

**THE RATES AND PATTERNS OF
DECOMPOSITION OF PORCINE REMAINS
BURIED IN DIFFERENT SOIL TYPES IN THE
HIGHVELD OF SOUTH AFRICA**

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Declaration

I **Artem Markov** declare that this Dissertation is my own, unaided work.

It is being submitted for the Degree of **MSc(Med) in Forensic Medicine** at the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination at any other University.

A handwritten signature in black ink, appearing to read 'Artem Markov', is centered on the page.

7th day of June 2023 in Johannesburg

I dedicate this paper to Professor Jeanine Vellema,
whose kindness and favourable judgement allowed me the opportunity
to study Forensic science and discover my passion for research.

Words cannot express my gratitude for everything you have allowed me to achieve.

Abstract

Limited research is available with regards to decomposition processes of buried bodies, especially in South Africa, which has some of the highest murder rates worldwide. This study aimed to investigate the effects of endemic soil types, as well as mine tailings, which has not yet been investigated at all, on decomposition. The effects of soil pH were also noted, and the study was repeated during the warm and cold seasons to investigate the effects of weather and temperature holistically. A total of 30 piglet carcasses were buried approximately 10cm deep in containers filled with one of three soil types: dolomite, quartzite, and gold mine tailing. This experiment was repeated for the cold and warm seasons of South Africa, using 15 carcasses in each season. The carcasses were partially exhumed at regular ADD intervals (50ADD for the first 400ADD, and every 100ADD thereafter) to record their state of decomposition, capture photographs, and take soil samples. It was found that mine tailing soil promoted decomposition more than the other soil types, while quartzite restricted it the most. TBS-ADD equations with high correlation coefficients were generated for each soil type in each season. Significant differences were found between the rate of decomposition during the warm and cold seasons of South Africa in all soil types tested. Notable fluctuations in pH were observed in the quartzite and mine tailing specimens, while dolomite specimens' pH remained fairly consistent. The breadth of this research covers many unexplored aspects of subterranean decomposition in South Africa, and invites more focused investigation. It is hoped that the findings will be useful to forensic investigations involving buried remains in Gauteng province and South Africa.

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1 Introduction

Decomposition is a complex process with multiple factors affecting the body to varying degrees (Pinheiro, 2006). The two most significant factors have been found to be temperature and insect activity (Simmons *et al.*, 2010). Temperature is significant because it facilitates the activity of necrophagous microorganisms which cause putrefaction. It is also an important factor because it promotes the colonisation of the body by arthropods, with the most significant decomposer arthropods being the Dipterans (Campobasso *et al.*, 2001). Simmons *et al.* (2010) showed that in two identical scenarios of decomposition, the introduction of necrophagous Dipterans to one specimen nearly halved the accumulated thermal energy required for the carcass to decompose, as compared to the non-exposed specimen. The burial of a body greatly limits the effects of both these factors. The deeper a body is buried, the less heat it gains from solar radiation, and the harder it is for insects to gain access to the body. Previous studies have shown that buried remains decompose substantially slower than remains left on the surface (Marais-Werner *et al.*, 2018).

The decomposition of bodies is a challenge experienced by forensic experts, who investigate unnatural deaths, particularly in buried bodies. South Africa has a very high homicide rate, which reached 64.92 homicides per 100 000 residents in 1995 (Macrotrends, 2020). Steyn *et al.* (1997) found that in 1995, just over 2000 unidentified bodies were found in the province of Gauteng alone. While homicide rates have decreased substantially over the past few decades, the figure in 2017 was still very high, at 36 homicides per 100 000 residents in South Africa, which was much higher than the global average of 6.1 per 100 000 (UNODC, 2019). Concealing a body through clandestine burial is still a common practice, and a relatively simple method of concealing a murder, which would mean that the number of clandestine graves in Gauteng (and by extension of the rest of South Africa) is similarly high (Myburgh *et al.*, 2013).

Several published studies have investigated the effects of subterranean decomposition, but most of them (Haslam and Tibbett, 2009, Carter *et al.*, 2010, Simmons *et al.*, 2010) were carried out in the northern hemisphere. Taphonomic

studies (i.e., the observation and reconstruction of post-mortem events) in Africa are limited in number and need to cover a plethora of variables which influence decomposition, such as the varying climates, flora, fauna, and conditions of the soil. Furthermore, these studies have not investigated the effects of burial within mine soil. This type of soil often has an extremely low pH and very low levels of macronutrients and microorganisms (Sheoran *et al.*, 2010). These mine tailings and shafts are present through much of the southern half of Gauteng and have presented a significant health risk to communities receiving water which may have filtered through them (McCarthy, 2011). Because they are often the site of illegal mining activities, many bodies are found buried either due to a tunnel collapse, or as victims of homicide whose valuables had been stolen.

Besides mine tailing soil, other soil types common in the Johannesburg region should also be investigated, not only to compare with mine tailing soil, but also to provide an indication of decomposition patterns in more natural soil types. Quartzite is an acidic type of soil, while Dolomite is more alkaline; both soil types are commonly found within the area of Johannesburg (Stratford, 2020).

A comparison of effects of different types of soil present in South Africa, including mine tailing soil, on the rates and patterns of decomposition will not only allow for comparison to similar international studies, but will also pilot the research into the effects of mine waste on decomposition. Further development of this study will allow for more accurate PMI estimations in forensic cases involving clandestine graves in different soil types in Gauteng, South Africa.

2 Literature review

2.1 Decomposition

Decomposition is the process of a body being reduced to its constituent factors through endogenous and exogenous processes. This consists of two broad stages: autolysis and putrefaction (Di Maio & Di Maio, 2001). Di Maio and Di Maio (2001) describe autolysis as the process of cellular necrosis due to the loss of circulating oxygen and release of intracellular enzymes, while putrefaction (which is often synonymous with decomposition) is the breakdown of the body's tissues by bacteria, and has many exogenous factors, including temperature and humidity.

Autolysis is macroscopically visible through three indicators, which are also used to approximate a post-mortem interval (PMI). This approximate PMI is usually accurate to a few hours but is only possible within two days of death. The three indicators are livor mortis (intravascular pooling of blood and the resulting staining of the vascular system), rigor mortis (muscular stiffening), and algor mortis (cooling) (Di Maio & Di Maio, 2001).

2.1.1 *Livor mortis*

Livor mortis, also termed hypostasis, refers to the gravitational pooling of the blood in the vascular system, resulting in a dark purple-red discolouration of the skin, which may be mistaken for bruising. This discolouration does not occur in areas that are compressed by a surface, tight clothing, or any other source of pressure on the skin; these areas will appear lighter in colour. Hypostasis will typically become "fixed" after a period of several hours due to staining of the tissues by the degradation of haemoglobin within ruptured erythrocytes; after this, the hypostasis does not shift with the body. Because of this, it is possible to approximate the posture of the deceased shortly after their death, as well as any restrictive clothing they may have been wearing or movement of the body within the window of hypostasis (Di Maio & Di Maio, 2001).

The interval until the onset of hypostasis is extremely varied and may not commence at all under sufficiently low temperatures; the same is true for the subsequent “fixing” of said hypostasis (Saukko and Knight, 2016). Onset and fixation both tend to be accelerated by higher temperatures and slowed by lower temperatures but tends to appear within two hours of death and become fixed between eight and 12 hours post-mortem (Di Maio & Di Maio, 2001).

2.1.2 Rigor mortis

Rigor mortis refers to the stiffening of the skeletal muscles due to the breakdown of the sarcoplasmic reticulum and the resulting flooding of muscles by the calcium reserves. The actin-myosin complexes forming skeletal muscle bands engage, causing the stiffening of the muscles. Until the exhaustion of adenosine triphosphate (ATP) reserves, the stiffness will persist unless broken by an external force. This onset of rigor occurs across the body at the same rate, but due to the varying sizes of the muscle groups, smaller muscles (e.g., facial muscles) exhibit signs of rigour first, while larger muscle groups in the arms and legs exhibit it last. As with hypostasis, the onset and fading of rigor mortis is affected by temperatures, with high temperatures causing an early onset and conclusion, and lower temperatures slowing the onset and conclusion, or pausing it entirely in freezing conditions (Di Maio & Di Maio, 2001).

Saukko and Knight (2016) have observed that the onset of rigor tends to occur three to six hours after death, reaching a maximal level after 6-12 hours. This state of rigour tends to last until 18-36 hours after death.

2.1.3 Algor mortis

The inability of a dead body to regulate its internal temperature leads to it taking on the temperature of its surroundings. In most environments, this leads to a cooling of the body after death. Algor mortis is as varied as the number of environments where a dead body may be found, as well as the number of conditions it may be found in, and the possible state the body itself may be in. The rate of temperature loss will be affected by the state of dress, presence of water, the subcutaneous fat of the deceased, and the conductivity of the surface the body is laying on, among other factors (Di Maio & Di Maio, 2001).

Saukko and Knight (2016) created a rough guide using their data on rigor mortis and algor mortis to create a preliminary approximation of time since death:

- A warm (i.e., near usual body temperature) and flaccid body has been dead for less than three hours.
- A warm and rigid body has been dead for between three and eight hours.
- A cold (i.e., near ambient temperature) and rigid body has been dead for between eight and 36 hours.
- A cold and flaccid body has been dead for over 36 hours.

2.1.4 *Putrefaction*

As the biological processes of a dying body begin to fail, it becomes more susceptible to other organisms that begin to use it for sustenance. The microbiome of the digestive tract will proliferate and rapidly expand beyond the lining of the intestines, causing a dark discolouration over the abdomen (particularly the lower right quadrant). As this gut microbiome and other microorganisms throughout the body continue to multiply and feed on the body, they produce gases that permeate the body's tissues, causing them to bloat. The anaerobic bacteria spread throughout the circulatory system and lyse the haemoglobin within the erythrocytes to create a pigment-like chemical called sulphhaemoglobin. This chemical stains the blood vessels, causing a superficial effect known as "marbling", where the vessels become dark, and are visible through the skin. The internal pressure from the gases within the body causes the liquefying tissues to be purged from the openings of the body (the nose, mouth and anus), while also voiding the bowels, bladder, and possibly even the uterus (Di Maio & Di Maio, 2001, Saukko and Knight, 2016).

By this stage, it is very likely that the body has been colonised by several necrophagous Dipteran species (i.e., flies). The presence of these maggot colonies accelerates the decomposition process, not only because of their voracious feeding habits, but also due to the proteolytic enzymes they secrete and the heat they generate as they feed and metabolise. Localised oedemas and gaseous accumulations will result in the formation of blisters and skin and hair slippage across the body. By this time the skin will have progressed through a greenish shade and into a black one. It should be noted that the internal organs will not necessarily

decompose at the same rate as the skin, or even uniformly among themselves. While the digestive system (especially the pancreas and intestines) will likely begin autolysing within hours of death, the brain will take up to a week before losing structural integrity, liquefying within a month. Other organs such as the heart, prostate or uterus may endure for much longer, and be recognisable even in a partially skeletonised body (Di Maio & Di Maio, 2001, Saukko and Knight, 2016).

2.1.5 External influencers of decomposition

As more time passes, the effects of the environment and its numerous biotic and abiotic factors accumulate, which makes creating a standardised model of decomposition more difficult, and the estimated PMI range becomes larger. Autolysis and putrefaction both share a similar relationship with temperature. These processes are largely halted by freezing and become more rapid as temperature increases until the ideal temperature (varying depending on necrophagous organisms) is reached. Beyond the ideal temperature range, the proteolytic enzymes denature and the necrophagous organisms are unable to flourish, resulting in mummification (Di Maio & Di Maio, 2001, Prangnell and McGowan, 2009). Some species are resistant to either end of the temperature spectrum but they are in the minority. Instances of brief “hibernation” have been recorded in some Dipteran species, where eggs may not hatch and mature larvae may delay pupation if conditions change so as to no longer be favourable. This is particularly visible in species which are dominant in lower temperatures and is a mechanism that allows them to survive brief dips in temperature beyond their range, such as nightly drops in temperature or cold snaps (Campobasso *et al.*, 2001).

Water and humidity are another chief abiotic factor affecting decomposition. Necrophagous Dipterans will only deposit their offspring on remains they deem suitable for the sustenance of their young. The ideal cadaver is moist enough to prevent desiccation and is protected from direct sunlight and rainfall (Campobasso *et al.*, 2001). Remains left out in direct sunlight and/or in an arid environment are likely to desiccate very quickly and not be an attractive food source for the necrophagous Dipterans. Necrophagous bacteria found in the soil also benefit from a higher moisture content to enable their motility but, depending on the soil type, an

excessive amount of moisture may also act as a detriment by reducing gaseous perfusion, thereby inhibiting aerobic processes (Carter *et al.*, 2010).

It is important to note that while Dipterans are the most forensically significant family, they are not the only arthropods found on a decaying body. Certain Coleopterans (beetles), such as Dermestidae, may be present to feed on desiccated tissue, while others, such as the Silphidae, may be present to prey on the fly larvae. Some other orders, such as ants and wasps, may opportunistically feed on the necrophagous insects, or the body itself, although their presence tends to have a net negative effect on the rate of decomposition. As with the Diptera, their level of activity greatly depends on temperature (Campobasso *et al.*, 2001)

2.2 Quantifying decomposition

2.2.1 Total body score

The progression of decomposition of a human body and the different patterns thereof has been described by Galloway *et al.* (1989) and subsequently quantified by Megyesi *et al.* (2005) into four phases (fresh, early decomposition, advanced decomposition, and skeletonization) with several stages within each phase. Each stage has a progressively larger numerical value and describes the visible signs of decomposition, with the values assigned to the head, the trunk, and the limbs. Each of the three body region scores are added together into a Total Body Score (TBS) (Table 2.1, Table 2.2, and Table 2.3). This quantification of the observable decompositional changes a body undergoes provides the possibility of statistical analysis of the process of decomposition in various circumstances and scenarios, as well as providing a basic, standardised method of describing a body's state of decomposition. This is an invaluable tool for consistent comparisons across different studies. Further studies have since been carried out to provide insight into how these descriptors change in the event of a burning (Keyes, 2016, 2019) or a submersion (van Daalen *et al.*, 2017).

Table 2.1: Categories and stages of decomposition for the head and neck of a human (Megyesi et al., 2005)

A. Fresh	
1 pt	Fresh, no discolouration
B. Early decomposition	
2 pts	Pink-white appearance with skin slippage and some hair loss
3 pts	Grey-green discolouration; some flesh still relatively fresh
4 pts	Discolouration and/or brownish shades, particularly at edges; drying of nose, ears, and lips
5pts	Purging of decompositional fluids out of eyes, ears, nose, mouth; some bloating of face and neck may be present
6pts	Brown-black discolouration of flesh
C. Advanced decomposition	
7 pts	Caving in of flesh and tissues of eyes and throat
8 pts	Moist decomposition with bone exposure <50% of area being scored
9 pts	Mummification with bone exposure <50% of area being scored
D. Skeletonisation	
10 pts	Bone exposure >50% of area being scored, with greasy substances and decomposed tissue
11 pts	Bone exposure >50% of area being scored, with dessicated or mummified tissue
12 pts	Bones largely dry, but retaining some grease
13 pts	Dry bone

Table 2.2: Categories and stages of decomposition for the trunk of a human (Megyesi et al., 2005)

A. Fresh	
1 pt	Fresh, no discolouration
B. Early decomposition	
2 pts	Pink-white appearance with skin slippage and marbling present
3 pts	Grey-green discolouration; some flesh relatively fresh
4 pts	Bloating with green discolouration and purging of decompositional fluids
5 pts	Post-bloating following release of abdominal gases, with discolouration changing from green to black
C. Advanced decomposition	
6 pts	Decomposition of tissue producing sagging of flesh; caving in of abdominal cavity
7 pts	Moist decomposition with bone exposure <50% of area being scored
8 pts	Mummification with bone exposure <50% of area being scored
D. Skeletonisation	
9 pts	Bones with decomposed tissue; sometimes body fluids and grease still present
10 pts	Bone exposure >50% of area being scored, with body fluids and grease still present
11 pts	Bones largely dry, but retaining some grease
12 pts	Dry bone

Table 2.3: Categories and stages of decomposition for the limbs of a human (Megyesi et al., 2005)

A. Fresh	
1 pt	Fresh, no discolouration
B. Early decomposition	
2 pts	Pink-white appearance with skin slippage of hands and/or feet
3 pts	Grey-green discolouration; marbling; some flesh still relatively fresh
4 pts	Discolouration and/or brownish shades, particularly at edges; drying of fingers, toes, and other projecting extremities
5 pts	Brown-black discolouration, with skin having a leathery appearance
C. Advanced decomposition	
6 pts	Moist decomposition with bone exposure <50% of area being scored
7 pts	Mummification with bone exposure <50% of area being scored
D. Skeletonisation	
8 pts	Bone exposure >50% of area being scored, with decomposed tissue and grease still present
9 pts	Bones largely dry, but retaining some grease
10 pts	Dry bone

These tables are based on observations of 68 human cases found either indoors or outdoors, with the majority (59%) found wearing clothing, and two were found with apparent attempts at concealing the body within a sleeping bag that had been tied shut (outdoor case), or underneath several blankets and sleeping bags (indoor case) (Megyesi *et al.*, 2005). Importantly, cases with missing limbs, or ones where the bodies had been buried, burned, or submerged, had been excluded from the study to provide a standardized view of the whole body. This limits the table to describing the decomposition of remains that have not been altered in any of the aforementioned ways (Megyesi *et al.*, 2005).

2.2.2 Accumulated Degree Days

Megyesi *et al.* (2005) also compared the TBS score to the total thermal energy a body has accumulated. This was done by adding the daily average temperatures (in °C) from the period of body placement until the date of “discovery”, while treating any

negative temperatures as 0 degrees Celsius [Thermal energy = Mean temperature on day 1 + Mean temperature on day 2 + ... Mean temperature on day n]. The unit developed for measuring this thermal energy is Accumulated Degree Days (ADD). Depending on the fly species present, decomposition may stop when temperatures drop as low as 6-10°C, but anecdotal evidence suggests that due to the salt concentration of the body, decomposition may progress as low as 0°C (Vass *et al.*, 1992; Megyesi *et al.*, 2005). Due to this uncertainty, it is difficult to confirm whether temperatures below 10°C contribute to the progression of decomposition or not. As a standard, 0°C is used as a baseline temperature.

During their studies in the United States, Megyesi *et al.* (2005) showed that approximately 85% of the changes during decomposition can be attributed to the thermal energy a body has absorbed. This theoretically allows one to determine the PMI by summing the average daily temperatures until the ADD corresponds to the TBS the body has reached (using an established equation). This study was limited by the fact that over 90% of its sample had a PMI from two to 75 days, reducing the reliability beyond this range. Moffat *et al.* (2016) subsequently provided a more correct ADD-derived PMI calculation by altering the formulae used by Megyesi *et al.* (2005) to reduce mathematical errors.

Myburgh *et al.* (2013) showed that in a South African context, only approximately 62% of decompositional changes were accounted for by ADD, with only one specimen out of 16 (6.25%) having an estimated PMI within a 95% confidence interval of the actual PMI. This shows that in the context applied in the Myburgh *et al.* study (i.e., an exposed body in an open grassland in South Africa), solely relying on TBS and ADD to determine the time since placement of the body would be very misleading due to the wide variability in the decomposition rate and process.

2.3 Decomposition within a buried environment

2.3.1 Biotic factors

Prangnell and McGowan (2009) have demonstrated that a burial as shallow as one metre has a substantial effect on the seasonal temperature fluctuation experienced

on a body, reducing the maximum temperature by 3°C and increasing the minimum temperature by 3°C. Decreasing mean temperature was shown to have slowed the development of any insects that may have colonised the body, as well as limiting the influence of most necrophagous bacteria. The insects most substantially involved with the decomposition of dead tissue are the Dipterans, or flies. It has been demonstrated that flies are able to colonise buried bodies up to depths of around 30cm, but no more than 60cm (Campobasso *et al.*, 2001). This may explain the decrease in the rate of decomposition observed by Marais-Werner *et al.* (2018); since post-bloat stages of decomposition are accelerated by Dipteran activity, an absence of this biotic factor will greatly slow the rate of decomposition compared to that of surface remains.

If a body was buried after exposure to Dipterans, the development of the larvae continued, but was significantly slowed ($p=0.0016$) (Simmons *et al.*, 2010). However, large maggot masses have been documented generating a substantial amount of heat. The effects of putrefaction due to the activity of aerobic and anaerobic microorganisms present within the body and the soil can also increase the temperature of a decomposing body above that of the surrounding soil, which can allow temperature-dependant organisms to flourish (Campobasso *et al.*, 2001).

Tumer *et al.* (2013) showed that a plethora of micronutrients circulating within the food chain of each soil type's ecosystem, as well as the micronutrients added by the decomposing remains will contribute to the condition of the soil after burial, as well as the traits of decomposition shown. Tumer *et al.* (2013) also stressed the significance of the structure of the soil in its effects on a body's decomposition, such as its ability to drain water and circulate air.

Carter *et al.* (2007) pointed out that a decaying body acts as a focal point of nutrient circulation, as it is a site of scavenging by necrophages, predation upon said necrophages, and a dumping site for any waste material these creatures may leave behind (including faecal matter, puparia, and dead insects). This means that the dead body's effects on its surroundings go beyond the nutrients within it and the body's state and rate of decay are in turn dictated by the extent to which biotic factors can interact with it.

2.3.2 Abiotic factors

Factors which affect a buried body to a similar or greater extent than a body on the surface are humidity and soil pH. Carter *et al.* (2010) have shown that the water content in soil has a strong influence on the rate of a body's decomposition, as it affects the motility of microorganisms, as well as the supply of oxygen to the microbiome (the decomposing body). The above research also suggested that the water content in soil affects the pH of the soil to a great degree; a finding which reiterates the complex and co-dependent nature of decomposition. Furthermore, a higher soil water content allows temperatures at the surface to affect the temperature of a body more easily in a shallow grave due to the thermal conductivity of water (Dimitrakopoulos & Martin, 1994). Carter *et al.* (2010) also found that Ninhydrin-reactive nitrogen (NRN) was the most reliable indicator of a decomposing body when tested across four soil types found in Queensland, Australia. This is a valuable finding, as it would provide a non-invasive, rapid technique for sampling large areas of terrain, if the means to perform this sampling were readily available.

Benninger *et al.* (2008) found that a body decomposing on the surface does not significantly affect the water content of the underlying soil. This suggests that a buried cadaver also would not significantly affect the water content of the surrounding soil. In the event of a poorly drained, anaerobic environment, Hopkins *et al.* (2000) found that the soil would become significantly more acidic due to a lack of buffer molecules in the soil, which would affect the diversity of the cadaver's microbiome.

Hill and Pokines (2022) found no significant impact upon decomposition when comparing remains buried at 20cm, as compared to remains buried at 60cm. This study noted a significant impact upon decomposition when the remains were wrapped in a plastic bag, which artificially limited access by invertebrates and soil microorganisms.

Soil with a lower pH (acidic) was found to stimulate decomposition to a greater degree than alkaline or neutral soil when the water content is equal, although the organic composition of the soil is also an important factor (Haslam & Tibbett, 2009). Furthermore, as the body decomposes, the ionic fluids within are released into the

environment, which can affect the pH of the environment. Haslam and Tibbett (2009) found that the soil surrounding a decomposing piece of sheep flesh (*Ovis aries*) initially became more alkaline but gradually reduced to a pH below the starting level. In contrast, Iancu *et al.* (2018) found that when they buried a whole rat (*Rattus norvegicus*) within it, the soil only became more alkaline. This difference may be because the study by Haslam and Tibbett extended over six weeks, while Iancu *et al.* (2018) only gathered data over a period of 30 days. It is possible that the latter study was too short to observe the rise in acidity. Other possibilities include the different species used, as well as the difference in the state of the interred remains: Haslam and Tibbett (2009) used 1.5g of skeletal muscle tissue, while Iancu *et al.* (2018) used an entire rat body.

2.4 Soil types prevalent in Johannesburg

Johannesburg's soil layout is almost entirely represented by two types: dolomite in the north, and quartzite in the south (Stratford, 2020). This has been confirmed by Rösner and van Schalkwyk (2000) and de Beer (1986), respectively. Stratford (2020) further indicated that while some other forms of shale and gold-bearing conglomerates are present, they are largely lithified, very thin, or *ex situ*, which makes finding pure samples very difficult. This means that a body buried in Johannesburg would very likely be interred within either of these two soils, or a mixture of the two.

Quartzite is a form of metamorphosed sandstone and is more acidic. It is also very slow to weather (Foth, 1990). It tends to break down into a medium sandy loam with a relatively high water retention, but has a lower micronutrient count (Fey, 2010). This soil was observed to have very fine grains.

Dolomite is a carbonate type and is more alkaline (Foth, 1990). It tends to break down into a clay with a slightly lower water retention than the quartzite derivative. Dolomite also has a high buffer capacity (including iron, magnesium, and potassium cations) that resists changes to pH from pollutants and tends to have more

micronutrients, such as manganese and copper (Fey, 2010). This soil's grains were observed to be more large .

Mine tailings in South Africa are usually covered up with the topsoil that was removed when they were first drilled or excavated. The remains of the ore after metal was extracted is consolidated, forming man-made hills known as mine tailings. Depending on the mineral extracted and the means of extraction, these tailings may require additional treatment to facilitate future vegetation growth (Fey, 2010). Gold mine tailings become extremely acidic due to pyrite oxidation and require lime treatment to become viable soil for vegetation to grow in to prevent future weathering (Fey, 2010). Inadequate liming can result in the pyrite oxidating to form sulphuric acid, which can drain through the soil and dissolve heavy metals such as uranium, making the soil even more hazardous, as well as polluting nearby groundwater sources and even major river systems, such as the Vaal river (Rösner and van Schalkwyk, 2000, McCarthy, 2011).

2.5 Confounding factors in PMI estimation

2.5.1 *Adipocere*

In sufficiently humid environments, burial in all soil types (very sandy and very clay-like) is conducive to the formation of adipocere, which is a fat-based residue deposited on the exterior of a decomposing body due to the breakdown of internal fat stores (Forbes *et al.*, 2005). This mechanism occurs via hydrolysis of the body's internal fat stores by anaerobic bacteria such as *C. perfringens* and is, therefore, more prominent in individuals with a higher body fat content. Since the process of hydrolysis consumes water, the body tissues are effectively dehydrated and further preserved by the fatty acids, which reduces the pH of the underlying tissues (oleic, palmitic, and stearic acids) (Di Maio & Di Maio, 2001; Saukko & Knight, 2016).

Forbes *et al.* (2005) performed an experiment wherein fatty tissue from a pig abdomen was buried in four different soil types, which were constantly kept moist. These specimens were enclosed in an airtight container to simulate an anaerobic environment. In this study, it was found that all soil types (sandy, silty, clay-like, and sterilised control) produced adipocere, but contrary to typical conditions, it was found

that the draining properties of sandy soil stimulated adipocere formation to a greater level than silty or clay-like soils.

This is contrasted by an experiment carried out by Durães *et al.* (2010), where pork samples with no visible fat were buried in four different soil types (organic, sandy, gravel, and clay-gravel). The first experiment had the soil dampened with water prior to sealing in an airtight container, while the second did not. Durães *et al.* (2010) found that the sandy soil (which had the smallest grain size) had extremely high levels of adipocere formation, while the gravel soil (which had the largest grain size) had very little. Furthermore, the clay gravel soil (which had the second-largest grain size) curiously displayed very low adipocere formation when water was added to the environment, but a very high adipocere level when no water was added. The explanation provided for this was that the microbiome present in this soil type may have benefited from the added motility provided by the increased moisture, thereby stimulating the decomposition of the sample before the formation of adipocere could begin.

Forbes *et al.* (2005) and Saukko & Knight (2016) also stated that while traditional views hold that adipocere requires a humid, anaerobic environment to form, several studies (Mant, 1987; Müller, 1913) have showed that the water content from the body undergoing decomposition is sufficient for adipocere to form.

2.5.2 Mummification

Mummification is the process of desiccation of the body's tissues to the point of causing a bactericidal effect, which only happens in arid environments, whether natural (e.g., a desert) or artificial (e.g., enclosed, dry rooms). These environments also tend to be warm but this is not a requirement as desiccation can also occur in arctic and other cold environments (Saukko & Knight, 2016). Saukko and Knight (2016) also reported on cases where adipocere is found in conjunction with mummification. In cases like these, it is likely that the fat hydrolysing process of adipocere formation aids in the desiccation of surrounding tissue, promoting mummification. An example of this phenomenon is provided by Schotsmans *et al.* (2011) in their case study of a clandestine burial with a murder victim exhibiting signs of desiccation and adipocere formation. In this case, despite a post-mortem interval

of seven months, the body was still in the bloat phase of decomposition. In this scenario, the forensic entomologist was unable to confidently provide a PMI range, due to the limited number of insects present, but speculated an interval of at least 3 months. It was only the confession of the perpetrator that revealed the true PMI of seven months.

In a study by Finaughty and Morris (2019), it was found that complete mummification of a pig body was possible within 17 days in warm season (397 ADD), and within 77 days in cold season (ADD 1035) in the Western Cape province of South Africa. Because such a rapid onset of mummification can greatly skew PMI estimates, such as those provided by Megyesi *et al.* (2005), conditions which can induce such a rapid onset would require a more detailed investigation (Finaughty and Morris, 2019).

Due to the unpredictable nature of decomposition and the variability of environmental conditions, any bodies found and brought to the attention of the Forensic Pathology Services may exhibit the features of adipocere and/or mummification, which greatly complicates the determination of a PMI, or may make it impossible.

2.5.3 Other confounding factors

It has also been noted by Buekenhout *et al.* (2018) that in cases of extreme skeletonization, it is very difficult to approximate the PMI, due to the extensive time periods involved. The above-mentioned study cited work by Behrensmeyer (1978) in the field of paleobiology as a more suitable model when examining bone weathering, although the ranges provided in this study are several years wide, which makes them less useful in a forensic setting.

Teo *et al.* (2021) investigated the effect of different body coverings on the rate of decomposition. Their findings indicate that a plastic covering will significantly affect the rate of decomposition of buried rabbit (*Oryctolagus cuniculus*) remains, due to the impermeable nature of plastic, which greatly impedes access to necrophagous organisms. In contrast, heavy clothing (which consisted of long-sleeve shirts, pants, socks, and jackets) did not significantly affect decomposition when compared to an unclothed specimen, since clothing is relatively easy for necrophagous organisms to penetrate.

Wilson *et al.* (2007) conducted a pilot study where two piglets were buried near each other but one was incidentally partially exhumed by mammalian scavengers (presumed to be foxes (*Vulpes vulpes*)) and was reburied upon discovery. At the conclusion of the study, it was noted that the scavenged pig was fully skeletonised, while the undisturbed pig still retained some soft tissue. This suggested that the exhumation process (with the aeration of the soil favouring more efficient aerobic micro-organisms) accelerated decomposition. Adlam and Simmons (2007) investigated the effects of repeated disturbance on a rabbit carcass's rate of decomposition. They found that while both weight loss (due to scavenging and fluid loss) and temperature were significantly different to those on an undisturbed body, the net TBS progression and time to skeletonisation (TTS) were not significantly different. They stated that using ADD provided a standardised method of measuring decay and that using a quantifiable description of decomposition, such as what is provided by Megyesi *et al.* (2005), makes a study more relevant and globally applicable.

2.6 The use of porcine analogues

Most prospective decomposition studies around the world are carried out with animal analogues for ethical reasons (Marais-Werner *et al.*, 2017). Pigs (*Sus scrofa domestica*) are generally accepted as the best proxies for human decomposition due to having a similar anatomy and microflora to humans, although Keough *et al.* (2017) have noted and recorded several differences in decomposition patterns observed in pigs decomposing in Gauteng, South Africa, to humans decomposing in 19 different states within the United States, which was recorded by Megyesi *et al.* (2005). By recording the decomposition patterns of pigs, Keough *et al.* (2017) have enabled other researchers in South Africa to draw direct comparisons between human and pig decomposition (Appendix A).

Debruyne *et al.* (2021) found in their studies that human and porcine remains had opposing effects on soil pH as they decomposed. While porcine remains caused the soil to become more alkaline, human remains caused it to become more acidic. These changes in pH largely depend on the most common amino acids the body

“sheds” as it decomposes and would determine the specific organisms found in the surrounding microbiome. The findings of Wilson *et al.* (2007) concur with this, showing that the pH of two different soil types rose by 2-3 units following the interment of their pig specimens. However, Debruyne *et al.* (2021) also noted that many other sources presented conflicting information regarding the effects of mammalian decomposition affecting soil pH; results varied by species, soil type, water content, and temperature. Benninger *et al.* (2008) noted repeated fluctuation in the pH of gravesoil beneath their surface-deposited *Sus scrofa domesticus* specimens. Debruyne *et al.* (2021) concluded this topic by saying that more research and data would be necessary to explain these variances.

Geissenberger *et al.* (2021) investigated the effects of dismemberment on protein degradation to provide a PMI estimate for the recovery of a dismembered corpse. Using porcine analogues, they discovered that dismemberment had no effect on the protein degradation, indicating (for their methodology, at least), an amputated body part will decompose identically to an articulated body part. However, this experiment was conducted in a controlled laboratory environment and therefore had a fixed temperature and humidity. Furthermore, there were no necrophagous organisms present for this experiment, which limits similarity to any field-based research.

There is a need for research that investigates the decomposition of buried bodies in a South African climate, while also investigating the impact of different soil types and seasons upon the rate of decomposition. The information thus gained can be used in investigations pertaining to bodies buried in soil types around Johannesburg.

3 Aim and Objectives

3.1 Aim

To compare the rates and patterns of decomposition of porcine (*Sus scrofa domesticus*) remains buried within three different soil types common in the Johannesburg area during the cold and hot seasons.

3.2 Objectives

1. To describe and compare the rates and patterns of decomposition of piglets buried in the following soil types, as well as to investigate the correlation between TBS and ADD in each soil type:
 - a. Soil from a gold mine tailing
 - b. Quartzite
 - c. Dolomite
2. To describe the effects of seasonal differences on decomposition in buried remains.
3. To describe and compare the effects of decomposition on soil pH within each soil type.

4 Methodology

4.1 Type of study

This research took the form of an observational, descriptive, prospective, longitudinal study.

4.2 Site of study

Research was carried out at two sites: the roof of the Forensic Pathology Services Johannesburg Medico-Legal Mortuary and the workshop of the mining company which donated their mine tailing soil (Figures 4.1 and 4.2).



Figure 4.1: Rooftop of JHB FPS Medico-legal mortuary, 25a Hospital street, Braamfontein, Johannesburg, 2000.



Figure 4.2: Mining company workshop, cnr Bridges ave and Cedar lane, Westonaria, 1781

The rooftop of the mortuary is only accessible by passing through the southern wing of the mortuary, with no access by unauthorised individuals. Previous studies in the vicinity of this site have indicated no scavenger activity, with birds in the area being almost exclusively attracted by the invertebrate colonisers (Keyes *et al*, 2022). The workshop was selected after discussions with representatives of the mining company, where it was decided that due to the risks of radioactive and toxic mineral exposure, mine tailing samples would need to be kept on their premises. The workshop is fenced off and is under constant guard.

4.3 Sample

A total of 30 piglet (*Sus scrofa domesticus*) carcasses (average weight 2kg) were obtained from GHB Farms (Work number: 012 940 4430). One piglet was obtained in August 2020 for a pilot study on a possible methodology (detailed in Chapter 4.6.1). During the cold season portion of the study (June 2021 - October 2021), 15 specimens were obtained, with five allocated to each soil type (Figure 4.3). During the warm season portion of this study (November 2021 - January 2022), only 14 specimens could be obtained; five were allocated to the mine tailing and Quartzite soil types, while the remaining four were allocated to the Dolomite soil (Figure 4.3). All were collected four weeks prior to the commencement of the warm season study and stored frozen in the mortuary fridge.

Since the goal of this research was to compare decomposition between the two different soil types present in Johannesburg as well as gold mine tailing, it was determined that a control would not be necessary. Comparisons are drawn between the different soil types and seasons, and compared to literature of unburied remains where valid.

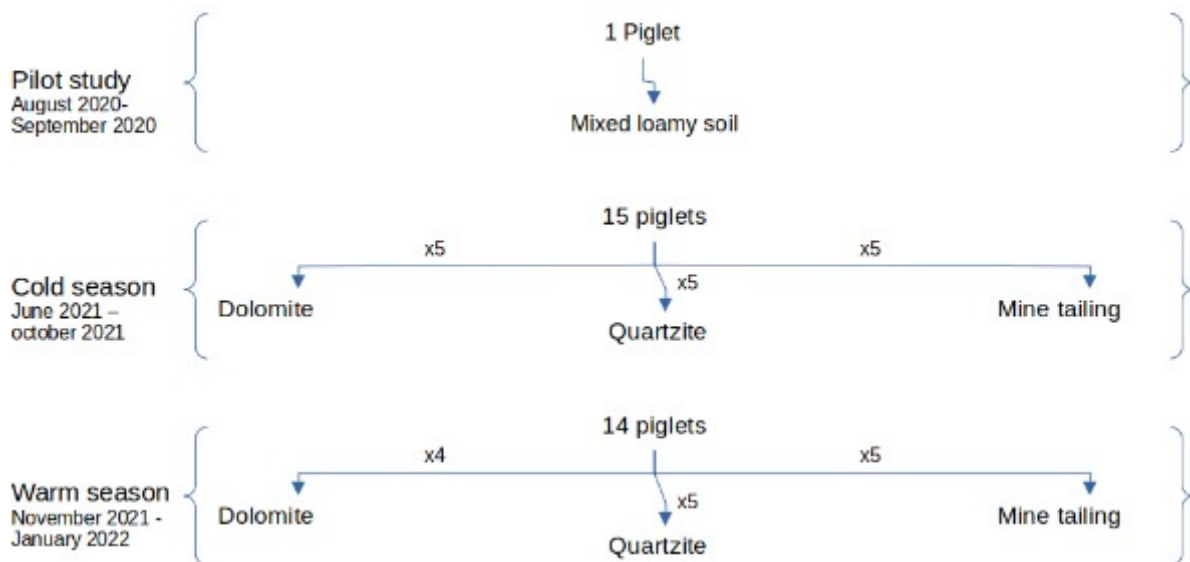


Figure 4.3: Diagram illustrating number of piglets used in each soil type throughout experiment

The specimens that were donated had died of natural causes; no slaughtering was carried out for the purposes of this study. The presumed cause of death for the piglets (as stated by the donor) was “red gut”, a generic term for some form of intestinal knotting. A necropsy of the carcasses could not be performed to confirm the cause of death as this would impact the study. However, this is the commonly assumed cause of death and such pigs are commonly used in taphonomic studies (Keough *et al.*, 2017, Matuszewski *et al.*, 2019, Keyes *et al.*, 2022). This cause of death is highly unlikely to impact the decomposition rates of the carcasses. The prolonged freezing of the remains prior to the commencement of the study was hoped to also neutralise any pathogens or microorganisms that would skew a particular specimen’s rate of decomposition. The piglets were kept frozen at the farm prior to collection (at an unknown temperature) and were immediately stored in

freezers on the JHB FPS mortuary's premises prior to the commencement of the experiment, where temperatures were maintained in a range of -10 - 0°C. According to findings by Stokes *et al.* (2008), freezing skeletal muscle tissue did not significantly affect its decomposition patterns when buried within soil in any way as compared to refrigeration. In contrast, Roberts and Dabbs (2015) found that freezing intact porcine remains significantly slowed the onset of early decomposition and active decomposition, while also possibly preventing the onset of bloating. However, this study kept the pigs at a temperature of -18°C, which was much lower than the temperature of the mortuary freezer. Furthermore, the current study's requirement of interring many piglets simultaneously with an uncertain supply necessitated preserving the specimens until a sufficient quantity was gathered. Freezing was, therefore, decided to be the most suitable method of storing the specimens prior to the beginning of the experiment.

The number of piglets chosen for this study was deemed to be the smallest possible amount to minimise the effects of outliers on determining a standard process of decomposition.

Approximately 60 cubic decimetres of each of the following types of soil were obtained: soil obtained from a gold mine tailing under management of the mining company (Soil M), acidic Quartzite soil from the West Park cemetery (Soil Q), and alkaline Dolomite soil from Bolts Farm Quarry the Sterkfontein region (Soil D).

4.4 Ethical clearance

The Wits Animal Research Ethics Committee provided ethical clearance for this research (2020/06/06/A) (Appendix B).

4.5 Materials

Each piglet was placed into its own open-roofed container made of plastic and enclosed in a slightly larger cardboard box to cover the sides (Figures 4.1 and 4.2). These containers each had a volume of 65 litres. An electric drill was used to create drainage holes in the container floors, with the holes having a diameter of

approximately four millimetres. This was done to allow drainage of rainwater, with the diameter being limited to minimise loss of soil through these holes.

A total of 17 iButton Thermochron data loggers from Cold Chain Thermodynamics were used during this study. One was placed in the containers on or near each piglet's neck and thorax and removed at the conclusion of each study, while another one was placed near each of the research sites to gather atmospheric data. This data was later compared against data gathered from publicly available weather reports by recording the average temperature at each location. This data came from station 0475879 0 (JHB BOT TUINE) for the mortuary temperatures and station 0475528B7 (ZUURBEKOM AWS) for the mining company workshop temperatures. This was done to compare the similarity of meteorological (Met) temperature reports to locally recorded temperatures. During the cold season portion of the study, the data loggers were placed into rubber balloons to protect them from excessive moisture. However, after the conclusion of the cold season study, it was discovered that five of the data loggers had failed, losing all their data on two in the quartzite and mine tailing piglets and one dolomite piglet. It was therefore decided that during the warm season study, the data loggers would instead be placed in Ziploc bags, so that they may easily be removed and their data recorded during every second exhumation to prevent total data loss in the event of failure partway through. The data was downloaded from the data loggers with the use of the Cold Chain ThermoDynamics software and related interface hardware, and subsequently stored on a private device.

An oven, a volumetric flask, and a digital scale (OHAUS Digital scale, C.C Imelmann Laboratory Supplies) were used to determine the water content of the soil by gravimetric assessment.

Deionised water, a pH meter (Eutech instruments, pH510), a magnetic stirrer/heater (FMH Instruments, C.C Imelmann Laboratory Supplies) with an accompanying stirring rod and volumetric flasks were used for the pH testing of the soil samples taken from the containers.

4.6 Experimental design

4.6.1 Pilot study

To minimise disturbance to the decomposition environment, a proposition was made to rest the piglet against the wall of a clear container that would then be filled with soil and observed from outside when data capture was necessary. To validate this method, a single piglet was obtained from GHB Farms. Several holes were drilled into the base of one 85 litre container with clear plastic walls. A 5-centimetre-deep soil bed of mixed loamy soil was placed into the container. Thereafter, the piglet was placed lying prone within the container. The piglet was positioned with its legs curled and was pressed against one of the walls of the container so that its head, torso, and at least two limbs were visible through the transparent wall. Thereafter, the rest of the container was filled with the soil. This container was placed on the extended premises of the Forensic Pathology Services Johannesburg Medico-Legal Mortuary. Cardboard sheets were placed to surround the walls of the containers to reduce the impact of solar radiation via lateral exposure, but the container was not sheltered above from the rain to simulate a typical clandestine burial more accurately.

The piglet was allowed to decompose in this manner for one month. After this time, a TBS score was determined based on what was observable through the clear wall of the container. Thereafter the piglet was exhumed and the side of its body which was completely surrounded by soil was assessed to determine its true TBS. Due to the poor visibility through the container's walls as a result of decompositional fluid and other condensation (Figure 4.4), as well as an observed difference in TBS between the two sides (TBS=13 for side pressed against plastic; TBS=11 for side surrounded by soil), this method was deemed inappropriate for the current experiment. It was instead decided that the piglets would be fully interred and partially exhumed at regular intervals to record TBS.



Figure 4.4: Pilot study piglet viewed through clear wall of container 1 month after interment

4.6.2 Design and data gathering

The first portion of the experiment was carried out during the cold season of the southern hemisphere (June - October 2021), and the second portion was carried out during the warm season (November 2021 - January 2022). Gauteng is a province in South Africa which experiences warm season rainfall, with dry cold seasons. Summers are warm, with average temperatures exceeding 20 °C, while the cold seasons are mild, with average temperatures near 10 °C and rare drops below 0 °C at night. The spring and autumn seasons were not deemed sufficiently distinct to warrant investigation.

The 15 containers and three soil samples were brought to the facility in advance and positioned in a way that provides similar exposure to sunlight and rainfall for the different soil types. Several holes were drilled into the base of each container to allow for water drainage, as is expected in a natural environment. A fine gauze was placed over the holes and secured with duct tape to prevent the soil from leaking out. The piglets were transported from the mortuary fridges to the mortuary roof, and within two body bags inside an enclosed car boot to the mining company workshop. Upon delivery, the TBS of each of the piglets was assessed using the TBS tables

developed by Keough *et al.* (2017). Due to delays in signing of agreement forms, the sampling at the mining workshop was postponed by 53 days, and the piglets obtained for interment within the mine tailing soil were collected from GHB Farms on the day of their interment, while the piglets interred in dolomite and quartzite soils had been collected a week in advance of their interment and stored frozen in the mortuary fridge.

Prior to the start of the experiment, each type of soil (soil obtained from the mine tailing (Soil M), acidic quartzite soil (Soil Q), and alkaline dolomite soil (Soil D)) was placed into five containers, and the container was labelled as the soil had been labelled and numbered 1 – 5 within each soil type (ie. M1, M2, M3, etc.). A 100g sample of each soil type was taken as a control to determine pH and water content.

The containers were positioned so that no soil type received overwhelmingly greater amounts of sun exposure. Furthermore, cardboard sheets were placed to surround the walls of the containers to reduce the impact of solar radiation via lateral exposure.

A shovel was used to dig a hole 15cm deep into each of the soil samples within the container, after which a piglet was placed into each one. Since depth of burial was not found to significantly affect decomposition (Hill & Pokines, 2022), the depth was chosen to entirely cover the piglets, while not making regular exhumation too difficult. The piglets were positioned on their side, with the balloon- or Ziploc bag-enclosed data logger near its chest. Thereafter, the piglets were buried in their corresponding soil types.

The average daily temperatures at both sites were recorded via publicly accessible Met data. When the sum of these average temperatures at either site reached a multiple of 50 ADD, the piglets at the corresponding site were partially exhumed so that one side of their body and two legs were visible to be scored using the TBS tables developed by Keough *et al.* (2017). Thereafter, the piglets were re-interred (i.e., the removed soil was replaced on top of the carcass). At every 100 ADD, a soil sample was taken from every specimen - 100g of soil was collected ventral to the piglet, as close to its abdomen as possible. This method of soil collection is similar to

that of DeBruyn *et al.* (2021) and was chosen over collecting from beneath the body to minimise the disturbance to the carcass. This soil was stored in a Ziploc bag and labelled with the container it came from and the season, as well as the date and atmospheric ADD (e.g. D1 Cold; 06/08/2021; ADD 100). Photographs of the piglets were captured every 200 ADD for future examination and demonstration purposes.

Upon reaching 400 ADD, the frequency of exhumation was reduced from multiples of 50 ADD to multiples of 100 ADD. This was done to reduce the disturbance to the decomposition microbiome, as well as because this was noted by Myburgh *et al.* (2013) to be the beginning of a significant decline in the rate of decomposition.

The final point of data collection was at 1200 ADD, after which time the piglets were rotated so that the side that was deeper down and always encased in soil could be photographed for future reference. After this, they were placed into body bags and stored in the JHB FPS freezers to await their incineration.

4.6.3 Analysis of soil

The soil samples were analysed at the Humphrey Raikes chemical laboratory at the University of the Witwatersrand, Johannesburg. The aim of this analysis was to determine pH and water content of the soil at regular Met ADD intervals, and the remainder of each specimen was labelled and stored at the Johannesburg Medico-Legal Mortuary for potential future studies.

Gravimetric assessment was used to determine water content. 50g of soil was weighed out on a digital scale (OHAUS Digital scale, C.C Imelmann Laboratory Supplies). Thereafter, this soil was placed into a dry heat oven at 110°C for 24 hours, after which it was weighed once again. The proportion of weight lost due to water evaporation was used to determine the water content of the soil as a percentage (Burt, 2004).

The 2:1-ratio suspension method was used to determine the pH of the soil sample. 10g of soil was suspended in 20ml of deionised water, and this mixture was stirred continuously over a period of 30 minutes on a magnetic stirrer (FMH Instruments, C.C Imelmann Laboratory Supplies) to evenly distribute the soil particles (Foth,

1990). Thereafter, a pH meter was used to determine the pH of the mixture, and thereby the soil.

4.6.4 Data analysis

Descriptive statistics and scatter plots were used to visually illustrate the relationship between the PMI and TBS, as well as progression of ADD and TBS. The Python programming language and associated statistical libraries were used to carry out statistical analysis.

Multiple Shapiro-Wilk tests were performed on the temperature data gathered, as well as the ADD-normalised TBS data to determine if it was normally distributed. Since all the data sets were found to not be normally distributed, it was decided that non-parametric tests would be performed during statistical analysis. The α value for these tests (as well as all subsequent statistical tests) was 0.05.

Spearman correlation was used to investigate the similarity between Met temperature data and the atmospheric temperatures recorded locally on the iButtons.

The two-sample Kolmogorov-Smirnov (KS) test was chosen as a statistical analysis tool for non-parametric data, as it determines the probability of two samples originating from the same data set, where $p \leq \alpha$ ($\alpha = 0,05$) indicates a significantly low probability, and therefore a significant difference between the two samples. These KS tests were used to find statistical differences between the ambient temperatures at the two research sites during both the cold and warm season phases, as recorded by data loggers kept at both sites and enclosed in an identical manner to the data loggers buried with each piglet. Two-sample KS tests were also used to find statistical differences between decomposition within each pairing of soil types (dolomite-quartzite, dolomite-mine tailing, and quartzite-mine tailing) in the cold and warm season phases.

To determine if there was a statistically significant correlation between TBS and ADD in each soil type, the TBS and the 10th log of soil ADD (recorded on the buried data loggers) (Megyesi *et al.*, 2005) from all the piglets buried within a specific soil type was tabulated and a mean soil plot was generated to represent the average rate of

TBS progression within each soil type. ADD-normalised TBS tables and graphs were created by recording the TBS reading at each recorded ADD interval and using linear interpolation to populate the entire table. To reduce the effect of outliers, combined data for each soil type was generated by taking the average of every piglet's TBS and ADD data in the relevant soil type that season and compiling it into a single table for inter-soil and inter-season comparison. Thereafter, the 10th log of the ADD data points was used to create a linear graph, the equation for which was used to compare the rate of TBS progression in each soil type to one another. The equations and correlation coefficients of these plots were tabulated. TBS-log10 (Atmospheric ADD) curves were also plotted for both seasons, and the equations and correlation coefficients for these plots were tabulated.

A standardised body region score (SBRS) table was generated for the head, trunk, and limb decomposition scores of each piglet whose temperature data was known. This was done with the following formula: $S = 10a/m$; where S= SBRS, a= assigned decomposition score based on the tables created by Keough *et al.* (2017), and m= the maximum possible value for the region, according to the aforementioned tables (m=13 for the head, 12 for the trunk, and 10 for the limbs). The SBRS data was subsequently used to investigate any correlation between the different body regions and between the TBS and ADD for each body.

KS tests were used to determine if the TBS-ADD curves of each piglet in a soil type were significantly different from each other and from the mean soil curve. This process was repeated for both seasons, and the results of these tests was tabulated.

Notes taken during data gathering as well as photos taken at regular Met ADD intervals were used to generate tables of decomposition patterns in each soil type for qualitative comparison.

The water content of each soil type (determined via gravimetric assessment in section 4.6.3) was graphed alongside the rainfall at both research sites across the Met ADD of the experiment.

To investigate trends in pH change as decomposition progresses, the recorded pH from each sample (determined via the 2:1-ratio suspension method in section 4.6.3)

was tabulated. The difference in pH from the pH of the solute (deionised water) was graphed to reflect the change in soil pH over the Met ADD progression.

To compare the rates of decomposition in the warm season to those in the cold season, two-sided Mann-Whitney U (MWU) tests were first used to determine if there was a significant difference in the temperatures of both sites. When this was proven to be the case, the progression of TBS in a soil type for both seasons was tabulated and graphed against the soil ADD for visual comparison. KS tests were used to determine if there were significant differences between the TBS progressions across either season.

5 Results

5.1 Temperature data

To ascertain if there was a significant difference in temperature at the two research sites (mortuary and workshop), KS tests were performed on the cumulative ADD data gathered at each location and for each season. This was necessary for further comparisons between results obtained at the two sites to be considered valid. The Met data used to decide the exhumation intervals was also compared to the readings on the ambient temperature data logger.

The change in the ADD was recorded for the cold season (Figure 5.1) and the warm season (Figure 5.2). There was a significant difference between temperatures during the warm season and during the cold season at both sites ($p < 0.001$ for both). A significant difference ($p < 0.001$) was observed between the mortuary and the workshop during the cold season but the correlation of these temperatures was high ($p = 0.9913$). No significant differences were observed between the sites during the warm season and the correlation was almost exact ($p \sim 1.0$). The most likely reason for the difference is the delayed burial of the mine tailing sample two months after the other samples during the cold season.

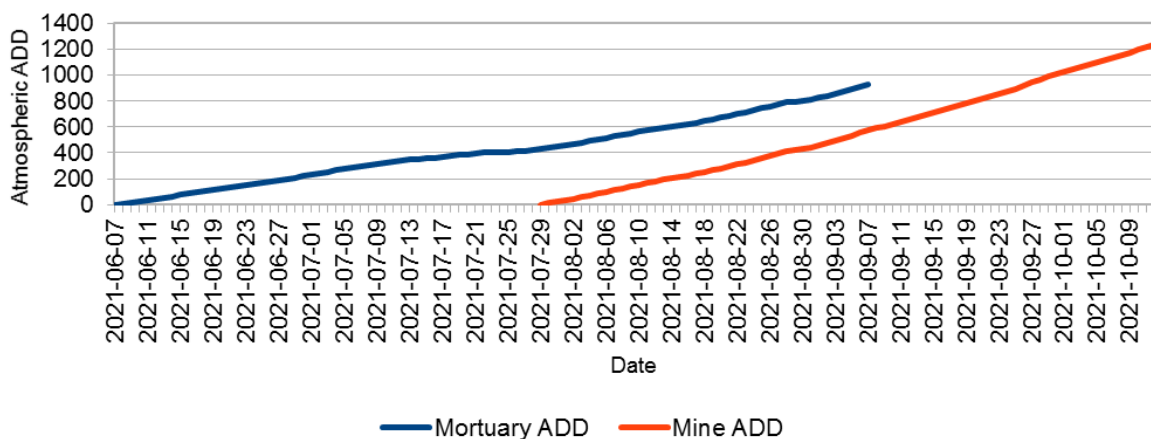


Figure 5.1: Change in Accumulated degree days over time for cold season study.

The frequency of observations depended upon the atmospheric data available from Met services and didn't absolutely reflect the local atmospheric temperatures. The daily mean temperatures from both the above-mentioned sources were compared at both research sites and for both seasons. During the cold season, the mean temperature at the mortuary, as recorded based on Met data, was 13.3°C (median value = 14°C), while the mean temperature captured by the data loggers was 10.1°C (median value = 11°C). There was a high degree of correlation between the temperature readings ($\rho = 0.921$), but an MWU test revealed that there was a significant difference between the two series of readings ($p < 0.001$). In contrast, at the mining workshop during the cold season, the Met and data logger data had different averages (15.9°C and 16.6°C, respectively) and medians (16°C and 15°C, respectively), had a high Spearman correlation ($\rho = 0.9153$) and were not significantly different from each other ($p = 0.219$).

The warm season readings were also different. At the mortuary, the mean temperature reported by Met services was 19.2°C (median value = 19°C), while the mean temperature captured by the data loggers was 21.7°C (median value = 19.5). The correlation remained high (although lower than in the cold season) at $\rho = 0.8323$ but a significant difference was again found ($p < 0.001$). A similar pattern was observed at the mining workshop, where the mean Met and data logger temperatures were 19.5°C and 21.2°C, respectively (with median values of 19°C and 21°C, respectively). The correlation was once again high ($\rho = 0.8476$), but in this case, the MWU test revealed a significant difference ($p = 0.001$).

This suggests that the Met data is not necessarily an absolutely accurate reflection of the temperatures at a particular location, which is affected by local microclimates and shadows. However, the strong Spearman correlation of all Met readings to their corresponding data logger readings suggest that using the former to set an ADD target will provide a reasonably consistent atmospheric ADD.

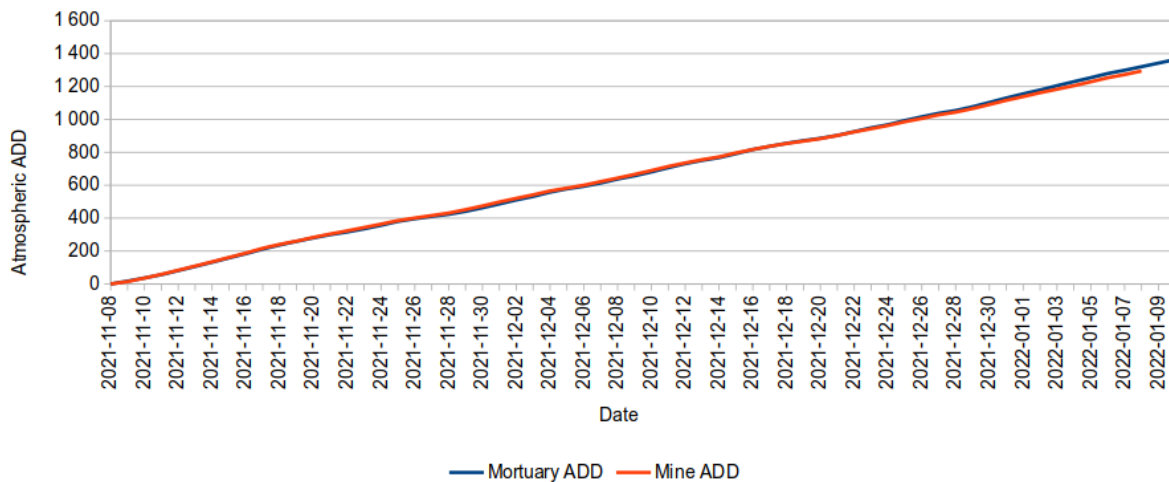


Figure 5.2: Change in Accumulated degree days over time for warm season study

Of the 17 data loggers used (five for each soil type, and one for each site of research), five were found to have become faulty during their use. This resulted in the loss of temperature data on two of the piglets buried in quartzite soil (Q3, Q5), as well as in mine tailing soil (M2, M5), as well as one piglet buried in dolomite (D1).

During the warm season portion of the study, only 13 data loggers were available for use. Four were allocated to the dolomite and to the mine tailing soil samples, while three were allocated for the quartzite samples. The remaining two data loggers were used to record atmospheric temperatures at each research site. All the data loggers survived, and temperature data was available for 11 piglets.

Due to the delays in the cold season study causing the mine tailing piglets to be buried almost two months after the dolomite and quartzite piglets, there was a significant difference in the atmospheric temperatures (Figure 5.1). However, during the warm season, it was shown that the ambient temperatures at these sites follow each other much more closely (Figure 5.2). This indicates that the sites used are sufficiently similar in terms of ambient temperature to be used in parallel.

Interment within the various soils influenced the thermal energy absorbed by the piglets, leading to an ADD that significantly differed from the Met temperatures in all cases during both seasons, with all piglets during the warm season having a significantly higher ADD than the Met temperature would suggest (Table 5.1). In contrast, the Met temperature during the cold season was significantly higher than

the buried piglets' temperatures at the mortuary but lower than those at the workshop (Table 5.1).

The ADD of all piglets except for D3 did not significantly differ from the ambient temperature during the warm season, with the majority of the piglets' ADD being slightly higher than the ambient temperature. The cold season also indicated that the majority of piglets had a higher ADD than the ambient temperature would suggest, with 6 of the 10 piglets' ADD being significantly different from that recorded by the ambient temperature iButton (Table 5.1).

These findings are most probably due to the containers the piglets were interred in absorbing a large amount of thermal radiation, despite attempts to shield them from lateral solar exposure.

Table 5.1: P-values of Kolmogorov-Smirnov tests comparing the ADD absorbed by the piglets compared to the locally captured ambient ADD, as well as the Met ADD by the end of the study (significant differences highlighted in red). Arithmetic differences of the ambient and Met temperatures to each piglet's total ADD also shown

Piglet	Ambient temperature		Met temperature	
	Significant difference (p-value)	ADD difference (Ambient – soil) (°C)	Significant difference (p-value)	ADD difference (Met – soil) (°C)
D2	<0.001	-209,49	0,001	85,03
D3	0,416	26,74	<0.001	321,26
D4	0,006	-169,77	<0.001	124,75
D5	0,319	61,18	<0.001	355,7
Q1	0,652	-33,12	<0.001	261,4
Q2	0,001	153,47	<0.001	447,99
Q4	0,059	103,74	<0.001	398,26
M1	0,017	-150,8	<0.001	-195,67

Piglet	Ambient temperature		Met temperature	
	Significant difference (p-value)	ADD difference (Ambient – soil) (°C)	Significant difference (p-value)	ADD difference (Met – soil) (°C)
Cold season				
M3	0,003	-194,77	<0.001	-239,64
M4	0,017	-147,85	<0.001	-192,72
Warm season				
D1	0,204	-61,69	<0.001	-216,92
D2	0,836	-19,69	<0.001	-174,92
D3	0,034	-101,84	<0.001	-257,08
D4	0,408	-36,44	<0.001	-191,67
Q1	0,836	-20,94	<0.001	-176,17
Q2	0,940	13,58	<0.001	-141,65
Q3	0,294	45,7	0,003	-109,53
M1	0,205	-1,87	0,002	-108,26
M2	0,138	-2,94	<0.001	-109,33
M3	0,560	-41,75	<0.001	-148,18
M4	0,560	-39,02	<0.001	-145,41

5.2 Comparing the decomposition progression and rates between soil types

The TBS of each piglet was graphed against the progression of time (Figures 5.3 and 5.5). Further graphs were generated with the TBS of all piglets in each soil type accompanied by a functional iButton being graphed against their ADD. Since it has been established that ADD is more closely correlated with TBS than the PMI (Megyesi *et al.*, 2005), subsequent graphs will only feature TBS and ADD unless explicitly stated otherwise (Figures 5.4 and 5.6).

5.2.1 Cold season decomposition progression between soil types

The total sample size across the three soil types for the cold season was $n = 10$, consisting of $n_{(\text{dolomite})} = 4$, $n_{(\text{quartzite})} = 3$, and $n_{(\text{mine tailing})} = 3$. The progression of TBS over time is presented in Figure 5.3. The mine tailing piglets progressed to the highest state of decomposition, in terms of the average final TBS ($M\text{Mean}_{\text{TBS}} = 24.67$), followed by the dolomite piglets ($D\text{Mean}_{\text{TBS}} = 22,50$) and the quartzite piglets ($Q\text{Mean}_{\text{TBS}} = 21,33$).

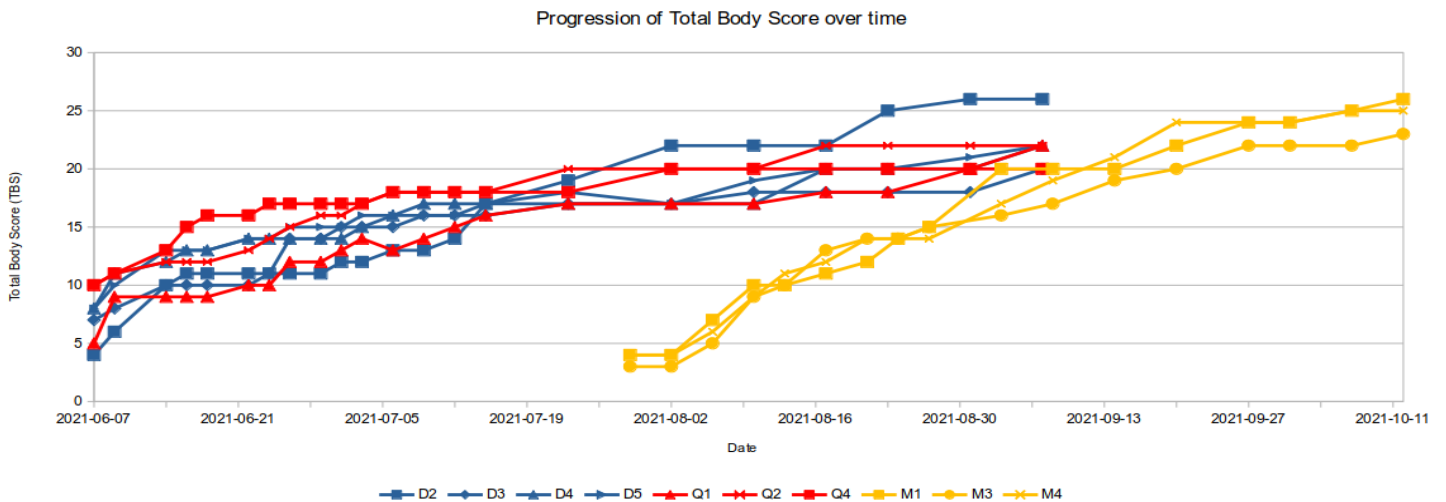


Figure 5.3: Change in TBS over time for each piglet during the cold season

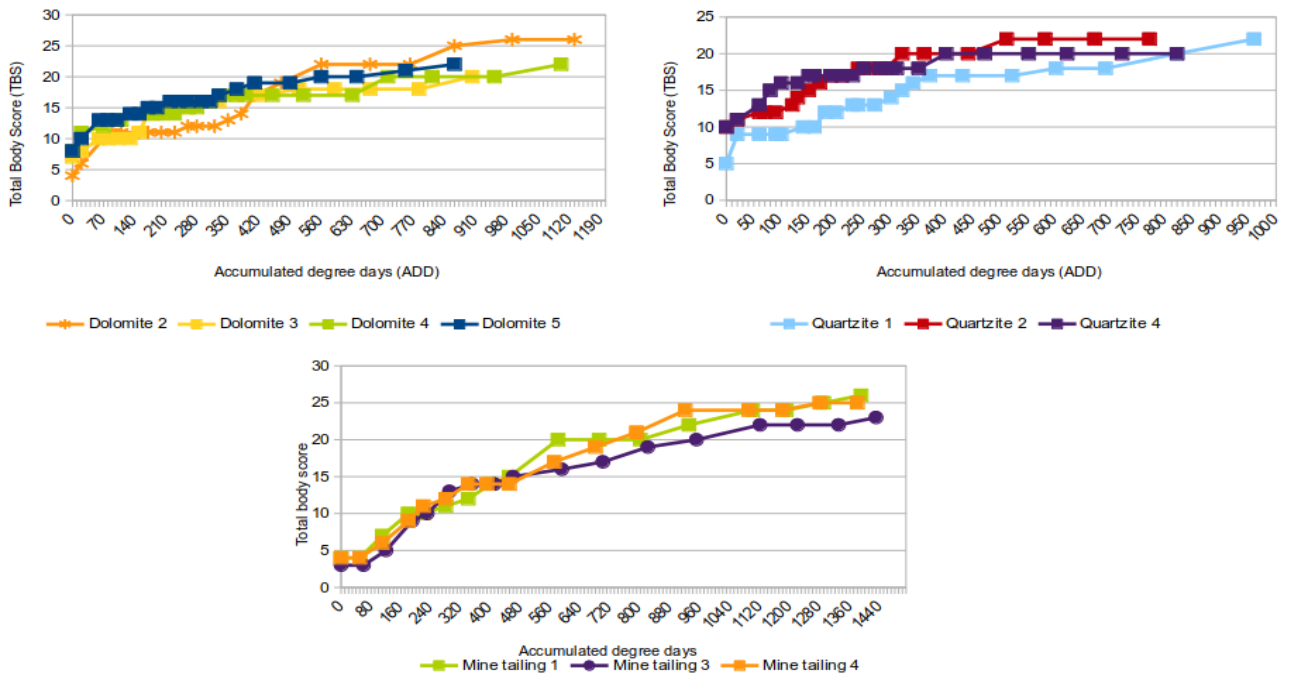


Figure 5.4: TBS vs soil ADD graphs for cold season decomposition of each piglet in Dolomite (top left), Quartzite (top right), and mine tailing (bottom)

Piglets buried in dolomite had the greatest variance in decomposition progression (final TBS range = 20-26 points: 6-point difference), followed by the mine tailing samples (final TBS range = 23-26 points: 3-point range), with quartzite samples having the least variance (final TBS range = 20-22 points: 2-point range) (Figures 5.3 and 5.4).

The rates of decomposition of all soil types appear to have three stages. The first stage (phase 1) consists of an initial sharp incline due to the specific and easily observable changes in early decomposition and this phase is where the rate of change of TBS is the fastest. The second stage (phase 2) consists of an extended intermediate phase, where TBS increases at a notably slower rate than Phase 1 but continues an upward trend. The last stage (phase 3) consists of a plateau trailing towards the end of the recorded interval, with very minor increases in only one or two piglets, and has a rate of change of $>0,01$ TBS per ADD.

Dolomite was noted to have the shortest Phase 1, while the mine tailings had the longest. Quartzite consistently had the lowest rate of TBS progression, and the lowest thermal energy (ADD) overall, while the mine tailing piglets had the highest rates of change in phases 1 and 2 (Table 5.2).

Table 5.2: Phases of decomposition of each soil type during the cold season, with the rate of change (m =slope of graph) in TBS of each phase

	Dolomite		Quartzite		Mine tailings	
	ADD duration	Rate (m)	ADD duration	Rate (m)	ADD duration	Rate (m)
Phase 1	0-70 ADD	0,069	0-150 ADD	0,038	0-350 ADD	0,077
Phase 2	70-850 ADD	0,013	150-690 ADD	0,011	350-1120 ADD	0,013
Phase 3	850-1130 ADD	0,009	690-960 ADD	0,005	1120-1430 ADD	0,005

5.2.2 Warm season decomposition progression between soil types

The total sample size across the three soil types for the warm season was 11 piglets, consisting of $n_{(\text{dolomite})} = 4$, $n_{(\text{quartzite})} = 3$, and $n_{(\text{mine tailing})} = 4$ (Figures 5.5 and 5.6). As with

the cold season study, it was found that the mine tailing piglets reached the highest TBS ($M_{\text{mean TBS}}=28,25$). It was also found that in the warm season, the quartzite ($Q_{\text{mean TBS}}=27,67$) and dolomite ($D_{\text{mean TBS}}=27,75$) piglets had an almost identical final TBS.

As in the cold season, it was found that dolomite had the highest variance in TBS progression (final TBS range = 26 – 30: 4-point difference). In the warm season, the quartzite and mine tailing TBS progression variance was identical (final TBS range = 27 – 29: 2-point difference for both) (Figures 5.5 and 5.6).

Normal variations in total decomposition rates were observed between specimens in the same sample groups (Figure 5.5). For instance, to reach a TBS of 20, D1 (420 ADD) required an additional 180 ADD's compared to D4 (240 ADD). The warm season data appears to correlate thermal energy with TBS more closely, with a difference no greater than 60 units of thermal energy between specimens achieving the same level of decomposition (Figure 5.6).

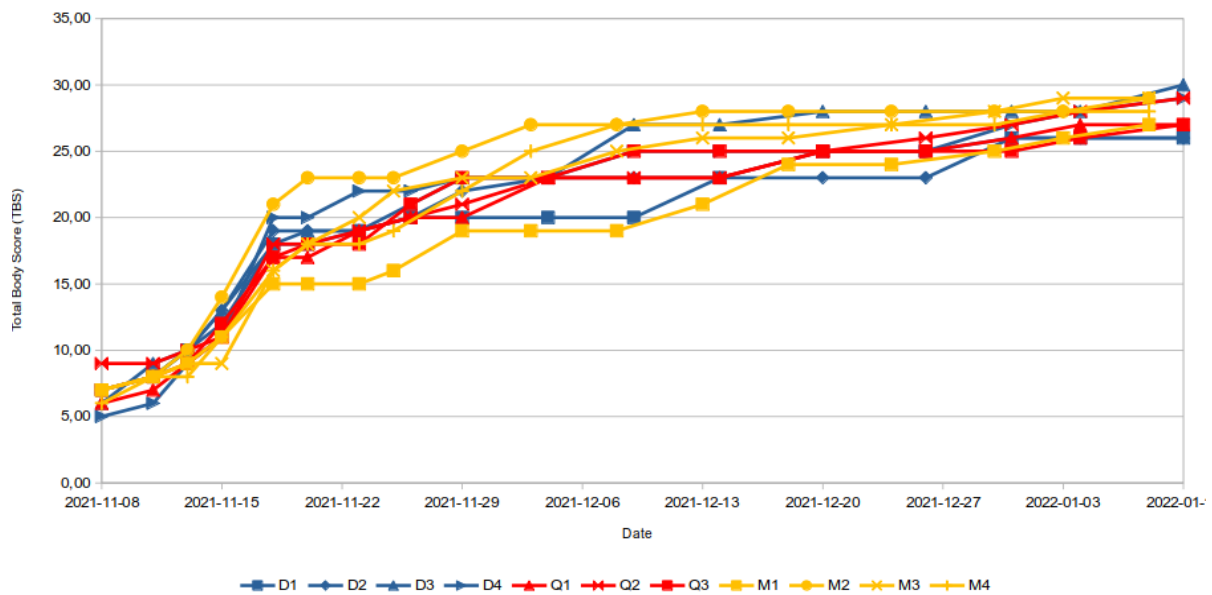


Figure 5.5 Change in TBS over time for each piglet during warm season study

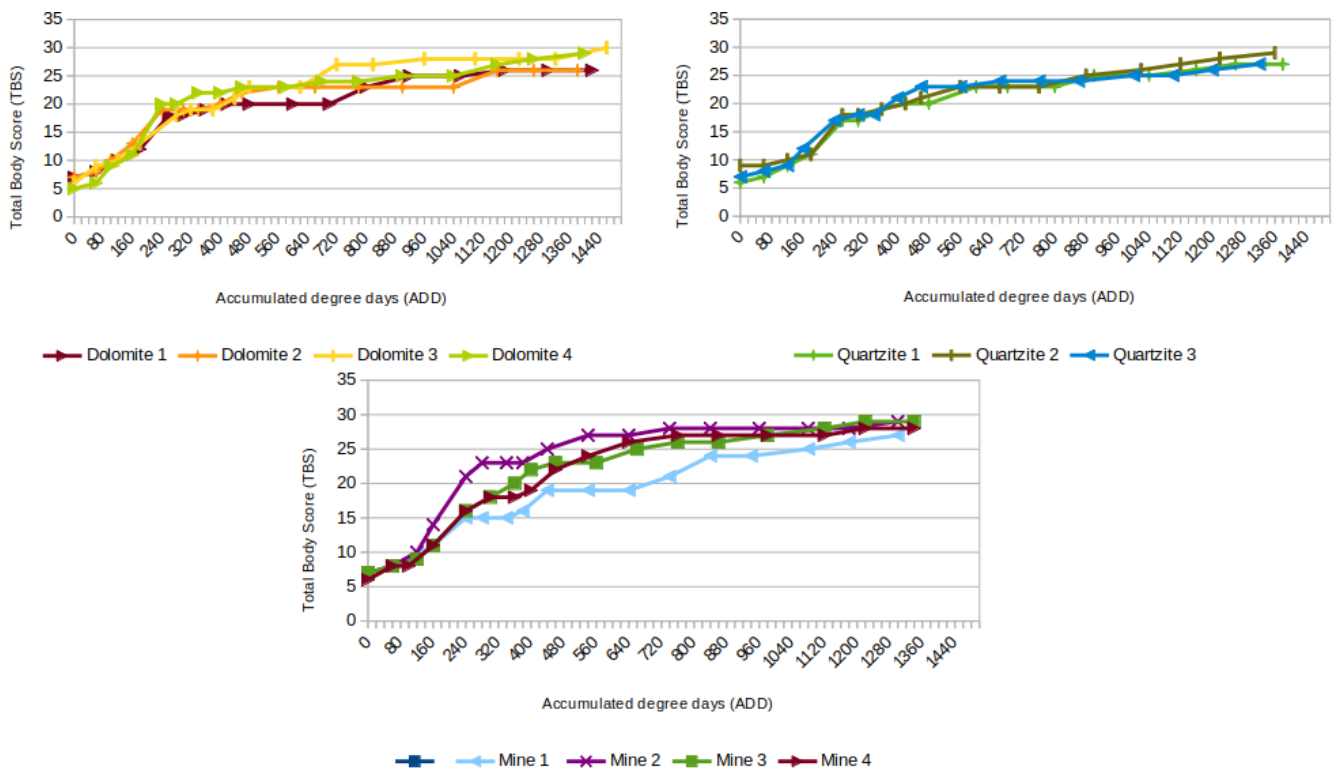


Figure 5.6: TBS vs soil ADD graphs for warm season decomposition in Dolomite (Top left), Quartzite (top right), and mine tailing (bottom)

Due to the more uniform progression of the piglets' decomposition in each soil type, the phases of decomposition are more apparent. Dolomite has the greatest rate of progression in phase 1 but dwindles to the lowest for phase 2 and 3. Phase 3 is only distinguished from phase 2 by the plateauing of one piglet's TBS. Quartzite has the lowest rate of progression in phase 1, but the highest rate (albeit marginally) in phase 3. This is partially due to the great length of phase 2, which may extend even beyond the range of this experiment. One piglet was seen to plateau in its TBS progression near ADD1200, but since this is very close to the end of the experiment, it is impossible to know if this is a transient plateau or not. The mine tailing TBS progression is more in line with the other soils than in the cold season study (due to the delay in commencing the mine tailing research in that study) and is higher than any other soil types in phase 2 (Table 5.3).

Table 5.3: Phases of decomposition of each soil type during the warm season, with the rate of change (m=slope of graph) in TBS of each phase

	Dolomite		Quartzite		Mine tailings	
	ADD duration	Rate (m)	ADD duration	Rate (m)	ADD duration	Rate (m)
Phase 1	0-280 ADD	0,049	0-260 ADD	0,040	0-240 ADD	0,043
Phase 2	280-1160 ADD	0,009	260-1200 ADD	0,010	240-840 ADD	0,017
Phase 3	1160-1460 ADD	0,003	1200-1380 ADD	0,006	840-1340 ADD	0,005

5.2.3 Comparisons of mean decomposition data (i.e. decomposition trends) within each soil type

Two-sample Kolmogorov-Smirnov (KS) tests were used to determine if specimens within a soil type followed a statistically similar trend of decomposition. To compare the decomposition within the same soil types, a “mean soil equation” had to be generated.

In the cold season, there was a significant variation in the decomposition progression of specimens within each soil type, as well as between the specimens and the mean plot of the soil type. The sole exceptions are the D2-D4 and Q4-QMean comparisons (Table 5.4).

In contrast, the variation is less significant for the warm season period. There was no significant difference recorded between the following warm season pairings: D1-D2, D4-DMean, M3-M4, M3-MMean, M4-MMean, as well as all quartzite specimens (Table 5.4). This suggests that buried remains decompose more consistently in the warm season than in the cold season, especially within quartzite soil.

Table 5.4: P-values of KS tests for cold season specimens (top) and warm season experiments (bottom). Significant differences are highlighted in red

DOLOMITE	D2	D3	D4	D5	Dmean		QUARTZITE	Q1	Q2	Q4	Qmean
D2		0.005	0.001	<0.000	<0.000		Q1	<0.000	<0.000	<0.000	<0.000
D3	0.005		0.044	0.081	<0.000		Q2	<0.000		0.00220	0.016
D4	0.001	0.044		0.032	<0.000		Q4	<0.000	0.002		0.081
D5	<0.000	0.081	0.032		0.008		Qmean	<0.000	0.016	0.081	
Dmean	<0.000	<0.000	<0.000	0.008							
			MINE TAILING	M1	M3	M4	Mmean				
			M1		<0.000	0.016	<0.000				
			M3	<0.000		<0.000	<0.000				
			M4	0.016	<0.000		<0.000				
			Mmean	<0.000	<0.000	<0.000					
DOLOMITE	D1	D2	D3	D4	Dmean		QUARTZITE	Q1	Q2	Q3	Qmean
D1		0.069	<0.000	0.003	0.044		Q1		0.217	0.301	0.406
D2	0.069		<0.000	0.002	0.017		Q2	0.217		0.406	0.797
D3	<0.000	<0.000		0.003	0.001		Q3	0.301	0.406		0.664
D4	0.003	0.002	0.003		0.406		Qmean	0.406	0.797	0.664	
Dmean	0.044	0.017	0.001	0.406							
			MINE TAILING	M1	M2	M3	M4	Mmean			
			M1		<0.000	<0.000	<0.000	<0.000			
			M2	<0.000		0.003	0.001	<0.000			
			M3	<0.000	0.003		0.406	0.973			
			M4	<0.000	0.001	0.406		0.069			
			Mmean	<0.000	<0.000	0.973	0.069				

5.2.4 Comparison of decomposition rates between different soil types

To illustrate the decomposition rates of the buried piglets, the mean TBS for each soil ADD interval across all specimens within a particular soil type was used to create an average plot of TBS-ADD for comparison between the soil types during the two seasons. Due to the piglets buried in mine tailing soil having a lower initial (pre-burial) TBS than those buried in both other samples, a secondary “TBS-corrected” plot was generated by shifting the primary mine tailing plot to the left by 110 ADD, to have a more similar y-intercept to the other plots (Figure 5.7). Analysis of the decomposition rates used the TBS-corrected plot when comparing with other soil types because of the substantial difference in initial TBS.

To analyse the equations relative to each other, a logarithmic scale of the ADD progression was generated, which created a linear version of the original TBS-ADD graph (Figure 5.8). The equations of these logarithmic graphs, as well as their correlation coefficients, were tabulated (Table 5.5).

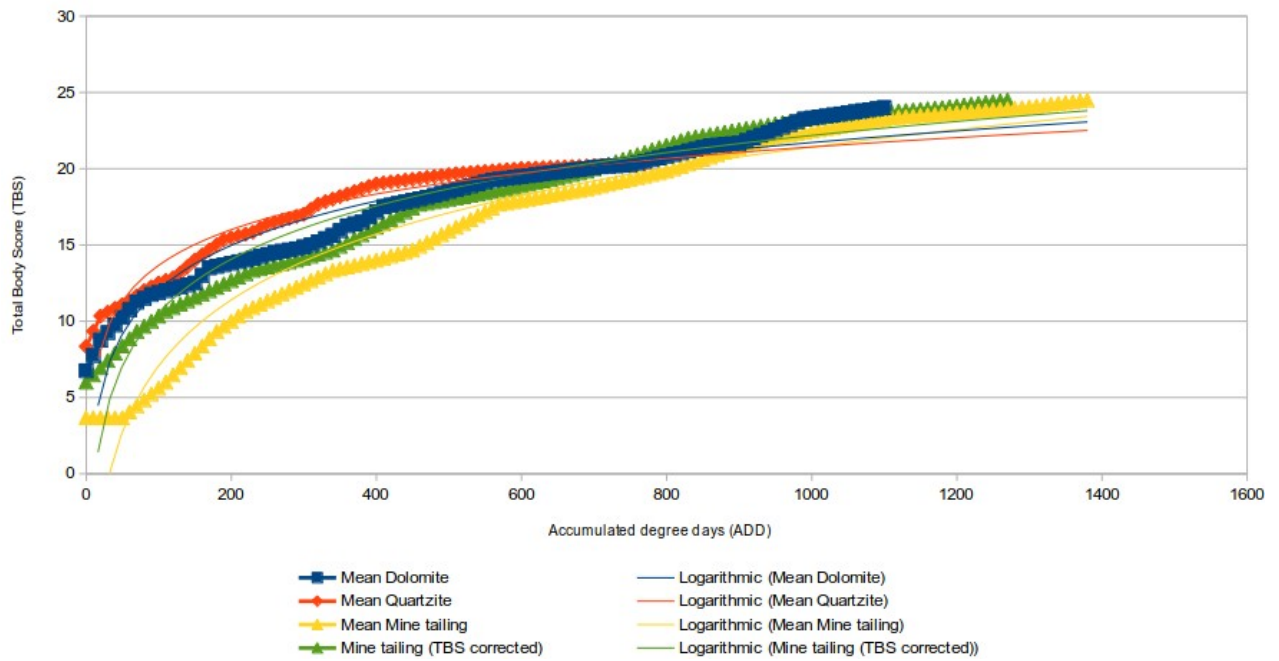


Figure 5.7: Mean TBS-ADD plot for cold season with logarithmic equation trend lines

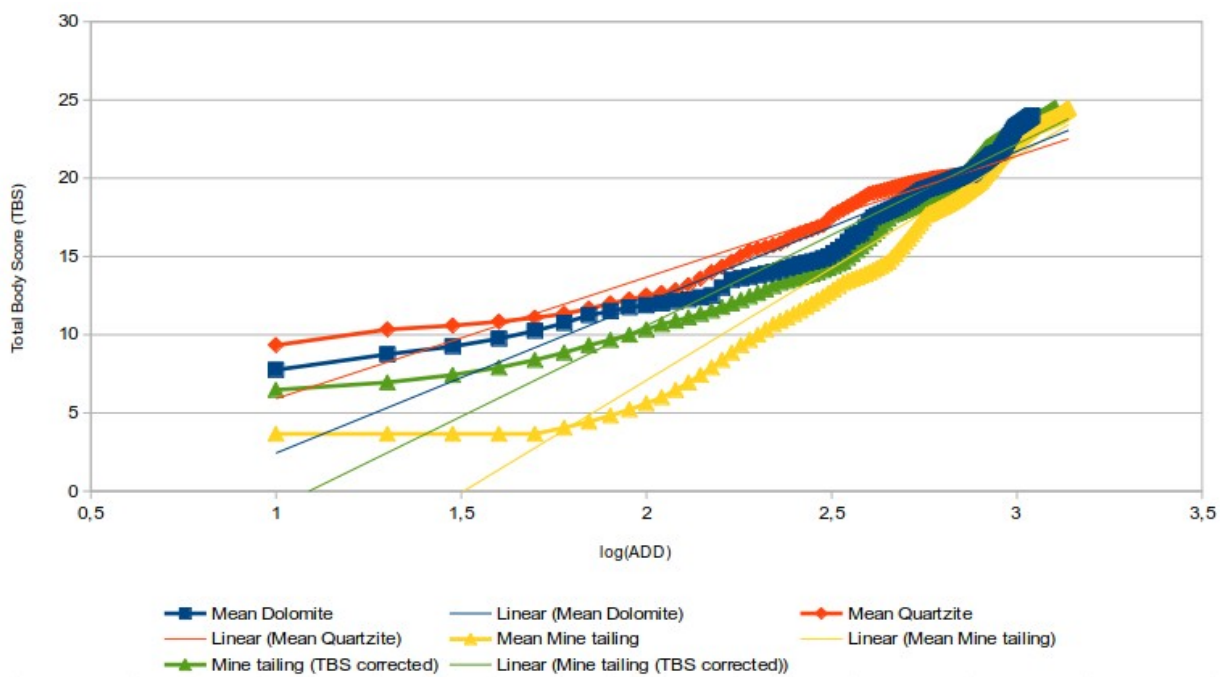


Figure 5.8: Mean TBS-log(ADD) plot for cold season with linear equation trend lines

The warm season specimens were all buried on the same day, and were in a similar state of decomposition, which removed the need for having a “TBS-corrected” plot (Figure 5.9).

As with the cold season specimens, a linear graph was generated by using the logarithms of the ADD axis to more easily visualise and compare the equations (Figure 5.10), and the equations and correlation coefficients were recorded (Table 5.5).

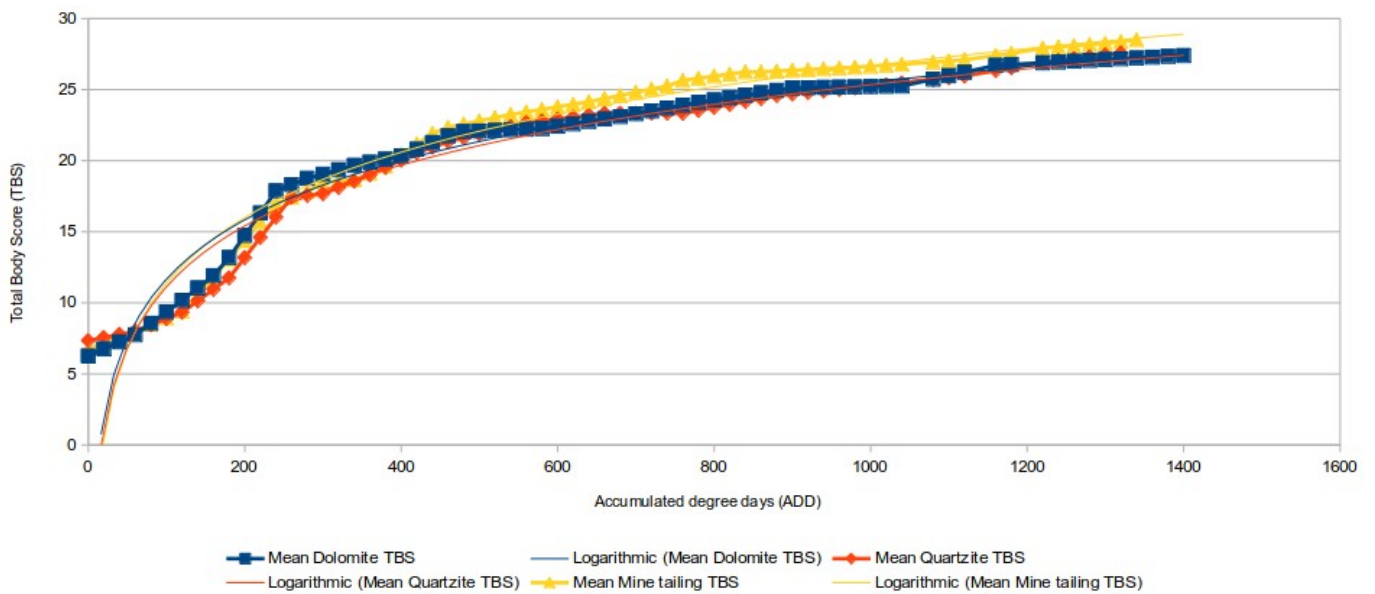


Figure 5.9: Mean TBS-ADD plot for warm season with logarithmic equation trend lines

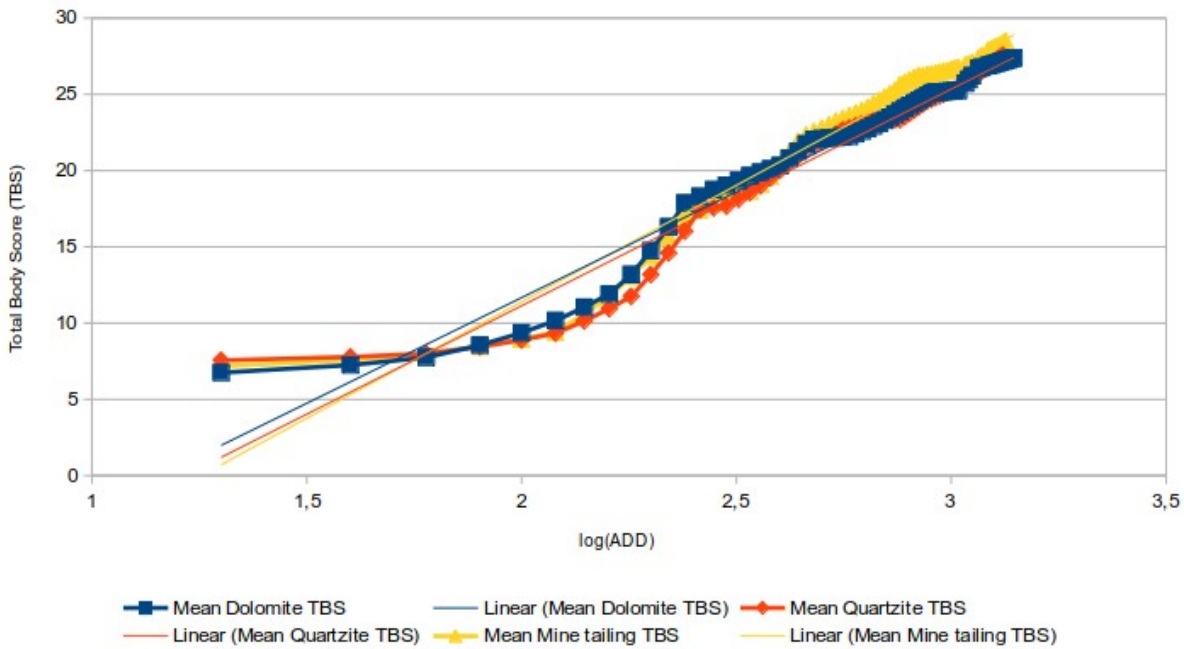


Figure 5.10: Mean TBS- $\log(ADD)$ plot for warm season with linear equation trend lines

Table 5.5: Logarithmic equations and correlation coefficients of mean TBS-soil ADD plots for cold and warm seasons ($\log(ADD)$ is the independent variable)

Cold season	Equation and Correlation Coefficient
Dolomite (linear(\log_{10}))	$f(d) = 9.64015464539276 d - 7.20368710643015$ $R^2 = 0.916729947584721$
Quartzite (linear(\log_{10}))	$f(q) = 7.75351063657287 q - 1.83449054587519$ $R^2 = 0.945812535630939$
Mine tailing (linear(\log_{10}))	$f(m) = 14.3371509938772 m - 21.5861391855735$ $R^2 = 0.930976108128495$
Mine tailing (TBS-corrected) (linear(\log_{10}))	$f(mA) = 11.6031676064677 mA - 12.6290104311946$ $R^2 = 0.92451227964192$
Warm season	
Dolomite (linear(\log_{10}))	$f(d) = 13.8544510268923 d - 16.039493661086$ $R^2 = 0.967288893372574$
Quartzite (linear(\log_{10}))	$f(q) = 14.2112717417099 q - 17.2893090670406$ $R^2 = 0.948792372820444$
Mine tailing (linear(\log_{10}))	$f(m) = 15.2773894662853 m - 19.156950485949$ $R^2 = 0.957266621588847$

During the cold season, the rate of decomposition (indicated by the slope of the graph) was the greatest in mine tailing soil ($m=11.603$), followed by dolomite ($m=9.640$), with quartzite being the lowest ($m=7.754$). All three of these plots have a high ($R^2>0.90$) correlation coefficient, which suggests a close adherence to the calculated equation, with few deviations.

During the warm season, the rate of decomposition was once again highest in mine tailing soil ($m=15.227$), although the other soil types didn't lag as much as in the cold season, with quartzite having the second-highest rate ($m=14.221$), and dolomite having the lowest rate ($m=13.854$). These plots have an even higher correlation coefficient than the cold season plots ($R\geq 0.95$), indicating that there are even fewer deviations from the determined equations.

5.2.4 Decomposition rates as a function of ambient temperature

When using the average ADD-TBS curves of the soil and ambient temperatures, there is no significant difference between the mean dolomite ($p=0,604$ in cold season, $p=0,747$ in warm season) or mean quartzite ($p=0,747$ in the cold season, $p=0,994$ in the warm season) curves in either season. However, there was a significant difference between the ADD-TBS curves of the mine tailing soil, both in the cold and warm season ($p<0,000$ for both).

As is shown by Figures 5.11 and 5.12, the graphs closely resemble those previously shown illustrating the relationship between soil ADD and TBS. The equations listed in Table 5.6 also show that the differences are not vast. The only noteworthy difference is that the correlation coefficients for the warm period are lower between ambient ADD and TBS than they are between soil ADD and TBS.

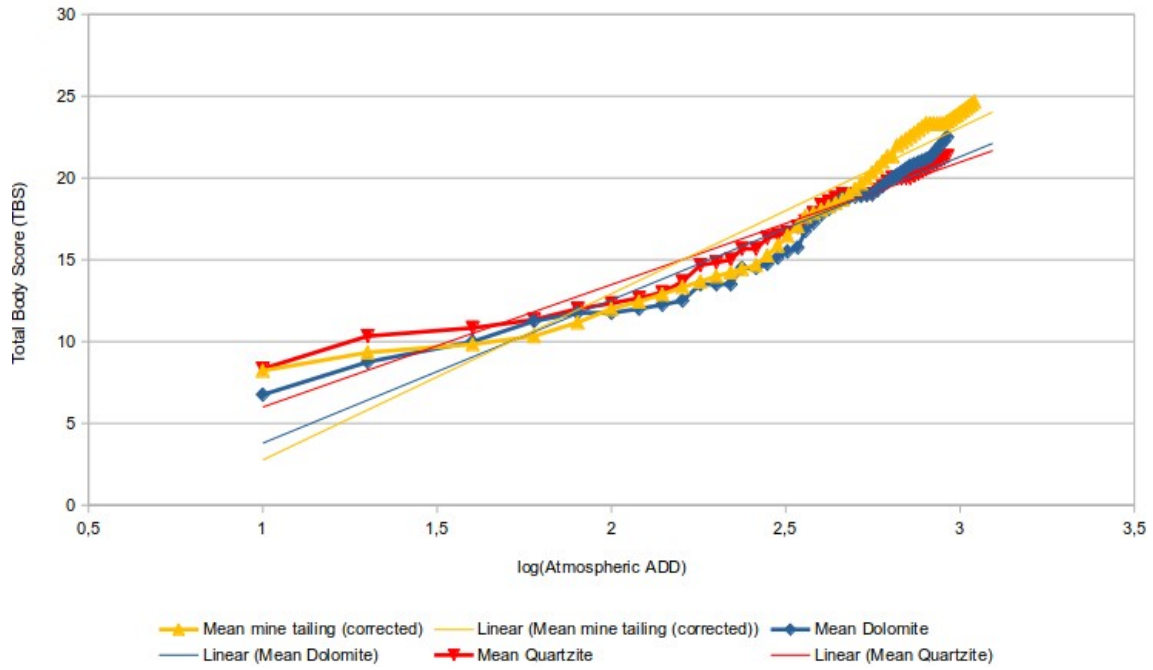


Figure 5.11: Mean TBS-log₁₀(Atmospheric ADD) graph for the cold season with linear equation trend lines

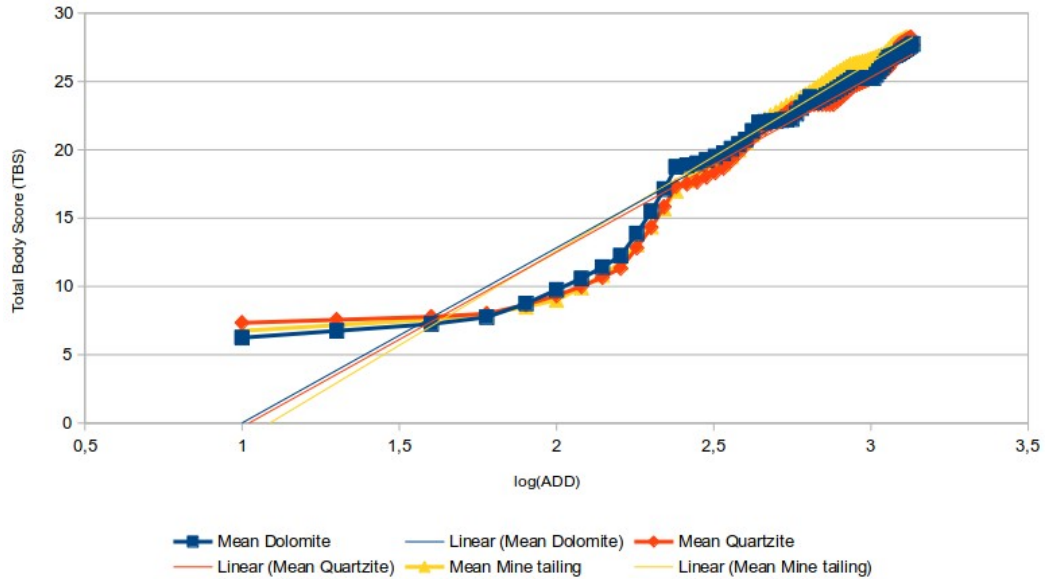


Figure 5.12: Mean TBS-log₁₀(Atmospheric ADD) graph for the warm season with linear equation trend lines

Table 5.6: Logarithmic equations and correlation coefficients of mean TBS-Atmospheric ADD plots for cold and warm seasons (log(ADD) is the independent variable)

Cold season	Equation and Correlation coefficient
Dolomite (linear (log10))	$f(d) = 8,75225266047401 d - 4,96046235088033$ $R^2 = 0,921363672537834$
Quartzite (linear (log10))	$f(q) = 7,48303003355099 q - 1,48681100237308$ $R^2 = 0,949696459390674$
Mine tailing (TBS-corrected) (linear (log10))	$f(m) = 10,1575855423858 m - 7,39247193539751$ $R^2 = 0,905361290426413$
Warm season	
Dolomite (linear (log10))	$f(d) = 12,8128483609638 d - 12,8000742545604$ $R^2 = 0,949928200736925$
Quartzite (linear (log10))	$f(q) = 12,789835286543 q - 13,0653571504684$ $R^2 = 0,928796316266213$
Mine tailing (linear (log10))	$f(m) = 13,8066677302769 m - 15,01356790189$ $R^2 = 0,931816845413428$

5.3 Body region decomposition

As the TBS is the sum of the scores assigned to three body regions (the head, the trunk, and the limbs), it is possible to assess these individually, as well as to compare their contributions to the TBS.

Tables populated by SBRS values rather than raw TBS data were used to determine the mean correlation between each region's score and the TBS within each soil type for the cold and warm seasons (Table 5.7). This was done to see which body region provides the most accurate reflection of the total decomposition for scenarios where only a part of the remains has been recovered, and how reliable each section would be.

In the cold season, all the SBRS-TBS correlation values exceed 90% (Table 5.7), but the head-body score correlation is the highest across all soil types which indicates that while any region is likely to reflect the total decomposition, estimating from the head is most valid. In the warm season, all the SBRS-TBS correlation values were very high, even exceeding 95%. The score for the head once again correlated most

closely to the TBS for most soil types, although it was very marginally exceeded by the trunk-TBS correlation in the dolomite soil. This once again shows that all regions tend to decompose at the same rate, but generally the head remains the best representative for total body decomposition (Table 5.7).

Table 5.7: Mean correlation coefficient of the SBRS of each region to the TBS, and the TBS-ADD correlation, in the different soils for the cold and warm seasons

Cold season			
Correlation	Dolomite	Quartzite	Mine tailing
Head – body score	0,97	0,95	0,99
Trunk – body score	0,92	0,94	0,98
Limb – body score	0,95	0,91	0,98
Body score – ADD	0,93	0,89	0,96
Warm season			
Head – body score	0.99	0.99	0.99
Trunk – body score	0.99	0.98	0.98
Limb – body score	0.98	0.97	0.98
Body score - ADD	0.88	0.91	0.90

K-S tests were performed on the decomposition progression of each piglet’s body regions across all soil types. The TBS progression was significantly different between all soil types in the cold season. When comparing each region across soil types for the cold period, it was found that the decomposition of the head and the trunk was not significantly different between the dolomite and quartzite means; only the decomposition of the limbs was significantly different. In contrast, decomposition within mine tailing soil was significantly different to either of the other soil types across all regions (Table 5.8).

Table 5.8: Kolmogorov-Smirnov test p-values in rates of decomposition of different body regions between each different soil type during the cold season (significant differences highlighted in red)

Body region	Dolomite – Quartzite	Dolomite – Mine tailing	Quartzite – Mine tailing
Entire body	0,001	<0.001	<0.001
Head	0,081	<0.001	<0.001
Trunk	0,234	<0.001	<0.001
Limbs	0,032	<0.001	<0.001

When comparing each region across soil types for the warm period, there was a shift from the cold season trends. The only TBS progressions significantly different from each other were the dolomite and mine tailing piglets, although the quartzite and mine tailing TBS progressions were far closer to being significantly different than the dolomite and quartzite piglets were. The dolomite and quartzite samples only differed significantly in the decomposition of the torso, while dolomite differed significantly from mine tailing in the trunk and limbs, and quartzite differed significantly from mine tailing in the head and trunk (Table 5.9).

Table 5.9: Kolmogorov-Smirnov test p-values in rates of decomposition of different body regions between each different soil type during the warm season (significant differences highlighted in red)

Body region	Dolomite – Quartzite	Dolomite – Mine tailing	Quartzite – Mine tailing
Entire body	0,956	0,046	0,073
Head	0,069	0,406	<0.001
Trunk	0,017	0,044	<0.001
Limbs	0,529	0,003	0,152

This shows that decomposition within mine tailings differs significantly from normal soils in most regions of the body during the warm season. The delay in commencing research at the mine workshop during the cold season is a likely reason for the even greater differences of the mine tailing decomposition from the normal soils in that season. It is also interesting that the trunk is observed to decompose significantly differently across all soil types during the warm season but not during the cold season when comparing dolomite and quartzite.

5.4 Inter-season comparison of decomposition

The temperatures during both experiments, as well as the rainfall data and soil water content (presented in section 5.6), were compared to determine if one variable has a greater effect on decomposition than the other. Both the mortuary and the Mining workshop site had significantly different ambient temperatures across the two tested seasons (Table 5.10).

Table 5.10: Mean and median temperatures at the research sites across both seasons, as recorded by data loggers. Two-sided MWU tests comparing daily mean temperatures in cold season to those in warm season ($\alpha=0.05$)

Location	Cold season mean ambient temp. (Median temp.)	Warm season mean ambient temp. (Median temp.)	Two-sided MWU value
Mortuary	10.1 (11)	21.7 (19,5)	<0.001
Mine workshop	16.6 (15)	21.1 (21)	<0.001

There was a significant difference in the TBS progression within all observed soil types when comparing the cold season progression to warm season progression (all $p < 0,001$). In general, the cold season decomposition progression tended to follow a classic logarithmic curve more closely, while the warm season progression had an initial lag, followed by a sharp incline, more closely resembling a sigmoidal curve. Furthermore, a greater level of net thermal energy was absorbed by the specimens in the warm season than in the cold season (Figure 5.23). Additionally, the warm season piglets reached a far higher TBS score than their cold season counterparts at

almost every stage of ADD, indicating that other factors besides temperature may have been contributing factors in the warm season.

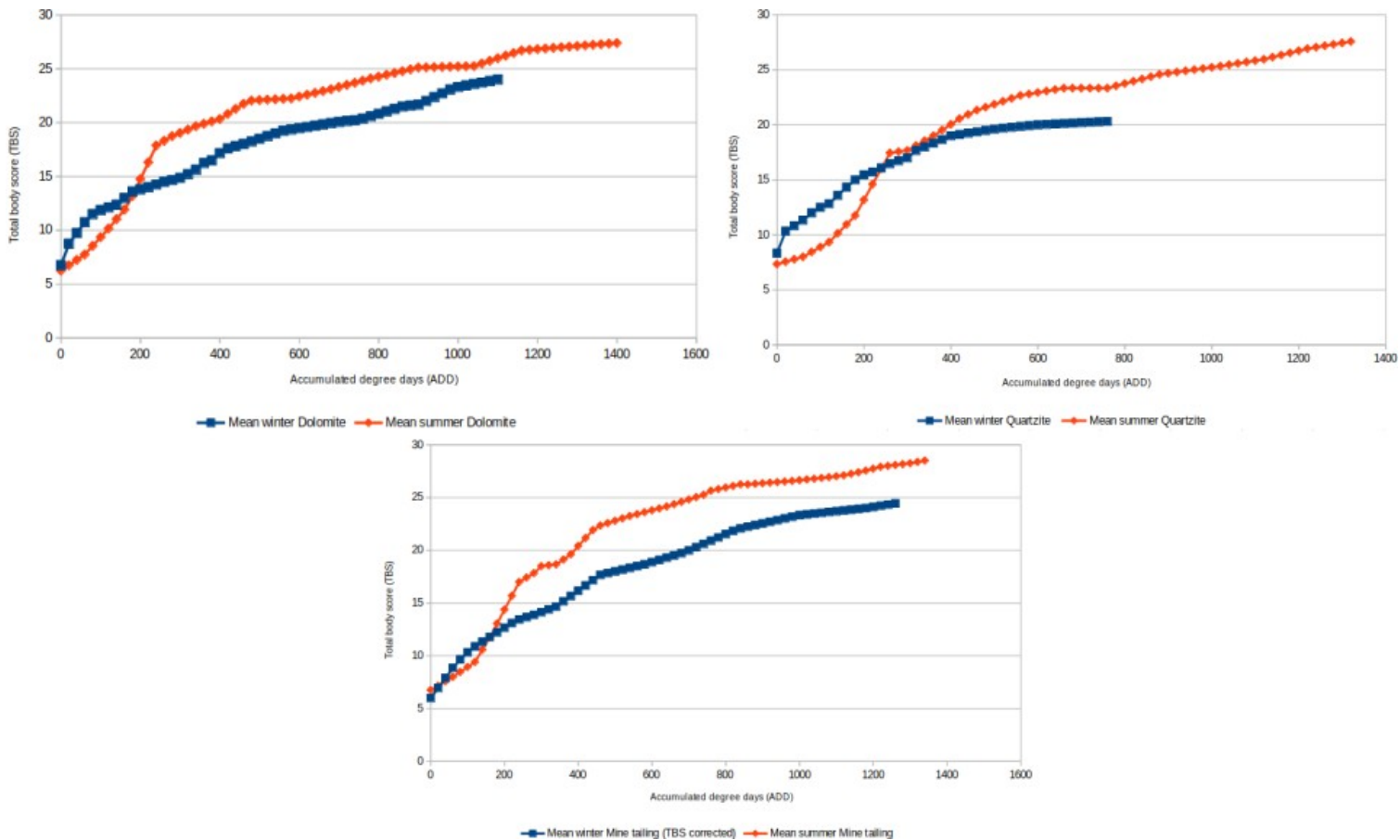


Figure 5.13: TBS-ADD graph comparing cold season TBS progression to that of the warm season in (top left) dolomite, (top right) quartzite, and (bottom) mine tailing soil

The TBS progression in all soil types was found to be significantly different when comparing the warm and cold season progression (Table 5.11). Based on observations made to patterns of decomposition (section 5.4) and soil water content (section 5.5), it is probable that the water content prevented mummification from inhibiting decomposition, thus keeping the piglets an attractive food source to the Dipteran species colonising them (the only necrophagous order observed in both seasons).

Table 5.11: P-values of two-sample KS tests comparing TBS progression in the cold season to TBS progression in the warm season in each soil type ($\alpha = 0,05$)

	P-value of inter-season comparison
Dolomite	<0.001
Quartzite	<0.001
Mine tailing	<0.001

5.5 Patterns of decomposition

5.5.1 Cold season inter-soil comparison

When comparing the decomposition of the piglets across the three soil types based on the Met ADD, a few contrasting characteristics were observed that merit highlighting (see Appendix D for greater detail).

Dipteran activity during the cold season correlated closely with the ambient temperature. Minimal activity was noted on days where the maximum temperature did not exceed 15°C but on days where the maximum temperature exceeded 20°C, activity peaked. However, maggot colonisation only occurred at Met ADD 450 (32 days after initial burial) in piglet D2 (Figure 5.13). Dolomite appears to be the soil type that least restricts Dipteran colonisation, since colonisation was observed 10 days sooner than that of the mine tailing-interred piglets (which occurred at ADD600). The quartzite-interred piglets showed signs of maggot colonisation one month later than the dolomite samples (at ADD800).



Figure 5.14: Piglet D2 at Met ADD 450. Signs of maggot activity circled in red.

Early signs of mummification appeared at the same PMI intervals (46 days) for both the dolomite- and quartzite-interred piglets (Figure 5.14). The mine tailing-interred piglets did not show signs of mummification at any point during the cold season experiment. When examining the undersides of the buried piglets, it was found that four of the five dolomite-interred piglets had mummified heads and limbs, while the trunk was still undergoing active decomposition. One of the quartzite-interred piglets was entirely mummified on its underside.



Figure 5.15: Piglet D4 at Met ADD800. Signs of mummification include leathery skin and dry mucosal linings around eyes, mouth, and nose

Adipocere formation was uncommon in this experiment, only occurring on one of the dolomite-interred piglets at a PMI of 77 days, as well as after 63 days in three of the mine tailing piglets. However, two of these mine tailing-interred piglets seem to have resumed normal decomposition before the conclusion of the experiment. In contrast, saponification was almost ubiquitous on the undersides of the piglets buried in quartzite, with four piglets showing signs of this phenomenon (Figure 5.15). One of the dolomite-interred piglets also appeared to be fully saponified.



Figure 5.16: Piglet Q2 at Met ADD1200 after having been flipped. Extreme desiccation is evident, with adipocere visible on the abdomen, thorax and neck

Burial in mine tailings appears to have a variable but noticeably different impact on early decomposition compared to the naturally occurring soils. Most piglets buried in mine tailings quickly showed a blackening of the skin that was previously stated by Keough *et al.* (2017) to be observed in later stages of decomposition. A later stage had clearly not been reached as several preceding signs had not occurred. Furthermore, only piglet M5 displayed any signs of bloating. Additionally, piglets M4 and M5 were the only ones to show signs of anal purging. One of the piglets (piglet M1) reacted very differently to its interment in the mine tailing soil, becoming initially a very pale pink colour with epidermal drying and cracking, all while the underlying dermis remained pliable and free of desiccation (Figure 5.16). Piglet M1 did, at a later stage, gain a black discolouration at a stage of decomposition more appropriate to the findings of Keough *et al.* (2017).



Figure 5.17: Piglets M1 (left) and M3 (right) at Met ADD200. Visible difference in skin colour as well as non-sunken eyes on M1

5.5.2 Warm season inter-soil comparison

The decomposition of the piglets during the warm season was recorded and tabulated (see Appendix E for greater detail), with several distinctions between the soil types and great differences to the cold season results. The unpredictable and often heavy rainstorms of the region also occasionally made it difficult to thoroughly observe the decomposition taking place.

In contrast to the cold season study, flies were present every day during early decomposition, and maggots were noted within five days of burial on two piglets buried in the mine tailing soil, and on all piglets three days later. The number of maggots present on the mine tailing piglets became quite substantial after three weeks (Figure 5.17). Maggots were only noted 10 days after burial in the quartzite specimens, and 12 days after burial in the dolomite specimens.



Figure 5.18: Piglet M2 at Met ADD400. Note the large maggot mass at head and neck

Maggot activity became apparent far more rapidly in the mine tailing soil; the activity noted after 10 days of interment in mine tailing soil looked similar to the activity observed in the dolomite- and quartzite-interred specimens after 21 days.

Mummification was not noted in any of the specimens during the warm season. This was to be expected as the frequent rainfall and subsequent soil dampness prevented the required desiccation from occurring.

Adipocere was not noted in any of the dolomite-interred piglets. In contrast to this, the majority of the quartzite-interred piglets revealed saponified tissue after being flipped at the conclusion of the experiment. There was, however, very little tissue remaining at this stage (Figure 5.18). The piglets interred in mine tailing soil all showed signs of adipocere formation during the course of the experiment, with the earliest manifesting 30 days after burial. Upon being flipped, two of these piglets were noted to show saponified tissue, as with the quartzite piglets.



Figure 5.19: Piglet Q2 at Met ADD1200 after being flipped. Head and limbs are skeletonised and disarticulated, while the thoracoabdominal mass shows signs of adipocere over blackened tissue

The Dipteran genera present at the mining workshop were different to the ones observed at the mortuary, with the former being larger and more numerous than the latter. This likely introduced another variable to the decomposition data. The premature blackening of the skin and soft tissue noted in the cold season experiment was less pronounced, due to the warm season piglets entering a more appropriate stage of decomposition (Keough *et al.*, 2017) quickly enough to possibly mask this unusual phenomenon. No analogue was noted to the unusual pattern noted in piglet 1 during the cold season experiment (i.e., pale skin with dried epidermis).

5.6 Soil water content

Since soil pH correlates closely with soil water content, the latter was recorded to compare against the former. There was minimal rainfall during the cold season experiment, with subsequently minimal impact on soil water content (Figure 5.19). The rainfall only present at the workshop at ~1000ADD is due to the aforementioned

delays in commencing research there. In general, quartzite appears to have the highest water content by a margin of ~1% mass, while the mine tailing soil is slightly more damp than the dolomite. Both the mine tailing and dolomite samples were below 0.5% mass as water content (Figure 5.19).

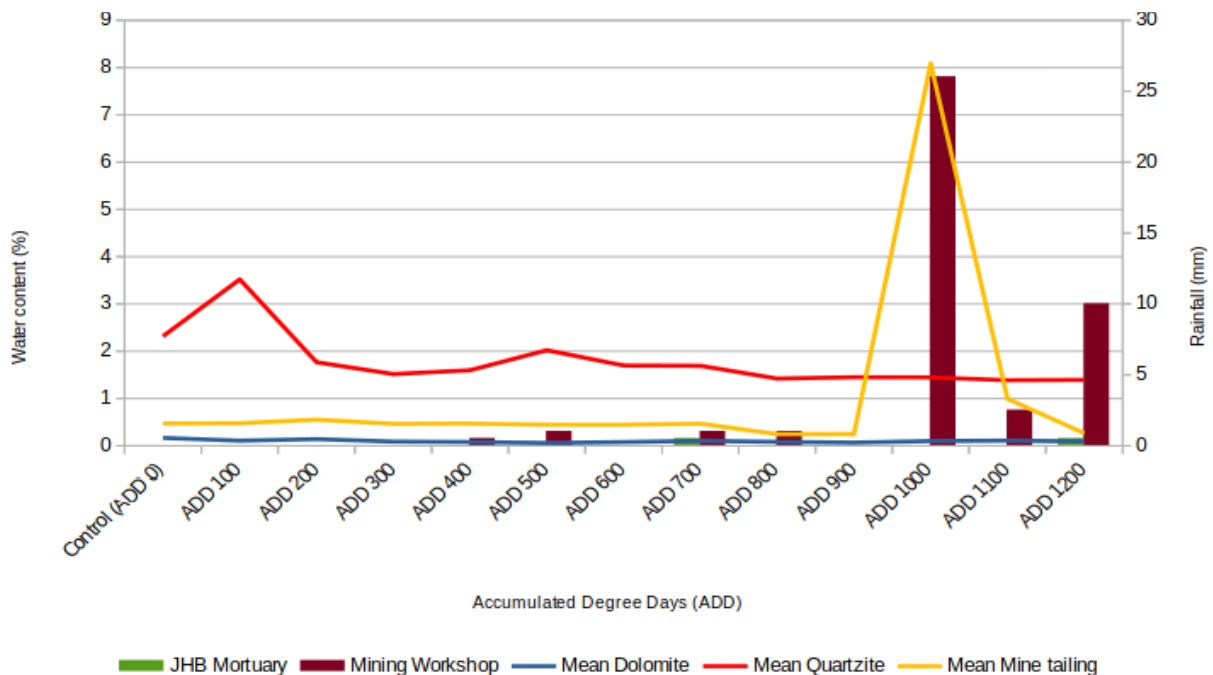


Figure 5.20: Soil water content (as a percentage of soil mass) shown as a line graph (left axis) and local rainfall shown as a bar graph (right axis) during the cold season research

Due to the frequent and often severe seasonal storms in the area, the warm season rainfall and soil water content is far more varied than in the cold season. Furthermore, since the piglets at both sites were interred on the same day, the dates correlating to the ADD at both sites were more similar, leading to a more accurate cross-site comparison (Figure 5.20).

Due to the experiment being carried out outdoors, and due to the speed with which the weather may turn, some of the samples were collected while it was raining, which likely skewed the soil water content to be higher than was indicated by the rainfall data. As was suggested in Figure 5.19, quartzite is far more prone to

retaining water than either of the other observed soil types. In Figure 5.21, the quartzite water content noticeably exceeds that of the mine tailing soil, and vastly exceeds that of the dolomite, despite sometimes experiencing lower rainfall than the former, and the same rainfall as the latter.

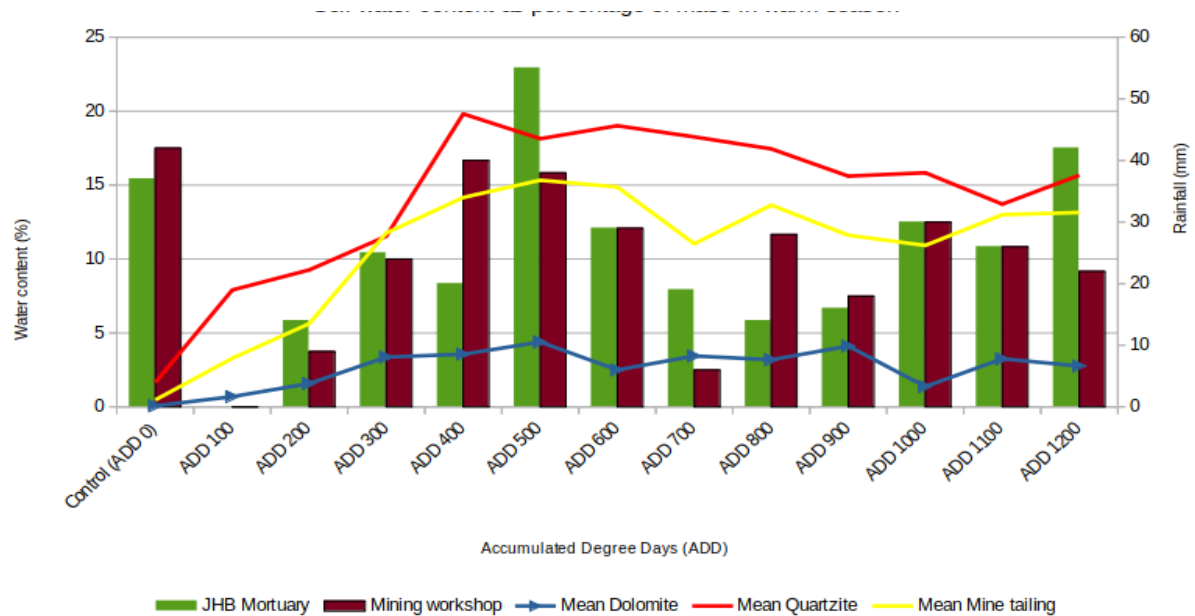


Figure 5.21: Soil water content (as a percentage of soil mass) shown as a line graph (left axis) and local rainfall shown as a bar graph (right axis) during the warm season research

5.7 Soil pH

During the cold season, minimal deviation from the control pH was noted in both the dolomite and mine tailing soils. However, quartzite was noted to shift to become more alkaline by a whole unit in a linear manner from Met ADD800 to ADD1200, which was when the experiment concluded (Figure 5.22).

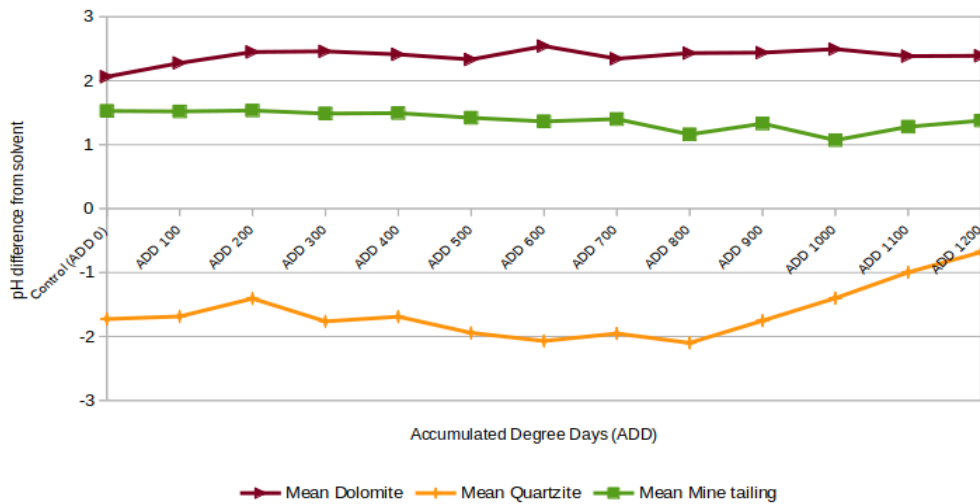


Figure 5.22: Cold season soil pH measured as a difference from the solvent (deionised water)

In contrast, all soil types had notable changes from their control pH during the warm season. The dolomite and mine tailing samples showed a slight amount of fluctuation until ADD600, at which point the pH of both decreased by one unit (mine tailing) or two (dolomite). The dolomite specimen then gradually returned to its initial pH, while the mine tailing remained more acidic (Figure 5.23). Quartzite in contrast rose two units by ADD200, then dropped to one unit more acidic than the control at ADD 500, before returning to the level of the control at ADD600 but slowly sinking by one unit from ADD1000 to ADD1200. No correlation was noted with the soil water content, aside from the higher water content apparently enabling the body fluids to permeate the soil.

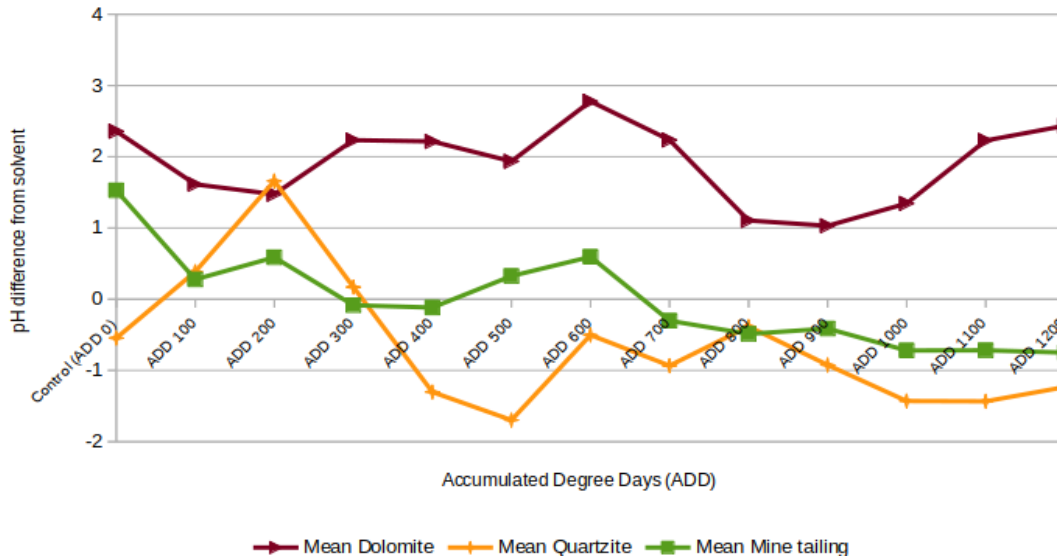


Figure 5.23: Summer soil pH, measured as a difference from the solvent (deionised water)

5.8 Summary of results

1. There are significant differences between soil temperature the ambient regional temperatures provided by the weather services during both seasons.
2. The overall rate of decomposition may be divided into three phases, where each successive phase shows a lower rate of TBS increase.
3. There is a significant degree of variation in the decomposition of piglets within the same soil type. The warm season quartzite specimens were the only ones not displaying a significant degree of difference in their rate of decomposition from each other.
4. In both seasons, the mine tailing piglets had the highest rate of decomposition. The dolomite piglets decomposed slightly faster than the quartzite piglets during the cold season, and the piglets in both soils had a similar rate of decomposition during the warm season.
5. The decomposition of the head correlates most closely to the decomposition of the entire body in all soil types and both seasons.
6. There is a significant difference in the rate of decomposition of the piglets in all soil types during the cold season. During the warm season, only the

dolomite and mine tailing piglets differ significantly from each other in their rate of decomposition.

7. There was a significant difference between the warm and cold season temperatures at both sites. The rate of TBS progression was also significantly different across the seasons in all soil types.
8. During the cold season, Dipteran colonisation is fastest in dolomite and slowest in quartzite. During the warm season, it was fastest in the mine tailing and slowest in dolomite.
9. Mummification was only observed during the cold season in the dolomite- and quartzite-interred piglets.
10. Saponification occurred in most quartzite- and mine tailing-interred piglets in both seasons. Only one dolomite specimen was noted to have developed adipocere, during the cold season.
11. During the cold season, most mine tailing piglets had premature blackening of the skin and soft tissue.
12. There was almost no pH fluctuation during the cold season of any soil type. During the warm season, quartzite showed numerous changes, while the mine tailing soil gradually trended downwards. There was very minor fluctuation noted in the dolomite soil.

6. Discussion

Very few studies have been carried out globally to investigate the effects of different soil types upon the gross decomposition patterns of buried remains. The African continent in particular is sorely lacking in this type of research. Furthermore, the effects of mine tailings upon a buried cadaver have not been investigated at all thus far, which presents a clear gap in existing literature. This study aimed to initiate such investigations, as well as comparing the effects of burial during different seasons upon the body's decomposition. Future studies with a more focused approach may clarify many questions posed in the current study to make its findings more useful to the broader forensic and scientific community.

6.1 Effects of burial on thermal energy

With regards to burial changing the thermal energy available to the decomposition environment, it was noted that temperature data provided by the weather service differed significantly from the temperatures recorded at the burial level of the piglets. Locally recorded ambient temperature was often significantly different from subterranean temperatures in the cold season, but the two were almost never significantly different in warm season. Pragnell and McGowan (2009) stated that shallow burials of approximately 10cm would follow the temperature trends of the surrounding atmosphere very closely. It is possible that the similarities during the warm season may be due to the higher soil water content (caused by frequent rainfall) allowing a more rapid transfer of thermal energy to the cadaver, as water is a more effective heat transfer medium than soil (Dimitrakopoulos & Martin, 1994).

Pragnell and McGowan (2009) showed that a burial depth of 1m is sufficient to offset the temperature from what is observed at the surface by approximately 3°C and Campobasso *et al.* (2001) showed that burial at greater than 60cm is sufficient to protect a cadaver from necrophagous insects. Conversely, Hill and Pokines (2022) showed no significant difference between burial at 20cm and 60cm, with only the first two months after burial showing variation between the two, due to delayed colonisation of the deeper-buried specimens. This incongruence may suggest that

longer-term research into the ability of Dipteran colonisers to access buried remains is necessary.

Since the current study showed a clear difference in Dipteran colonisation patterns of buried remains between the warm and cold seasons, it may be inferred that these colonisers would be a lesser factor during the cold season (especially early in the decomposition stages), but a prominent one during the warm season. Further studies should investigate this theory, and further determine how greatly Dipteran colonisation of buried remains is affected by depth, temperature and soil type.

6.2 TBS progression in a buried environment

The dolomite piglets consistently had the greatest variance in TBS between themselves during both seasons, suggesting that other factors may have been influencing these specimens to a greater degree than in the other soils. Since the precise cause of death for each piglet was not noted, it is possible that this may have influenced the results in an unclear way.

In contrast, the piglets decomposing in quartzite had very similar TBS scores, especially when adjusted across their individual soil ADD. The differences between these soil types include a greater fluctuation in pH and a smaller grain size for quartzite, as well as a greater drainage of rainwater in the dolomite. Some or all these factors, and even some not investigated in this study, may have caused this difference in decomposition consistency. It is possible that the pH fluctuations of quartzite in a relatively anaerobic environment may have encouraged a more consistent progression of decomposition, compared to the more aerated and consistently alkaline dolomite.

During the cold season, nearly every piglet in every soil type followed a TBS progression that was significantly different from that of every other piglet in the same soil type. During the warm season, there were no significant differences between any of the quartzite-interred piglets, while the mine tailing-interred piglets also had a few similarities. This indicates that the soil type a body is buried in did not necessarily dictate a statistically similar rate of decomposition. A possible explanation is that the

exact time and cause of death of each individual piglet was not known or controlled for, which may have caused variation when the piglets were randomly assigned to each soil type. Some studies (Turner & Wiltshire, 1999; Carter *et al.*, 2010; Rysavy & Goff, 2015) have specifically stated the use of specimens culled under controlled conditions for the purposes of their study and buried shortly thereafter, but they remain in the minority for forensic research (especially for larger specimens such as adult pigs) (Myburgh *et al.*, 2013, Keough *et al.*, 2017, Matuszewski *et al.*, 2019, Keyes *et al.*, 2022).

Similar intra-soil decomposition comparison was not noted in other publications (Carter *et al.*, 2010; Tumer *et al.*, 2013) but may be an important factor to determine how similar decomposition is within a soil type before comparing different soil types. A larger sample size would also help in determining whether the soil type truly does not dictate a specific decomposition pattern.

The piglets' decomposition followed a trend of an initial stage of rapid TBS increase, followed by a period of slowed TBS increase, and a final stage where the TBS largely plateaued (Phases 1 – 3, respectively). A logarithmic trend in TBS progression is widely noted in both buried (Hill & Pokines, 2022; Marais-Werner *et al.*, 2017; 2018; Teo *et al.*, 2021) and surface remains (Galloway *et al.*, 1989, Megyesi *et al.*, 2005, Myburgh *et al.*, 2013). The use of phases is not commonly noted in earlier literature, as it hasn't been refined past the stage of being mostly subjective. Since each phase is usually much longer than the preceding one, identifying the phase a discovered body is in will provide some indication of the size of the margin of error when determining the PMI. Since Phase 3 can extend as far as total skeletonisation, this would be a worst-case scenario for forensic investigators. Keyes (2016) similarly noted three phases in TBS progression, in the decomposition of burned remains, and noted that phase 3 showed a continuation in linear TBS progression, rather than a plateau as in the present study.

The mean plot for each soil type had correlation coefficients of >90% during the cold season and >=95% during the warm season. A correlation coefficient this high suggests that the equations used should be further reviewed to determine if they can be useful in estimating the PMI of remains found in shallow graves.

6.3 Body region decomposition

Since it is possible that a body may be found dismembered, and different body regions decompose at different rates, knowing which body region is most reflective of the body's TBS may be useful in narrowing down the PMI estimate. In general, it was found that the decomposition of the head correlated most closely to the TBS, while the limbs tended to be the least closely correlated. Even this correlation exceeded 90%; however, Geissenberger *et al.* (2021) showed that there was no difference in protein degradation of dismembered limbs, as compared to articulated limbs. This was the only study found comparing decomposition of attached and disarticulated limbs. Since it involves microscopic analysis, it does not necessarily compare well to the present research, but nevertheless suggests that there is a similarity between attached and amputated limbs in terms of their decomposition. Using the present study's findings of body region decomposition to reflect the decomposition of partial remains may therefore be corroborated by the findings of Geissenberger *et al.* (2021).

The comparison of TBS-ADD progression between each soil showed that during the cold season, decomposition in each soil type was significantly different from the other soil types. In contrast, during the warm season, only the dolomite and mine tailing piglets had significantly different decomposition from each other. It is possible that the lack of significant difference between dolomite and quartzite, and between quartzite and mine tailings is due to the many changed variables in the warm season (temperature, water supply, increased Dipteran activity, etc.) obscured the effects of the soil's properties on decomposition. These findings suggest that the TBS-ADD equations generated for the cold season should be used only with the matching soil type for cases examined during the cold season, while a case being examined during the warm season may provide similar results no matter the equation used (except for using the dolomite equation for a body found in mine tailings and vice versa).

6.4 Inter-season comparison

A significant difference was found between the warm and cold season TBS-ADD plots of all the measured soil types. It was also interesting to note that the shape of the warm season curves was similar to each other, but visibly different from the shape of the cold season curves (which were also similar to each other). While the former had a sigmoidal shape with an initial lag in decomposition, the latter resembled a logarithmic curve, with an initial rapid rise in TBS that gradually plateaued out until the end of the experiment. The logarithmic curve of the cold season matches the findings of studies looking at decomposition on the surface (Myburgh et al., 2013) as well as decomposition in a buried environment (Marais-Werner et al., 2018). This is the expected trend of rapid progression through the bloat stage followed by an extended period of active decomposition and advanced decomposition with or without mummification and/or adipocere lasting many weeks or months depending on the environment (Galloway et al., 2018). The reason for the sigmoidal curve of TBS-ADD progression in all soil types during the warm season is unclear and appears to have no precedent in existing literature.

It is also noteworthy that even on an ADD-equalised graph, the warm season specimen in each soil type reached a more advanced state of decomposition, as well as (particularly with quartzite and dolomite) a higher ADD. The latter was a likely contributor to the former, as a higher overall temperature is very favourable to the development of Dipteran larva and general activity (Campobasso et al., 2001). Furthermore, the frequent rainfall during the warm season would prevent desiccation and allowing the maggots on the body to continue feeding on it. The higher ADD would also be affected by the increased thermal conductivity of the soil after a large amount of rainfall (Dimitrakopoulos & Martin, 1994). Another factor which contributed to the higher ADD score is the weathering and destruction of the cardboard boxes protecting the containers from lateral solar radiation during the warm season. The strong rainstorms quickly damaged these cardboard boxes, reducing their efficiency and exposing more of the containers to the sun's rays. Future studies following a similar methodology should use opaque (preferably light-coloured) plastic sheets to protect the containers.

6.5 Patterns of decomposition

6.5.1 Naturally occurring soils

The general decomposition patterns observed in remains buried in dolomite and quartzite often corresponded with what was described by Keough *et al.* (2017) for a carcass decomposing on the surface. During the cold season, the piglets were prone to desiccation on the more elevated side, while their undersides had sufficient liquid to allow for adipocere or active decomposition. Notably, both quartzite and dolomite (a clay and a sandy loam, respectively) caused desiccation and partial mummification on their upper sides during the cold season. While the latter is supported by the reviews of Fiedler and Graw (2003), as being a low moisture content soil with higher rates of gas diffusion, the former was expected to form adipocere over the entirety of the body. Marais-Werner *et al.* (2017) also observed the formation of adipocere on their buried specimens after 33 days of internment, which were reported to have been interred in a clay-like soil. The most probable cause for the discrepancy with Marais-Werner *et al.* is that their pig was buried at a depth of 0,75m, at which depth the natural water table was supplying sufficient water for full-body saponification. The quartzite piglets were observed to have formed adipocere on their undersides, which suggests that their bodily fluids were drawn downwards, facilitating adipocere on their lower portions, while the more elevated portions were desiccated and mummified. The differences in observed adipocere formation correlate to the findings of Durães *et al.* (2010), which indicate that soil with a larger grain size (in this case dolomite) is less likely to stimulate adipocere formation than soil with a smaller grain size (i.e., Quartzite), which was explained by the extensive water drainage of the soil limiting the water content needed for saponification. Forbes *et al.* (2005); however, showed a different observation; they found that the soil of the largest grain type was the most likely to cause the formation of adipocere, but only in a humid environment. The explanation provided was that the larger grain sizes facilitated the removal of glycerol, while the higher soil water content provided a sufficiently anaerobic environment for adipocere formation. It is likely that other factors besides the grain size of the soil may be the determining

factor, since the Forbes *et al.* (2005) study used only fatty tissue, while the Durães *et al.* (2010) study used non-fatty muscle tissue.

Despite being the only quartzite-interred piglet showing signs of maggot colonisation during the cold season, piglet Q3 did not show any noteworthy deviation from the decomposition patterns of other quartzite-interred piglets; it didn't even have the highest TBS score of the quartzite piglets. This is in direct contrast with the findings of Simmons *et al.* (2010), which showed that a maggot-colonised body on the surface could reach temperatures up to 5 °C greater than that of the surrounding air. Since a similar shift in temperatures would be expected in buried remains, the lack of a noteworthy difference in the decomposition of the maggot-infested piglet and its non-scavenged counterparts is unexpected. Since neither the upper side nor the underside of piglet Q3 showed many visible signs of maggot consumption, it can only be assumed that the colder temperature resulted in a prolonged hatching period for the larvae (Campobasso *et al.*, 2001), after which period the piglet's desiccated flesh was no longer as appealing a food source. It is also possible that the bodily fluids seeping into the surrounding soil distracted the larvae from the piglet itself.

The dolomite piglets were noted to maintain an active state of decomposition on their trunks' undersides, while their legs and head had almost completely skeletonised. Teo *et al.* (2021) did note a slower decomposition of the trunk in its entirety relative to the head and limbs in their research, which used rabbit (*Oryctolagus cuniculus*) carcasses. Their explanation was that the relatively greater soft tissue mass of the abdomen requires more time to decompose. The closest approximation of the phenomenon of widely different states of decomposition of a body's different regions was noted in a case study by Schotsmans *et al.* (2011), where an individual was found in a clandestine grave, buried in the foetal position on his right side. The soil was reported to be a strongly draining sandy soil, with a low pH varying from 2.6 - 4. In this case, the parts of the body closer to the surface were found to have formed adipocere, the right leg (which was partially exposed) was desiccated and partially mummified, and the torso and arms were in a post-bloat stage. Since no literature was found that mentioned the decomposition of the part of the buried body that was lower down in the soil compared to the part closer to the surface, it is difficult to

confirm if this is a common phenomenon or not. Nevertheless, this lagging of the decomposition of the trunk does not match what was described in other literature of buried pig decomposition within the Gauteng province (Marais-Werner *et al.*, 2017; 2018), who reported fairly uniform decomposition in their buried remains (even though these studies only described the upper part of the pig). These discrepancies in the observable decomposition patterns suggest that one side of a corpse's body (the side deeper in the soil, or the side closer to the surface) may be more accurate in determining the PMI, which requires further investigation.

During the warm season, the dolomite-interred piglets did not display signs of adipocere or mummification. Instead, there was a uniform progression into a state of partial skeletonisation, with some adherent soft tissue. The upper side of these piglets remained in an apparent state of articulation, while the underside had been almost entirely defleshed. It was expected that mummification would not occur, since the frequent warm season rainfall keeps the body tissue hydrated. The lack of adipocere may have been caused by the rapid colonisation by maggots and subsequent mass loss reducing the amount of body tissue which could form adipocere.

The quartzite specimens showed no signs of mummification during the warm season, which was expected. These specimens did show signs of adipocere on their upper side during the warm season, although the Dipteran activity greatly reduced body mass and led to some degree of bone exposure. The upper sides also superficially resembled a partially intact piglet. The undersides of these remains had saponified and were broken apart in the process of flipping them, revealing extensive decomposition prior to the onset of adipocere.

Since no significant difference was calculated between the decomposition of piglets in dolomite and quartzite in the warm season, their differences according to the Keough *et al.* (2017) tables are predictably minor. The commonly observed formation of adipocere on the quartzite specimens is a noteworthy characteristic of that soil type, however. As previously stated, no literature was found comparing the underside of a corpse to its upper half, suggesting a gap in the knowledge pool that may clarify which surface can be more informative regarding a possible PMI.

6.5.2 Mine tailing soil

There were several noteworthy differences between the patterns of decomposition in mine tailing soils and the natural soils. During the cold season, there were two distinctly different patterns during the early decomposition stage, with a third, moderate difference from the former two. The most common pattern, observed in three piglets, was the earlier appearance of blackening of the skin with desiccation of the eyes, nose, and ears. According to Keough *et al.* (2017), this blackening of the soft tissue is not expected to occur until a much later stage of decomposition. A variation was noted in one other piglet where the skin was also blackened, but the mucosal linings did not desiccate. The second major difference was a “bleaching” effect that caused the epidermis to become brittle and peel easily, while the light pink dermis remained pliable. However, this second pattern took on a black discolouration at a stage of decomposition more appropriate to the tables by Keough *et al.* (2017). Both patterns converged in the active decomposition stage, with some expressing adipocere formation, while others continued with normal decomposition.

During the warm season, the piglets buried in mine tailings were rapidly colonised (within five days) by Dipterans, leading to skeletonisation of the head and limbs, as well as general loss of mass. This rate of colonisation was even greater than what was observed by Iancu *et al.* (2018), although their study used rats (*Rattus norvegicus*) buried at 40cm, which would slow the detection of the remains by Dipterans. Simmons *et al.* (2010) showed that large maggot masses can elevate the temperature of the corpse by as much as 5°C, allowing an even more rapid decomposition than the ambient temperature would suggest. This is a very plausible explanation for the extreme progression of TBS in the maggot-infested mine tailing soil.

Since no previous studies have examined the effects of mine tailing soils on the decomposition of buried remains, these results are the first of their kind, and require further research to be validated and contextualised. At present, it appears that tissue darkening is not a suitable method of determining TBS score of bodies buried in mine tailings during the cold season. Furthermore, clarifying the cause of two distinct patterns of early decomposition during the cold season is necessary.

6.6 Soil pH

In contrast to the findings of Carter *et al.* (2010), very little change in soil pH was observed in the dry (cold) season of decomposition. The only change noted was a slow increase of one unit from Met 800ADD until Met 1200ADD (the termination of the experiment) within the quartzite soil. This change in soil pH was very different to what was recorded by Carter *et al.* In their study, a rapid increase in pH, followed by a plateau was noted, which was not reflected in any of the pH graphs in the present experiment. The main difference between the current experiment and that executed by Carter *et al.* (2010) was the species of choice; the current study used domestic pig neonates (*Sus scrofa domesticus*), while the Carter *et al.* study used black rats (*Rattus rattus*). Beyond this, the Carter *et al.* study also took place in a laboratory environment where the water content of the soil was tightly controlled. However, this should theoretically make little difference as the experiment was split to mimic the water availability of a wet and a dry season, similarly to the present experiment.

The soil pH fluctuations recorded by Haslam and Tibbett (2009) are very similar to what was noted in the present study during the warm season. Specifically, the two acidic soils (quartzite sourced from Gauteng, South Africa, and podsol sourced from Dorset county, England) both show a sharp upward pH shift soon after interment of decaying matter, followed by a prolonged decline (Figure 5.21 and Figure 6.1). The difference in pH trends between the two soils are that the total fluctuation of the quartzite pH was less than that of the podsol. Additionally, while the podsol progressed towards a gradual upward trend after its initial spike and decline, the quartzite maintained a similar pH level after its spike and decline until the end of the experiment. This may be because the Haslam and Tibbett (2009) study concluded after 924ADD, while the present study reached a local atmospheric ADD of 1364. The two alkaline soils (dolomite sourced from Gauteng, South Africa, and rendzina sourced from Dorset county, England) are less similar in their specific trends, but both fluctuate very little throughout the course of the experiment, barely deviating from their original pH by more than one unit. The limited pH fluctuation of dolomite is explained by its high buffer capacity, allowing it to resist changes in pH from pollution or (in this case) decompositional fluids (Fey, 2010). The more significant fluctuations

of both the quartzite and the mine tailing pH indicate a conversely lower level of micronutrients, leading to a lower buffer capacity from free metal cations such as iron and magnesium (Fey, 2010). This suggests that for investigations of burials in dolomite or similar soils, examining soil pH would not provide any useful information, while investigations of burials in quartzite or mine tailing might gain some information from testing soil pH. The pH trend line of the mine tailing soil does not have an analogue in the Haslam and Tibbett (2009) study, as expected due to its chemically altered origin. A more detailed understanding of the correlation between soil pH and the state of decomposition of a buried body will provide another data point in the determination of PMI, which will be of great benefit to forensic investigators.

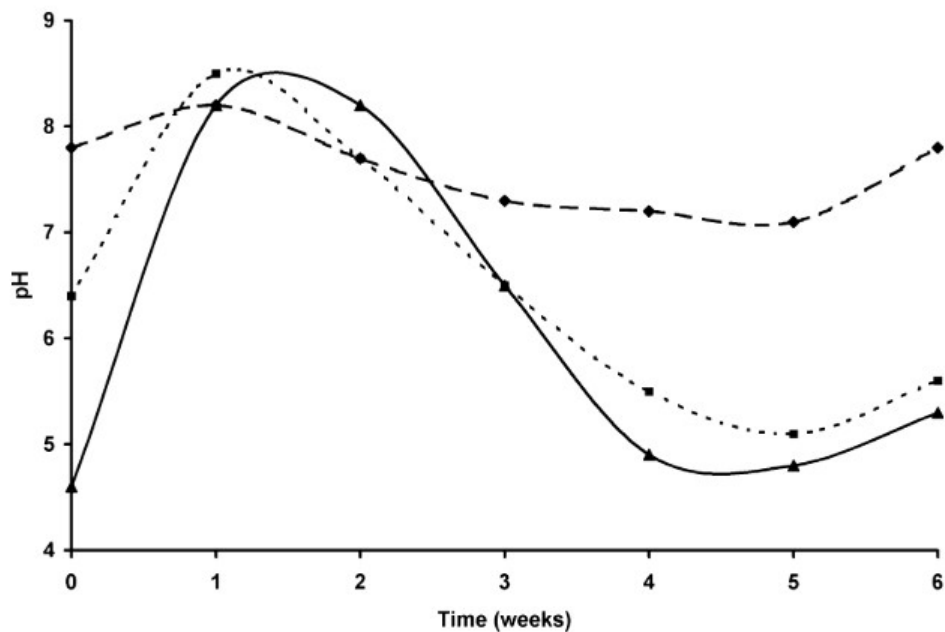


FIG. 3—pH change after the introduction of skeletal muscle tissue (1.5 g) to soil microcosms containing acidic Podsol (solid line with triangles), neutral Cambisol (Brown Earth) (dotted line with squares), and alkaline Rendzina (dashed line with diamonds). $n = 6$.

Figure 6.1: pH fluctuation over time in three different soil types after the introduction of sheep (*Ovis ares*) muscle tissue, as reported by Haslam and Tibbett (2009)

6.7 Limitations

The delay between obtaining the piglets and their interment introduced a period of pre-burial decomposition despite the piglets being stored in a freezer. The poor reliability of the freezer meant that there were some periods where the temperature was not low enough to halt decomposition entirely. The availability of a higher-quality freezer would mitigate this issue, although better coordination of the related parties would eliminate this issue altogether.

The use of two research sites introduced an undesirable variable that could have been difficult to correct for. There was not a significant difference between the daily average temperatures at the two sites during the warm season, suggesting that these sites are sufficiently similar enough to be used for temperature-dependant research. Since commencement of data gathering was delayed at the mining workshop, the cold season average temperatures were significantly different between the research sites. The ADD progression correlation of both sites to each other was very high, which suggests similar trends in temperature shifts and the recording of ADD and not temperature alone will have mitigated any significant differences. The rainfall; however, is a likely cause for the absence of mummification in the mine tailing-interred piglets, as compared to the other soil types where mummification was very frequent. There is precedent set by the research of Wilson *et al.* (2007), which involved the use of three geographically separated sites for *in situ* burial of porcine remains. However, that study was conducted before the development of ADD in the publication of Megyesi *et al.* (2005). Therefore, the limitation of comparing two different sites should not have any significant effect on the results of this burial study.

The corruption of five data loggers during the cold season phase of research resulted in the loss of several data points (in particular, two each from the quartzite and the mine tailing samples). This reduced the quantity of the data obtained during the cold season.

During the warm season, sudden rainstorms interrupted data gathering and skewed the results of the water content data. This is an unavoidable limitation of taphonomic

research, which aims to test variables in natural environments and limit controlled laboratory environments.

Rainstorms also rapidly broke down the cardboard outer boxes used to prevent lateral solar exposure from heating up the containers, potentially resulting in a higher recorded soil temperature. It is unlikely that this significantly affected the results of the study. It is suggested that future studies use materials that are more waterproof and provide sufficient solar insulation to the containers.

6.8 Suggestions for future research

Repeating the methodology while burying the piglets *in situ* would be more accurate in reflecting the effects of burial in a particular soil type. This would also simplify the possibility of increasing the depth of burial to investigate the effects of this factor upon decomposition within each soil type.

Smaller, more focused studies should investigate the rates and patterns of decomposition when temperature is controlled (either a warm or cold environment), while only the water supplied is altered, and vice versa. This will help to determine the impacts of each factor upon decomposition. In addition, Determining the depth of each soil at which Dipteran colonisers can no longer reach the body will provide information on pre-burial insect access and the depth at which decomposition is expected to stagnate due to a lack of colonisers.

Since there are a variety of different minerals extracted all over South Africa, each with their own means of extraction and soil treatment, it would be inaccurate to claim that the current research has provided data on mine tailings as a whole. There is a possibility to investigate the effects of a variety of different mine tailings upon interred bodies.

Collaboration with a chemistry laboratory would allow for the use of more complex analytical tools to examine the soils for nutrients, minerals, and microorganisms to provide a clearer difference between the soils. This would provide an easier comparison for international studies, where the soil may be structurally similar, but have a different ecosystem (Durães *et al.*, 2010, Forbes *et al.*, 2005).

7. Conclusion

This study featured a multifaceted approach at investigating the effects of different soil types on the decomposition of buried remains. The study produced TBS-ADD equations to estimate the PMI of remains buried in quartzite, dolomite, and gold mine tailing soil from TBS and ADD data with very high correlation coefficients. This suggests that the equations hereby generated are potentially reliable for preliminary and supplementary use to determine PMI of buried remains but validation and refinement. A significant difference between warm and cold season decomposition was shown, with many differences in patterns observed in all soil types. It was also shown that while dolomite pH fluctuated only very slightly, quartzite and mine tailing pH values changed notably through the course of the experiment. The absence of this fluctuation during the cold season suggests that an increase in soil water content from the rain is necessary to change the pH.

References

- Adlam, R. E. and Simmons, T. (2007). The effect of repeated physical disturbance on soft tissue decomposition – Are taphonomic studies an accurate reflection of decomposition? *Journal of Forensic Sciences*, 52(5): pp 1007-1014. doi: 10.1111/j.1556-4029.2007.00510.x
- Behrensmeyer, A. (1978). Taphonomic and ecologic information from bone weathering. *Paleobiology*, 4(2): pp 150-162. doi: 10.1017/S0094837300005820
- Benninger, L. A., Carter, D. O., and Forbes, S. L. (2008) The biochemical alteration of soil beneath a decomposing carcass. *Forensic Science International*, 180(2-3): pp 70-75. doi: 10.1016/j.forsciint.2008.07.001
- Buekenhout, I., Cravo, L., Vieira, D. N., Cunha, E., and Ferreira, M.T. (2018) Applying standardized decomposition stages when estimating the PMI of buried remains: reality or fiction? *Australian Journal of Forensic Sciences*, 50(1): pp 68-81. doi: 10.1080/00450618.2016.1212268
- Burt, R. (ed) (2004). Soil Survey Investigations Report No. 42 (4th edn). United States Department of Agriculture, Lincoln.
- Campobasso, C. P., Di Vella, G., and Introna, F. (2001). Factors affecting decomposition and Diptera colonization. *Forensic Science International*, 120(2001): pp 18-27.
- Carter, D. O., Yellowlees, D., and Tibbett, M. (2007). Cadaver decomposition in terrestrial ecosystems. *Naturwissenschaften*, 2007(94): pp 12-24. doi: 10.1007/s00114-006-0159-1
- Carter, D. O., Yellowlees, D., and Tibbett, M. (2010). Moisture can be the dominant environmental parameter governing cadaver decomposition in soil. *Forensic Science International*, 200(1-3): pp 60-66. doi: 10.1016/j.forsciint.2010.03.031
- de Beer, J. H. (1986). Geology of Johannesburg, Republic of South Africa. *Environmental and Engineering Geoscience*, 23(2): pp 101-137. <https://doi.org/10.2113/gseegeosci.xxiii.2.101>

- DeBruyn, J. M., Hoeland, K. M., Taylor, L. S., Stevens, J. D., Moats, M. A., Bandopadhyay, S., *et al.* (2021). Comparative Decomposition of Humans and Pigs: Soil Biogeochemistry, Microbial Activity and Metabolomic Profiles. *Frontiers in Microbiology*, 11(608856): pp 1-16. doi: 10.3389/fmicb.2020.608856
- Di Maio, D. and Di Maio, V. (2001). *Forensic Pathology* (2nd edn). CRC Press, Boca Raton.
- Dimitrakopoulos, A. P., and Martin, R. E. (1994). Effect of moisture content on soil heating during simulated wildland fire conditions. In: Sala, M., and Rubio, J. L. (Eds.) *Soil Erosion and Degradation as a Consequence of Forest Fires*. Geoforma Ediciones, Logrono. pp. 207-216.
- Durães, N., Cortez, D., Algarra, M., Sánchez, F. G., Rodríguez-Borges, J. E., Bobos, I., and Esteves da Silva, J. C. G. (2010). Comparison of adipocere formation in four soil types of the Porto (Portugal) district. *Forensic Science International*, 195(2010): pp 168.e1-e6. doi: 10.1016/j.forsciint.2009.11.010
- Fey, M. (2010). *Soils of South Africa*. Cambridge University Press, Cape Town.
- Fiedler, S. and Graw, M. (2003). Decomposition of buried corpses, with special reference to the formation of adipocere. *Naturwissenschaften*, 90(7): pp 291-300. doi: 10.1007/s00114-003-0437-0
- Finaughty, D. A. and Morris, A. G. (2019). Precocious natural mummification in a temperate climate (Western Cape, South Africa). *Forensic Science International*, 303(2019): pp 109948. doi: 10.1016/j.forsciint.2019.109948
- Forbes, S. L., Dent, B. B., and Stuart, B. H. (2005). The effect of soil type on adipocere formation. *Forensic Science International*, 154(1): pp 35-43. doi: 10.1016/S0379-0738(02)00127-5
- Foth, H. D. (1990). *Fundamentals of Soil Science* (8th edn). John Wiley and Sons, New York.

Galloway, A., Birkby, W. B., Jones, A. M., Henry, T.E., and Parks, B.O. (1989). Decay rates of human remains in an arid environment. *Journal of Forensic Sciences*, 1989(34): pp607-616.

Geissenberger, J., Ehrenfellner, B., Monticelli, F. C., Pittner, S., and Steinbacher, P. (2021). Dismembered porcine limbs as a proxy for postmortem muscle protein degradation. *International Journal of Legal Medicine*, 2021(135): pp 1627-1636. doi: 10.1007/s00414-021-02571-6

Haslam, T. C. F. and Tibbett, M. (2009). Soils of contrasting pH affect the decomposition of buried mammalian (*Ovis aries*) skeletal muscle tissue. *Journal of Forensic Sciences*, 54(4): pp 900-904. doi: 10.1111/j.1556-4029.2009.01070.x

Hill, M. A. and Pokines, J. T. (2022). Comparative analysis of fetal pig decomposition processes in burials of variable depths and wrapping. *Journal of Forensic Sciences*, 2022(00): pp 0-11. doi: 10.1111/1556-4029.15120

Hopkins, D. W., Wiltshire, P. E. J., and Turner, B. D. (2000) Microbial characteristics of soils from graves: an investigation at the interface of soil microbiology and forensic science. *Applied Soil Ecology*, 14(2000): pp 283-288. doi: 10.1016/S0929-1393(00)00063-9

Iancu, L., Junkins, E. N., Necula-Petrareanu, G., and Purcarea, C. (2018). Characterizing forensically important insect and microbial community colonization patterns in buried remains. *Scientific reports*, 8(15513): pp 1-16. doi: 10.1038/s41598-018-33794-0

Keough, N., Myburgh, J., and Steyn, M. (2017). Scoring of Decomposition: A Proposed Amendment to the Method When Using a Pig Model for Human Studies. *Journal of Forensic Sciences*, 62(4): pp 986-993. doi: 10.1111/1556-4029.13390

Keyes, C. A. (2016). 'A forensic taphonomic study into the differential decomposition rates and patterns of bodies subjected to varying degrees of burns'. MSc(Med) in Forensic Medicine, University of the Witwatersrand, Johannesburg.

Keyes, C. A. (2019). How reliable is the charred body scale? An interobserver reliability study on scoring burned remains. *Burns*, 45(2019): pp 1673-1679. doi: 10.1016/j.burns.2019.02.012

Keyes, C. A., Myburgh, J., and Brits, D. (2022). Identifying forensically relevant urban scavengers in Johannesburg, South Africa. *Science and Justice*, 62(2022): pp 399-409. doi: 10.1016/j.scijus.2022.04.007

Macrotrends (2020). South Africa Murder/Homicide Rate 1995-2020. *Macrotrends*, accessed on: 18 February 2020, available from:

<https://www.macrotrends.net/countries/ZAF/south-africa/murder-homicide-rate>

Mant, A. K. (1987). Knowledge acquired from post-war exhumations. In: Boddington, A., Garland, A. N., and Janaway, R. C. (eds), *Death, Decay, and Reconstruction: Approaches to archaeology and forensic science*. Manchester University Press, Manchester. pp 65-78.

Marais-Werner, A., Myburgh, J., Becker, P. J., and Steyn, M. (2018). A comparison between decomposition rates of buried and surface remains in a temperate region of South Africa. *International Journal of Legal Medicine*, 132(1): pp 301-309. doi: 10.1007/s00414-017-1618-2

Marais-Werner, A., Myburgh, J., Meyer, A., Nienaber, W. C., and Steyn, M. (2017). Decomposition patterns of buried remains at different intervals in the Central Highveld region of South Africa. *Medicine, Science, and the Law*, 57(3): pp 115-123. doi: 10.1177/0025802417705263

Matuszewski, S., Hall, M. J. R., Moreau, G., Schoenly, K. G., Tarone, A. M., and Villet, M. H. (2019). Pigs vs people: the use of pigs as analogues for humans in forensic entomology and taphonomy research. *International Journal of Legal Medicine*, 134(2019): pp 798-810. <https://doi.org/10.1007/s00414-019-02074-5>

McCarthy, T. S. (2011). The impact of acid mine drainage in South Africa. *South African Journal of Science*, 107(5/6): pp 1-7. doi:10.4102/sajs.v107i5/6.712

Megyesi, M. S., Nawrocki, S. P., and Haskell, N.H. (2005) Using accumulated degree-days to estimate the postmortem interval from decomposed human remains. *Forensic Science International*, 50(3): pp 618-626.

Moffat, C., Simmons, T., and Lynch-Aird, J. (2016). An improved equation for TBS and ADD: Establishing a reliable postmortem interval framework for casework and experimental studies. *Journal of Forensic Sciences*, 61(1): pp 201-207. doi: 10.1111/1556-4029.12931

Müller, W. (1913). Postmortem Decomposition and Adipocere formation: The Excavation of the Friedhof High Promenade in Zurich. Leemann, Zurich.

Myburgh, J., L'Abbé, E. N., Steyn, M., and Becker, P. J. (2013). Estimating the postmortem interval (PMI) using accumulated degree-days (ADD) in a temperate region of South Africa. *Forensic Science International*, 229(1-3): pp 165e1- 165e6. doi: 10.1016/j.forsciint.2013.03.037

Pinheiro, J. (2006). Decomposition process of a cadaver. In: Schmitt, A., Cunha, E., Pinheiro, J. (eds), *Forensic anthropology and medicine: complementary sciences from recovery to cause of death*. Humana Press, Totowa, pp 85–116.

Prangnell, J. and McGowan, G. (2009). Soil temperature calculation for burial site analysis. *Forensic Science International*, 191(1-3): pp 104-109. doi: 10.1016/j.forsciint.2009.07.002

Rösner, T. and van Schalkwyk, A. (2000). The environmental impact of gold mine tailings footprints in the Johannesburg region, South Africa. *Bulletin of Engineering Geology and the Environment*, 59(2000): pp 137-148.

<https://doi.org/10.1007/s100640000037>

Rysavy, N. M. and Goff, M. L. (2015). Preliminary observations of arthropods associated with buried carrion on Oahu. *Journal of Forensic Sciences*, 60(2): pp 462-467. doi: 10.1111/1556-4029.12643

Saukko, P. and Knight, B. (2016). *Knight's Forensic Pathology* (4th edn). CRC Press, Boca Raton.

- Schotsmans, E. M. J., Van de Voorde, W., De Winne, J., and Wilson, A. S. (2011). The impact of shallow burial on differential decomposition to the body: a temperate case study. *Forensic Science International*, 206(2011): pp 43-48. doi: 10.1016/j.forsciint.2010.07.036
- Sheoran, V., Sheoran, A., and Poonia, P. (2010). Soil Reclamation of Abandoned Mine Land by Revegetation: A Review. *Interational Journal of Soil, Sediment, and Water*, 3(2): pp 1-20.
- Simmons, T., Cross, P. A., Adlam, R. E., and Moffatt, C. (2010). The influence of insects on buried and surface remains. *Journal of Forensic Sciences*, 55(4): pp 889-892. doi: 10.1111/j.1556-4029.2010.01402.x
- South African National Weather Service. (2023). Weather station list Case 36626. Extracted on: 05/06/2023 [data request]
- Steyn, M., Meiring, J. H., and Nienaber, W. C. (1997). Forensic anthropology in South Africa: a profile of cases from 1993 to 1995 at the Department of Anatomy, University of Pretoria. *South African Journal of Ethnology*, 20(1): pp 23-26.
- Stokes, K. L., Forbes, S. L., and Tibbett, M. (2008). Freezing skeletal muscle tissue does not affect its decomposition in soil: Evidence from temporal changes in tissue mass, microbial activity and soil chemistry based on excised samples. *Forensic Science International*, 183(2009): pp 6-13. doi: 10.1016/j.forsciint.2008.08.013
- Stratford, D. (2020). *Common soil types*. [email].
- Teo, C. H., Hing, H. L., Hamzah, N. H., and Hamzah, S. P. A. A. (2021). The effect of different coverings on Total Body Score development of buried carcasses. *Malaysian Journal of Medical Sciences*, 28(4): pp 103-112. doi: 10.21315/mjms2021.28.4.11
- Tumer, A. R., Karacaoglu, E., Namli, A., Keten, A., Farasat, S., Akcan, R., *et al.* (2013). Effects of different types of soil on decomposition: An experimental study. *Legal Medicine*, 15(2013): pp 149-156. doi: 10.1016/j.legalmed.2012.11.003

Turner, B. and Wiltshire, P. (1999). Experimental validation of forensic evidence: a study of the decomposition of buried pigs in a heavy clay soil. *Forensic Science International*, 101(1999): pp 113-122.

UNODC. (2019). Global study on homicide, 2019. United Nations, Vienna.

Van Daalen, M. A., de Kat, D. S., Oude Grotebevelsberg, B. F. L., de Leeuwe, R., Warnaar, J., Jan Oostra, J., *et al.* (2017). An aquatic decomposition scoring method to potentially predict the Postmortem Submersion Interval of bodies recovered from the North sea. *Journal of Forensic Science*, 62(2): pp 369-373. doi: 10.1111/1556-4029.13258

Vass, A. A., Bass, W. M., Wolt, J., Foss, J., and Ammons, J. (1992). Time since death determinations of human cadavers using soil solution. *Journal of Forensic Science*, 1992(37): pp 1236-1253.

Wilson, A. S., Janaway, R. C., Holland, A. D., Dodson, H. I., Baran, E., Pollard, A. M., and Tobin, D. J. (2007). Modelling the buried human body environment in upland climates using three contrasting field sites. *Forensic Science International*, 169(2007): pp 6-18. doi: 10.1016/j.forsciint.2006.07.023

Appendices

Appendix A: TBS table for decomposition of *Sus scrofa domesticus* (Keough *et al.*, 2017)

Table 8. Modified categories and stages of decomposition for the head and neck (pig)

A	Fresh
(1pt)	1. Fresh, no discolouration – slight lividity (pink/red)
B	Early decomposition
(2pts)	1. Insect activity; pronounced lividity (dark pink/red)
(3pts)	2. Dark red discolouration with some flesh still relatively fresh; odema of ears; maggot colonisation (mouth); initial bloating of neck and skin slippage
(4pts)	3. Discolouration and/or brownish shades particularly at edges, drying of nose, ears and lips; prominent bloating of neck; maggot colonisation (mouth & eyes); purging of decompositional fluids (mouth)
(5pts)	4. Purging of decompositional fluids (mouth, eyes, nose); brown discolouration; hair loss and skin slippage; drying of lips, nose and ears
(6pts)	5. Black discolouration of flesh; extensive maggot colonisation and migration
C	Advanced decomposition
(7pts)	1. Caving in of the flesh and tissues of eyes and throat
(8pts)	2. Moist decomposition with bone exposure less than one half that of the area being scored
(9pts)	3. Mummification with bone exposure less than one half that of the area being scored
D	Skeletonization
(10pts)	1. Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue
(11pts)	2. Bone exposure of more than half the area being scored with desiccation of mummified tissue
(12pts)	3. Bones largely dry, but retaining some grease
(13pts)	4. Dry bone

Table 9. Modified categories and stages of decomposition for the trunk (pigs)

A	Fresh
(1pt)	1. Fresh, no discolouration – slight lividity (pink)
B	Early decomposition
(2pts)	1. Skin appears shiny/glossy with early bloating; may show purple-black discolouration over abdominal area
(3pts)	2. Grey-purple to green discolouration: some flesh still relatively fresh; marbling of abdomen with maximum bloat
(4pts)	3. Purple-black discolouration and purging of decompositional fluids; skin slippage with maggot filled blisters present; hair loss
(5pts)	4. Post-bloating following release of the abdominal gases, with extensive skin slippage and drying out of blisters
C	Advanced decomposition
(6pts)	1. Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity
(7pts)	2. Moist decomposition with bone exposure less than one half that of the area being scored
(8pts)	3. Mummification with bone exposure less than one half that of the area being scored
D	Skeletonization
(9pts)	1. Bones with decomposed tissue, sometimes with body fluids and grease still present
(10pts)	2. Bones with desiccated or mummified tissue covering less than one half of the area being scored
(11pts)	3. Bones largely dry, but retaining some grease
(12pts)	4. Dry bone

Table 10. Modified categories and stages of decomposition for the limbs (pigs)

A	Fresh
(1pt)	1. Fresh, no discolouration – slight lividity (pink) with rigor present
B	Early decomposition
(2pts)	1. Pink-white appearance with bloating of proximal parts of limbs
(3pts)	2. Grey to green discolouration: marbling and shiny appearance of skin; some flesh still relatively fresh; skin slippage and hair loss
(4pts)	3. Discolouration and/or brownish shades particularly at edges, drying of skin (starting distal to proximal)
(5pts)	4. Brown to black discolouration, skin having a leathery appearance
C	Advanced decomposition
(6pts)	1. Moist decomposition with bone exposure less than one half that of the area being scored
(7pts)	2. Mummification with bone exposure less than one half that of the area being scored
D	Skeletonization
(8pts)	1. Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining
(9pts)	2. Bones largely dry, but retaining some grease
(10pts)	3. Dry bone

Appendix B: Animal Research Ethics Committee form

ANIMALS RESEARCH ETHICS COMMITTEE (AREC)



STRICTLY CONFIDENTIAL

CLEARANCE CERTIFICATE NUMBER: 2020/06/06/A

APPLICANT: Mr A Markov

School: School of Pathology; Department: N/A; Location: Forensic Pathology Services - Johannesburg Medico-Legal Mortuary

PROJECT TITLE: The rates and patterns of decomposition of porcine (*Sus scrofa*) remains buried in different soil types in the highveld of South Africa
Category: A; Species and Numbers involved: 30X 10kg male/female *Sus scrofa*

Approval is hereby given for the use of animals for the research project named above and described in the application reviewed by a quorate meeting of the AREC held on 30 Jun 2020. This approval remains valid until 22 Jul 2022 and is conditional to the following (if blank there are no special conditions):

Condition 1	Condition 2	Condition 3	Condition 4

All material changes to the approved research must be reported to the AREC before they are implemented. Failure to do so will invalidate this clearance certificate.

An annual progress report must be provided to the AREC.

The use of these animals is subject to AREC guidelines on the use and care of laboratory animals, is limited to the procedures described in the application and is subject to additional conditions listed below:

I, the Chair of the AREC (or my designated representative) am satisfied that the proposed research is ethical as judged by local law, international standards and University policy.

Signed: _____ Date: 23/07/2020
(Chairperson of the AREC)

I am satisfied that the persons listed in this application are competent to perform the procedures described in the application, in the context of Section 23 (1) (c) of the veterinary and Para-veterinary Professions Act (19 of 1982).

Signed: _____ Date: 24 July 2020
(Registered Veterinarian)

CC: Student supervisor: «Title1» «Initials1» «Supervisor_surname»
Director Central Animals Service: Dr Kim Jardine

Appendix C: Equations and correlation coefficients for logarithmic and linear (log10) TBS-soil ADD plots, where the TBS is the subject of the formulae

Cold season	Equation and Correlation coefficient
Dolomite (logarithmic)	$f(d) = 4,18666596718809 \ln(d) - 7,20368710643021$ $R^2 = 0,916729947584721$
Dolomite (linear (log10))	$f(d) = 9,64015464539276 d - 7,20368710643015$ $R^2 = 0,916729947584721$
Quartzite (logarithmic)	$f(q) = 3,36730688484178 \ln(q) - 1,83449054587524$ $R^2 = 0,945812535630938$
Quartzite (linear (log10))	$f(q) = 7,75351063657287 q - 1,83449054587519$ $R^2 = 0,945812535630939$
Mine tailing (logarithmic)	$f(m) = 6,22654556285459 \ln(m) - 21,5861391855736$ $R^2 = 0,930976108128495$
Mine tailing (linear (log10))	$f(m) = 14,3371509938772 m - 21,5861391855735$ $R^2 = 0,930976108128495$
Mine tailing (TBS-corrected) (logarithmic)	$f(mA) = 5,0391916640875 \ln(mA) - 12,6290104311946$ $R^2 = 0,924512279641921$
Mine tailing (TBS-corrected) (linear (log10))	$f(mA) = 11,6031676064677 mA - 12,6290104311946$ $R^2 = 0,92451227964192$
Warm season	
Dolomite (logarithmic)	$f(d) = 6.01691163077819 \ln(d) - 16.039493661086$ $R^2 = 0.967288893372574$
Dolomite (linear (log10))	$f(d) = 13,8544510268923 d - 16,039493661086$ $R^2 = 0,967288893372574$
Quartzite (logarithmic)	$f(q) = 6.17187689825223 \ln(q) - 17.2893090670406$ $R^2 = 0.948792372820444$
Quartzite (linear (log10))	$f(q) = 14,2112717417099 q - 17,2893090670406$ $R^2 = 0,948792372820444$
Mine tailing (logarithmic)	$f(m) = 6.63488594309458 \ln(m) - 19.156950485949$ $R^2 = 0.957266621588848$
Mine tailing (linear (log10))	$f(m) = 15,2773894662853 m - 19,156950485949$ $R^2 = 0,957266621588847$

Appendix D: Variations of decomposition noted for each piglet during the cold season study (hyphen indicates no deviation from earlier observation and general progression of decomposition)

Meteorological ADD	Dolomite Piglet 1	Dolomite Piglet 2	Dolomite Piglet 3	Dolomite Piglet 4	Dolomite Piglet 5
0	-	-	-	-	-
150	-	-	-	-	-
300	-	-	-	-	-
450	-	Maggot colonisation	-	-	-
600	-	-	Signs of mummification	Signs of mummification	-
800	-	Ongoing maggot colonisation; head and limbs largely skeletonised	Maggot colonisation	Mummification of entire visible body	Maggot colonisation; partial skeletonisation of head
1000	Pupae present	Pupae present	Adipocere – rear haunches	Pupae present	Ongoing maggot colonisation
1100	Torso appears mummified	-	Adipocere over most of the body	-	Head and limbs largely skeletonised, disarticulated
1200	Skeletonisation of head and limbs; mummified torso	-	Largely intact body; partially mummified	-	-
1200 (Flipped)	Head and limbs skeletonised and mostly disarticulated; actively decomposing thoraco-abdominal mass	Head and limbs skeletonised and disarticulated; actively decomposing thoraco-abdominal mass	Skin loss with patches of saponified tissue	Head and limbs skeletonised; actively decomposing thoraco-abdominal mass	Head and limbs skeletonised and disarticulated; actively decomposing thoraco-abdominal mass

Meteorological ADD	Quartzite piglet 1	Quartzite piglet 2	Quartzite piglet 3	Quartzite piglet 4	Quartzite piglet 5
0	-	-	-	-	-
150	-	-	-	-	-
300	-	-	-	Eyes sunken	-
450	Eyes sunken; skin pliable	-	-	-	-
600	-	Signs of mummification	Signs of mummification	-	Distal limb bone exposure; upper limb pliable
800	Sunken, pliable skin over entire visible body	-	Maggot colonisation	Skin of lower limbs closely adherent to underlying bone	-
1000	-	Skin of lower limbs closely adherent to underlying bone	-	-	Desiccation of all limbs
1100	Bone exposure on limbs	Mummified	Mummified; Pupae present	-	-
1200	-	-	-	-	-
1200 (Flipped)	Saponified on underside; small patches of active decomposition	Saponified on underside	Saponified on underside; small patches of active decomposition	Skin loss, desiccated tissue	Saponified on underside; small patches of active decomposition

Meteorological ADD	Mine tailing piglet 1	Mine tailing piglet 2	Mine tailing piglet 3	Mine tailing piglet 4	Mine tailing piglet 5
0	-	-	-	-	-
200	Pale-pink discolouration; parchment-like skin	Blackened, pliable skin, desiccated ears, nose, and eyes	Blackened, pliable skin, desiccated ears, nose, and eyes	Blackened, pliable skin, desiccated ears, nose, and eyes	Blackened, pliable skin, bloated, undesiccated eyes and ears
400	Blackened, pliable skin, desiccated ears, nose, and eyes	Drying of distal limbs	Drying of distal limbs	Anal purging; drying distal limbs; skin slippage	Anal purging; drying distal limbs; skin slippage
600	Disarticulated limbs, wet tissue present	-	-	Maggot colonisation	Disarticulated lower limbs; dry tissue
800	Pupae found	-	-	Pupae found	-
1000	Signs of adipocere	Signs of adipocere	-	Signs of adipocere	-
1200	Rapid loss of soft tissue around head and limbs	Adipocere	-	Return to normal decomposition	-

Appendix E: Variations of decomposition noted for each piglet during the warm season study (hyphen indicates no deviation from earlier observation and general progression of decomposition)

Meteorological ADD	Dolomite Piglet 1	Dolomite Piglet 2	Dolomite Piglet 3	Dolomite Piglet 4
0	-	Sunken eyes	-	-
200	Post-bloat abdominal collapse	Post-bloat abdominal collapse	Post-bloat abdominal collapse	Post-bloat abdominal collapse; desiccated skin; Cranial collapse
400	Maggots present	Maggots present	Cranial bone disarticulation	Maggots present
600	No visible maggot activity	Distal limb disarticulation	-	No visible maggot activity
800	-	-	Distal limb disarticulation	-
1000	Disarticulated jaw	-	-	Distal limb disarticulation
1200	-	-	-	Cranial bone disarticulation
1200 (Flipped)	Extensive decomposition and disarticulation with very little soft tissue remaining	Extensive decomposition with very little soft tissue remaining; vertebral column largely intact	Extensive decomposition and disarticulation with very little soft tissue remaining	Extensive decomposition and disarticulation with very little soft tissue remaining

Meteorological ADD	Quartzite piglet 1	Quartzite piglet 2	Quartzite piglet 3	Quartzite piglet 4	Quartzite piglet 5
0	-	-	Sunken eyes	Sunken eyes	-
200	Post-bloat abdominal collapse	Post-bloat abdominal collapse; desiccated skin	Maggot activity; bloated body and limbs	Post-bloat abdominal collapse; desiccated skin	Bloated body and limbs
400		Maggot activity	Extensive maggot activity	-	Extensive maggot activity; post-bloat abdominal collapse
600	Maggot activity; cranial bone disarticulation	-	-	Signs of adipocere; cranial bone disarticulation	Signs of adipocere
800	No visible maggot activity	No visible maggot activity	No visible maggot activity; signs of adipocere	-	Waterlogged, inaccessible
1000	-	Distal limb disarticulation	Distal limb and cranial bone disarticulation	-	-
1200	-	-	Maggot activity	-	-
1200 (Flipped)	Head and limbs skeletonised and mostly disarticulated; actively decomposing thoraco-abdominal mass	Largely disarticulated body; chunks of soft tissue with signs of saponification	Largely disarticulated body; chunks of soft tissue with signs of saponification	Largely disarticulated body; chunks of soft tissue with signs of saponification	-

Meteorological ADD	Mine tailing piglet 1	Mine tailing piglet 2	Mine tailing piglet 3	Mine tailing piglet 4	Mine tailing piglet 5
0	-	Sunken eyes	Sunken eyes	-	-
200	Extensive maggot activity	Blackened skin; post-bloat sunken abdomen; desiccated nose and ears extensive maggot activity	Post-bloat sunken abdomen; desiccated skin, nose, and ears; extensive maggot activity	Extensive maggot activity	Extensive maggot activity; pliable skin
400	Blackened skin	Skeletonised head	Blackened skin; skeletonisation of head and distal limbs	Extensive skin loss; blackened tissue	-
600	No visible maggot activity	Blackened skin; distal limbs disarticulated; no visible maggot activity	Signs of adipocere	Many ants present in soil	Blackened tissue; skeletonised head and distal limbs; no visible maggot activity
800	Signs of adipocere	Signs of adipocere	No visible maggot activity	Signs of adipocere; no visible maggot activity	Signs of adipocere; disarticulated limbs
1000	Maggot activity	-	-	Maggot activity	-
1200	Facial collapse	-	-	-	-
1200 (Flipped)	Largely disarticulated body; chunks of soft tissue with signs of saponification	Largely disarticulated and skeletonised body	Largely disarticulated and skeletonised body	Largely disarticulated body; chunks of soft tissue with signs of saponification	Largely disarticulated and skeletonised body

Appendix F: Turnitin plagiarism report

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