presence of adipocere in the sandy environment.

Fig. 3 illustrates the infrared spectrum characteristic of the adipocere identified in the silty sand environment. A strong saturated fatty acid band is visible at 1700 cm^{-1}. Salts of fatty acids are also observed at 1576 and 1539 cm^{-1}, respectively, whilst a small shoulder at 2669 cm^{-1} represents hydroxy-fatty acids. The spectrum lacks any bands relating to triglycerides but a small amount of unsaturation is visible at 3019 cm^{-1}. A greater number of bands were observed in the range 1450–600 cm^{-1} of this spectrum, when compared to the sand spectrum, due to variations in soil parameters.

Spectroscopic analysis demonstrated the presence of adipocere in the clay soil environment. Fig. 4 illustrates an infrared spectrum characteristic of the adipocere samples

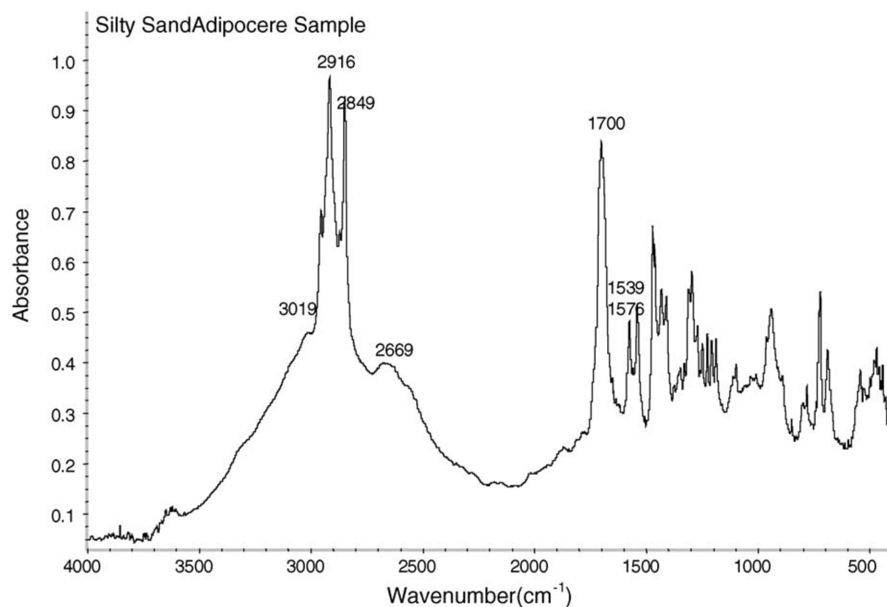

Fig. 3. Characteristic infrared spectrum of adipocere formed in a silty sand environment.

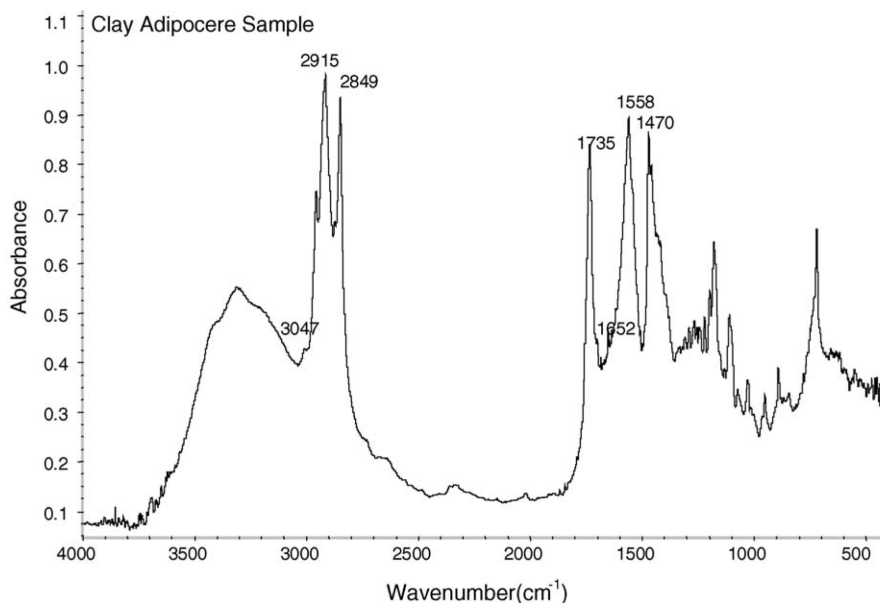

Fig. 4. Characteristic infrared spectrum of adipocere formed in a clay environment.

identified in clay. Strong bands are visible in the C–H stretching region (2950–2800 cm^{-1}) and triglyceride C=O stretching region (1737 cm^{-1}). The high concentration of triglycerides remaining in the adipocere sample may account for the reduced mass which formed. Smaller bands relating to unsaturation of fatty acids are observed at 3047 and 1652 cm^{-1}.

Fig. 5 illustrates the infrared spectrum characteristic of the adipocere samples identified in a sterilised soil environment. Moderate salts of fatty acid bands (1576 and 1540 cm^{-1}) and a moderate triglyceride C=O stretching band (1715 cm^{-1}) are visible along with strong C–H stretching bands. The spectrum lacks bands attributable to unsaturated fatty acids and demonstrates the formation of adipocere in a sterilised soil environment.

3.4. ICP-MS

The infrared spectroscopic analysis identified the presence of moderate amounts of salts of fatty acids in some of

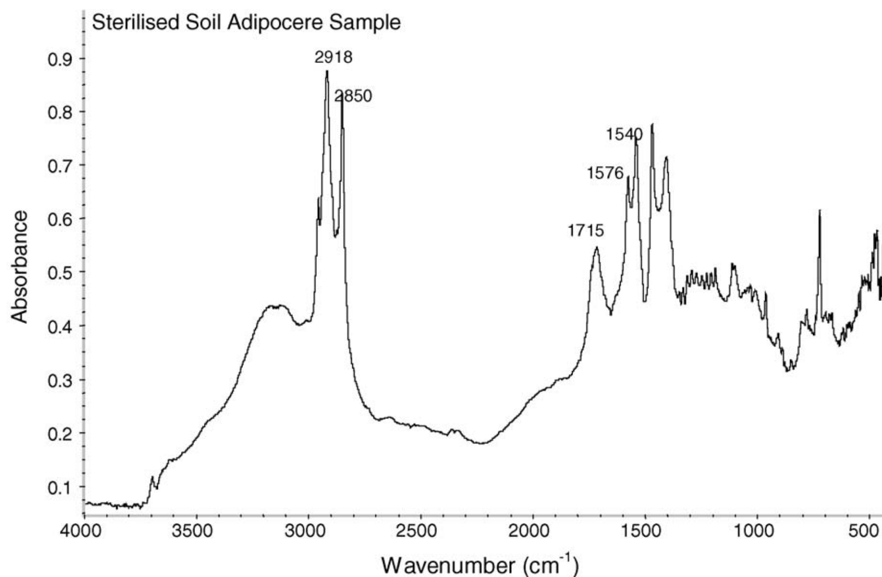

Fig. 5. Characteristic infrared spectrum of adipocere formed in a sterilised soil environment.

Table 1
Average major cation composition of adipocere samples using ICP-MS

Soil type	Na	K	Ca	Mg
Control	0.01	0.09	0.75	0.15
Sand	0.00	0.02	0.49	0.49
Silty sand	0.01	0.05	0.80	0.14
Clay	0.03	0.03	0.47	0.47
Sterilised soil	0.01	0.21	0.39	0.39

Relative abundance as a proportion of total cations determined.

the adipocere samples. The samples were subsequently analysed by ICP-MS in order to determine the major cations which were present. The cations which are thought to occur in adipocere are sodium, potassium, calcium and magnesium [16]. The absolute abundance of each cation was calculated as a concentration in ppm for each adipocere sample. These values were converted to a relative abundance value (as a proportion of the total cations of interest) and an average calculated for each soil environment.

Table 1 lists the average composition for the major cations identified in the adipocere samples. Calcium salts of fatty acids are the dominant salt in all of the samples, followed by magnesium salts of fatty acids. The relative abundances of potassium and sodium salts of fatty acids are particularly reduced in comparison.

In the early stages of decomposition, adipocere will form utilising sodium from the interstitial fluid and high concentrations of sodium salts of fatty acids are observed. As decomposition progresses, potassium salts of fatty acids become more abundant as adipocere utilises potassium from the failing cell membranes. Later stages of decomposition will result in adipocere formation containing high concentrations of calcium and magnesium salts of fatty acids as the sodium and potassium ions are displaced by minerals present in the surrounding environment. This process is called 'hardening' and results in a brittle adipocere product [16].

The adipocere samples collected from the different soil environments demonstrated a brittle quality and contain relatively high abundances of calcium and magnesium salts of fatty acids. The presence of these two salts is expected based on the extended (12 months) decomposition interval in which adipocere was able to form. The results suggest that all samples were able to undergo cation exchange with the surrounding environment during the decomposition interval.

3.5. GC–MS

GC–MS analysis was used to analyse and determine the fatty acid composition of the adipocere samples. Table 2 lists the relative percentage composition of the fatty acids identified in the samples collected from the various soil environments. The fatty acid value represents an average of three repeat measurements for each of the replicate samples collected from the soil environments. Calculating the average of each set of samples gives an indication of the adipocere composition for the various soil environments of the decomposed remains. A characteristic fatty acid composition of the original adipose tissue is listed in Table 2 for comparative purposes.

The adipocere samples which formed in the control soil environment demonstrate a composition which is high in saturated fatty acids and low in unsaturated fatty acids. Palmitic acid represents the dominant saturated fatty acid followed by stearic acid. Small quantities of 10-hydroxy stearic acid were identified in the samples. Approximately 94% of the relative composition is comprised of saturated fatty acids. The samples collected from the control environment are not chemically stable due to the remaining oleic acid which can undergo hydrogenation but are representative of adipocere.

The adipocere samples collected from the sandy environment demonstrate an even stronger saturated fatty acid composition with less than 3% of the total composition comprising unsaturated fatty acids. A higher concentration of palmitic acid is evident when compared to the control adipocere samples, and the concentration of stearic acid is reduced. The fatty acid composition for the samples which formed in the sand environment is a more chemically stable product than the control samples and is representative of a more advanced stage of formation.

Adipocere samples collected from the silty sand environment also show a fatty acid composition high in saturated fatty acids and low in unsaturated fatty acids. The concentration of oleic acid is slightly less than the control adipocere samples but not as low as the sandy adipocere samples. Similarly, the concentration of palmitic acid (the dominant

Table 2
Relative percentage (%) composition of fatty acids detected using GC–MS

	Saturated fatty acids				Unsaturated fatty acids	
	Myristic ($C_{14:0}$)	Palmitic ($C_{16:0}$)	Stearic ($C_{18:0}$)	10-Hydroxy stearic	Palmitoleic ($C_{16:1}$)	Oleic ($C_{18:1}$)
Adipose tissue	1.4	32.4	25.8	0.0	0.9	36.0
Control	5.1	58.7	29.2	1.1	0.0	6.0
Sand	3.7	74.8	16.5	2.2	0.0	2.9
Silty sand	2.6	67.6	20.7	4.1	0.0	4.9
Clay	1.8	53.3	27.9	9.3	0.0	7.8
Sterilised soil	2.4	50.4	29.5	10.6	0.1	7.0

acid) is higher than the control adipocere samples but lower than the sandy adipocere samples. An increase in the concentration of 10-hydroxy stearic acid is evident. The silty sand environment was conducive to adipocere formation and appears to have produced adipocere which is slightly more stable than the adipocere which formed in the control soil environment.

The clay soil environment yielded adipocere samples which were comparable in composition to the control adipocere samples. When compared to the control samples, the concentrations of palmitic and stearic acid are similar as are the concentrations of oleic acid. A relative increase in the concentration of 10-hydroxy stearic acid is noted when compared to the control, sand and silty sand samples. Saturated fatty acids represent approximately 93% of the total fatty acid composition but the samples are not chemically stable as hydrogenation of the remaining oleic acid may still occur.

The adipocere samples collected from the sterilised soil environment also demonstrated similar concentrations of palmitic, stearic and oleic acids when compared with the control samples, however an increased concentration of 10-hydroxy stearic acid was observed. The total concentration was dominated by saturated fatty acids demonstrating that adipocere was able to form in a sterilised soil environment. Accordingly, we speculate that adipocere formation is independent of normally resident soil bacteria. If its formation is mediated by bacterial reactions, then these are likely to originate from within the decomposing tissue.

4. Discussion

The X-ray diffraction and particle size analyses were useful in demonstrating the range of soil types used in this study and quantifying their components. The various soil types were chosen to include the extremes of the soil particle size spectrum as well as those which lay between the extremes. The results demonstrated that sufficient variations existed between the soil types, and the experiments therefore covered a broad range of soil environments.

The control environment represented the formation of adipocere in a relatively common soil type. High levels of saturated fatty acids were evidenced by the infrared spectroscopy and GC–MS results. The ICP-MS results confirmed the presence of salts of fatty acids which are known to comprise adipocere. The soil environment was representative of a common soil and the successful formation of adipocere in this environment allowed it to be classed as the control for experimental purposes.

The formation of adipocere in sand was confirmed by the high concentrations of saturated fatty acids using infrared spectroscopy and GC–MS. The infrared spectrum also demonstrated strong peaks indicative of calcium salts of fatty acids and their presence was confirmed by ICP-MS. When compared to the control adipocere samples, the adipocere which formed in a sand environment was more stable, as demonstrated by the lower concentration of unsaturated fatty acids. The product showed a more advanced stage of formation suggesting an influence by the sand environment. The well draining properties of sand may have resulted in the accelerated formation of adipocere by allowing the rapid removal of glycerol following hydrolysis of the triglycerides. Following the removal of glycerol, and in the presence of an anaerobic environment, saturated fatty acids are more readily able to undergo formation into adipocere [1]. However, it must be kept in mind that the sand environment used in this study was kept moist and at a mild temperature for the duration of the experiments. This type of environment would be representative of a temperate, sandy beach or dune environment, but not of a dry, sandy desert environment. Hence, the suggestion that a sand environment accelerates adipocere formation cannot be applied to all situations.

Similarly, the silty sand environment also demonstrated a stable adipocere product in a more advanced stage of formation. High concentrations of saturated fatty acids and low concentrations of unsaturated fatty acids combined with salts of fatty acids and hydroxy fatty acids confirmed the presence of adipocere. The moist, silty sand environment appears to have accelerated adipocere formation but not to the same extent as the sand environment.

The clay soil environment produced an adipocere product which was similar in composition to the control and sterilised soil samples. The product was less stable than the sand and silty sand adipocere samples due to the higher concentration of oleic acid and was not as advanced in its formation. The clay soil environment was successful in forming adipocere but did not appear to have any additional affect on its formation when compared with the control environment. The clay environment contained moderate proportions of silt which is not as well draining as sand and thus could account for the presence of triglycerides and its reduced formation.

The sterilised soil environment was able to form adipocere as confirmed by the infrared spectroscopy and GC–MS results. The presence of salts of fatty acids, as evidenced in the infrared spectrum, was confirmed by ICP-MS analysis. The chemical composition of the adipocere which formed in the sterilised environment was expectantly similar to the control samples. The soil type was identical for both environments and the lack of soil bacteria in the sterilised soil environment does not appear to have affected the rate of adipocere formation. This finding suggests that sufficient bacteria are present in the decomposing tissue to induce adipocere formation.

A study by Mant [1] published in 1957 which investigated the effect of soil type on adipocere formation was found to be inconclusive. However, a further study published by Mant [3] in 1987 suggested that the type of soil had little effect on the rate of decomposition of a cadaver when all other factors appeared equal. That study found that a dry, well drained soil was conducive to mummification, but a

damp soil would form adipocere regardless of the soil type. Our results appear to correlate with Mant's results [3] as adipocere was identified in all of the moist soil environments investigated as part of this study.

5. Conclusion

The results of this study have demonstrated that adipocere is able to form in a range of soil types. Particular soil types, including sand and silty sand, were able to accelerate adipocere formation when kept moist and in a temperate environment. Other types of soil, including clay, representative 'soil' and sterilised soil, had no affect on adipocere formation in comparison. This study acts as a preliminary investigation of soil type on adipocere formation. For the purposes of the study, all soils were investigated in a controlled temperate environment. The results are useful for understanding the formation of adipocere in similar soil environments, but cannot be extrapolated to soil environments which significantly differ in moisture content and/or temperature.

References

[1] A.K. Mant, Adipocere—a review, J. Forensic Med. (1957) 4.
[2] P.F.M. Mellen, M.A. Lowry, M.S. Micozzi, Experimental observations on adipocere formation, J. Forensic Sci. 38 (1998) 91–92.
[3] A.K. Mant, Knowledge acquired from post-War exhumations, in: A. Boddington, A.N. Garland, C. Janaway (Eds.), Death, Decay and Reconstruction: Approaches to Archaeology and Forensic Science, University Press, Manchester, 1987, pp. 65–78.
[4] S. Fiedler, M. Graw, Decomposition of buried corpses, with special reference to the formation of adipocere, Naturwissenschaften 90 (2003) 291–300.
[5] T.L. Bereuter, W. Mikenda, C. Reiter, Iceman's mummification—implications from infrared spectroscopical and histological studies, Chem. Eur. J. 3 (1997) 1032–1038.
[6] T. Takatori, Investigations on the mechanism of adipocere formation and its relation to other biochemical reactions, Forensic Sci. Int. 80 (1996) 49–61.
[7] F. Yan, R. McNally, E. Kontanis, O. Sadik, Preliminary quantitative investigation of postmortem adipocere formation, J. Forensic Sci. 46 (2001) 609–614.
[8] C.J. Polson, D.J. Gee, B. Knight, The Essentials of Forensic Medicine, 4th ed. Pergamon Press, Oxford, 1985.
[9] S.L. Forbes, Ph.D. Thesis, University of Technology, Sydney, 2003.
[10] B.H. Stuart, S. Forbes, B.B. Dent, G. Hodgson, Studies of diffuse reflectance infrared spectroscopy, Vib. Spectrosc. 24 (2000) 233–242.
[11] S.L. Forbes, B.H. Stuart, B.B. Dent, The identification of adipocere in grave soils, Forensic Sci. Int. 127 (2002) 225–230.
[12] M.L. Goff, Comparison of insect species associated with decomposing remains recovered inside dwellings and outdoors on the Island of Oahu, Hawaii, J. Forensic Sci. 36 (1991) 748–753.
[13] N.H. Haskell, Testing reliability of animal models in forensic entomology with 50-200 lb. pig vs. humans in Tennessee, in: Proceedings of the XXI International Congress on Entomology, Brazil, 2000 (abstract 2943).
[14] B. Craze, G.J. Hamilton, Soil physical properties, in: P.E.V. Charman, B.W. Murphy (Eds.), Soils: Their Properties and Management, University Press, Sydney, 1993, p. 166.
[15] R.C. Murray, J.C.F. Tedrow, Forensic Geology, Prentice-Hall, Englewood Cliffs, 1992.
[16] H. Gill-King, Chemical ultrastructural aspects of decomposition, in: W.D. Haglund, M.H. Sorg (Eds.), Forensic Taphonomy: The Postmortem Fate of Human Remains, CRC Press, Florida, 1999, pp. 93–106.