CHARACTERIZATION OF A CORTICAL DEFECT OF THE ULNA FOUND IN THE FERNVALE ARCHAEOLOGICAL POPULATION (40WM51) OF THE SOUTH HARPETH RIVER VALLEY IN MIDDLE TENNESSEE

by

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Dedicated to my incredible grandmother, Arlene Elise Seibert Grau.

Thank you for all you taught me and for reminding me daily that we continue to teach those left on earth once we move on to ‘bigger and better things.’

I love you, Grandma.

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♪ *"I've been waiting for the time that I can finally say,*
This has all been beautiful; now I'm on my way." ♪

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♪ *“It turns out, it’s not where, but who you’re with that really matters.”* ♪

ABSTRACT

Osteological analyses of human remains from Fernvale (40WM51), a multicomponent site with Late Archaic Period interments along the South Harpeth River in Middle Tennessee, were conducted as part of a re-analysis project implemented by the Tennessee Division of Archaeology (TDOA). The main goal of this research was to describe and characterize a cortical defect, observed in 14 of 16 individuals (23 of 26 ulnae) from the site, that had not been previously documented in the anthropological or clinical literature and offer explanations to the biomechanical origins of the defect. The cortical defect, located in the proximal radioulnar joint appeared to be the imprint of soft tissue damage in response to physical stressors. Activities biomechanically similar to climbing and canoeing or accidental falls caused by habitually traversing rugged terrain possibly caused the avulsion injury to the lateral ligament complex that resulted in the cortical defect at the posterior attachment site of the annular ligament.

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CHAPTER I: INTRODUCTION

This research is focused on the specific musculoskeletal actions of the elbow and the osteological response to remodeling processes as an effect of trauma and biomechanical strain on the stability of the joint. Initial examinations of human remains excavated from Fernvale, a prehistoric site in northwestern Williamson County, Tennessee (40WM51), revealed a specific cortical defect in the proximal ulna suspected to be the result of trauma or biomechanical strain on the ligamentous structures contributing to the stability of the proximal radioulnar joint of the elbow. Biology, environment, and lifestyle patterns all contribute to morphological variations in the human skeleton (Larsen 1997). Morphological variation caused by disease and trauma can be difficult to distinguish from variation caused by the physical and social environments of the individual. Therefore, in a systematic study of the underlying pathology of a skeletal defect, it is important to place the individual in his or her proper environmental and cultural context. "Clearly, the incidence and location of traumatic events is greatly influenced by culture (Ortner and Putschar 1981)." Peebles (1977) states:

> *"A human burial contains more anthropological information per cubic meter of deposit than any other type of archaeological feature. A burial represents the latent images of a biological and cultural person frozen in a clearly delimited segment of space and time."*

For these reasons, the anatomical and paleopathological data collection, description, and analyses of the observed cortical defect in the proximal ulna have been approached from a biocultural viewpoint. This offers a unique perspective and understanding of the external influences on the internal mechanics of the joint.

1.1 The Skeletal Sample

This analysis is based on data collected from the skeletal remains excavated from the Fernvale archaeological site in Williamson County, TN (40WM51). Osteological and paleopathological analyses of human remains were conducted as part of a re-analysis project implemented by the Tennessee Division of Archaeology (TDOA). This thesis research focuses on a specific skeletal defect discovered among the Fernvale remains during a graduate independent study course in human osteology.

Twenty-six ulnae from sixteen of the thirty-two individuals excavated from the Fernvale site proved useful for detailed examination. Subadult, charred, and severely fragmented remains were not used, nor were burials that did not possess the bones necessary for the investigation (i.e., bones of the forearm, specifically the articular surfaces comprising the elbow joint). From those sixteen individuals, a total of twenty-six (26) ulnae, twenty-nine (29) humeri, and ten (10) radii were examined for the presence and degree of degenerative joint disease of the elbow. The ulnae were examined thoroughly and scored for presence or absence of a cortical defect near the radial notch. If the defect was present, metric measurements were taken according to North American bioarchaeological standards of data collection (Buikstra and Ubelaker 1994) as well as techniques developed by the researcher specifically for this Master's thesis (see Chapter 3, Section 3.3 for more detail). If the skeletal elements necessary for the estimation of age, sex, and stature were available, a biological profile was constructed according to standard North American bioarchaeological principles and practices (Buikstra and Ubelaker 1994) to provide a demographic context for the defect's origin. The results were then used to assess whether any commonalities existed among the individuals in which the defect was present.

1.2 Research Problem

This thesis proposes a description, characterization, and possible etiology of a previously unrecognized and unidentified skeletal anomaly of the proximal ulna observed in several osteological[1] specimens. This research focuses on describing and characterizing this defect within the context of joint degeneration and articular capsule destruction as a response to biomechanical stressors of the proximal radioulnar joint. These data will help answer the primary question of this research: Can the cortical defect under consideration be used as a marker for identifying activity-induced trauma to the lateral ligament complex of the elbow in osteological remains with or without the presence of osteoarthritis? If so, this discovery offers a novel approach to the study of activity-induced traumatic elbow injuries in both archaeological and clinical contexts.

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[1] For the purposes of this thesis, the terms osteological and osteological specimen(s) are preferred in lieu of macerated, cadaveric, anatomical, dry bone, archaeological, archaeological specimen(s), anthropological, and anthropological specimen(s). These terms are used to refer to bone that is free of soft tissue, regardless of identity and regardless of whether they are examined by a medical doctor, a pathologist, an anatomist, an anthropologist, a bioarchaeologist, a paleopathologist, or an anatomist.

1.3 Research Objectives

The objectives of this thesis are: (1) to provide a full qualitative description of the defect observed in osteological specimens referring to literature from both clinical anatomy and paleopathology; (2) to provide a quantitative description of the defect through metric measurements and statistical tests of dependence and variance by age, sex, side, defect size, and presence/absence of degenerative joint disease; and (3) to relate the etiology of the cortical defect to particular biomechanical processes known to involve this specific ligament complex of the elbow.

To provide an accurate and reliable description of the skeletal defect, this study first considers normal bone biology and typical individual variation in morphology resulting from specific pathological conditions, comparing the individuals from the Fernvale site with comparative skeletal collections, and then supplements the data with the utilization of reference literature of both paleopathology and clinical contexts. Statistical analysis was performed to test the following null ($H_{\emptyset}$) hypotheses against the alternative hypotheses (H_a).

1.4 Summary of Statistical Hypotheses

1.4.1 Hypothesis 1 (a & b)

1.4.1.a *The occurrence of the defect is associated with the sex of the individual.*

1.4.1.b *The overall size of the defect depends on the sex of the individual.*

1.4.2 Hypothesis 2 (a & b)

1.4.2.a *The occurrence of the defect is associated with the location of the defect (in either the left or the right arm).*

1.4.2.b *The overall size of the defect depends on the side of the body on which it occurs.*

1.4.3 Hypothesis 3 (a & b)

1.4.3.a *The occurrence of the defect is associated with the age of the individual.*

1.4.3.b *The overall size of the defect depends on the age of the individual.*

1.4.4 Hypothesis 4 (a & b)

1.4.4.a *The occurrence of the defect is associated with the occurrence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.*

1.4.4.b *The size of the defect depends on the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.*

1.5 Summary

Testing these hypotheses will allow for demographic characterization of the occurrence of this defect in terms of prevalence by age and sex, and illuminate any associations that may exist with presence of the defect and with evidence of other forms of skeletal wear-and-tear. These results will provide the social and biological context in terms of susceptibility to and severity of the defect within the constraints of the biomechanics of the elbow. The remaining chapters of this thesis offer a characterization of the skeletal defect in a qualitative and descriptive manner while offering an explanation to its biomechanical etiology. This thesis provides an overview of the functional anatomy of the elbow joint and the contributions to its stability under normal conditions, followed by a discussion of the ways in which overuse of the joint can lead to ligament destruction and, eventually, an osteological response. Furthermore, a brief consideration of ecological and economic factors is presented that might show the ways in which the prehistoric inhabitants of Fernvale were forced to adapt their lifestyles in response to the changing cultural and environmental landscapes of the Late Archaic period in Middle Tennessee, thereby supporting the model that the defect observed is associated with physically demanding activities.

CHAPTER II: LITERATURE REVIEW

2.1 Functional Anatomy of Normal Elbow Stability

2.1.1 Introduction

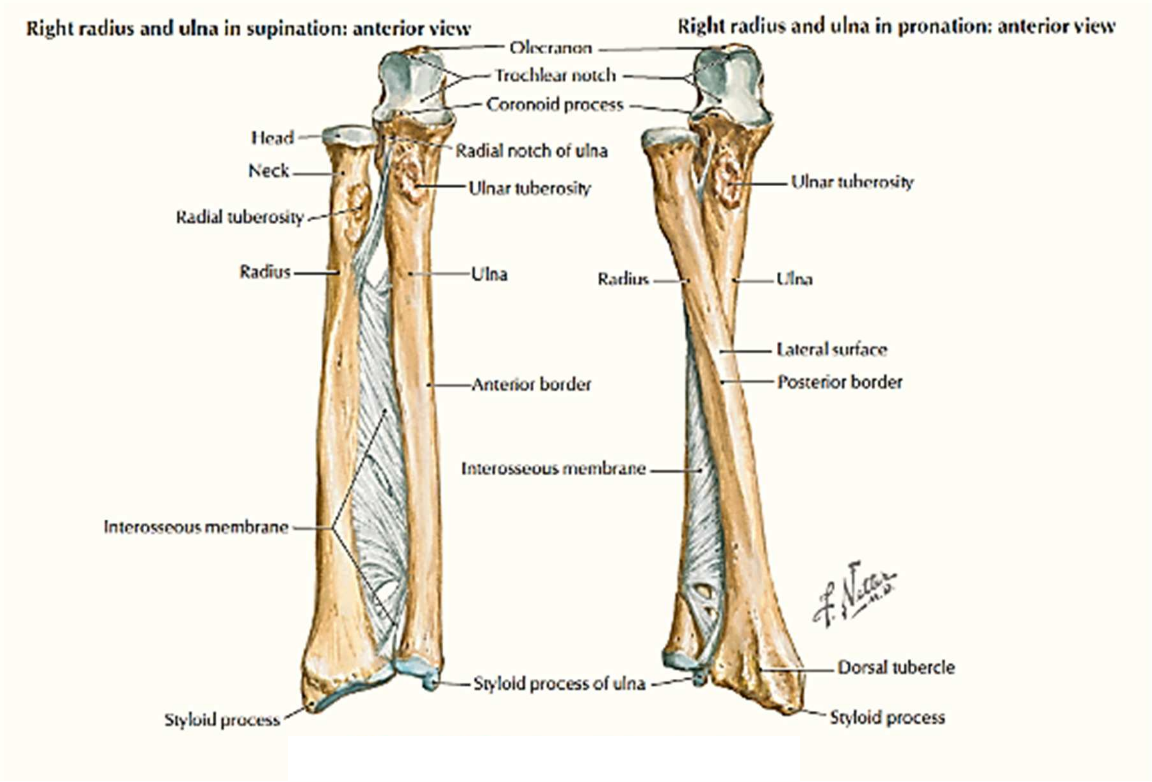
The complex and collaborative motions of the elbow joint are essential to the minute movements of the hands, contributing to our distinctiveness as humans. The functional anatomy of the elbow joint is adapted to specific movements of flexion and extension of the forearm and of pronation and supination of the hand. The operations performed by these hand movements are highly variable in humans (Cohen and Hastings 1997; Deutch et al. 2003; Fleisig and Escamilla 1996; Gerr et al. 1991; Jurmain 1977, 1980; Morrey et al. 1981, 1985; Nicholson and Driscoll 1993; O’Neil et al. 2001; Ortner 1968; Resnick and Niwayama 1981; Stroyan and Wilk 1993). Complex hand movements allow for a variety of activities, such as turning a screwdriver, knitting, feeding oneself, turning a door knob, lifting heavy objects, or throwing a projectile, among others. Presumably, there is potential for overuse injuries to the elbow joint among humans, regardless of temporal or spatial distribution. A traumatic injury to the elbow can hinder the day-to-day activities of an individual because of the complex and interconnected nature of the structures of the elbow joint.

2.1.2 Descriptive Anatomy of the Osteological Structures of the Elbow

The human elbow joint includes articulations of three separate bones establishing three distinct joints. These bony articulations provide stability to the elbow during movements of flexion and extension along with pronation and supination (Deutch et al. 2003; Drake et al. 2009; O'Driscoll et al. 1991; Savoie et al. 2006; Resnick and Niwayama 1981). The trochlea (or trochlear groove) of the humerus articulates with the trochlear notch (or semilunar notch; greater sigmoid cavity) of the ulna to form the humeroulnar joint (Bass 1995; Gray 1985; White and Folkens 2005). The humeroulnar (or ulnohumeral) joint is a diarthrodial true hinge joint, or a synovial joint that allows movement in a single plane (Drake et al. 2009; Gray 1985). This articulation facilitates flexion and extension of the forearm (Drake et al. 2009; Ortner 1968; Resnick and Niwayama 1981).

The capitulum of the humerus articulates with the cup-shaped proximal epiphysis of the radius to form the humeroradial joint (Bass 1995; Gray 1985; White and Folkens 2005). The humeroradial (or radial-humeral) joint is a non-axial gliding joint involved in flexion and extension and pronation and supination of the forearm (Drake et al. 2009; Ortner 1968; Resnick and Niwayama 1981). Ortner (1968) explains that the radial-humeral joint endures most of the mechanical stress of the elbow, because the major muscles of both pronation (*pronator teres* and *pronator quadratus*) and supination (*biceps brachii* and *supinator*) insert on the proximal radius. Thus, the head of the radius undergoes a great deal of stress during pronation and supination, and during flexion and extension, making it a common site for traumatic overuse injuries (Cohen and Hastings 1997; Fleisig and Escamilla 1996; Gerr et al. 1991; Jurmain 1980; Morrey 1985; Nicholson and Driscoll 1993; O'Driscoll et al. 2000; Ortner and Putschar 1981; Stroyan and Wilk 1993).

The broad, circumferential, articular surface of the head of the radius articulates with the radial notch of the ulna to form the proximal radioulnar joint (Bass 1995; Gray 1985; White and Folkens 2005). The radioulnar joint, a diarthrodial pivot joint created by the head of the radius held in place at the radial notch of the ulna by the annular and quadrate ligaments (Gray 1985), assists in supination and pronation of the forearm (Drake et al. 2009; Ortner 1968; Resnick and Niwayama 1981). During supination, the radius and ulna lie parallel to one another in anatomical position (Figure 2.1); during pronation, the radius crosses over the ulna at the proximal radioulnar joint (Drake et al.


Right radius and ulna in supination: anterior view

Right radius and ulna in pronation: anterior view

Figure 2.1: Right radius and ulna, anterior view-in supination and in pronation
Adapted from: *Netter's Atlas of Human Anatomy, 6th edition. 2014*

2009; Netter 2014; O'Driscoll et al. 1991; Savoie et al. 2006; Resnick and Niwayama 1981). These bony articulations provide the static limitations necessary to stabilize the elbow.

2.1.3 Descriptive Anatomy of the Soft Tissue Structures of the Elbow

In addition to the bony articulations, the arrangement of soft tissue structures provides a more flexible and dynamic restraint in helping to stabilize the articular capsule of the elbow. Several muscles, both superficial and deep, pass through the elbow capsule to contribute to the movements of flexion and extension in conjunction with pronation and supination and establish their tendons of origin and/or insertion within the proximal radioulnar joint (Drake et al. 2009; Gray 1985; Morrey et al. 1981; Morrey 1985; Nicholson and Driscoll 1993; Stroyan and Wilk 1993).

2.1.3.a Muscles of Flexion

The major muscles involved in flexing the arm at the elbow (*brachioradialis* and *brachialis*) both have their origins on the distal end of the humerus (Drake et al. 2009; Gray 1985). *Brachioradialis* originates from the supracondylar ridge of the humerus and inserts on the lateral surface of the distal end of the radius while *brachialis* originates from the distal half of the anterior surface of the humerus and inserts onto the coronoid process and tuberosity of the ulna (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). Several superficial flexor muscles in the anterior compartment of the forearm share an origin at the common flexor tendon, which attaches at the medial epicondyle of the humerus (Gray 1985; Drake et al. 2009; Morrey et al.

1981; Nicholson and Driscoll 1993; Sampath et al. 2003). The placement of the flexor muscles causes the elbow to function as a fulcrum for flexion of the arm, putting a great deal of stress on the joint.

2.1.3.b Muscles of Extension

Triceps brachii (or, simply, the triceps), the chief extensor of the forearm, originates from three heads: (1) the long head from the infraglenoid tubercle of the scapula, (2) the lateral head from the posterior surface of the humerus, superior to the radial groove, and (3) the medial head from the posterior surface of the humerus, inferior to the radial groove; they all converge and insert into the proximal portion of the olecranon process of the ulna and the fascia of the forearm (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). *Anconeus* originates from the lateral epicondyle of the humerus and inserts into the lateral and posterior surfaces of the olecranon on the ulna; its primary function is to assist the triceps in extension of the forearm while also stabilizing the elbow joint (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). The common extensor tendon serves as the origin for several muscles in the posterior compartment of the forearm and attaches to the lateral epicondyle of the humerus (Gray 1985; Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Sampath et al. 2003).

2.1.3.c Muscles of Pronation

The main muscles involved in pronation of the forearm are *pronator quadratus* and *pronator teres* (Drake et al. 2009; Gray 1985). Pronator quadratus both originates and inserts on the anterior aspect of the distal radioulnar joint (i.e., the inside of the wrist).

Pronator teres arises from the medial epicondyle of the humerus and the coronoid process of the ulna and inserts on the lateral surface of the radius, assuming the added function of flexing the arm at the elbow (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993).

2.1.3.d Muscles of Supination

The primary muscle of supination is the *supinator*. The *supinator's* origin is from the lateral epicondyle of the humerus, the supinator crest of the ulna, and the radial collateral and annular ligaments of the proximal radioulnar joint; it inserts along the anterior, posterior, and lateral surfaces of the proximal radius, along a line just above (e.g., proximal to) the insertion of *pronator teres* (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). The *biceps brachii* (or, simply, *bicep*) is a double-headed muscle that originates at the supraglenoid tubercle and coracoid process of the scapula (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). The *bicep* inserts on the radial tuberosity, providing additional power to the action of supination by powerfully rotating the head of the radius over the ulna, especially when the elbow is flexed (Drake et al. 2009; Morrey et al. 1981; Nicholson and Driscoll 1993; Stroyan and Wilk 1993). Because of the size and strength of the bicep, supination is a more forceful action than pronation.

2.1.3.e Ligament Complexes

The ligaments stabilizing the proximal radioulnar joint of the elbow are divided into two main functional groups: (1) the medial/ulnar complex and (2) the lateral/radial ulnohumeral complex (Savoie et al. 2006). The medial/ulnar complex (or the ulnar collateral ligament) is composed of three bundles (the anterior bundle, posterior bundle, and the transverse oblique bundle) that assist in stabilizing the elbow joint during flexion and provide the primary restraint to valgus stress at the elbow (Cain et al. 2003; Eygendaal and Safran 2006; Fuss 1991; Morrey and An 1983; O'Driscoll et al. 1991; Savoie et al. 2006). The posteromedial compartment of the elbow (Figure 2.2) is the site most at risk for damage from valgus and extension overload in overhead throwing athletes (Cain et al. 2003; Eygendaal and Safran 2006; Loftice et al. 2004; Mamanee et al. 2000).

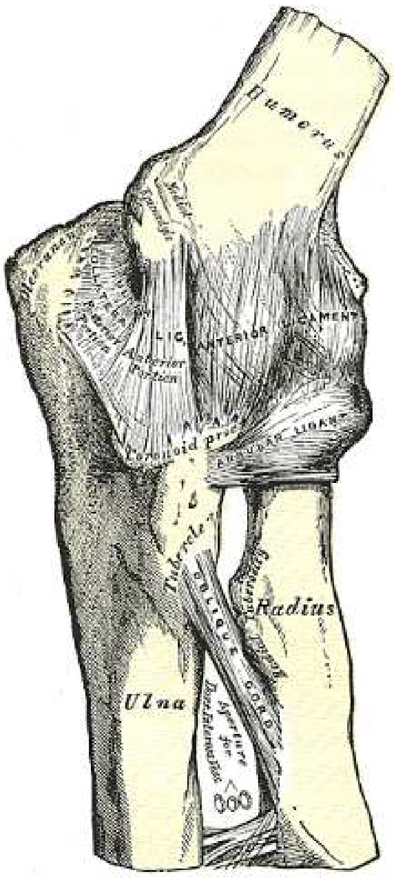


Figure 2.2: Left elbow-joint, showing anterior and ulnar collateral ligaments.
Adapted from *Gray's Anatomy, via Bartleby.com (Figure 329)*

The lateral/radial ulnohumeral complex (Figure 2.3) involves four components: (1) the lateral ulnar collateral/radial ulnohumeral ligament, (2) the radial collateral ligament, (3) the annular ligament, and (4) the accessory lateral collateral ligament, collaboratively contributing to the stabilization of the elbow against varus stress (Cohen and Hastings 1997; Imatani et al. 1999; O'Driscoll et al. 1991; O'Driscoll et al. 2000; Savoie et al. 2006). O'Driscoll and colleagues find the lateral ligament complex to be the key structure in chronic instability of the elbow (O'Driscoll et al. 1991).

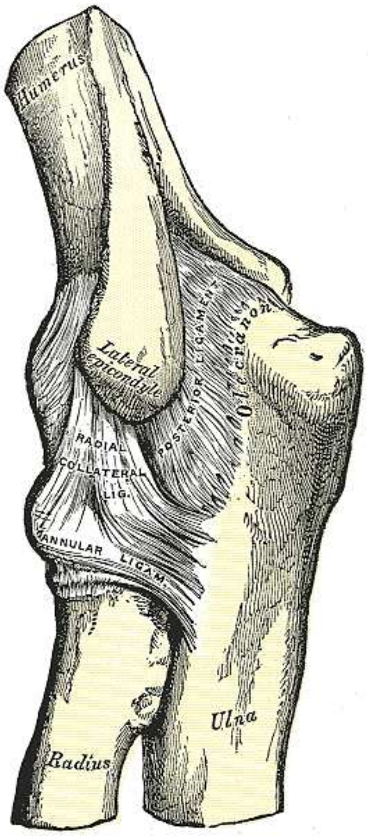


Figure 2.3: Left elbow-joint, showing posterior and radial collateral ligaments.
Adapted from *Gray's Anatomy, via Bartleby.com (Figure 330)*

The annular and quadrate ligaments are essential to the function and stability of the proximal radioulnar joint. The annular ligament extends from the anterior margin of the radial notch to the supinator crest of the ulna, and the quadrate ligament covers the synovial membrane below the annular ligament and inserts into the anterior and posterior portions of the radial notch (Martin 1958; Tubbs et al. 2006). As shown in Figures 2.4 and 2.5, both ligaments function to hold the head of the radius tightly in the radial notch of the ulna (Cain et al. 2013; Drake et al. 2009; Gray 1985; Mak et al. 2014; Martin 1958; Morrey 1985; Morrey and An 1985; Regan et al. 1991; Tubbs et al. 2006). The annular ligament is a composite ligament, arranged from the insertion of fibers of the various

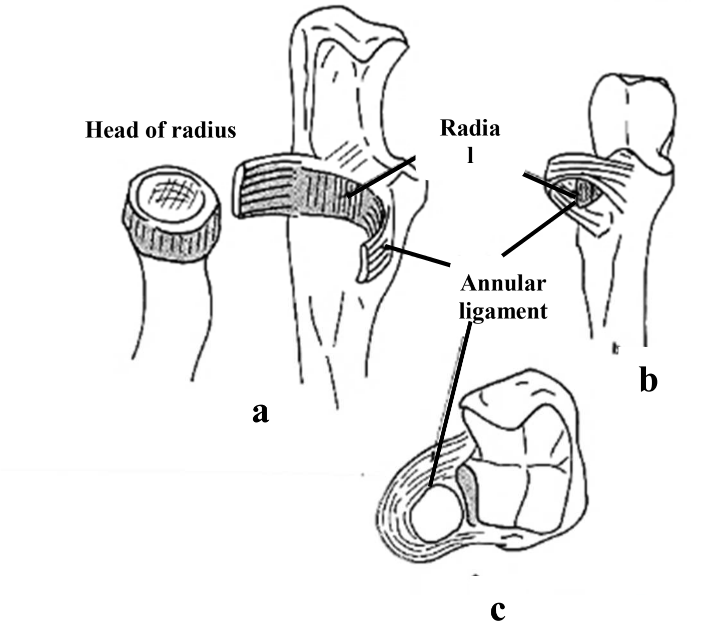


Figure 2.4: Articular surfaces of the superior radioulnar joint: a) annular ligament-cut, radial notch exposed; b) anterior view (front); c) superior view (above).
Adapted from:
Palastanga N, Field D, Soames RW. 1994. Anatomy and human movement: structure and function. Burlington: Elsevier Science, 1994. Print.

ligaments of the proximal radioulnar joint; this aids in its function as a primary stabilizer of the radioulnar joint (Martin 1958).

2.2 Traumatic Injuries to the Elbow

Along with a complex array of movements comes a complex array of injuries. "Next to the almost ubiquitous degenerative changes seen in archaeological specimens, the most common pathological condition affecting the skeleton is trauma (Ortner and Putschar 1981)." According to Lovell (1997), trauma can have a range of definitions, but "is conventionally understood to refer to an injury to living tissue that is caused by a force or mechanism extrinsic to the body (Lovell 1997)." Traumatic injury to the elbow joint is typically in the form of either fracture or dislocation of one of the bones of the forearm or

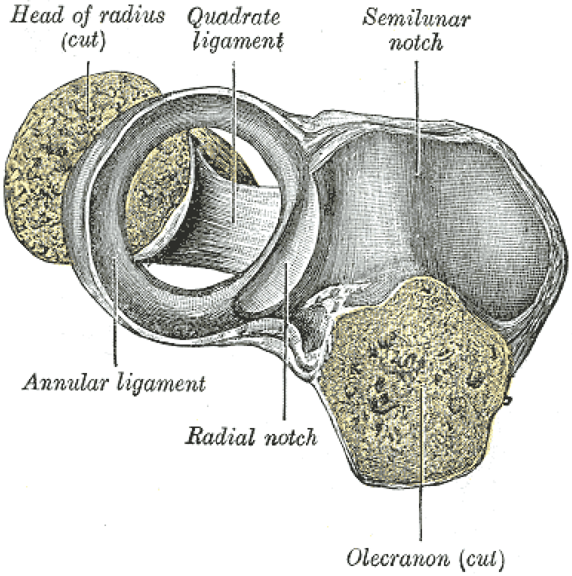


Figure 2.5: Annular and quadrate ligaments of superior radioulnar joint, from above**.** *Note: The head of the radius has been sawn off and the bone dislodged from the ligament.*
Adapted ***from Gray's Anatomy, via Bartleby.com***

is the result of an injury to the overlying soft tissue (Drake et al. 2009; Fuss 1991; Gray 1985; Imatani et al. 1999; Morrey et al. 1981; Morrey 1985; Nicholson and Driscoll 1993; O'Driscoll et al. 1991; Ortner 1968; Savoie et al. 2006; Stroyan and Wilk 1993; Resnick and Niwayama 1981). The following sections (2.2.1-2.2.3) outline a sampling of traumatic injuries to the anatomical structures of the proximal radioulnar joint of the elbow commonly reported in the peer-reviewed literature. The injuries described herein are all plausible mechanisms for the generation of the osseous cortical defect observed in the Fernvale skeletal remains.

2.2.1 Injuries to the Elbow Resulting from Acute Stress

The nature of injuries from acute stress refers to a specific event causing direct or indirect trauma to the osseous structures with deferred damage to surrounding soft tissue, or direct or indirect trauma to the soft tissue with deferred trauma to osseous structures. These types of injuries are not necessarily the result of chronic overuse but of a particular forceful blow to the joint, such as a fracture or dislocation, caused by a fall or other accidental injury. According to Lovell (1997), "Clinically, the ulna and radius are fractured more commonly than are any other skeletal elements […] likely due to falls and mishaps rather than violence (Lovell 1997)." Frequently, the presence of certain fractures to the radius and ulna are indicative of additional soft tissue damage and joint instability that is unobservable in osteological specimens. Those will be discussed here.

2.2.1.a Dislocation of the Radial Head

The most common instance of radial head dislocation is seen in infancy or childhood and is usually an isolated injury (Nicholson and Driscoll 1993). Prior to age six, the head of the radius is almost completely spherical and is composed almost completely of cartilage (Baker et al. 2005). This lack of ligamentous restraint allows the radial head to roll out of the radial notch rather easily. Termed Nursemaid's Elbow, the head of the radius may be subluxated (e.g., partially dislocated) through the annular ligament by a sudden jerk on the arm, such as that exerted by an adult to prevent a child from falling (Morrey 1985; Nicholson and Driscoll 1993). The annular ligament, then, either loosens or tears, allowing the radial head to disarticulate from the ulna. This type of injury may be reduced spontaneously or with rapid supination and usually requires little to no medical intervention to correct (Nicholson and Driscoll 1993; Morrey 1985). Because the injury occurs at an age when the bones are mostly cartilaginous and rapid osteogenic formation is still taking place, dislocation of the radial head in infancy does not affect the skeletal integrity of the proximal radioulnar joint (Baker et al. 2005). However, the osseous and ligamentous constraints of the joint are significantly compromised following a dislocation event of any kind (Bennett et al 1898; Charlambous and Stanley 2008; Cohen and Hastings 1997; Deutch et al. 2003; McKee et al. 2003; O'Driscoll et al. 1991; Osborne and Cotterill 1966; Savoie et al. 2006; Singleton and Conway 2004; Smith et al. 2001).

Other circumstances can cause the head of the radius to dislocate from the ulna and/or the humerus. One dislocation event, described below, occurs as the result of a fall on an outstretched hand and the other as the result of posterolateral rotatory instability of the elbow or PLRI. The two trauma patterns are comparable in both the osteological and soft tissue effects on joint stability and the eventual osteological response involved.

2.2.1.b Fall on an Outstretched Hand (FOOSH)

Several different fracture and dislocation patterns can occur as the result of a fall on an outstretched hand (or FOOSH). The Monteggia fracture-dislocation, considered a hallmark of FOOSH, is a dislocation of the radial head and a fracture of the proximal shaft of the ulna due to forced pronation (Aufderheide and Rodriguez-Martin 1998; Lovell 1997; Mann and Hunt 2005; Morrey 1985; Nicholson and Driscoll 1993; Ortner and Putschar 1981; Resnick and Niwayama 1981). It should be noted, however, that caution should be exercised when interpreting an ulnar midshaft fracture as a Monteggia fracture-dislocation, as this is the same area of the ulnar midshaft affected in self-defense wounds known as a “parry” fractures, when the victim uses the back side of their forearm to shield their face from an attack; the difference in the two being that “parry” fractures are not normally accompanied by dislocation of the radial head (Aufderheide and Rodriguez-Martin 1998; Capasso et al. 1999; Cox and Mays 2000; Lovell 1997; Ortner and Putschar 1981).

Fractures of the radial head and neck are among the most common injuries in adults accounting for about half of all fractures in the elbow (Nicholson and Driscoll 1993:1061). Fractures to the proximal end of the radius are caused by falls on an outstretched hand, as are fractures to the distal radius. A fracture on the distal radius is called a Colles’ fracture. Colles’ fractures are the most common fractures in adults over the age of 40, especially females (Lovell 1997:161).

Clinical and paleopathological evidence points to daily activities, rather than unusual causes or warfare, as the source of acute stress in the elbow (Lovell 1997). Occupational hazards, the loads carried, and the features of the landscape in which all of this is to be accomplished can have a significant impact on how often individuals fall onto their hands and injure their elbows. Obviously, bipedalism has been a glorious adaptation for humans, as long as they can stay on their feet.

2.2.2 Injuries to the Elbow Resulting from Chronic Stress

Due to the distinctive joints that form the elbow and help to facilitate the movements of the hands and forearms, there is potential for increased mechanical stress from movements of both flexion/extension and pronation/supination (Morrey 1985; O'Neil et al. 2001; Ortner 1968; Ortner and Putschar 1985; Mann and Hunt 2005; Resnick and Niwayama 1981). The types of injuries and consequential osteologic response resulting from chronically repeated movements vary based on the particular actions performed and, therefore, lead to the overuse of specific musculoskeletal elements that become damaged in the joint.

Inflammation of the joint capsules and tendon attachment sites are common overuse conditions of the elbow that have a wide range of origins. The terms "golfer's elbow" and "tennis elbow," denoting medial and lateral epicondylitis (tendonitis), respectively, are terms commonly used to refer to chronic overuse conditions characterized by inflammation of the tendon attachment sites on the epicondyles on the distal end of the humerus. In contrast to tendonitis, the degeneration of the tendon cells themselves is a condition called tendonosis that occurs when the muscles surrounding the tendon increase in strength faster than the tendon, leaving the tendon weak and deficient in blood supply (Aufderheide and Rodriguez-Martin 1998; Cain et al. 2003; Drake et al. 2009; Morrey 1981; Nicholson and Driscoll 1993; Ortner and Putschar 1981; Eygendaal and Safran 2006). This difference in growth rates can lead to, but does not necessarily occur simultaneously with, tendonitis (Cain et al. 2003; Eygendaal and Safran 2006).

The inflammation and associated tissue degeneration of the common flexor tendon attachment site, medial epicondylitis or "golfer's elbow," is usually caused by an overuse injury involving a powerful grip and forceful swinging motion, as with using a golf club or shovel, rowing a canoe, or in the overhand motion of certain athletes (Cain et al. 2003; Cox 1992; Eygendaal and Safran 2006; Gerr et al. 1991; Larsen 1987; Lin et al. 2007; Loftice et al. 2004; Mamanee et al. 2000; Shaw and Stock 2009; Weiss 2003). The inflammation of the common extensor tendon attachment site and associated tissue degeneration, called lateral epicondylitis or "tennis elbow," is usually caused by an injury involving a forceful blow to the stability of the elbow caused by recurrent motions of powerful gripping and twisting with the arm held away from the body, such as the repetition and weight lifting required in the activities of carpenters, gardeners, mechanics, painters, and plumbers (Cain et al. 2003; Eygendaal and Safran 2006; Gerr et al. 1991; Larsen 1987; Lin et al. 2007; Loftice et al. 2004; Mamanee et al. 2000; Shaw and Stock 2009; Spigelman et al. 2012).

2.2.2.a Injuries Sustained from an Overhead Throwing Motion

The result of mechanical stress from movements of flexion and extension is a decrease in the stability of the articulation between the humerus and ulna (Morrey 1985; O'Neil et al. 2001; Ortner 1968; Ortner and Putschar 1985; Mann and Hunt 2005; Resnick and Niwayama 1981). Instability in the bony articulation of the medial compartment of the elbow puts more pressure on the associated soft tissue structures to compensate for the increased mechanical load. The resulting injuries to the medial ligament complex of the elbow are commonly in the form of ligament sprains or tears, tendonitis, avulsion injuries, or fractures of the ulna (Cain et al. 2003; Ciccotti and Mamani 2003; Fuss 1991; Mamanee et al. 2000; Morrey 1985; Nicholson and Driscoll 1993; O'Driscoll et al. 1991; O'Driscoll et al. 2000; Resnick and Niwayama 1981; Savoie et al. 2006).

The ulnar collateral ligament (UCL) sustains the greatest amount of mechanical stress from the combination of flexion and torsion forces produced by the overhead motion of throwing of a projectile, such as a baseball or javelin/atlatl (Angel 1966; Aufderheide and Rodriguez-Martin 1998; Brues 1959; Bridges 1990; Cain et al. 2003; Capasso et al. 1999; Ciccotti and Ramani 2003; Eygendaal and Safran 2006; Fleisig and Escamilla 1996; Lin et al. 2007; Mamanee 2000; Mann and Hunt 2005; Morrey 1985; Ortner and Putschar 1981; Shaw and Stock 2009; Whittaker 2003). The combination of the overload of valgus stress and rapid elbow extension of the motions of overhead throwing athletes exerts the injurious combination of tensile stress in the medial compartment, shear stress in the posterior compartment, and compressive stress in the lateral compartment (Cain et al. 2003; Eygendaal and Safran 2006; Fleisig and Escamilla;

Lin et al. 2007; Morrey 1985). Termed "valgus extension overload syndrome," this combination of forces is the fundamental basis of the most common elbow injuries in throwing athletes (Cain et al. 2003; Eygendaal and Safran 2006). Rupture of the UCL is an injury most frequently associated with high-level baseball pitchers, although Eygendaal and Safran (2006) explain that its earliest identification was in javelin throwers.

Repetitive strain and "cumulative microtrauma" (Gerr et al. 1991) in the medial compartment of the elbow can result in partial or complete rupture of the ulnar collateral ligament, avulsion injuries, trauma to the joint capsule caused by inflammation or joint effusion, posterior impingement due to osteophytes and loose bodies, stress fractures, or a combination of these (Cain et al. 2003; Eygendaal and Safran 2006; Fleisig and Escamilla; Gerr et al. 1991; Glajchen et al. 1998; Lin et al. 2007; Morrey 1985; Resnick and Niwayama 1981).

The same overhead throwing motions that result in UCL injuries in the adult athlete can lead to traumatic injury to major tendinous insertion sites in younger athletes, such as the medial epicondyle apophyseal plate (Cain et al. 2003; Mafulli 1990; Peck 1995). "Little Leaguer's Elbow," a condition unique to adolescent athletes, prior to the fusion of the growth plate inhibits the union of the medial epicondylar apophysis and can lead to conditions of osteochondritis dissecans or posterior impingement (Cain et al. 2003; Eygendaal and Safran 2006; Glajchen et al. 1998; Mafulli 1990; Peck 1995).

2.2.2.b Posterolateral Rotatory Instability of the Elbow (PLRI)

Posterolateral rotatory instability (PLRI) is considered by many researchers to be the most common type of symptomatic chronic instability of the elbow (Bennett et al 1898; Charlambous and Stanley 2008; Cohen and Hastings 1997; Deutch et al. 2003; McKee et al. 2003; O'Driscoll et al. 1991; Osborne and Cotterill 1966; Savoie et al. 2006; Singleton and Conway 2004; Smith et al. 2001). In recent years, extensive research into the biomechanics of elbow instability in athletes has concluded that repetitive strain on the lateral ligament complex of the elbow is the most significant contribution to the growing number of reported clinical cases of posterolateral dislocation of the elbow and PLRI (Cohen and Hastings 1997; Deutch et al. 2003; Hannouche and Béqué 1999; O'Driscoll et al. 1991; Savoie et al. 2006).

The radius bears most of the mechanical burden of the elbow. As such, the elbow's response to stress exerted on its lateral compartment is most commonly in the form of posterolateral dislocation of the radius from its articulations with the ulna and the humerus (Cohen and Hastings 1997; Deutch et al 2003; Fleisig and Escamilla 1996; O'Driscoll et al 1991; O'Driscoll et al 2000; Savoie et al 2006). Mechanical stress related to pronation and supination pulls on the annular and quadrate ligaments and draws the radius away from its articulation with the ulna (Ortner 1968). Radioulnar instability resulting from posterolateral instability of the elbow would also affect the lateral stabilizers and muscles of supination. Depending on factors such as the age of the individual and the physical integrity of the joint capsule, the resulting injury oftentimes takes the form of a fracture to the radial head/neck, an avulsion injury to the soft tissue complexes, or both (Morrey 1985; Resnick and Niwayama 1981).

2.2.3 Soft Tissue Injuries Resulting in Cortical Defects

The musculature and ligamentous complexes of the elbow are subject to overuse injuries by a multitude of activities, only a portion of them referenced here. It is important to note, however, that the purpose of these examples is to emphasize the manner in which this soft tissue damage occurs. Thus, attention can be focused on the resulting cortical lesions that develop in response to the soft tissue damage sustained by the individual.

Entheses, sites of stress concentration where tendons, ligaments, or joint capsules attach to bone, go by various names when they are the focus of an activity-induced overuse injury: enthesopathy, musculoskeletal stress marker, or markers of occupational stress (Benjamin et al. 2002; Kennedy 1998; Villotte et al. 2010; Weiss 2003). A cortical defect by any other name is still a cortical defect, though. The bony pits that develop result from chronic overuse of the soft tissue attachment site. Avulsion injuries occur when a portion of periosteum is ripped from the underlying cortical bone by the attached tendon (Morrey 1985; Nicholson and Driscoll 1993; Stroyan and Wilk 1993; Resnick and Niwayama 1981).

2.3 Osteogenic Response to Trauma and Biomechanical Stress

Regardless of the mechanism of injury, there is an osteologic response (Bass 1985; Mann and Hunt 2005; Ortner and Putschar 1985; Ruff 2005; White and Folkens 2005). This osteologic response can be used to help determine the details of that traumatic event when the soft tissue is gone and there is only bone left to examine.

Bone is a living tissue that responds to biological and mechanical stress by means of either repair and rejuvenation, or decay and degeneration. A pathological state results when one of these processes (i.e., either growth or resorption) dominates (Resnick and Niwayama 1981). The idea that a bone is shaped and formed through interactions with its mechanical environment is known as Wolff's Law (Wolff 1892; 1986). Wolff's Law states that healthy bone will adapt to the loads under which it is placed. Wolff's Law encompasses everything related to the concept of the functional adaptation of bone to mechanical stimuli (Pearson and Lieberman 2004; Ruff et al. 2006). After a bone experiences some type of strain (e.g., chronic stress, trauma, disease), osteogenic cells evoke one of four possible outcomes: (1) no response at all, (2) the employment of osteoblasts to grow new bone, (3) the recruitment of osteoclasts to resorb bone along the surface of the bone, or (4) Haversian remodeling in cortical bone (Pearson and Lieberman 2004). "It is variation in the cell population balance and in cell activity that accounts for all the variation in the morphology of abnormal bone (Ortner and Putschar 1981: 36)." By analyzing the osteologic response at the cellular level, it is possible to identify a specific type of pathology or traumatic event that initiated that osteologic response with greater accuracy, i.e., bone adapts to the mechanical stresses placed upon it during life and can therefore be utilized in the reconstruction of that past mechanical environment (Ruff et al. 2006).

2.4 Osteoarthritis: A Pathologic Response to Chronic Biomechanical Stress

Degenerative joint diseases occur in the human body as a response to biomechanical stressors. Cox and Mays (2000) define joint disease as “any disease afflicting any or all of the structures, such as ligaments, joint capsule, synovium, cartilage, and bone, which compromise the various tissues found in the joint.”

Osteoarthritis (OA) is one of the most common degenerative joint diseases in both modern and ancient populations (Cox and Mays 2000), and yet its exact etiology is still unknown (Jurmain 1977). Mann and Hunt (2005) propose several mechanisms that explain the etiology of specific disease patterns resulting from traumatic injury to the joints, including biochemical hypotheses, biomechanical hypotheses, and several degenerative processes. Clinical investigations have determined that some systemic influential factors are those such as age, sex, metabolism, nutrition, hormones, and heredity, and that the mechanical or functional components include chronic or acute trauma and obesity (Jurmain 1977). Systemic factors relate to the entire organism rather than individual parts, which would have a uniform effect on the joints, but mechanical or functional factors would have a more localized effect.

Little (1973) describes OA as a mechanical imbalance that can happen in almost any joint because of either trauma or excessive pull of muscles. However, OA more commonly affects the synovial joints (e.g., shoulder, elbow, hip, and knee), is more frequent among older individuals than among young individuals, and occurs more often in females than in males (Bridges 1992; Cox and Mays 2000; Cushnaghan and Dieppe

1991; Jurmain 1977). OA is most often the result of age or physical stressors, such as chronic workloads and trauma (Bridges 1992). OA involves the mechanical degradation of skeletal articulations (Larsen 1995) and the initial defect is the breakdown of the gel structure of the articular cartilage (Little 1973). When the joint capsule begins to break down, the bones are no longer separated from each other by the synovium and they begin to grind against each other. The destruction of the articular cartilage results in characteristic bony changes including peripheral osteophytes (or bony lipping), porosity of the joint surface, eburnation (the development of dense smooth areas where cartilage has been destroyed exposing underlying bone), or a combination of these features (Bass 1995; Bridges 1992; Bridges 1989; Buikstra and Ubelaker 1994; Cox and Mays 2000; Larsen 1995; Ortner and Putschar 1981; Mann and Hunt 2005; White and Folkens 2005).

2.5 Chapter Summary

The stability of the elbow is constrained by numerous osseous, muscular, and ligamentous structures. Biomechanical stress from various daily activities can put a significant amount of additional strain on the joint and can lead to chronic instability, ultimately resulting in complete failure of ligament complexes, dislocations, or fractures of the bones. If these injuries occur a significant amount of time before death, then evidence of healing and osteogenic response will be observable in the skeletal remains of the individual. The identification of the biomechanical processes that lead to these specific osteogenic reactions can offer insight into the daily lives of past individuals by determining which types of movements and activities require the use of those specific biomechanics.

CHAPTER III: Materials and Methods

This chapter introduces the materials utilized for the research, provides an archaeological context and provenience for the samples, and outlines the selection criteria for the osteological specimens used. This chapter also defines and describes the measurement and calculation techniques employed for characterization of the cortical defect of the proximal ulna. Finally, this chapter details the hypotheses tested in the determination of possible associations between the cortical defect and several variables.

3.1 Archaeological Context

Thirty years ago, the Tennessee Department of Transportation (TDOT) began a bridge replacement project over the South Harpeth River in northwestern Williamson County, Tennessee (Figure 3.1). Between February 1985 and June 1985, the Tennessee Division of Archaeology (TDOA) began the initial excavations at Fernvale (40WM51) to recover and relocate the human remains unearthed by the mechanical stripping of the backhoe (see Deter-Wolf 2013 for detailed report on these excavations). These preliminary TDOA investigations resulted in the exposure of numerous prehistoric features, including the recovery of thirty-two burials containing the remains of thirty-two humans and two canines (see Appendix A for detailed burial information and photographs). In September 2007, the TDOA and the Department of Sociology and Anthropology at Middle Tennessee State University (MTSU) re-analyzed the excavated material from Fernvale (Deter-Wolf 2013). The subject for this Master's thesis, the cortical defect on the

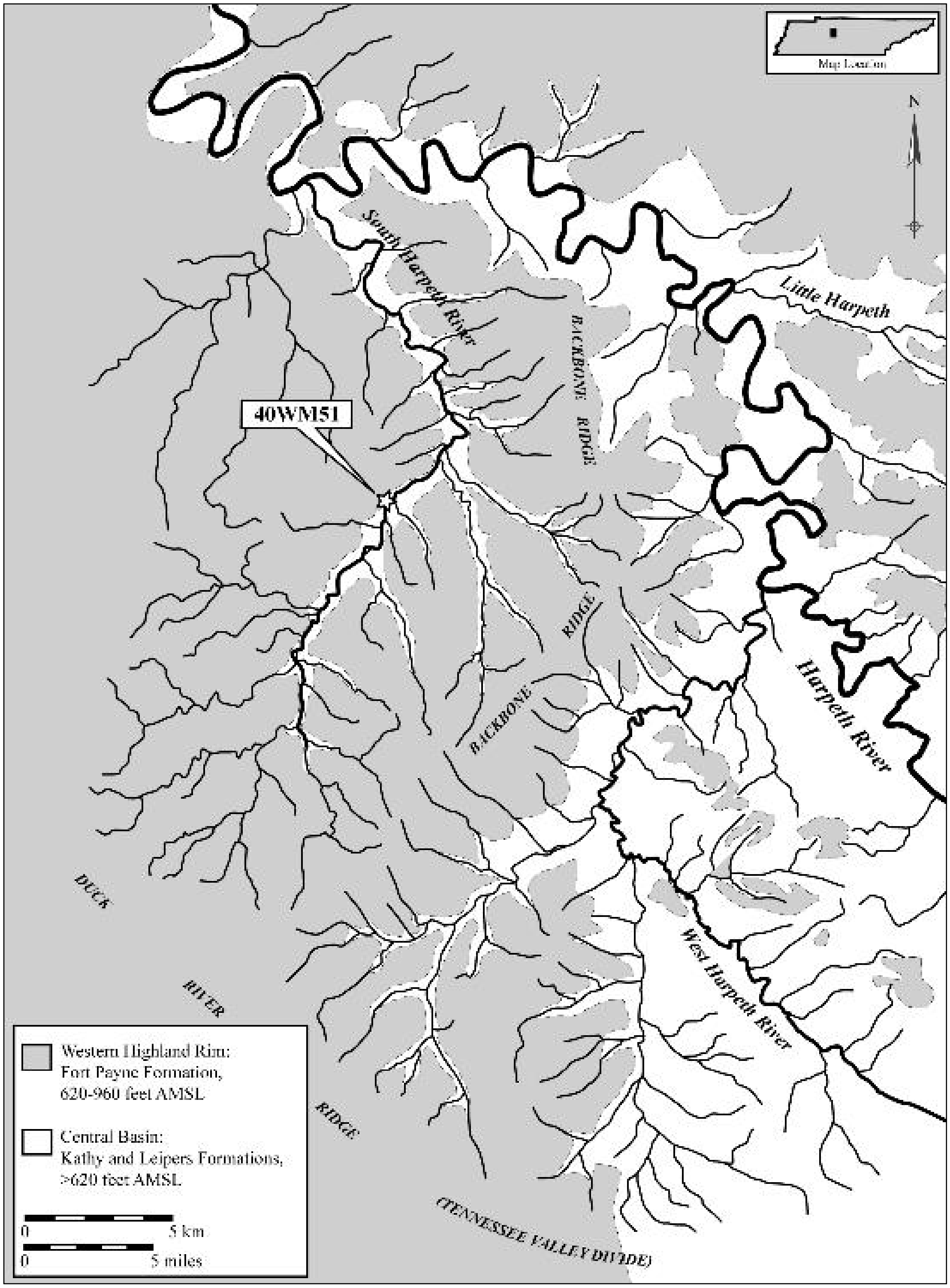


Figure 3.1: Generalized physiographic map showing the location of the Fernvale site at the intersection of the Central Basin and Western Highland Rim provinces.

(Image © Aaron Deter-Wolf, 2013)

proximal ulna, was initially discovered during a 2008 graduate independent study in human osteology while helping to reexamine the human remains from the Fernvale site.

3.2 The Skeletal Sample

Located at the junction of the Central Basin (Nashville Basin) and Western Highland Rim physiographic provinces (Figure 3.2), Williamson County, Tennessee is an area with a cultural heritage that reaches far back into prehistory. An uncalibrated radiocarbon date obtained from one of the burials (3490 ± 300 uncalibrated years BP) places the occupants of the Fernvale site in the Late Archaic Period of prehistory in the Middle Cumberland Region (Bense 1994; Deter-Wolf 2013; Steponaitis 1986). The osteological remains of thirty-two individuals from the site, temporarily housed at MTSU, were inventoried and recorded, following North American bioarchaeological principles and practices (Buikstra and Ubelaker 1994). A summary of the demographic data for each burial is shown in Table 3.1.

Figure 3.2: Tennessee Geographic Regions; star, denoting location of Fernvale archaeological site.

(Image adapted from Tennessee Environmental Protection Agency, 2010)

Table 3.1: Summary of 40WM51 Burials

Burial No.	Age Category	Age	Sex	Sex Category
1	*indeterminate*	*indeterminate*	*indeterminate*	*indeterminate*
1b	subadult	7-8 years	*indeterminate*	*inconclusive*
2	old adult	>50 years	female	female
3	middle adult	*indeterminate*	male	male
4	young adult	20-25 years	female	female
4b	subadult	24-48 weeks gestation	*indeterminate*	*indeterminate*
5	subadult	18-30 months	*indeterminate*	*indeterminate*
6	middle adult	25-40	female	female
7	old adult	*indeterminate*	male	male
8	*indeterminate*	*indeterminate*	probable female	female
9	middle adult	35-50 years	probable male	male
10	middle adult	20-50 years	female	female
11	subadult	3-12 months	*indeterminate*	*indeterminate*
12	young adult	18-24 years	probable female	female
13	young adult	<25 years	probable female	female
14	subadult	9-12 months	*indeterminate*	*indeterminate*
15	middle adult	35-50 years	probable male	male
16	middle adult	35-55 years	male	male
17	*indeterminate*	*undetermined*	probable female	female
18	*indeterminate*	*undetermined*	probable male	male
19	*indeterminate*	*undetermined*	probable male	male
20	middle adult	25-50 years	probable male	male
21	subadult	4-5 years	*indeterminate*	*indeterminate*
22	*indeterminate*	*indeterminate*	*indeterminate*	*indeterminate*
23	subadult	40 wks. gestation-3 mos. of life	*indeterminate*	*indeterminate*
24	middle adult	25-55 years	probable male	male
25	*dog*	*unknown*	*unknown*	*unknown*
26	subadult	8-14 years	*indeterminate*	*indeterminate*
27	middle adult	35-50 years	female	female
28	young adult	18-24 years	female	female
29	subadult	39 wks. gestation-3 mos. of life	*indeterminate*	*indeterminate*
30	middle adult	35-45 years	*indeterminate*	*indeterminate*
31	young adult	19-25 years	*indeterminate*	*indeterminate*
32	*dog*	*unknown*	*unknown*	*unknown*

(Table adapted from SC Hodge & CB Davis, 2013)

The Fernvale osteological specimens exhibit variable preservation, with many burials poorly preserved, in some cases preventing full assessment of age, sex, and pathologies. Sub-adult, charred, and severely fragmented remains were not used. Individuals that did not possess the bones necessary (e.g., ulna, radius, and humerus) for the investigation were also omitted from analyses. Sixteen (16) of the thirty-two (32) total osteological specimens were omitted from the sample: Burials 1, 7, 22, and 30 were poorly preserved and too fragmentary to obtain accurate measurements; Burial 8 was badly burned because of taphonomic destruction (possibly a partial cremation); Burials 20 and 31 were missing the distal upper extremities due to trophy-taking (Hodge and Davis 2013); Nine (9) subadults (Burials 1b, 4b, 5, 11, 14, 21, 23, 26, and 29) were omitted from the study because of the interference of various stages of epiphyseal fusion. The numbers and percentages of specimens included in and omitted from the sample are presented in Table 3.2 along with rationale for selection or omission.

Table 3.2: Numbers and percentages of population sampled

Number of Individuals	Percentage (%) of Population	Sample Selection Rationale
3	9%	*Omitted from sample:* Antemortem trauma rendered necessary skeletal elements unobservable
4	13%	*Omitted from sample:* Poor preservation/severe fragmentation rendered necessary skeletal elements unobservable
9	28%	*Omitted from sample:* Subadult remains
16	50%	*Included in sample*
32	***100%***	***Population Total***

Of the thirty-two osteological specimens, sixteen proved useful for detailed examination. From those sixteen individuals, a total of twenty-six (26) ulnae, twenty-nine (29) humeri, and ten (10) radii were examined for the presence and degree of joint degeneration. The ulnae were examined thoroughly and scored for presence or absence of the cortical defect near the radial notch. If the defect was present, metric measurements were taken according to North American bioarchaeological standards of data collection (Buikstra and Ubelaker 1994) as well as standards developed by the researcher specifically for this Master's thesis (described in Section 3.3). If the skeletal elements necessary for the estimation of age, sex, and stature were available, a biological profile was constructed according to the standards of Buikstra and Ubelaker (1994) to provide a biologically-specific context for the defect's origin (Table 3.3). The results were then used to determine what, if any, associations existed among the individuals that possessed the defect.

3.3 Examination of Remains

This project explored the etiology of a previously undescribed feature of the proximal ulna. I evaluated the distal end of the humerus and proximal ends of both the radius and ulna (both left and right sides, where available) to assess: (1) the presence of degenerative joint disease, and (2) to what degree the joint was affected. Overall, the analyses were both general and specific, encompassing the entire articular capsule of the elbow as well as specific features of the ulna.

The Fernvale remains were examined for skeletal pathologies such as trauma, degenerative joint disease, and specific and nonspecific infection according to protocols set forth in Buikstra and Ubelaker's Standards of Data Collection (1994) and MTSU Pathology Coding Sheets (see Appendix C). Complete pathological analyses of the bones and associated osteological structures of the elbow were necessary to understand the possible etiology of the anomaly. This included the distal articular surfaces of the humerus, the proximal articular surfaces of the radius and ulna, and associated joint surfaces. Each incidence of the defect was measured according to techniques developed by the researcher (described below), derived in part from the paleopathological recording procedures of Buikstra and Ubelaker (1994), and modeled after Mann's measurements of Stafne's defects of the mandible (2001).

I, in conjunction with other MTSU Osteology Lab Workers, developed distinctive measurement techniques and methods of osteometric data collection specific to this project to describe the anomaly and surrounding skeletal tissue. Three measurements were devised to calculate the overall size of the defect: (1) the maximum anterior-posterior (AP) length of the defect, taken parallel to the radial notch (Figure 3.3 a), (2) the maximum superior-inferior length, taken perpendicular to the AP length (Figure 3.3 b), and (3) the maximum depth of the defect. Mitutoyo® Digimatic™ pointed tip sliding calipers were used to measure the overall surface area of cortical bone affected, obtaining AP and SI dimensions, and a graduated dental probe was used to measure the depth of the anomaly.

Table 3.3: Osteological specimens sampled from population with biological profile summary information

Burial No.	**Age Category**	**Sex**	**Side (ulna)**
2	old adult	female	left
2	old adult	female	right
3	middle adult	male	right
4	young adult	female	left
4	young adult	female	right
6	middle adult	female	left
9	middle adult	male	left
9	middle adult	male	right
10	middle adult	female	left
10	middle adult	female	right
12	young adult	female	left
13	young adult	female	left
13	young adult	female	right
15	middle adult	male	right
16	middle adult	male	left
16	middle adult	male	right
17	indeterminate	female	right
18	indeterminate	male	left
19	young adult	male	left
19	young adult	male	right
24	middle adult	male	left
24	middle adult	male	right
27	middle adult	female	left
27	middle adult	female	right
28	young adult	female	left
28	young adult	female	right

The involvement of lytic or sclerotic activity around the defect was quantified by calculating the amount of surface area affected on each ulna, using the formula for the surface area of an ellipse: $A = \pi ab$ where $a =$ the radius of the anterior-posterior (AP) measurement of the defect and $b =$ the radius of the superior-inferior (SI) measurement of the defect. The overall volume of bone loss was calculated using a modified formula for the volume of an ellipsoid, where the ellipsoid is treated as a hemisphere[2]: $V = \frac{4}{3}\pi abc$ where $a =$ the radius of the AP measurement of the defect, $b =$ the radius of SI measurement of the defect, and $c =$ the depth measurement of the defect. Finally, the

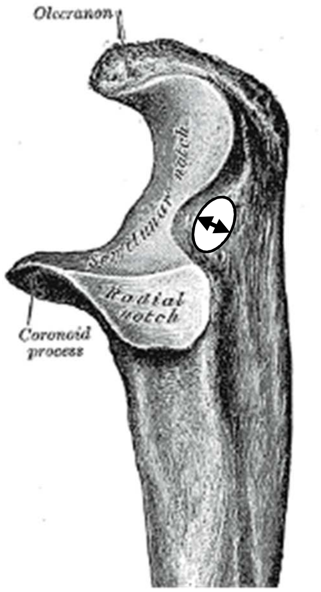


Figure 3.3 (a): Proximal left ulna , showing the anterior-posterior (AP) measurement, taken parallel to radial notch

Image adapted from Gray's Anatomy, via Bartleby.com (FIG. 212)

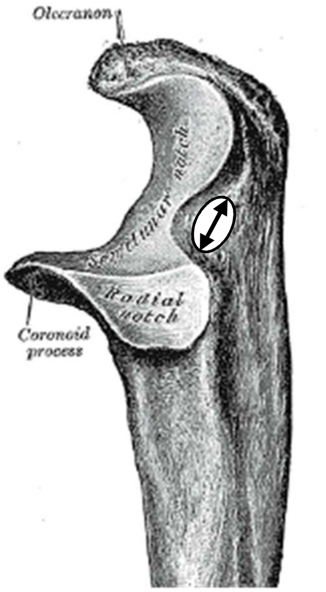


Figure 3.3 (b): Proximal left ulna , showing the superior-inferior (SI) measurement, taken perpendicular to AP measurement

Image adapted from Gray's Anatomy, via Bartleby.com (FIG. 212)

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[2] The defect is not a complete ellipsoid but, rather, a bisection of an ellipsoid. Therefore, the measured depth of the defect rather than the radius was used for the 'c' value of the volume formula.

Cortical Avulsion Index[3] was formulated out of necessity, specifically for this project. The index compares the depth of the defect to its total calculated surface area in order to give each defect a unified value that serves as an indicator of overall size and the degree of severity of soft tissue avulsion.

High-resolution images were taken of each ulna that exhibited the pathology using a Canon® Digital Rebel™ XTi™ EOS DSLR camera and a modified light stand. Data collection was done in a university osteology laboratory setting. All observations were made by gross examination, supplemented by 10x magnification with a hand-held geologist's loupe if necessary. Observations were made under direct and oblique light, sufficient to observe surface detail visible to the unaided eye.

3.4 Statistical Analysis of Data

The following hypotheses were tested using either the Chi-squared Goodness of Fit test or a two-sample t-test assuming unequal variances, dependent upon the types of data for each variable (McDonald 2014). In addition, descriptive statistics were computed for each data set. For the purposes of these hypotheses, "occurrence of the defect" will refer to the presence or absence of the defect and "overall defect size" will refer to the Cortical Avulsion Index calculation value. All statistical analysis of data was performed using Microsoft® Excel® 2010 on a Hewlett-Packard® Pavilion dm4 Notebook Computer running a 64-bit Windows® 7 Operating System and Microsoft® Excel® 2013 via Office 365™.

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[3] Cortical Avulsion Index $= \frac{Depth}{Surface\ Area} \times 100$; on a scale of 0 to 100, where 0 is absent and a larger number indicates a more severe injury

3.4.1 Hypothesis 1 (a & b)

3.4.1.a The occurrence of the defect is associated with the sex of the individual.

- Criteria: Statistically significant differences between the presence and absence of the defect in individuals by sex.
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for males and females.
- H_a: The probability of the presence of the defect is not the same for males and females.

3.4.1.b The overall size of the defect depends on the sex of the individual.

- Criteria: Statistically significant relationship between mean defect size and sex.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_{\emptyset}$: The overall size of the defect (as measured by the Cortical Avulsion Index) is the same in males and females.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is not the same in males and females.

3.4.2 Hypothesis 2 (a & b)

3.4.2.a The occurrence of the defect is associated with the location of the defect (in either the left or the right arm).

- Criteria: Statistically significant differences between the presence and absence of the defect in individuals by side (left or right).
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for left and right ulnae.
- H_a: The probability of the presence of the defect is not the same for left and right ulnae.

3.4.2.b The overall size of the defect depends on the side of the body on which it occurs.

- Criteria: Statistically significant relationship between overall defect size and left or right side.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_{\emptyset}$: The overall size of the defect (as measured by the Cortical Avulsion Index) is the same for defects occurring on the left and right sides.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is not the same for defects occurring on the left and right sides.

3.4.3 Hypothesis 3 (a & b)

3.4.3.a The occurrence of the defect is associated with the age of the individual.

- Criteria: Statistically significant differences between the number of affected and unaffected individuals by age.
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for all [adult] age groups.
- H_a: The probability of the presence of the defect is not the same for all [adult] age groups.

3.4.3.b The overall size of the defect depends on the age of the individual.

- Criteria: Statistically significant relationship between overall defect size and age.
- Test: Quantitative/Measurement; Visual comparison of data
- $H_{\emptyset}$: The overall size of the defect (as measured by the Cortical Avulsion Index) is the same for all [adult] age groups.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is not the same for all [adult] age groups.

3.4.4 Hypothesis 4 (a & b)

3.4.4.a The occurrence of the defect is associated with the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.

- Criteria: Statistically significant differences between affected and unaffected individuals by presence/absence of degenerative joint disease/osteoarthritis of the elbow.
- Test: Qualitative; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for individuals with or without DJD/OA of the elbow.
- H_a: The probability of the presence of the defect is not the same for individuals with or without DJD/OA of the elbow.

3.4.4.b The size of the defect depends on the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.

- Criteria: Statistically significant relationship between defect size and DJD/OA.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_{\emptyset}$: The overall size of the defect (as measured by the Cortical Avulsion Index) is not affected by the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is affected by the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow in the individual.

CHAPTER IV: RESULTS

Archaeological investigations at the Fernvale site (40WM51) in northwestern Williamson County, Tennessee resulted in the exposure of numerous prehistoric features, involving the recovery of thirty-two (32) burials that included 30 people and 2 dogs. The previous chapter provided summary information regarding each burial excavated by the TDOA in 1985 as well as a list of individual osteological specimens utilized for this study. This chapter reports the results of this study in two parts: (1) a descriptive analysis of the anomaly is presented along with a biomechanical characterization of the possible mechanism(s) of injury that could have caused its occurrence; and (2) qualitative and quantitative analyses of the metric data collected on the cortical defect of the proximal ulnae. The following chapter provides an interpretation of these results. A short narrative description, biological profile, pathology notes on the findings of each specimen, and original excavation photographs of each burial are provided in Appendices A and B.

4.1 Summary of Findings

The cortical defect of the proximal ulna was present, in varying degrees, on 23 of the 26 ulnae examined, which involved 14 of 16 individuals (Tables 4.1, 4.2). The following two tables show the demographic distribution of the results, expressed as percentage of ulnae affected (Table 4.1) and percentage of individuals affected (Table 4.2). These numbers and percentages are broken down by variable to aid in the interpretation of the data: Number of ulnae/individuals affected by sex (male or female), number of ulnae

Table 4.1: Numbers and percentages of ulnae with cortical defect, by characteristic

	No. of ulnae with cortical defect	***Total no. of ulnae in sample***	***% of sub-sample***	***% of sample***
Total:	23	26	*N/A*	88%
By Sex:				
Male	8	11	73%	31%
Female	15	15	100%	58%
By Side:				
Left	12	13	92%	46%
Right	11	13	85%	42%
By age:				
Young Adult	9	9	100%	35%
Middle Adult	10	13	77%	38%
Old Adult	2	2	100%	8%
Indeterminate	2	2	100%	8%
Associated OA:				
Yes	18	21	86%	81%
No	5	5	100%	19%

Table 4.2: Numbers and percentages of individuals exhibiting cortical defect, per variable

	No. of individuals with cortical defect	***Total no. of individuals in sample***	***% of sub-sample***	***% of sample***
Total:	14	16	*N/A*	88%
By Sex:				
Male	5	7	71%	31%
Female	9	9	100%	56%
By age:				
Young Adult	5	5	100%	31%
Middle Adult	6	8	75%	38%
Old Adult	1	1	100%	6%
Indeterminate	2	2	100%	13%
Associated OA:				
Yes	11	13	85%	69%
No	3	3	100%	19%

affected by side (left or right), and number of ulnae/individuals affected by age (young adult, middle adult, old adult, or indeterminate age). The mean volume of the defect as it is present in the Fernvale osteological specimens is 43.85 ± 8.17 mm^3 covering a mean surface area of 10.48 ± 1.08 mm^2. The osteological specimens sampled from Fernvale had an average Cortical Avulsion Index of 32.46 ± 4.70.

4.2 Descriptive Analysis of the Defect

The cortical defect observed in this study is located on the lateral side of the proximal ulna at the attachment site of the lateral ligament complex of the elbow (Figure 4.1). The defect is a single, focal lytic bone defect located on the lateral side of the bone, just

Figure 4.1: Proximal right ulna, showing location of cortical defect (denoted by arrowheads) *Burial 2, 40WM51. Image © author, AE Jordan Foster, 2015*

posterior to the radial notch and slightly superior to the supinator crest. The defect is circumscribed, markedly the result of the periosteum being pulled from the cortical bone very quickly; however, there does not appear to be any associated periostitis, nor does it show any other signs of pathological infection. The defect does not show any signs of being a cloaca of any form, nor does it appear to be a connective foramen (e.g. foramen for blood supply).

The cortical defect observed in the ulna of the Fernvale osteological specimens is indicative of a cellular level reaction, occurring as the result of trauma to the annular ligament of the proximal radioulnar joint, causing it to become avulsed from its attachment to the posterior portion of the radial notch. The mechanism of injury that would cause this type of reaction is laxity and eventual rupture or tear of the annular ligament or the entire lateral collateral ligament (LCL) complex due to posterolateral rotatory instability of the elbow (PLRI). PLRI can be caused by chronic overuse injuries or acute traumatic events such as a fall on an outstretched hand (FOOSH) resulting in either complete or partial dislocation of the radius from its osseous constraint.

4.3 Cortical Defect-Measurement Data

Table 4.3 displays the summarized results of data collection, metric measurements, and index calculations of the cortical defect of the proximal ulna. The average size of the defect was 2.47 ± 0.16 mm (AP) by 4.71 ± 0.22 mm (SI) by 2.96 ± 0.35 mm (depth), resulting in an overall average surface area of 10.48 ± 1.08 mm^2 and an overall average volume of 43.85 ± 8.17 mm^3. This gives the defect in the Fernvale osteological specimens an overall average Cortical Avulsion Index of 32.46 ± 4.70.

4.4 Results of Statistical Analyses

The hypotheses testing the presence of the defect in relation to each variable were tested using the Chi-squared Goodness of Fit test. The hypotheses testing the overall size of the defect in relation to each variable were tested with a two-sample t-test, assuming unequal variance. The results are summarized under each respective hypotheses' heading. Both the Chi-squared Goodness of Fit tests and the two-sample t-tests were calculated using 95% confidence limits ($\alpha = 0.05$). Descriptive statistics for each measurement are presented in Tables 4.4 through 4.9.

Table 4.3: Cortical defect measurement and index calculation data

Burial Number	Age Category	Sex	Side	A-P Diameter (mm)	S-I Diameter (mm)	Depth (mm)	Surface Area (mm^2)	Volume (mm^3)	Cortical Avulsion Index
2	old adult	female	left	2.5	5.6	4.5	10.9	65.6	41.1
2	old adult	female	right	4.7	7.5	4.5	27.5	164.7	16.4
3	middle adult	male	right	3.0	5.2	1.0	12.4	16.5	8.1
4	young adult	female	left	1.9	4.4	1.0	6.6	8.8	15.1
4	young adult	female	right	2.1	2.9	1.0	4.8	6.4	20.8
6	middle adult	female	left	3.9	5.1	5.0	15.6	104.2	32.0
9	middle adult	male	left	3.0	4.8	2.5	11.4	38.0	21.9
9	middle adult	male	right	2.9	5.8	2.0	13.1	34.9	15.3
10	middle adult	female	left	2.1	5.1	1.0	8.4	11.2	11.9
10	middle adult	female	right	2.5	5.4	2.0	10.4	27.7	19.2
12	young adult	female	left	2.4	4.1	7.0	7.8	72.8	89.8
13	young adult	female	left	1.9	3.4	3.0	5.1	20.6	58.3
13	young adult	female	right	2.1	4.9	2.5	7.8	26.1	31.9
15	middle adult	male	left	--	--	--	--	--	--
16	middle adult	male	left	2.5	3.5	4.0	6.7	35.5	60.1
16	middle adult	male	right	2.1	3.7	3.0	6.1	24.4	49.1
17	indeterminate	female	right	2.6	5.6	1.5	11.5	23.1	13.0
18	indeterminate	male	left	3.0	3.3	2.5	7.8	26.1	32.0
19	young adult	male	left	4.2	5.4	5.0	17.8	119.0	28.0
19	young adult	male	right	2.6	4.2	1.0	8.5	11.3	11.8
24	middle adult	male	left	--	--	--	--	--	--
24	middle adult	male	right	--	--	--	--	--	--
27	middle adult	female	left	2.5	5.4	4.0	10.4	55.6	38.4
27	middle adult	female	right	3.9	5.5	2.0	17.0	45.3	11.8
28	young adult	female	left	2.3	3.6	2.5	6.6	21.9	38.0
28	young adult	female	right	2.2	3.9	5.5	6.7	48.9	82.5
			Mean Values	**2.73**	**4.71**	**2.96**	**10.48**	**43.85**	**32.46**

Table 4.4: Descriptive Statistics | Cortical Defect Anterior-Posterior (AP) Measurement Calculations

A-P Diameter (mm)	
Mean	2.73
Standard Error	0.16
Median	2.47
Standard Deviation	0.77
Sample Variance	0.59
Range	2.76
Minimum	1.92
Maximum	4.68
Count	23
Confidence Level (95.0%)	0.33

Table 4.5: Descriptive Statistics | Cortical Defect Superior-Inferior (SI) Measurement Calculations

S-I Diameter (mm)	
Mean	4.71
Standard Error	0.22
Median	4.86
Standard Deviation	1.06
Sample Variance	1.13
Range	4.55
Minimum	2.92
Maximum	7.47
Count	23
Confidence Level (95.0%)	0.46

Table 4.6: Descriptive Statistics | Cortical Defect Depth Measurement Calculations

Depth (mm)	
Mean	2.96
Standard Error	0.35
Median	2.50
Standard Deviation	1.69
Sample Variance	2.86
Range	6.00
Minimum	1.00
Maximum	7.00
Count	23
Confidence Level (95.0%)	0.73

Table 4.7: Descriptive Statistics | Cortical Defect Surface Area Calculations

Surface Area (mm^2)	
Mean	10.48
Standard Error	1.08
Median	8.51
Standard Deviation	5.19
Sample Variance	26.93
Range	22.64
Minimum	4.82
Maximum	27.46
Count	23
Confidence Level (95.0%)	2.24

Table 4.8: Descriptive Statistics | Cortical Defect Volume Calculations

Volume (mm^3)	
Mean	43.85
Standard Error	8.17
Median	27.72
Standard Deviation	39.19
Sample Variance	1535.88
Range	158.32
Minimum	6.42
Maximum	164.74
Count	23
Confidence Level (95.0%)	16.95

Table 4.9: Descriptive Statistics | Cortical Avulsion Index Calculations

Cortical Avulsion Index	
Mean	32.46
Standard Error	4.70
Median	28.01
Standard Deviation	22.55
Sample Variance	508.52
Range	81.69
Minimum	8.07
Maximum	89.76
Count	23.00
Confidence Level (95.0%)	9.75

4.4.1.a Hypothesis 1(a): The occurrence of the defect is associated with the sex of the individual.

- Criteria: Statistically significant differences between the presence and absence of the defect in individuals by sex.
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for males and females.
- H_a: The probability of the presence of the defect is not the same for males and females.

The cortical defect under consideration was present in 23 of 26 ulnae in the sample (Table 4.10), corresponding to 14 of 16 individuals sampled, with a distribution by sex of nine out of nine females and five out of seven males (Table 4.11). A chi-squared goodness of fit test on this data determined that there is no statistically significant difference between the occurrence of the defect in males and the occurrence of the defect in females. I fail to reject the null ($H_{\emptyset}$) hypothesis because the value of the test statistic falls within the rejection region for the two-tailed test. Therefore, the differences observed between affected males and females are within the parameters of chance and not due to an extrinsic factor.

Table 4.10: Chi-square Goodness of Fit Test | Presence of defect by number of ulnae, per sex

	Observed	***Expected***	$\frac{(\boldsymbol{O}-\boldsymbol{E})^2}{\boldsymbol{E}}$	df = 1 $\alpha = 0.05$
Male	8	0.50*(23) = 11.5	1.07	Critical value = 3.84
Female	15	0.50*(23) = 11.5	1.07	
Totals:	23	23	$\chi^2 = 2.14 < 3.84$, **fail to reject $H_\emptyset$**	

Table 4.11: Chi-square Goodness of Fit Test | Presence of defect by number of individuals, per sex

	Observed	***Expected***	$\frac{(\boldsymbol{O}-\boldsymbol{E})^2}{\boldsymbol{E}}$	df = 1 $\alpha = 0.05$
Male	5	0.50*(14) = 7	0.57	Critical value = 3.84
Female	9	0.50*(14) = 7	0.57	
Totals:	14	14	$\chi^2 = 1.14 < 3.84$, **fail to reject $H_\emptyset$**	

4.4.1.b Hypothesis 1(b): The overall size of the defect depends on the sex of the individual.

- Criteria: Statistically significant relationship between mean defect size and sex.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_\emptyset$: The overall size of the defect (as measured by the Cortical Avulsion Index) is the same in males and females.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is not the same in males and females.

Based on the results of a two-sample t-test assuming unequal variances (Table 4.12), I fail to reject the null ($H_{\emptyset}$) hypothesis. The observed difference between sample means is not convincing enough to say with certainty that the average overall size of the cortical defect between males and females differs significantly (-2.09<1.60<2.09).

Table 4.12: Two Sample t-Test, assuming unequal variances between males and females

	Female		***Male***
Mean	34.68		28.28
Variance	615.95		335.73
Observations	15		8
Hypothesized Mean Difference		0	
df		19	
t Stat		0.70	
P(T<=t) one-tail		0.25	
t Critical one-tail		1.73	
P(T<=t) two-tail		0.49	
t Critical two-tail		2.09	

4.4.2.a Hypothesis 2(a): The occurrence of the defect is associated with the location of the defect (in either the left or the right arm).

- Criteria: Statistically significant differences between the presence and absence of the defect in individuals by side (left or right).
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for left and right sides.
- H_a: The probability of the presence of the defect is not the same for left and right sides.

The cortical defect under consideration was present in 14 of 16 individuals sampled, with a distribution per side of 12 left and 11 right. A chi-squared goodness of fit test on this data determined that there is no statistically significant difference in the occurrence of the defect in the left ulna and the occurrence of the defect in the right ulna. I fail to reject the null ($H_\emptyset$) hypothesis because the value of the test statistic is less than the critical value for the two-tailed test (Table 4.13). Therefore, I can conclude that the differences observed in the affected left and right ulnae are within the parameters of chance and not due to an extrinsic factor.

Table 4.13: Chi-square Goodness of Fit Test | Presence of defect by number of ulnae, per side

	Observed	***Expected***	$\frac{(O-E)^2}{E}$	df = 1 $\alpha = 0.05$
Left	12	0.50*(23) = 11.5	0.02	Critical value = 3.84
Right	11	0.50*(23) = 11.5	0.02	
Totals:	23	23	$\chi^2 = 0.04 < 3.84$, **fail to reject $H_\emptyset$**	

4.4.2.b Hypothesis 2(b): The overall size of the defect depends on the side of the body on which it occurs.

- Criteria: Statistically significant relationship between overall defect size and left or right side.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_\emptyset$: The overall size of the defect is the same for defects occurring on the left and right sides.
- H_a: The overall size of the defect is not the same for defects occurring on the left and right sides.

Based on the results of a two-sample t-test assuming unequal variances (Table 4.14), I fail to reject the null ($H_\emptyset$) hypothesis. The observed difference between sample means is not convincing enough to say with certainty that the average overall size of the cortical defect observed in left and right ulnae differs significantly (-2.08<1.46<2.08).

Table 4.14: Two Sample t-Test, assuming unequal variances between left and right ulnae

	Left		***Right***
Mean	38.89		25.44
Variance	474.12		493.45
Observations	12		11
Hypothesized Mean Difference		0	
df		21	
t Stat		1.46	
P(T<=t) one-tail		0.08	
t Critical one-tail		1.72	
P(T<=t) two-tail		0.16	
t Critical two-tail		2.08	

4.4.3.a Hypothesis 3(a): The occurrence of the defect is associated with the age of the individual.

- Criteria: Statistically significant differences between the number of affected and unaffected individuals by age.
- Test: Qualitative/Nominal; Chi-squared goodness of fit test
- $H_\emptyset$: The probability of the presence of the defect is the same for all [adult] age groups.
- H_a: The probability of the presence of the defect is not the same for all [adult] age groups.

Considering the individual bones sampled, the cortical defect was present in 23 of 26 ulnae, with the following age distribution: nine of nine belonging to young adults, 10 of 13 belonging to middle adults, two of two belonging to old adults, and two of two belonging to individuals of indeterminate age (Table 4.15). Considering the presence of the cortical defect in number of people rather than number of ulnae, the defect was present in 14 of 16 osteological specimens sampled, with a distribution by age of five of five young adults, six of eight middle adults, one of one old adult, and two of two of indeterminate age (Table 4.16).

A chi-squared goodness of fit test on this data (Table 4.16) determined that there is no statistically significant difference in the occurrence of the defect in individuals, regardless of age. I fail to reject the null ($H_\emptyset$) hypothesis considering the data on the level of the individual because the value of the test statistic falls within the rejection region for the two-tailed test ($-7.82 < \chi^2 = 4.86 < 7.82$). Therefore, I can conclude that the difference observed in the affected age ranges is within the parameters of chance and not due to an extrinsic factor. However, considering the data for each specific ulna (Table 4.15), the calculated chi-squared value ($\chi^2 = 9.88$) is greater than the critical value (7.82), thereby leading to the rejection of the null ($H_\emptyset$) hypothesis and the tentative acceptance of the alternative (H_a) hypothesis, that the probability of the presence of the cortical defect is not the same for all of the age groups.

Table 4.15: Chi-square Goodness of Fit Test | Presence of defect by number of ulnae, per age category

	Observed	***Expected***	$\frac{(O-E)^2}{E}$	df = 3 $\alpha = 0.05$
Young Adult	9	0.25*(23) = 5.75	1.84	Critical value = 7.82
Middle Adult	10	0.25*(23) = 5.75	3.14	
Old Adult	2	0.25*(23) = 5.75	2.45	
Indeterminate	2	0.25*(23) = 5.75	2.45	
Totals:	23	23	$\chi^2 = 9.88 > 7.82$, **reject $H_\emptyset$**	

Table 4.16: Chi-square Goodness of Fit Test | Presence of defect by number of individuals, per age category

	Observed	***Expected***	$\frac{(O-E)^2}{E}$	df = 3 $\alpha = 0.05$
Young Adult	5	0.25*(14) = 3.5	0.64	Critical value = 7.82
Middle Adult	6	0.25*(14) = 3.5	1.79	
Old Adult	1	0.25*(14) = 3.5	1.79	
Indeterminate	2	0.25*(14) = 3.5	0.64	
Totals:	14	14	$\chi^2 = 4.86 < 7.82$, **fail to reject $H_\emptyset$**	

4.4.3.b Hypothesis 3(b): The overall size of the defect depends on the age of the individual.

- Criteria: Relationship between overall defect size and age
- $H_\emptyset$: The overall size of the defect (as measured by the Cortical Avulsion Index) is the same for all [adult] age groups.
- H_a: The overall size of the defect (as measured by the Cortical Avulsion Index) is not the same for all [adult] age groups.

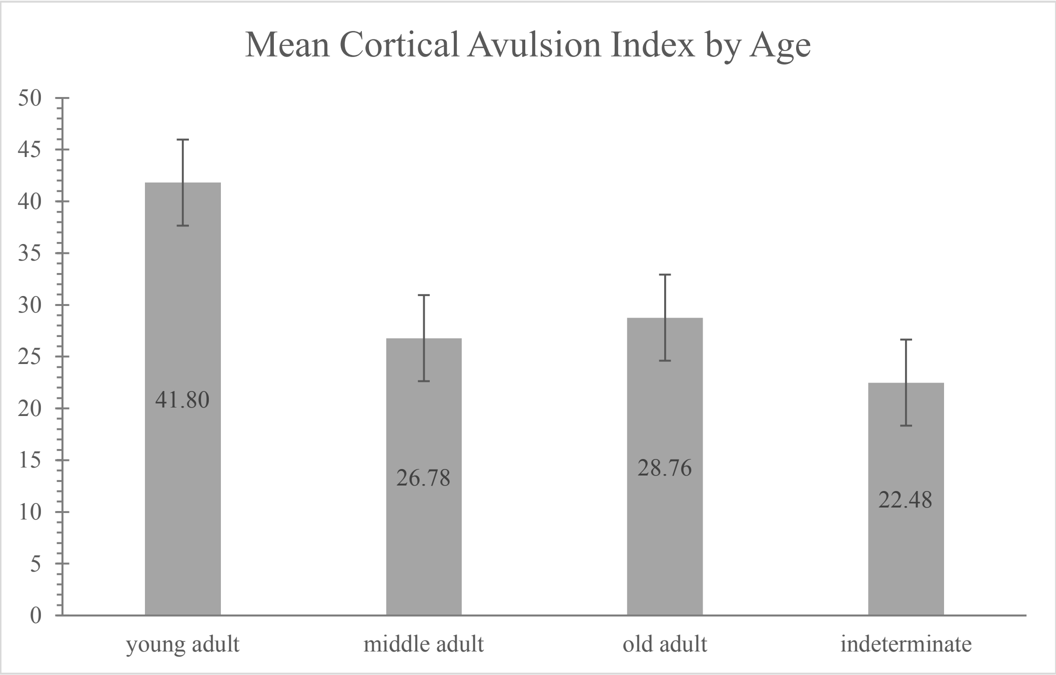

Figure 4.2: Mean Cortical Avulsion Index (overall size of the defect) by age category

The data suggest that the size of the defect, as calculated with the Cortical Avulsion Index (Figure 4.2), is similar among the middle adult, old adult, and the indeterminate age groups. However, this result could be skewed based on the number of individuals in the old adult age category (one individual) and the indeterminate age category (two individuals) and by the fact that there is an indeterminate category in the first place.

4.4.4.a Hypothesis 4(a): The occurrence of the defect is associated with the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the upper limb in the individual.

- Criteria: Statistically significant differences between affected and unaffected individuals by presence/absence of degenerative joint disease/osteoarthritis of the upper limb.
- Test: Qualitative; Chi-squared goodness of fit test
- $H_{\emptyset}$: The probability of the presence of the defect is the same for individuals with or without DJD/OA of the upper limb.
- H_a: The probability of the presence of the defect is not the same for individuals with or without DJD/OA of the upper limb.

Thirteen (13) of the 16 individuals sampled exhibited some degree of osteoarthritis (OA) in the upper extremities. Eleven (11) of those specimens exhibiting OA were also found to have the cortical defect of the proximal ulna. A chi-squared goodness of fit test was performed on the data, considering individual bones (e.g., ulnae) (Table 4.17) and the entire individual (Table 4.18) separately, to determine any statistical significance of the presence of the cortical defect in both the presence and absence of OA of the upper limb. The calculated chi-squared value is greater than the critical value for ulnae-specific data (χ^2 = 7.34) as well as individual-specific data (χ^2 = 4.58). The null ($H_{\emptyset}$) hypothesis is rejected and the alternative (H_a) hypothesis tentatively accepted; the probability of the presence of the defect is not the same for individuals with or without DJD/OA of the upper limb. Thus, the presence of the cortical defect of the proximal ulna is influenced by the occurrence of degenerative joint disease (DJD/OA) in the upper limb. In the Fernvale osteological specimens specifically, the cortical defect of the proximal radioulnar joint occurs more frequently in individuals with OA in the upper limb.

Table 4.17: Chi-square Goodness of Fit Test | Presence of defect by number of ulnae, per presence/absence of OA in the upper limb

	Observed	***Expected***	$\frac{(\boldsymbol{O}-\boldsymbol{E})^2}{\boldsymbol{E}}$	df = 1 $\alpha = 0.05$
OA	18	0.50*(23) = 11.5	3.67	Critical value = 3.84
No OA	5	0.50*(23) = 11.5	3.67	
Totals:	23	23	χ^2 = 7.34 < 3.84, **reject** $\boldsymbol{H_\emptyset}$	

Table 4.18: Chi-square Goodness of Fit Test | Presence of defect by number of individuals, per presence/absence of OA in the upper limb

	Observed	***Expected***	$\frac{(\boldsymbol{O}-\boldsymbol{E})^2}{\boldsymbol{E}}$	df = 1 $\alpha = 0.05$
OA	11	0.50*(14) = 7	2.29	Critical value = 3.84
No OA	3	0.50*(14) = 7	2.29	
Totals:	14	14	χ^2 = 4.58 < 3.84, **reject** $\boldsymbol{H_\emptyset}$	

4.4.4.b *Hypothesis 4(b): The overall size of the defect depends on the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the upper limb in the individual.*

- Criteria: Statistically significant relationship between overall defect size and DJD/OA.
- Test: Quantitative/Measurement; Two-sample t-test assuming unequal variances
- $H_\emptyset$: The overall size of the defect is not affected by the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the upper limb in the individual.
- H_a: The overall size of the defect is affected by the presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the upper limb in the individual.

Based on the results of a two-sample t-test assuming unequal variances (Table 4.19), I fail to reject the null ($H_\emptyset$) hypothesis. The observed difference between sample means is not convincing enough to say with certainty that the average overall size of the cortical defect between individuals with presence of degenerative joint disease (DJD)/osteoarthritis (OA) of the upper limb differs significantly ($-2.26 < 0.11 < 2.26$).

Table 4.19: Two sample t-Test, assuming unequal variances between individuals with OA present in upper limb and individuals with no OA present in the upper limb

	no OA	*OA*
Mean	31.63	32.69
Variance	276.00	592.89
Observations	5	18
Hypothesized Mean Difference	0	
df	9	
t Stat	0.11	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.91	
t Critical two-tail	2.26	

4.5 Chapter Summary

This chapter provided the results of the examination of the Fernvale osteological specimens in two parts: (1) a descriptive analysis of the cortical defect and (2) qualitative and quantitative analyses of the metric data collected on the cortical defect of the proximal ulnae.

The cortical defect observed in this study is a single, focal lytic bone lesion located on the lateral side of the proximal ulna at the attachment site of the lateral ligament complex of the elbow, just posterior to the radial notch and slightly superior to the supinator crest. The defect is circumscribed, markedly the result of the periosteum being pulled from the cortical bone very quickly. This particular cortical defect can be viewed in terms of an avulsion injury to the annular ligament of the lateral ligament complex of the elbow, resulting from a complete or partial dislocation of the radius from its articulation with the ulna.

The defect is present in a high percentage of the population sampled, 14 of 16 individuals (23 of 26 ulnae), with a sex distribution of nine females and five males and the majority of the affected individuals falling in the age range of young and middle adults (approximately <50 years of age). There was no predilection for side of the body in the occurrence of the defect. In terms of association with osteoarthritis (OA), a greater number of individuals in the population had associated OA of the upper limb, but that did not necessarily affect the overall size of the defect in the proximal ulna. The following chapter (Chapter 5) provides further interpretation of these results.

CHAPTER V: DISCUSSION AND CONCLUSIONS

5.1 Discussion

The defect is present in a high percentage of the population sampled, 14 of 16 individuals (23 of 26 ulnae). The 1:1 sex ratio observed in the Fernvale skeletal series (Hodge and Davis 2013) also existed in the sample utilized for this research. However, the resulting number of males (five) and females (nine) with the presence of the defect is closer to a 1:2 ratio than the original sample size of seven males and nine females. Additional studies are required to determine if the defect is twice as likely to occur in females as in males or if this ratio is associated with the small sample size. In addition to the normal distribution of sex, the skeletal series displays a normal distribution of juvenile mortality rates specific to the Late Archaic period (Hodge and Davis 2013).

The majority of the affected individuals fall into the age categories of young and middle adults (approximately <50 years of age). The occurrence of the defect in individuals <50 years of age is not surprising because of the amount of work and energy exerted by younger members of any community or population compared with older members of the community. Conversely, it is safe to assume that younger adults are eventually becoming older adults in their lifetimes, assuming a normal distribution of age, sex, and mortality rates in the population. Any distribution that differs from a relative ratio of age and mortality rates of the population may be the result of a small sample size. This issue should be considered in further research.

There was no predilection for side of the body in the occurrence of the defect. Perhaps the defect is not the result of a chronic overuse injury related to activity patterns, because there is no preference for side. Some paleopathological studies of occupational markers in skeletal remains suggest that one side is typically favored over the other in hunting and agricultural activities such as throwing a spear, shooting a bow, seed-grinding, animal-hide processing, chopping, digging, and other associated activities (Angel 1966; Aufderheide and Rodriguez-Martin 1998; Bridges 1989, 1990, 1992; Brues 1959; Butler 1975; Capasso et al. 1999; Gerr et al. 1991; Ho 1995; Jurmain and Kilgore 1995; Lai and Lovell 1992; Lambert 2000; Larsen 1987, 1995; Mann and Hunt 2005; O'Neil et al. 2001; Ortner and Putschar 1981; Villotte et al. 2010; Weiss 2003(a), 2003(b); Weiss et al. 2012; Whittaker 2003). However, I argue that the Late Archaic Period stands to be collectively reexamined as well as on a site-specific and temporally-specific basis. Further research is necessary to explore the possibility that bilateral symmetry can be explained by several combined activity patterns contributing to the chronic overuse and eventual injury to numerous anatomical elements. However, this bilateral symmetry observed in the Fernvale specimens could be the effect of sampling bias (e.g. small sample size, number of preserved ulnae available from site) and should be explored further in future research.

Not surprisingly, the majority of Fernvale osteological specimens had OA of the upper limb, likely the result of the hard working and living conditions of the site's inhabitants. The presence of upper limb OA was a major contributing factor to the frequency of occurrence of the defect of the proximal radioulnar joint in the elbow, but did not necessarily affect the overall size of the defect. Furthermore, the presence and patterns of OA of the upper limb undoubtedly have a significant impact on the understanding of this defect and need to be explored in greater detail in future studies.

5.2 Limiting Factors of Research

One of the main limitations to this research was the size of the sample. However, because of the constraints involved with research on prehistoric museum specimens and the need for a detailed examination before the remains are repatriated, the sample size was deemed suitable for the scope of this project. For future studies involving this cortical defect, it would be beneficial to examine ulnae from varying temporal and geographical locations to draw conclusions on the associations of the variables presented in this project.

Another confounding factor of this research is the temporal affiliation of the osteological specimens. In cases of modern clinical diagnoses, communication with a patient is often a key factor in making a differential diagnosis based on symptoms presented to the patient, providing clinically relevant information about their health. In cases of archaeological analysis, the bioarchaeologist is presented with only the skeletal remains to reconstruct the history of the individual. The close examination of skeletal remains and holistic interpretation of the spatial and temporal context of the site contribute to a better understanding of the etiology of the cortical defect found at the attachment site of the annular ligament in the proximal radioulnar joint exhibited in the individuals at the Fernvale site in Williamson County, Tennessee (40WM51).

5.3 Biomechanical Interpretations of Skeletal Remains

Arguably, one of the main biological characteristics that make us human is our ability to use our hands in ways unique from almost every other being on the planet. Human hands transcend barriers of language and communication to become symbolic gestures, art immortalized on prehistoric cave walls, or even used as deadly weapons. On a more personal level, we use our hands as tools on a daily basis. Indeed, it is easy to take for granted the essential movements of our hands in our daily activities; it is even easier to overlook the incredibly complex anatomical processes that facilitate those movements.

An individual's environment greatly influences the type and degree of variation in osteogenic processes. The patterns of stress as indicated in bone can range from nutritional deficiencies to interpersonal violence to "environmentally or occupationally facilitated misadventure and accident (Lovell 1997: 139)." The anthropological literature is packed with interpretations of behavior from skeletal remains. However, the biomechanical movements generating the resultant osseous trauma and pathological processes are seldom considered concordantly. Although it is important to be cautious when interpreting trauma and pathological processes in skeletal remains, objectivity lends itself to a more comprehensive understanding of the activity patterns of individuals and populations in the past when considered in terms of the anatomical mechanisms of movement rather than social and cultural behavior patterns.

The remains analyzed from the Fernvale site support the ideas that various lifestyle factors played a significant role in the destruction of various joints of these individuals (specifically the elbow joint). The individuals at Fernvale exhibit typical skeletal evidence of having lived and worked in a physical environment involving rugged terrain (Hodge and Davis 2013). Most individuals from Fernvale have robust muscle attachment sites, indicating a significant amount of stress placed on the body through continual physical activity (Capasso et al. 1998; Jurmain and Kilgore 1995; Mann and Hunt 2005; Ortner and Putschar 1981). Adults in this population exhibit degenerative skeletal conditions, including osteoarthritis (Hodge and Davis 2013). Epidemiological studies have shown a relationship between occupational stress and the incidence of osteoarthritis (Angel 1966; Berryman 1984; Bridges 1989 and 1990; Capasso et al. 1998; Deutch et al. 2003; Fleisig and Escamilla 1996; Gerr et al. 1991; Jurmain 1977; Jurmain and Kilgore 1995; Lambert 2000; Larsen 1995; Morrey 1985; O'Neil et al. 2001; Ortner and Putschar 1981; Resnick and Niwayama 1981; Stroyan and Wilk 1993). Overuse and overdevelopment of some muscle attachments and degeneration of others suggest the specific biomechanics involved in the types of habitual activities of the people of Fernvale. In addition, several of the individuals from Fernvale have evidence of fractures of the upper extremity (in various stages of healing) associated with a fall on an outstretched hand (FOOSH) including Colles' fractures, ulnar midshaft fractures, and clavicular fractures (Hodge and Davis 2013). These fractures support the idea that there was potential risk involved in living and working among the hills and rocky terrain. However, similar injuries to the forearm are also observed in prehistoric canoers and kayakers (Angel 1966; Bridges 1992; Jurmain 1980; Kennedy 1989; Lai and Lovell 1992; Larsen 1987; Ortner 1968; Steen and Lane 1998) and in modern, clinical cases of competitive paddlers (Cox 1992; Stanton 1999; Weiss 2003a).

From an anthropological perspective, it is important to maintain a diachronic (rather than synchronic) perspective of ancient culture. That is, it is crucial to remember that not everything observed in the archaeological record materialized at the same time. Multi-causal explanatory models are an advantage of modern bioarchaeological studies of human history (i.e., there is no single cause for most things that happen in life). This perspective aptly applies to studies of paleopathology and biomechanics. The impact of biomechanical stress on the elbow cannot be measured by a single determining factor. Therefore, it is beyond the scope of this research to pinpoint a single cause of the injury observed in the Fernvale osteological specimens. All I can say with certainty is that the cortical defect is the result of the lateral ligament complex (specifically the annular ligament) reaching its maximum capacity and avulsing from its attachment site on the proximal ulna. The mechanism was most likely a radial head dislocation that caused the annular ligament to become detached from its posterior attachment site, but I cannot say with absolute certainty what specific action caused that dislocation.

> *"It is important to recognize that the specific cause or etiology of an abnormal bone condition cannot always be derived from even the most careful analysis of the paleopathological specimen (Ortner and Putschar 1981)."*

5.4 Life in the Late Archaic Period in Middle Tennessee: Providing a context for the theory of activity-induced overuse injuries of the elbow

A brief description of the Fernvale site provides basic contextual information on the probable activities of the individuals inhabiting the area that could affect their skeletal remains, supporting the idea that some of the people of Fernvale were regularly participating in an activity that resulted in damage to the lateral ligament complex of the elbow. Overall, this contributes to a more holistic understanding of the people of a specific area of the Middle Cumberland Region of Tennessee by providing insight into the interrelatedness of the biological, cultural, ecological, and economic forces shaping the people of Middle Tennessee during the Late Archaic period. For this research project, it will allow a multi-causal explanatory model to help contextualize the types of biomechanical strain being placed on the arm of individuals at the site.

The Fernvale Site is located in northwestern Williamson County on an alluvial terrace of the South Harpeth River Valley with the South Harpeth River forming the southeastern and eastern boundaries of the landform, and smaller streams forming the northern, western, and southern boundaries (Deter-Wolf 2013). The location of site 40WM51 along the interface of the Western Highland Rim and Central Basin physiographic provinces provided access to a variety of lithic materials, such as limestone and sandstone, for stone tool manufacture (Deter-Wolf and Tune 2013). Furthermore, the prehistoric occupation site is one seemingly conducive to the collecting and foraging of plant, aquatic, and faunal resources (Deter-Wolf 2013; Steponaitis 2001). These materials are not only essential to one's daily survival, but are rich in resources for the manufacture of trade goods (e.g., jewelry from marine resources; cord and textiles from plant resources; hides and bone from faunal resources).

One of the most important changes to daily activities in the course of human history has been the changes in subsistence patterns of populations, which brought about changes in settlement patterns and the development of long-distance trade networks; this is no different in the Southeastern United States (Bridges 1992; Larsen 1995; Steponaitis 2001). The Late Archaic Period of the Middle Cumberland Region saw an increase in long distance trade, which was linked to an overall higher population density and the beginning of more sedentary populations (Steponaitis 2001). For the inhabitants of Fernvale, the development of more elaborate long-distance trade networks made navigating the rugged terrain of the Western Highland Rim a necessity (Hodge and Davis 2013; Deter-Wolf 2013). Therefore, the increased mechanical load put on the body of these individuals increased significantly, as seen in the skeletal remains from Fernvale.

5.5 Summary

The presence of the cortical defect at the posterior annular ligament attachment site in the proximal radioulnar joint observed in 14 of the 16 Fernvale osteological specimens can tentatively be understood as the imprint of soft tissue damage in response to physical stressors. Habitually traversing hilly and rocky terrain would inevitably lead to accidental falls and would explain the fractures exhibited in several of the individuals. A fall on an outstretched hand is often associated with dislocation of the radial head, which causes instability of the lateral ligament complex of the elbow. Extensive paddling (while canoeing or kayaking) and climbing could explain the weakening of the elbow and laxity of this particular ligament complex. Chronic subluxation and hyperextension of the arms at the elbow are consistent with injuries abundantly observed in the modern clinical literature (Cohen and Hastings 2007; Deutch et al. 2003; Fleisig and Escamilla 1996; Morrey 1981). Excessive climbing and canoeing are plausible causes for the increased physical stress placed on the skeletons of these individuals, as are accidental falls while navigating the rolling hills of Middle Tennessee; any of these activities would explain a traumatic avulsion of the ligament at this particular location on the ulna.

The presence of the cortical defect of the proximal radioulnar joint is intriguing for several reasons; mainly, because it has not been previously described in anthropological or clinical literature on the subject of the elbow. Presumably, the people of Fernvale were not the only individuals examined to date to be participating in these types of activities. Therefore, the same types of over-use injuries should be apparent across populations, yet the bioarchaeology of Fernvale is unique (Hodge and Davis 2013). This could explain why the defect described here has not been detailed in the literature.

Another possibility is that the defect could have developed solely as a response to overuse. In other words, the area of bone destruction could appear only under stress. Yet another possible explanation is that the defect was seen and described as something else entirely. This is most likely the case, as it happens often, and can cause a good bit of confusion. For example, a recent publication in the Journal of Anatomy indicated the presence of a “new” ligament in the knee with no clear anatomical description yet provided (Claes et al. 2013). The ligament described, the anterolateral ligament (ALL) has seemingly always been present, but identified by numerous other names, which became confusing in the literature (Claes et al. 2013). In addition, some attention is paid to the conflicting results of anthropological studies of entheses when medical literature is not consulted regularly (Villotte et al. 2010). For this reason, it would be beneficial to be able to examine both archaeological and modern remains so that both the osseous and soft tissue can be examined.

5.6 Conclusions

Osteoarthritis and degenerative joint conditions have been thoroughly studied in archaeological populations. Most often, these conditions are the response of bone response to biomechanical stressors, be it the result of trauma or the excessive pull of muscles. Osteoarthritis is generally referred to as an overuse injury to the joint in which the articular capsule is broken down and the bones of the joint are degraded. If an enthesopathy occurs, however, a pathological change occurs at the attachment site that affects the degradation of the joint to an excessive degree. Far less attention has been paid to the existence of enthesopathies in an anthropological context (Villotte 2010), the means by which they develop, and the characteristics they assume in osseous tissue.

By combining a study of archaeological specimen with the biology of human tissue, my hopes for this research were to characterize the specific osteological anomaly observed in the individuals of the Fernvale Site in Williamson County, Tennessee (40WM51) in a descriptive and quantifiable way. In addition, it is my intention to point out the need for a more standardized terminology use among the sciences and the subfields of research. I believe that this will greatly increase the likelihood of research collaboration, of which there is a great need and even greater reward. Finally, through an anthropological interpretation of the activity patterns causing the biomechanical stress that inflicted the pathological deterioration of the annular ligament attachment site on the ulna, I propose that the presence of this cortical defect can be used as an indicator of biomechanical activity patterns resulting in traumatic avulsion injuries in past populations. In addition, there is potential for the use of this cortical defect in the fields of orthopaedics and radiology. With further investigation into the occurrence of this defect in modern individuals, there is potential for its presence to be used as an indicator of specifying tissue damage, thereby foregoing invasive surgery.

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APPENDICES

APPENDIX A: 40WM51 ORIGINAL EXCAVATION INFORMATION AND PHOTOGRAPHS

Figure A.1: *"Cabin on the South Harpeth River"*

Located adjacent to the Fernvale archaeological site (40WM51)
Williamson County, Tennessee

(Image use courtesy of Frank Tuttle, 2014)

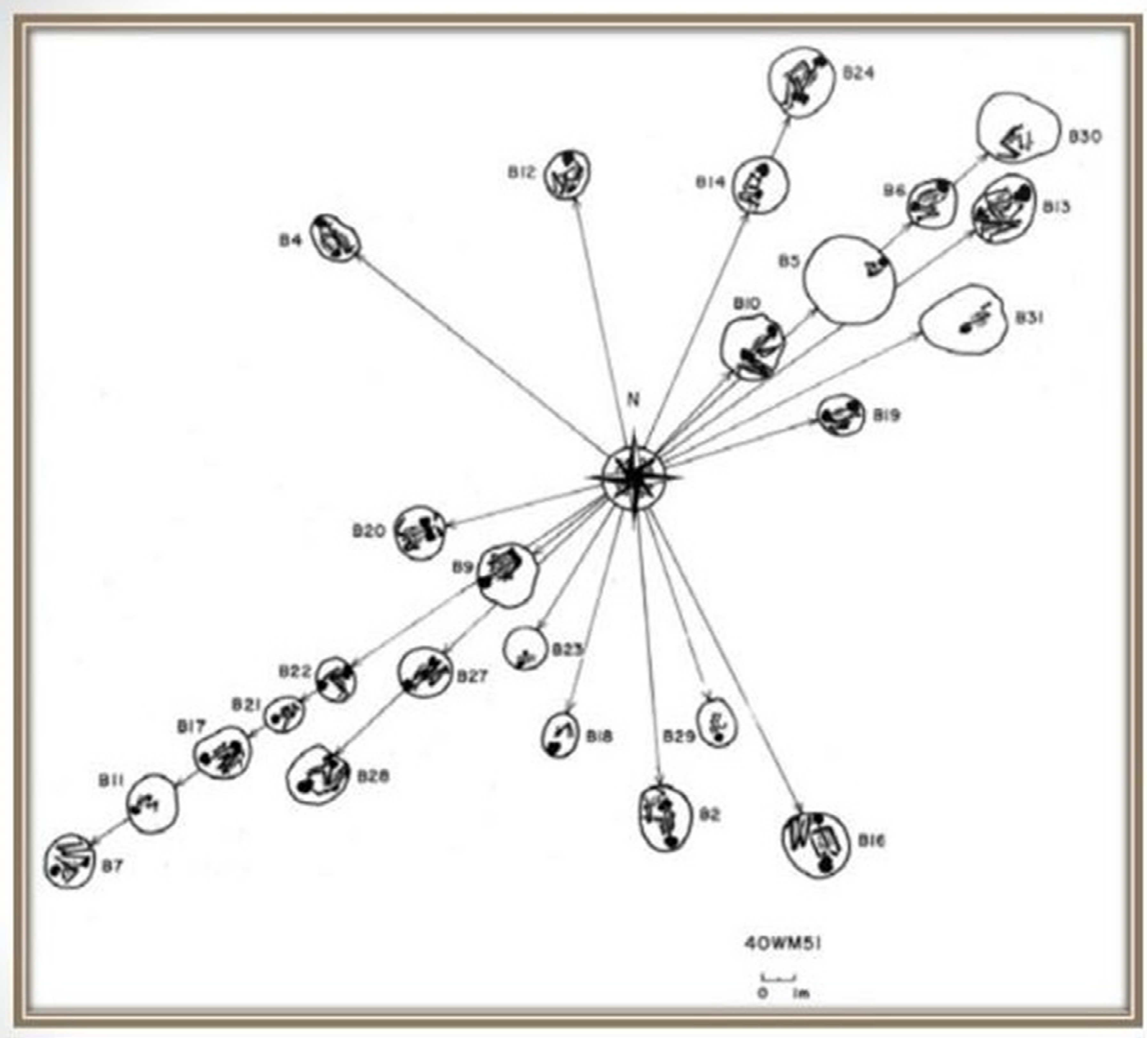


Figure A.2: *Excavated burial arrangement, 40WM51*

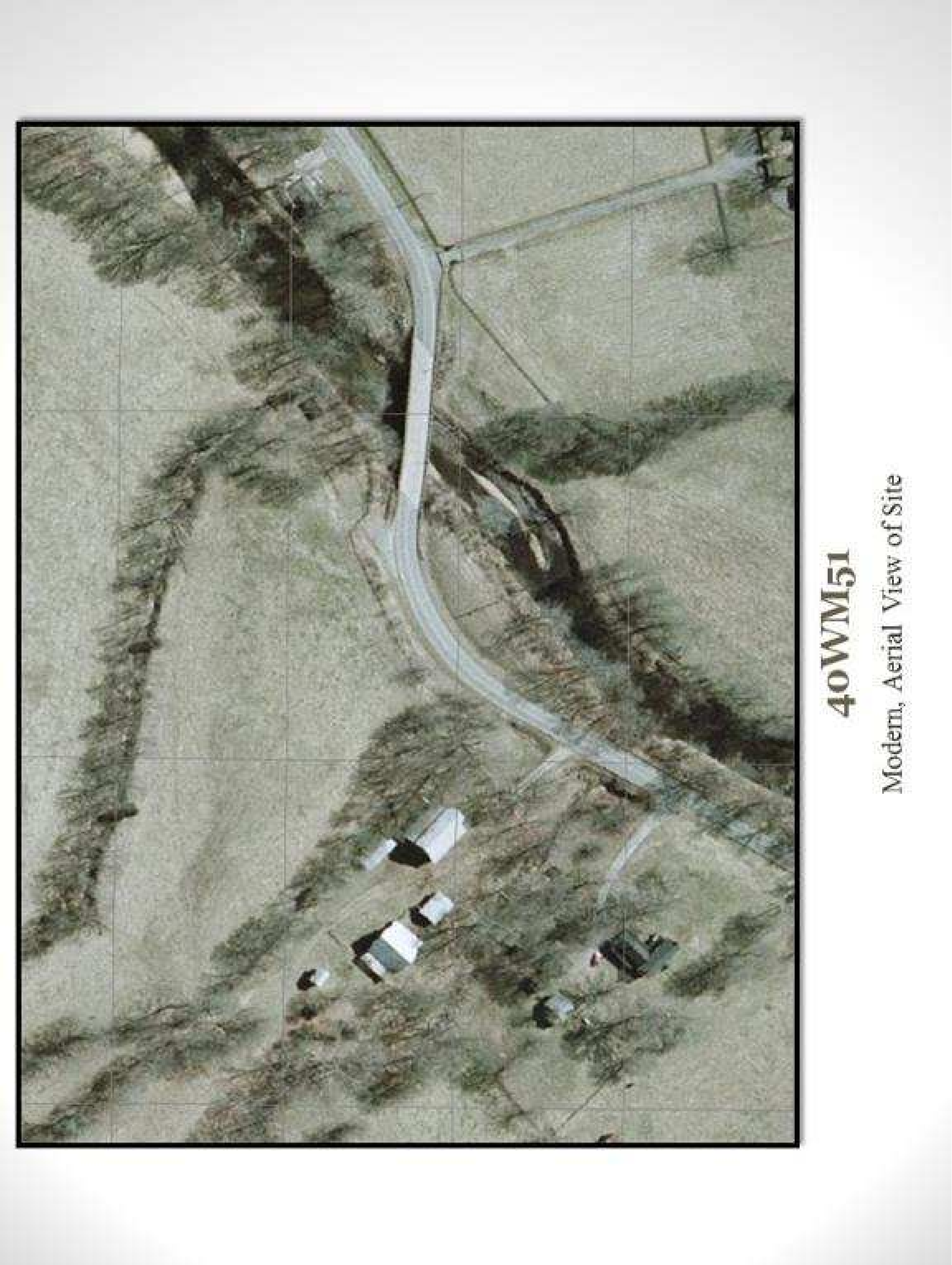


Figure A.3: *Modern aerial view of the site, 40WM51*

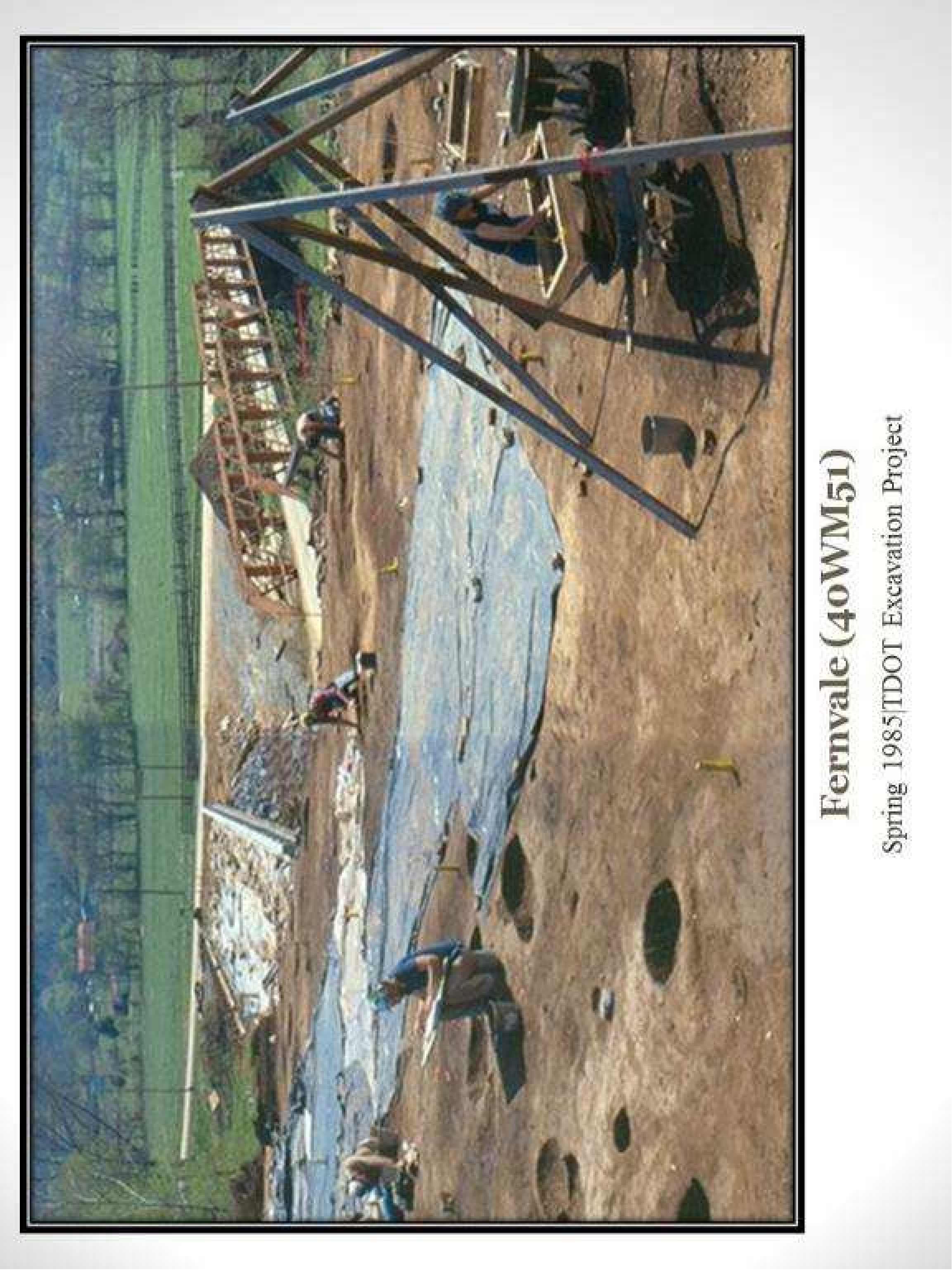


Figure A.4: *TDOA Reconaissance | Spring 1985 | TDOT Excavation Project, 40WM51*

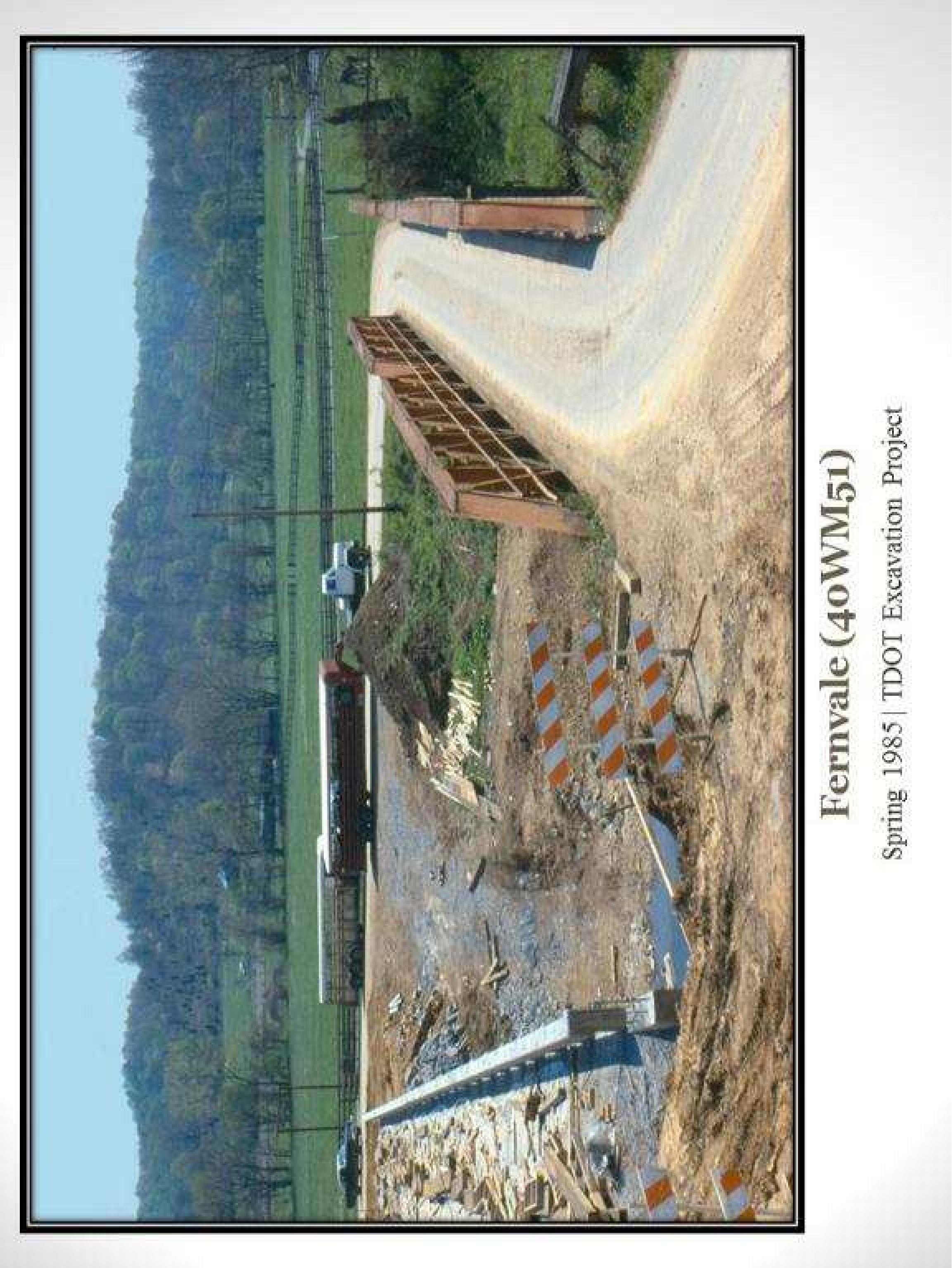


Figure A.5: *Bridge Construction | Spring 1985 | TDOT Excavation Project, 40WM51*

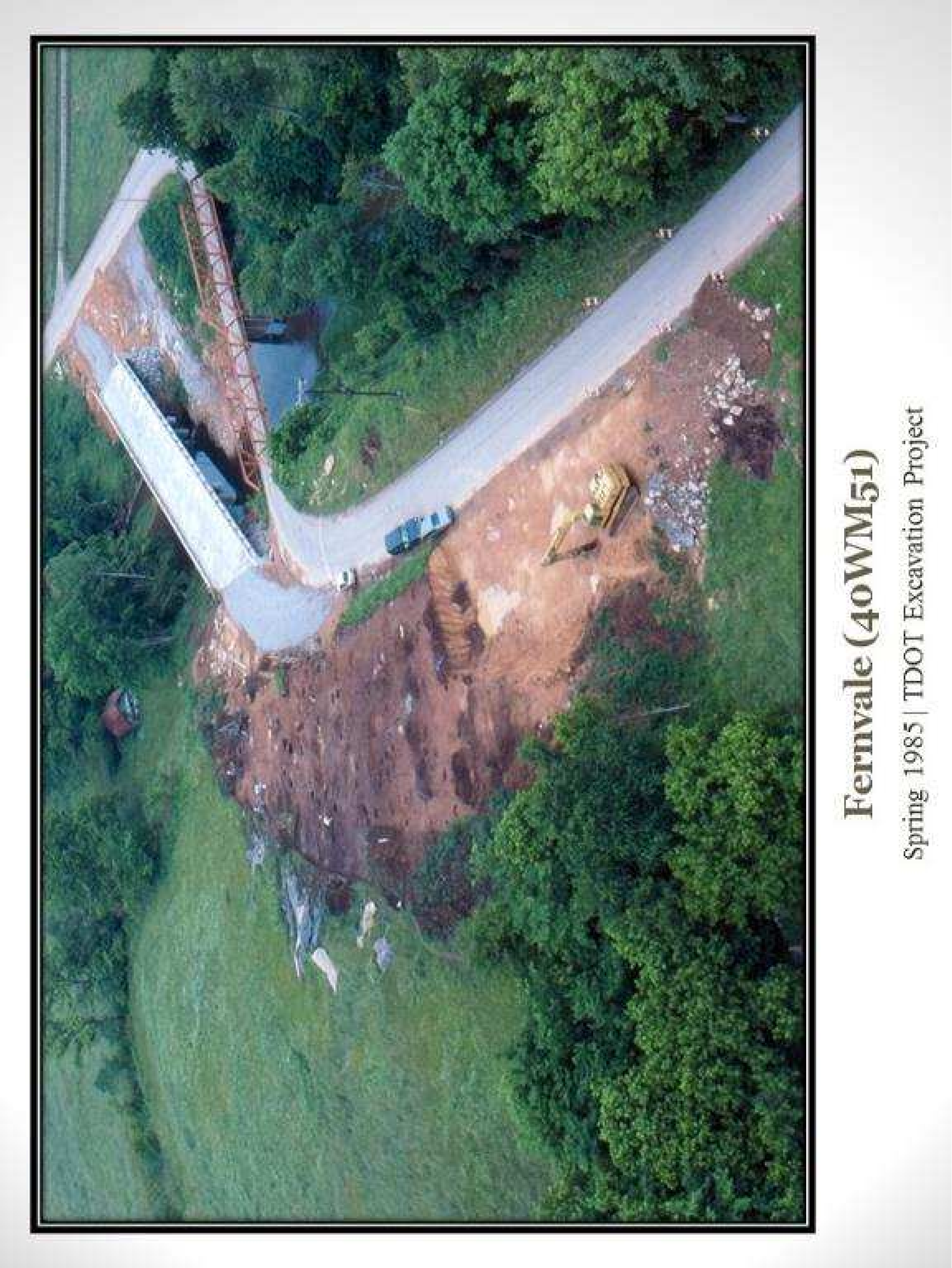


Figure A.6: *Aerial Photograph | Spring 1985 | TDOT Excavation Project, 40WM51*

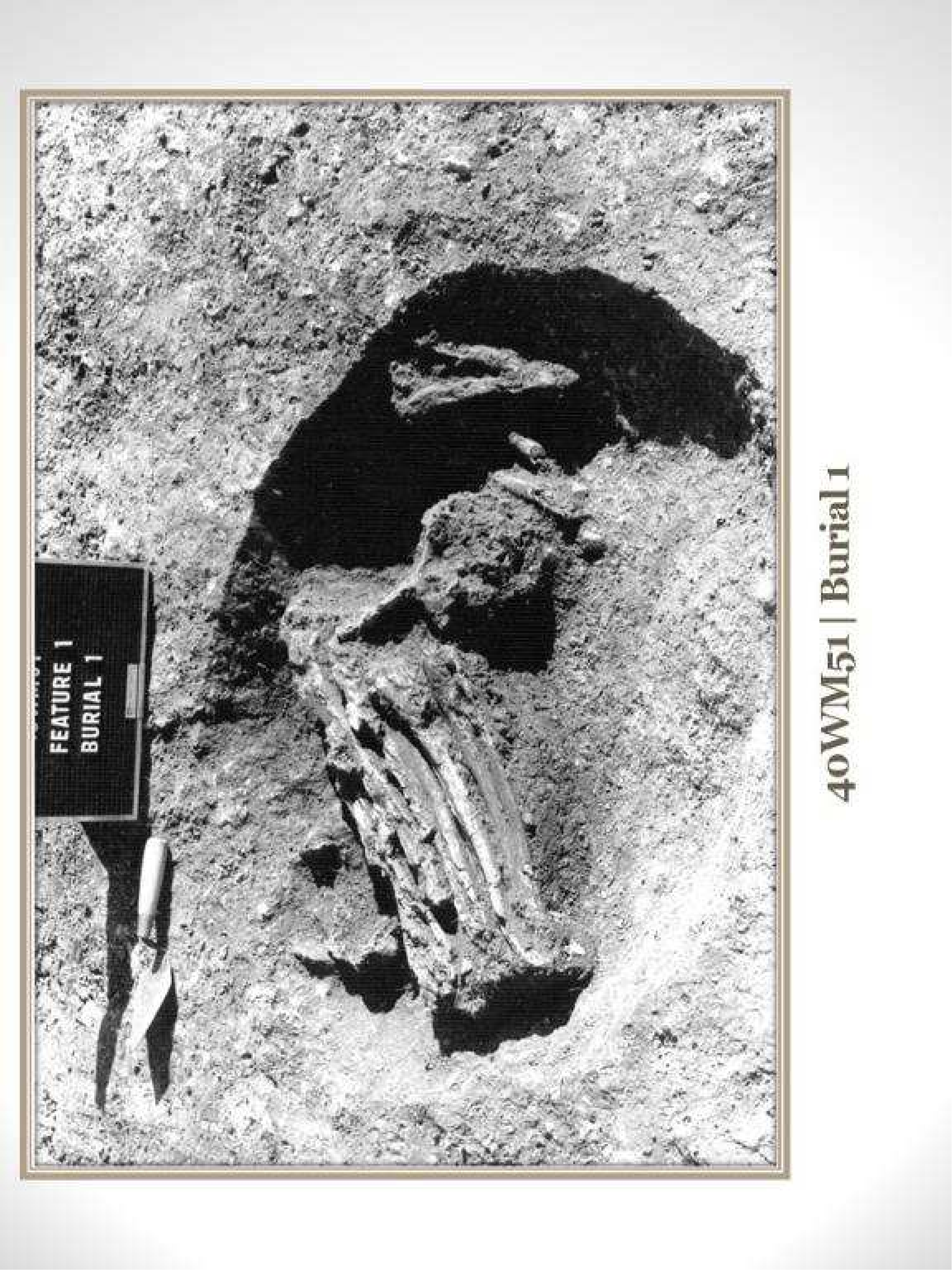


Figure A.7: *Burial 1 and Burial 1b, 40WM51*

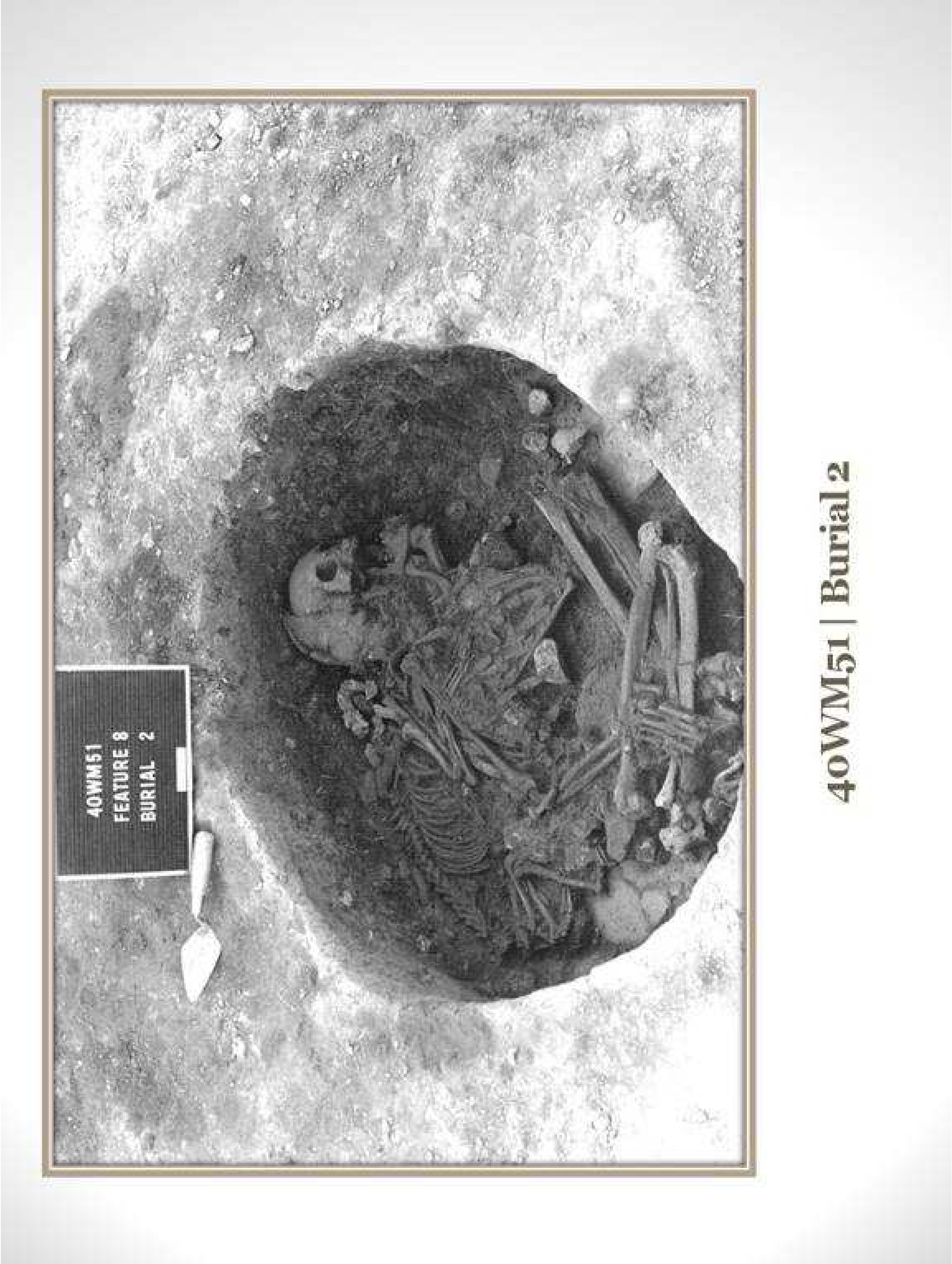


Figure A.8: *Burial 2, 40WM51*

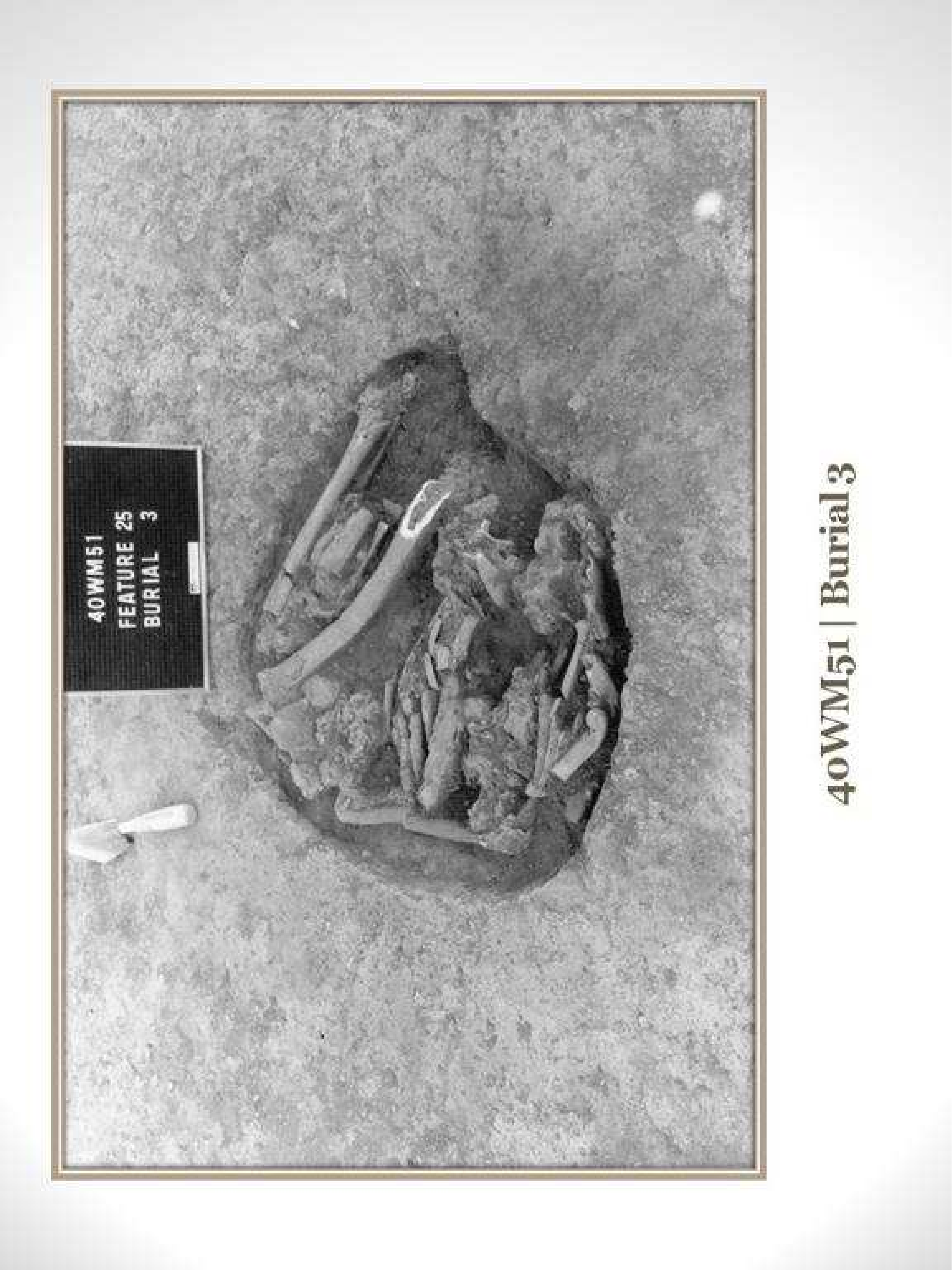


Figure A.9: *Burial 3, 40WM51*

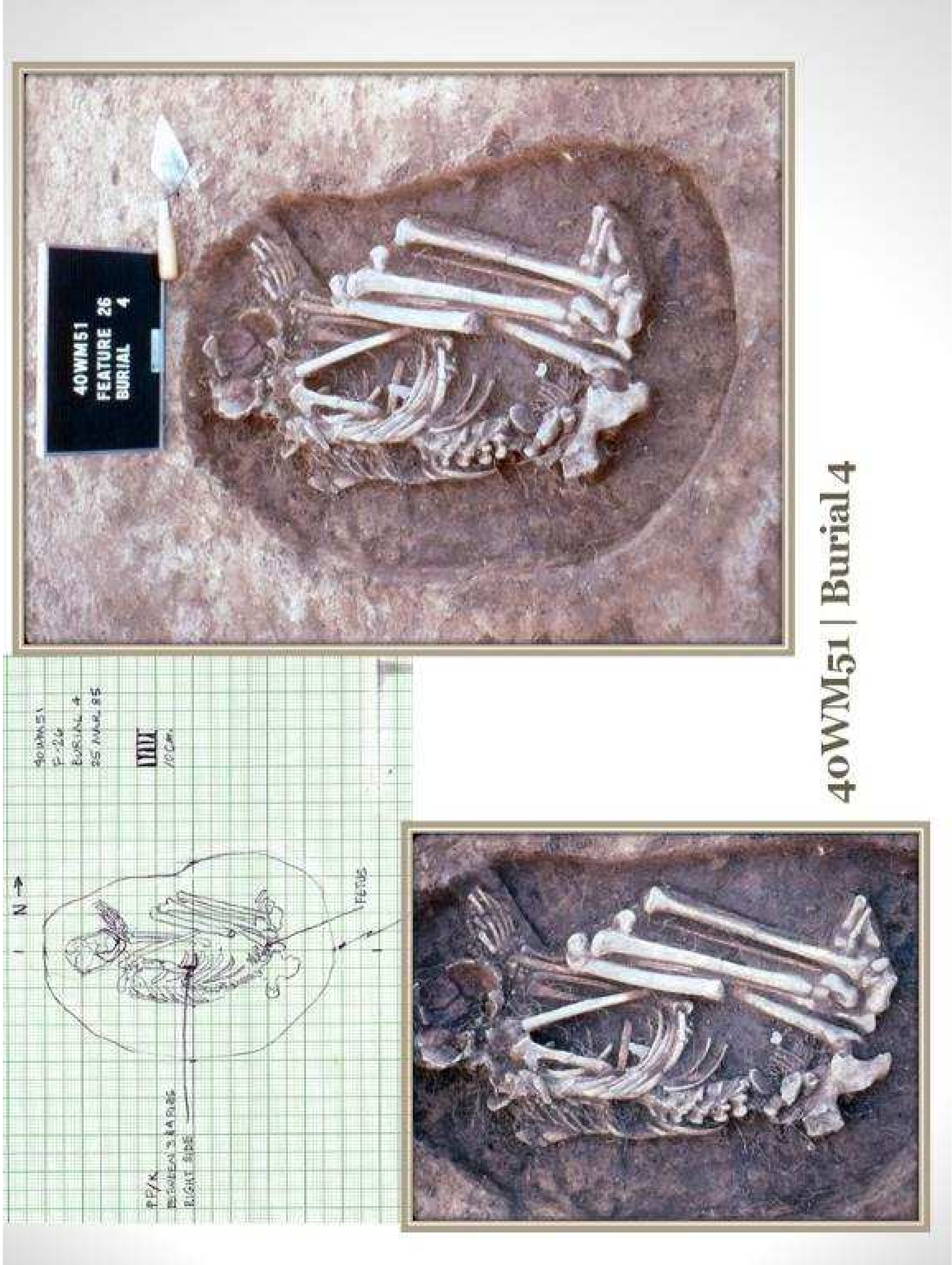


Figure A.10: *Burial 4 and Burial 4b, 40WM51*

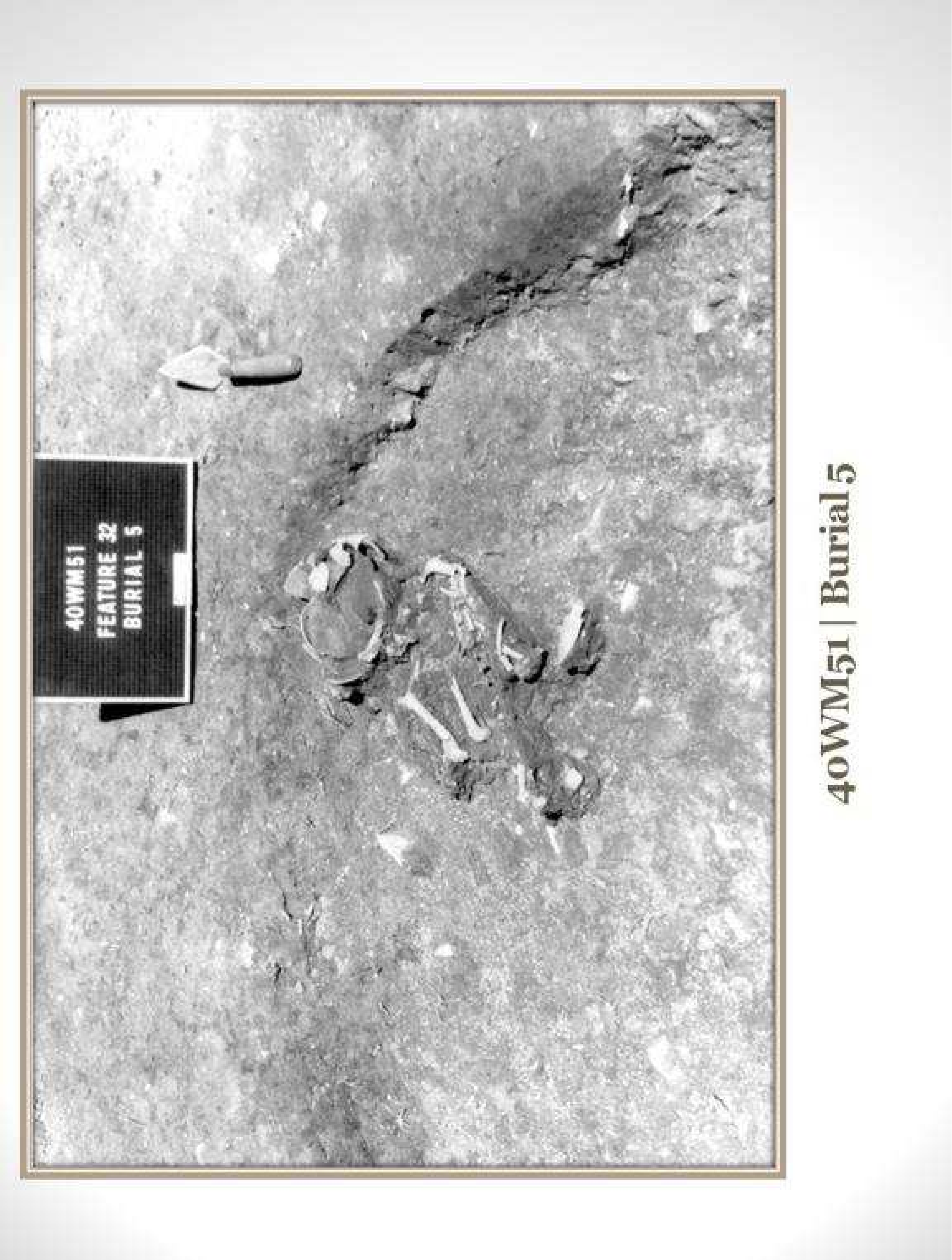


Figure A.11: *Burial 5, 40WM51*

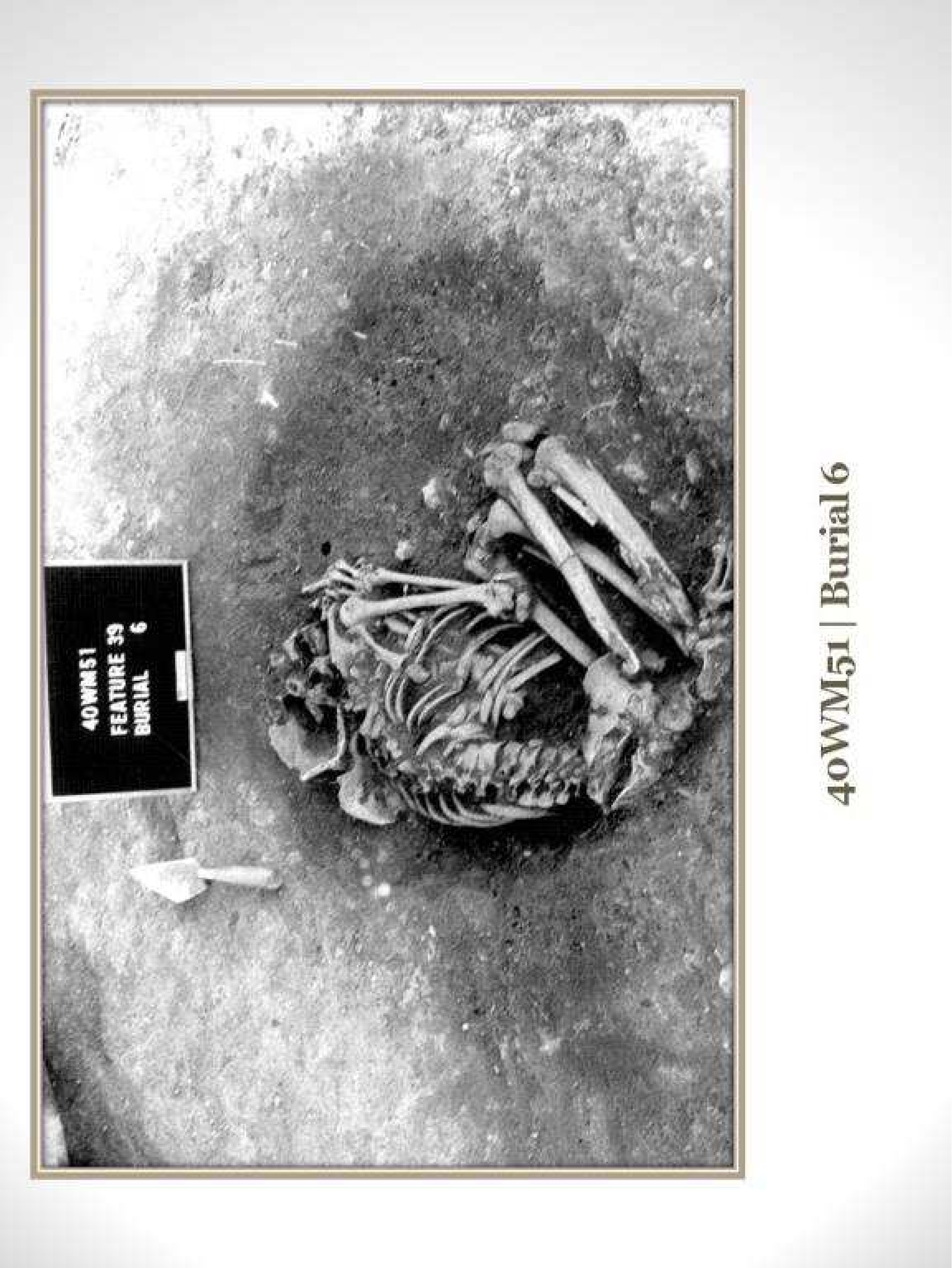


Figure A.12: *Burial 6, 40WM51*

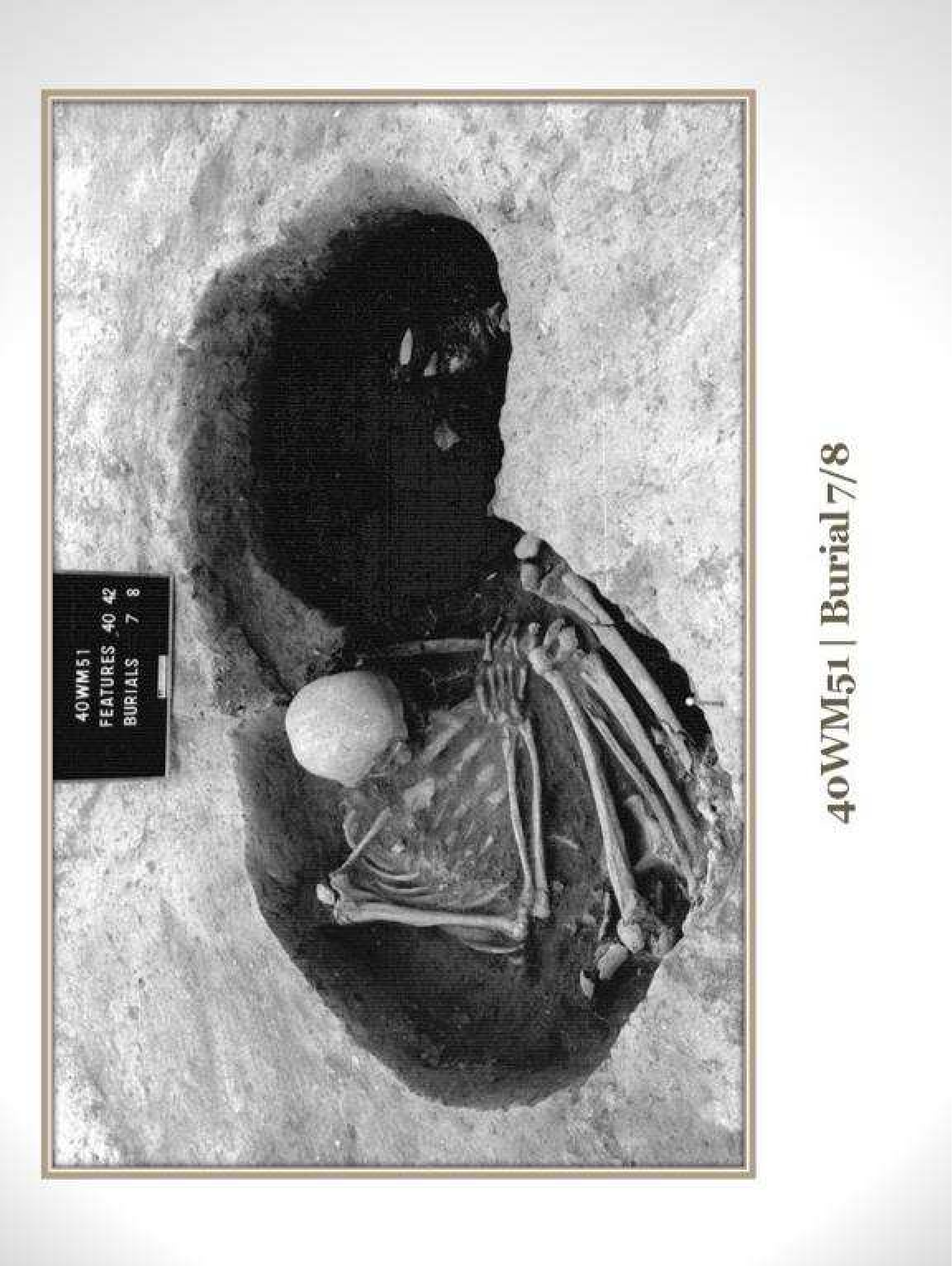


Figure A.13: *Burial 7 and Burial 8, 40WM51*

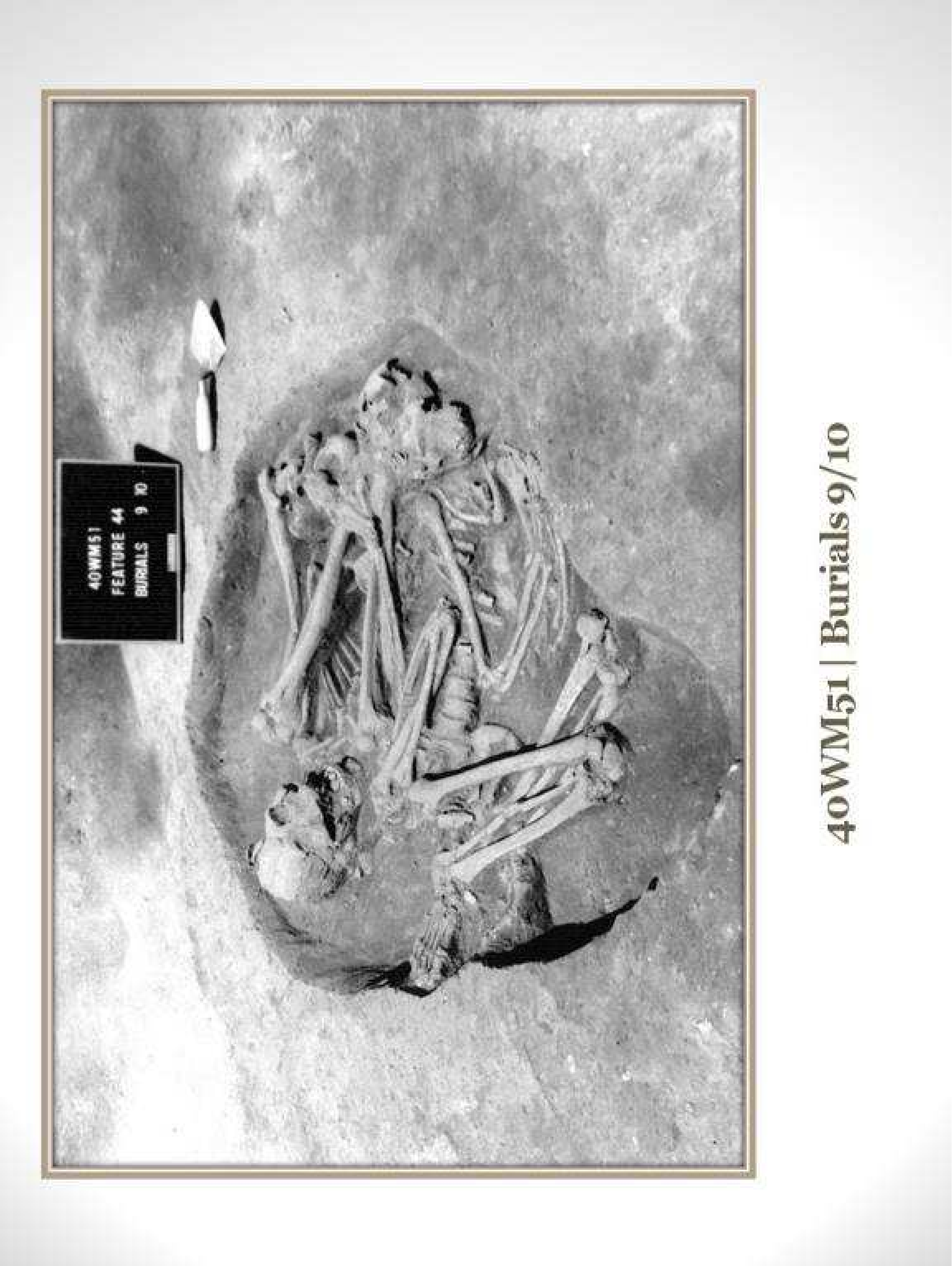


Figure A.14: *Burial 9 and Burial 10, 40WM51*

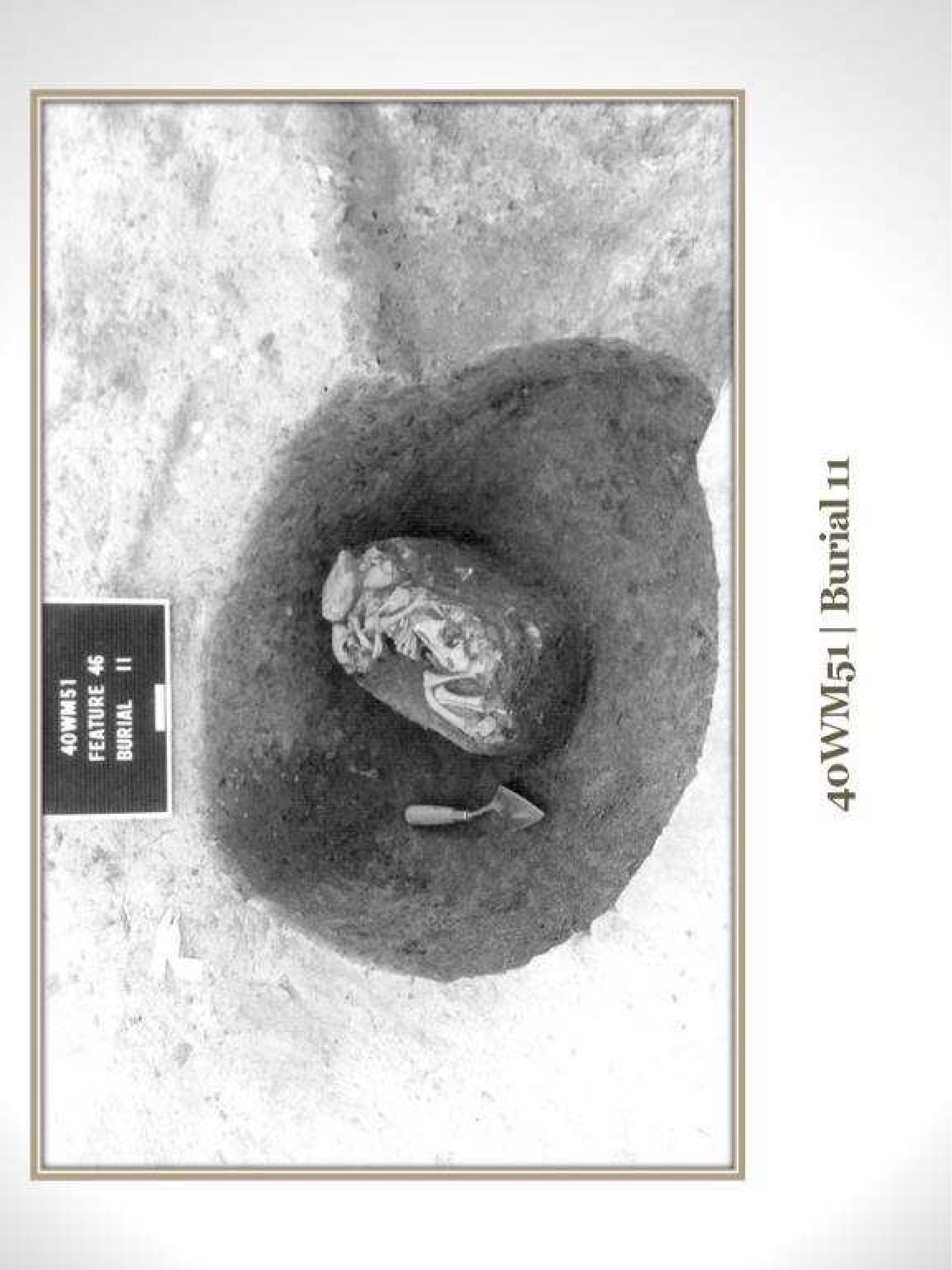


Figure A.15: *Burial 11, 40WM51*

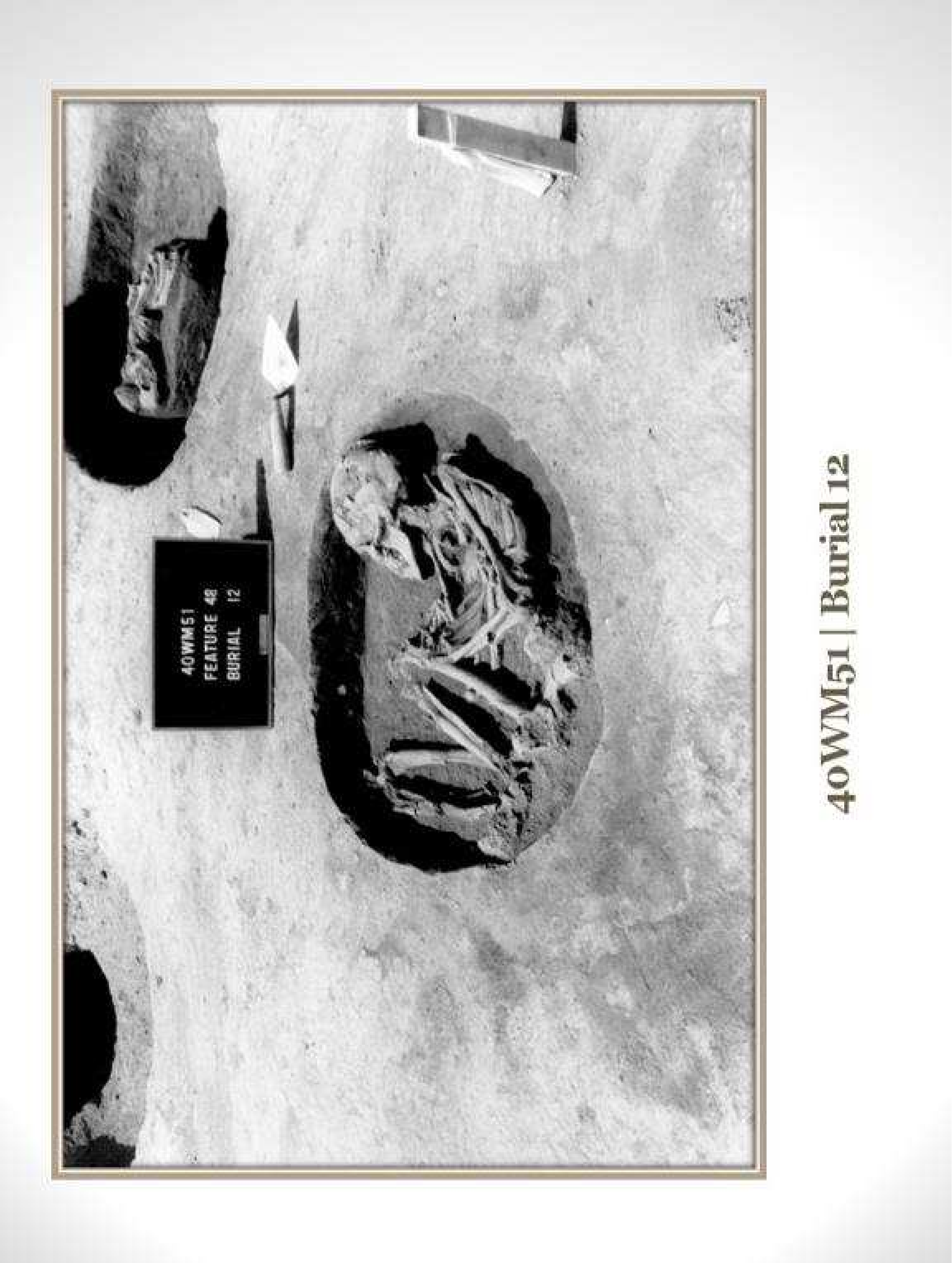


Figure A.16: *Burial 12, 40WM51*

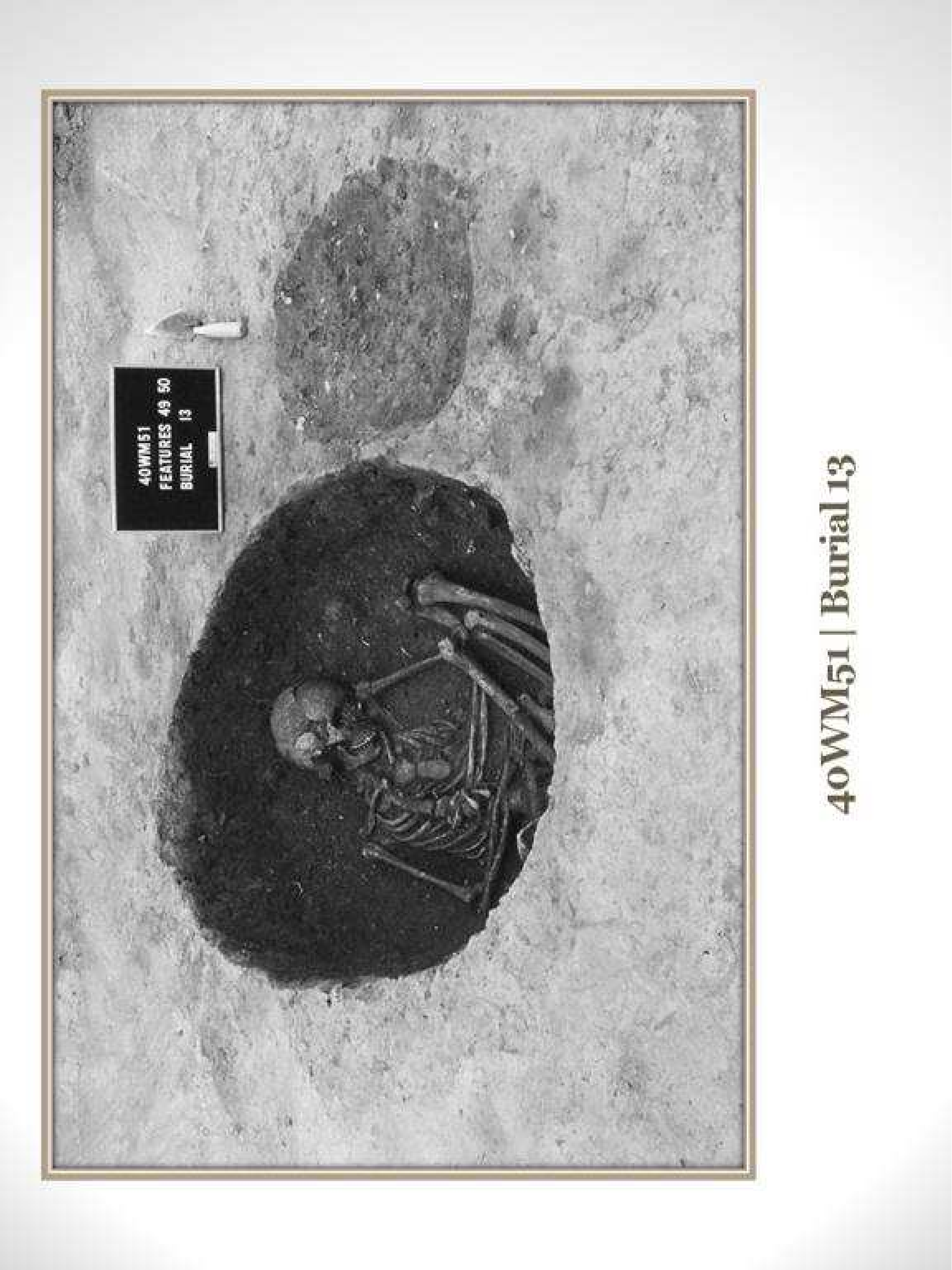


Figure A.17: *Burial 13, 40WM51*

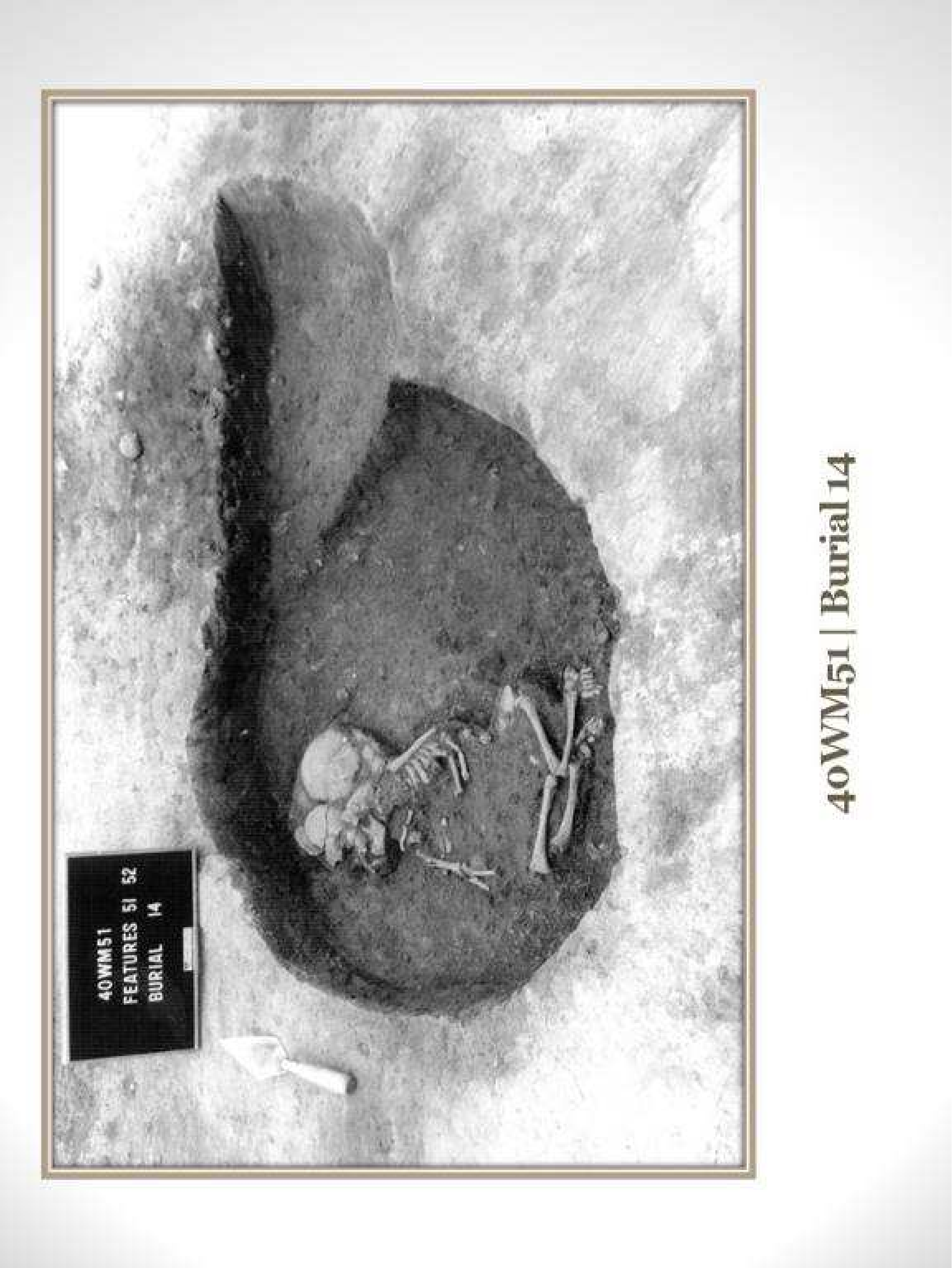


Figure A.18: *Burial 14, 40WM51*

Figure A.19: *Burial 15, 40WM51*

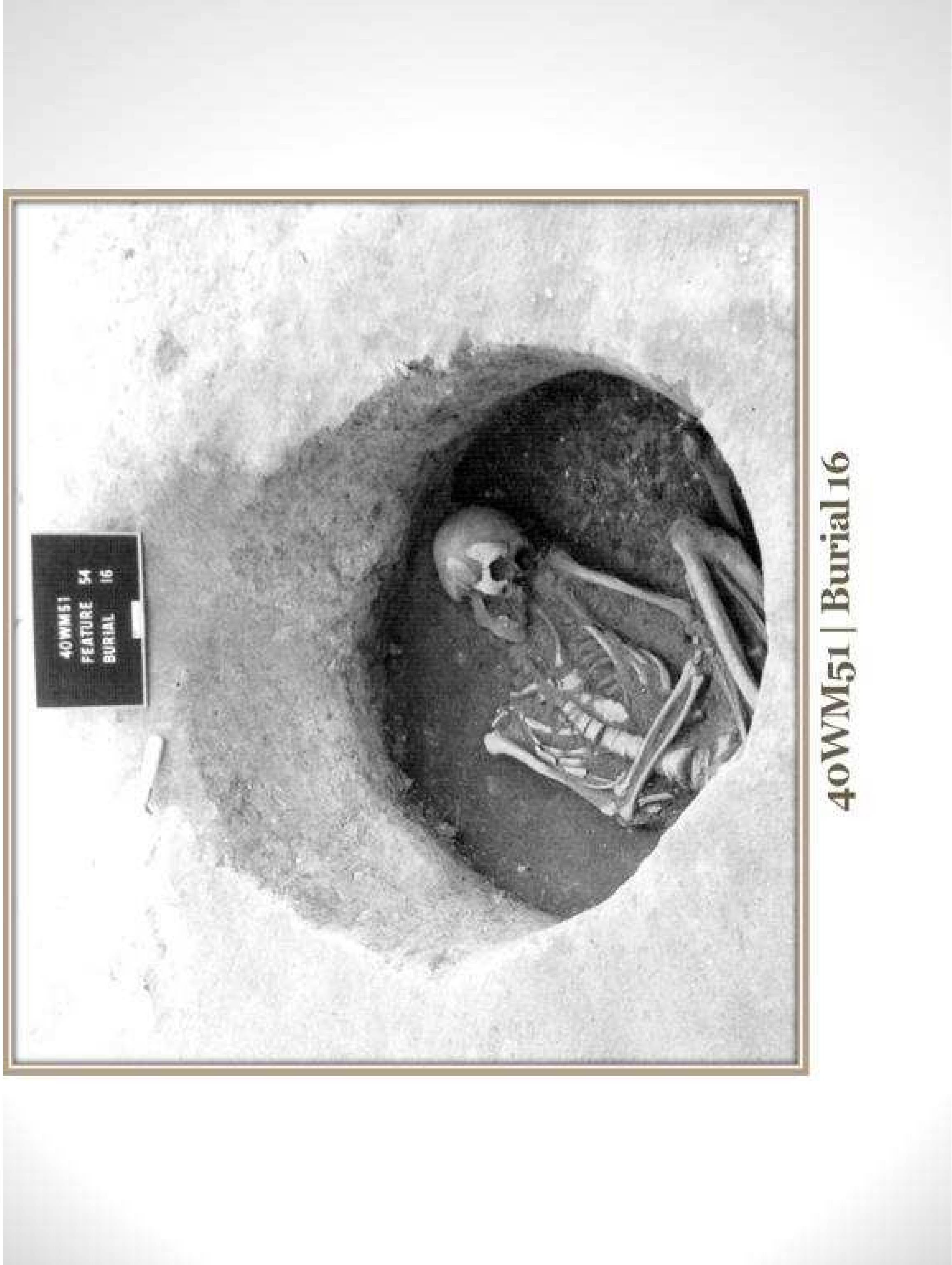


Figure A.20: *Burial 16, 40WM51*

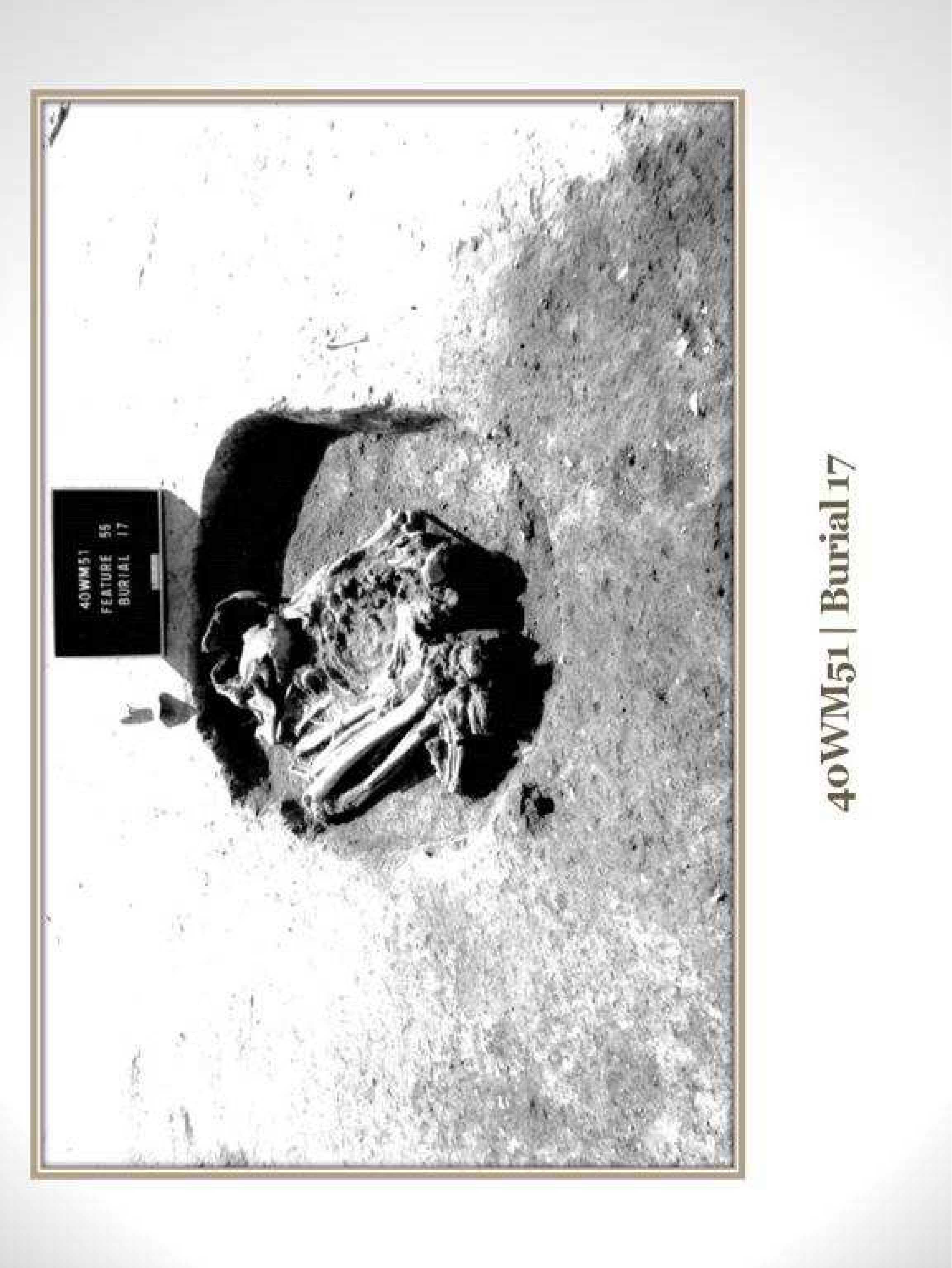


Figure A.21: *Burial 17, 40WM51*

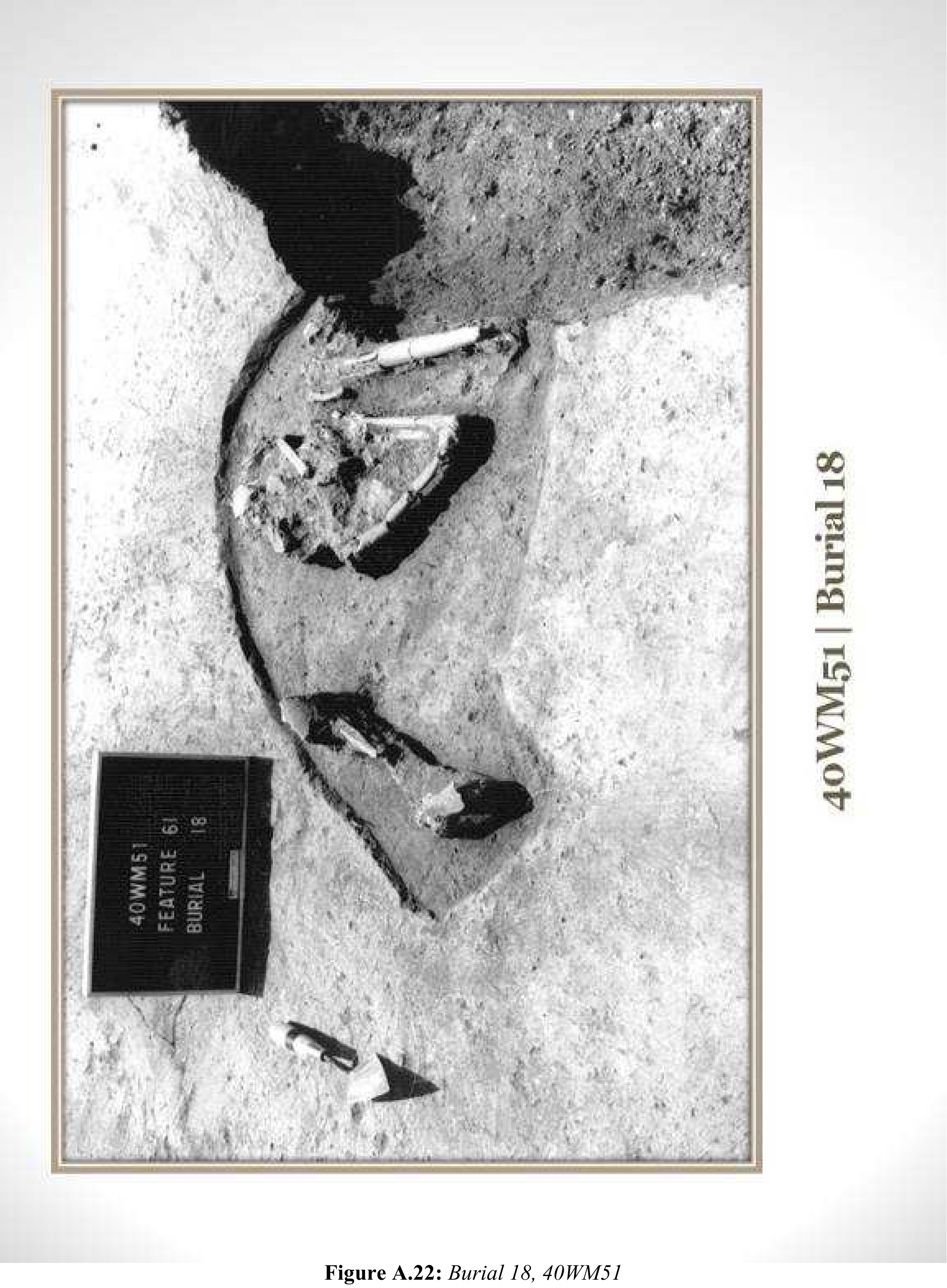


Figure A.22: *Burial 18, 40WM51*

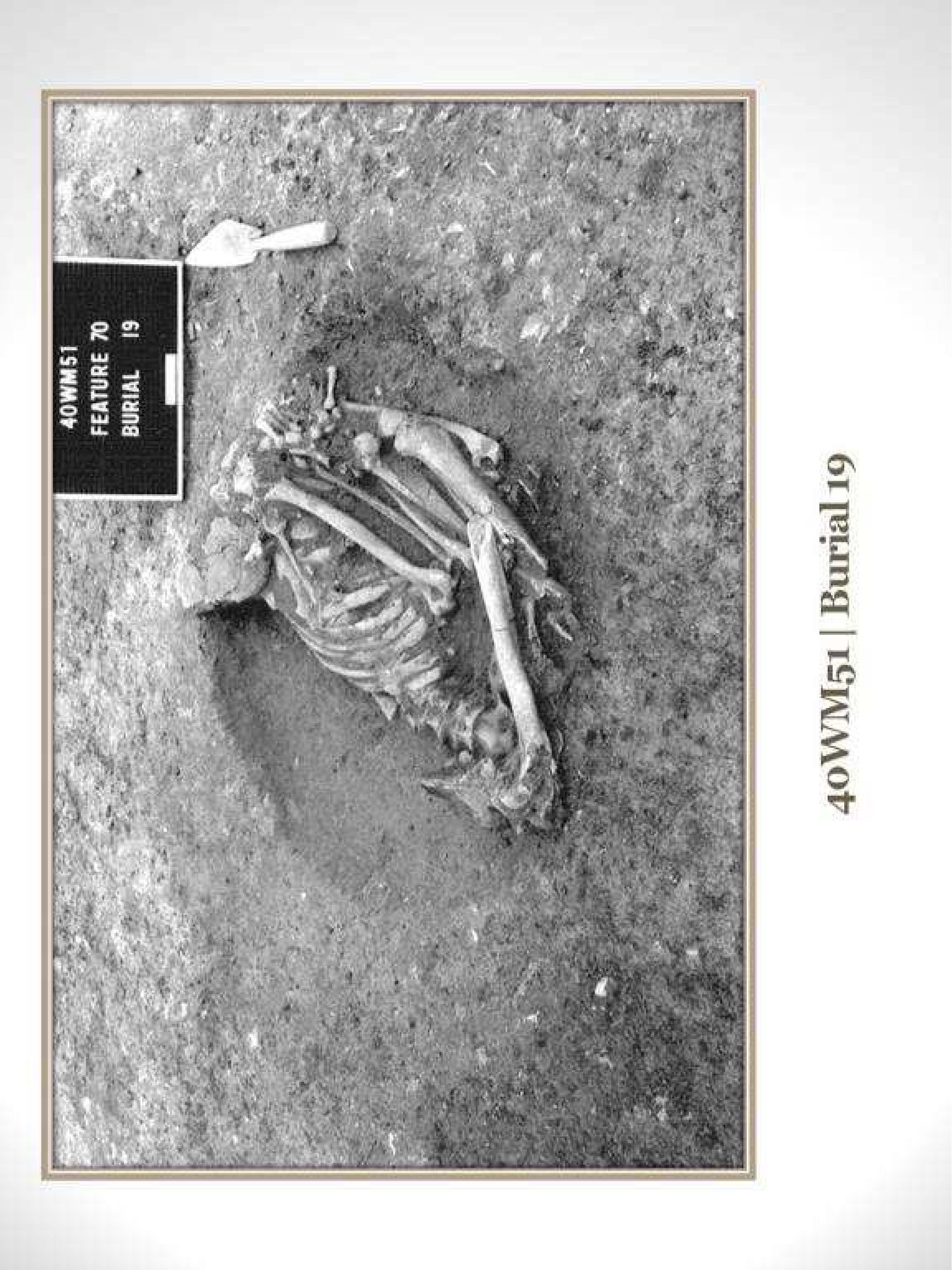


Figure A.23: *Burial 19, 40WM51*

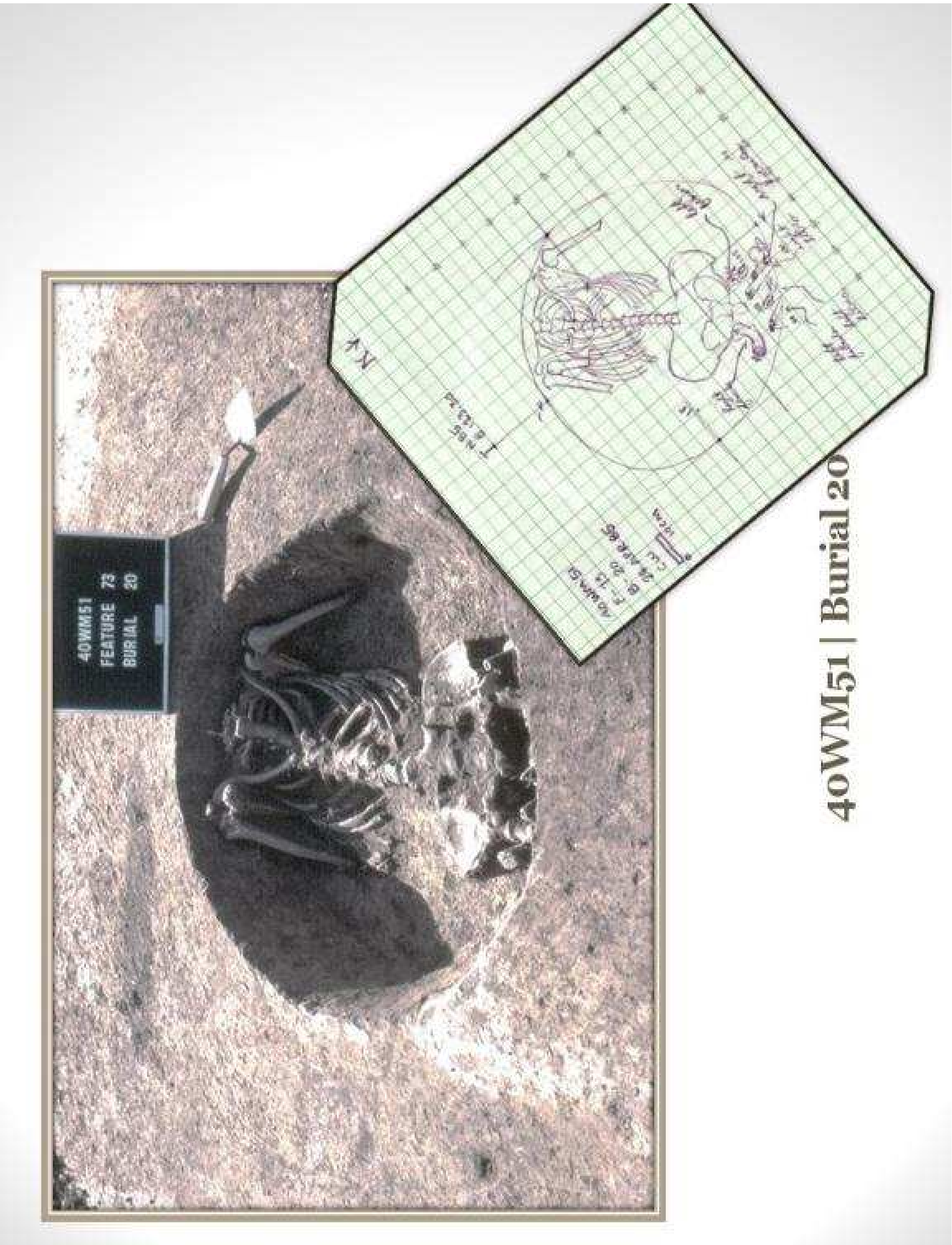


Figure A.24: *Burial 20, 40WM51*

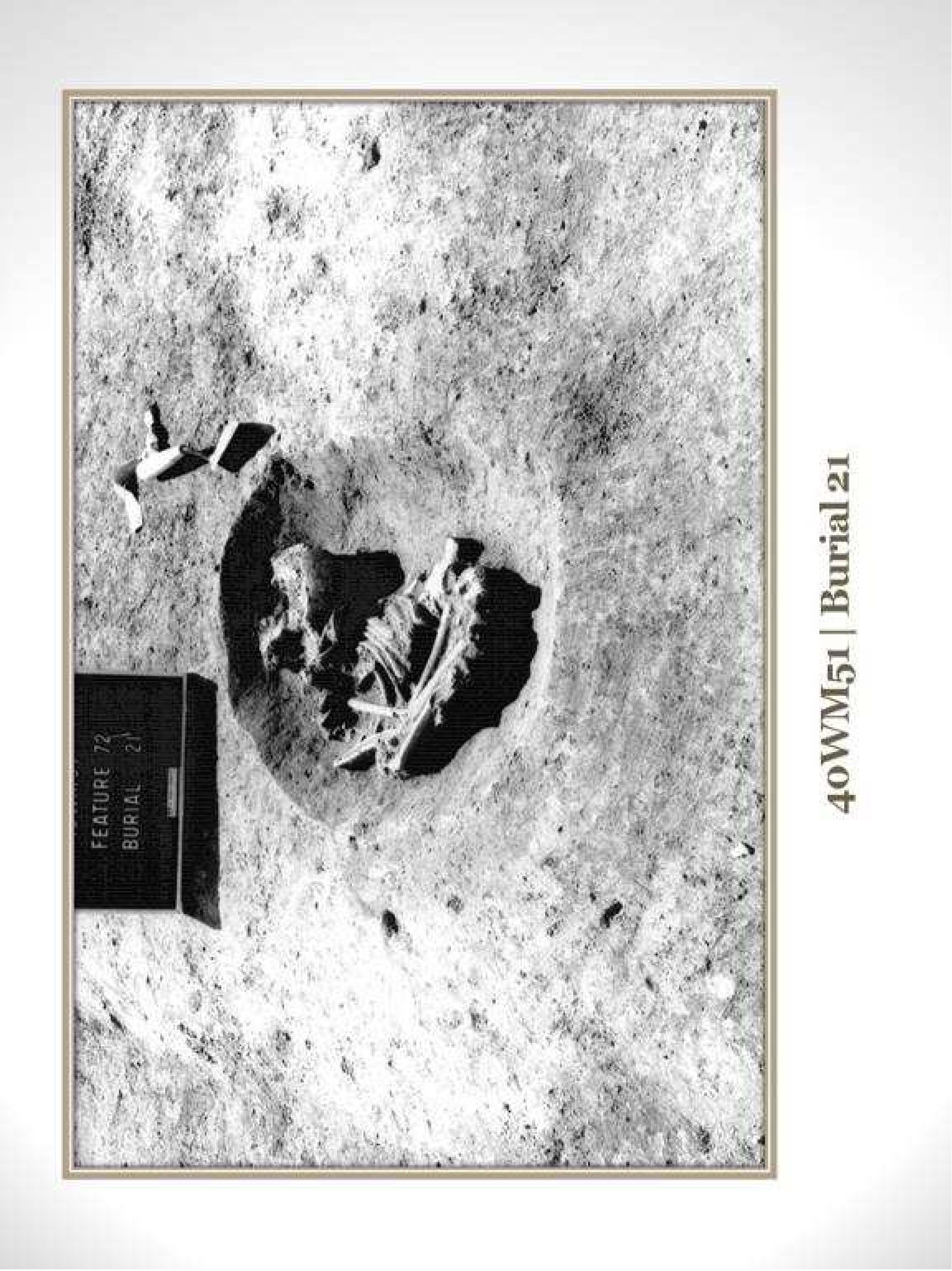
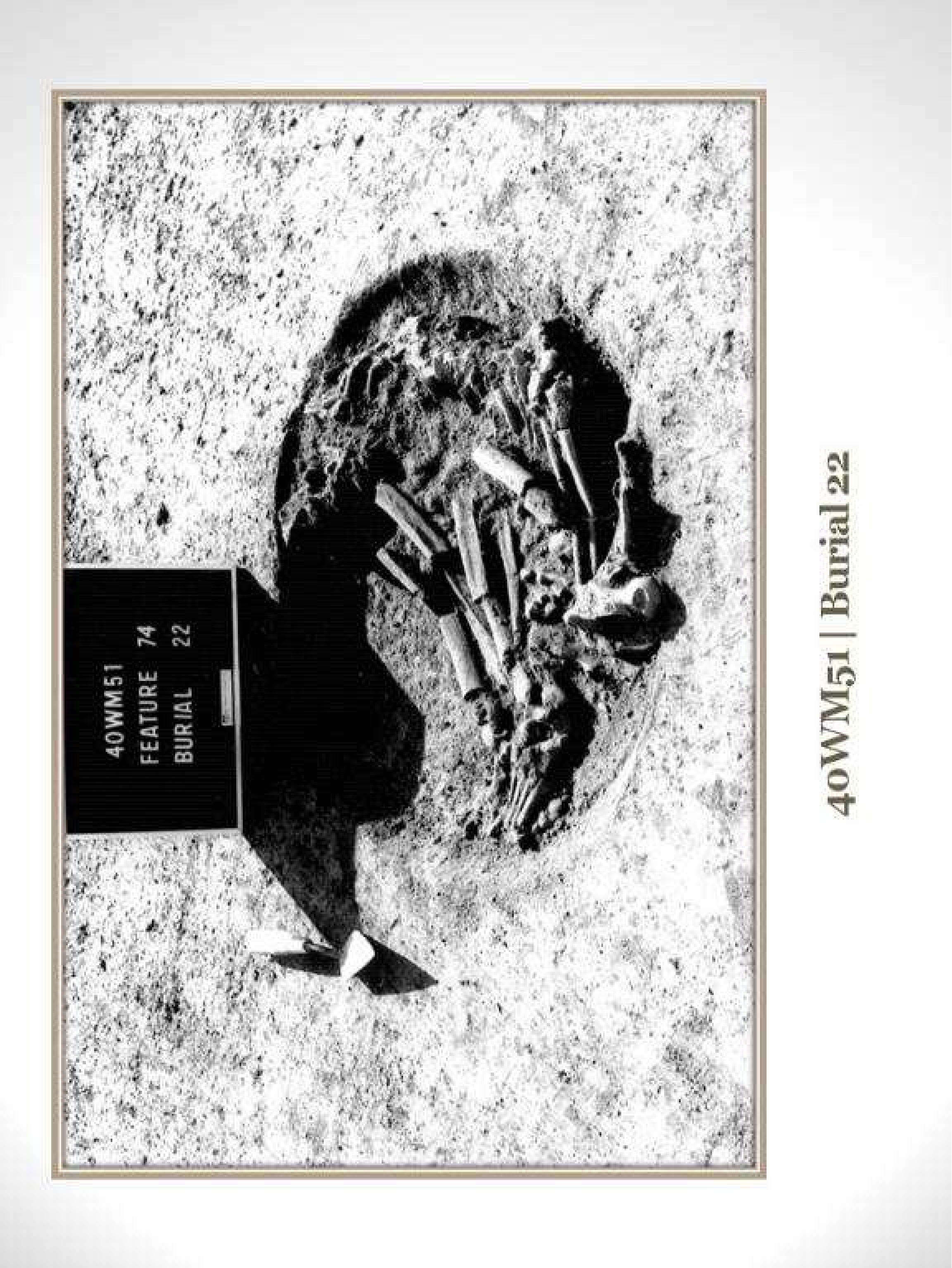


Figure A.25: *Burial 21, 40WM51*



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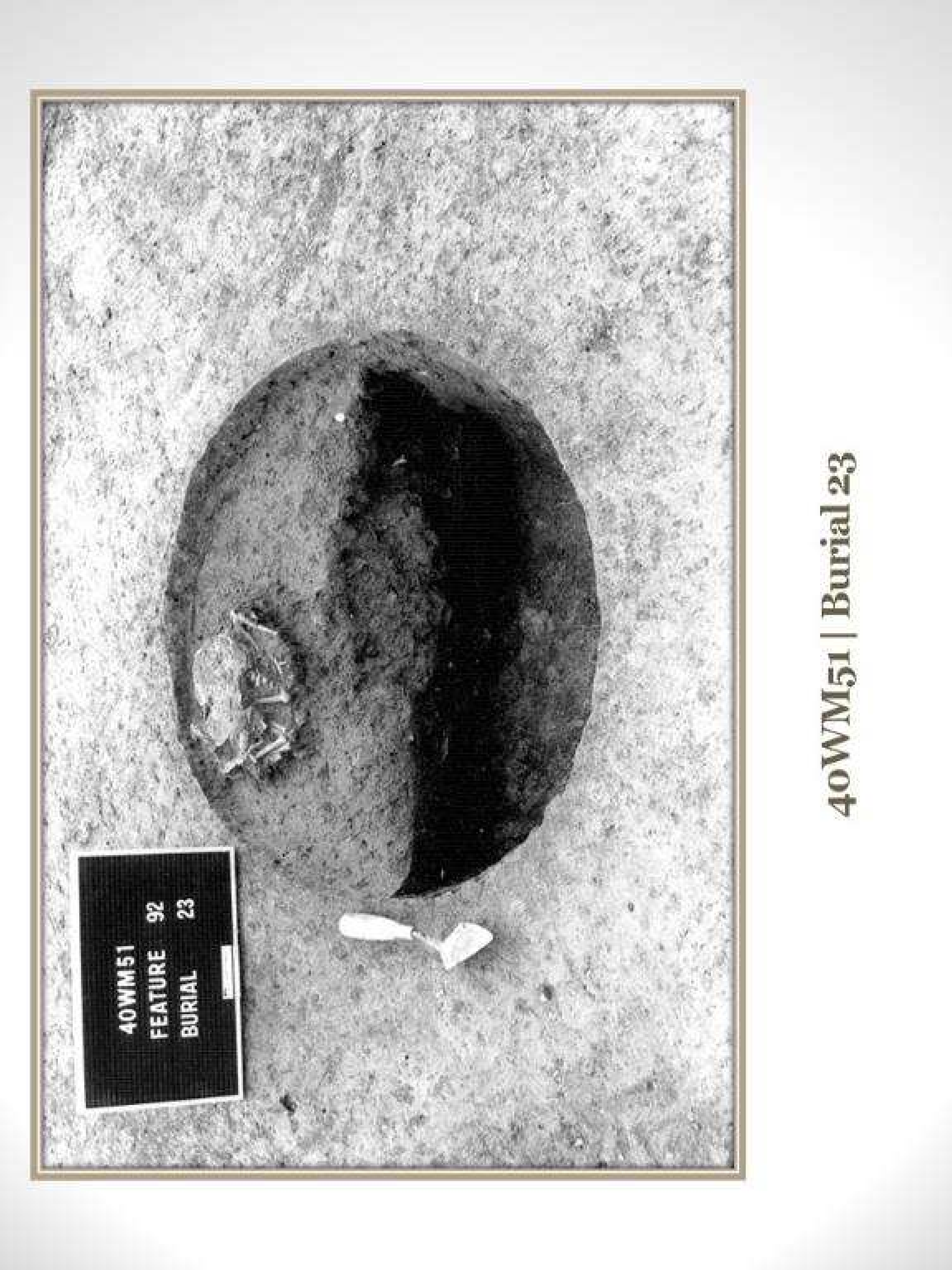


Figure A.27: *Burial 23, 40WM51*

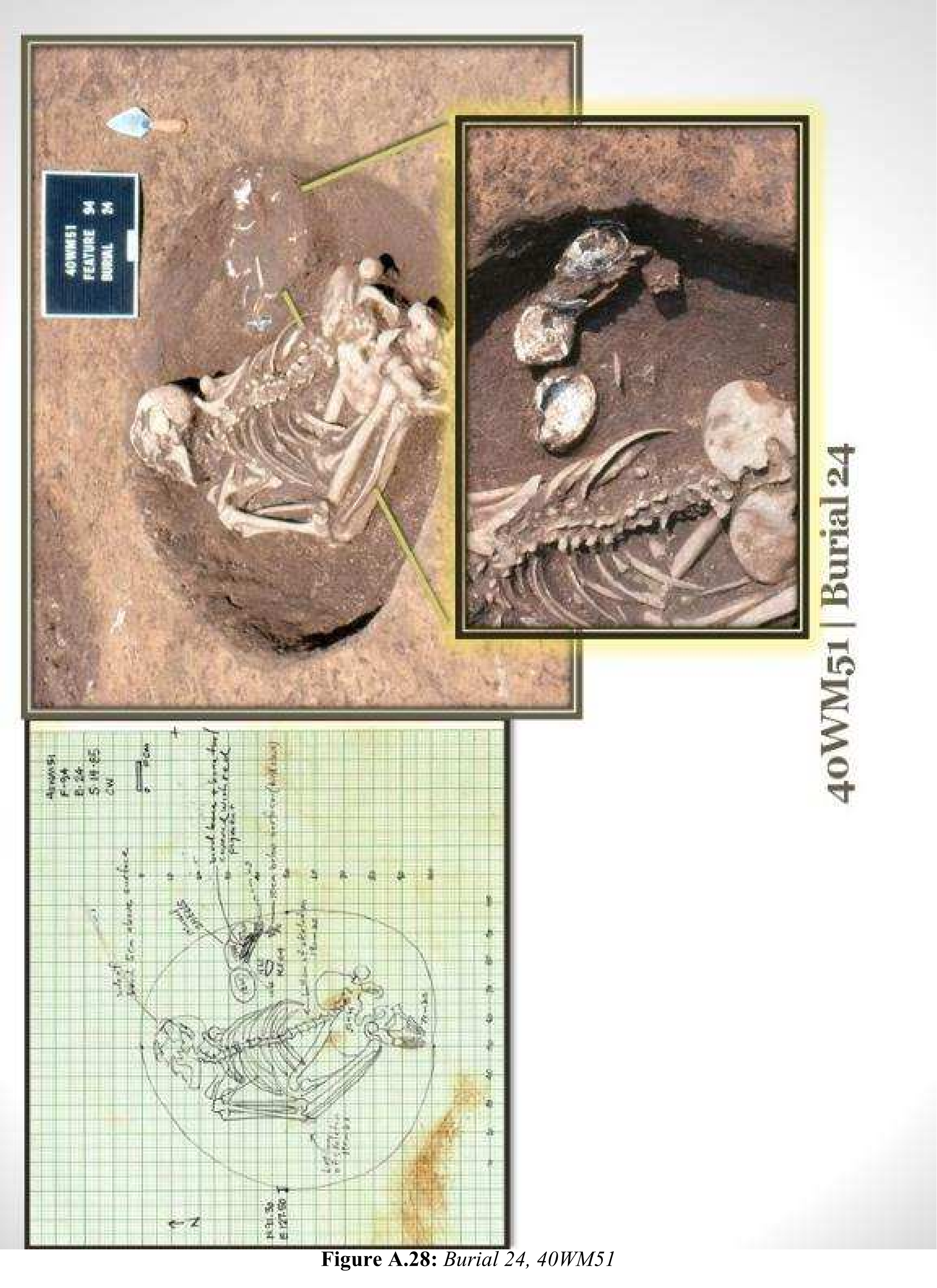


Figure A.28: *Burial 24, 40WM51*

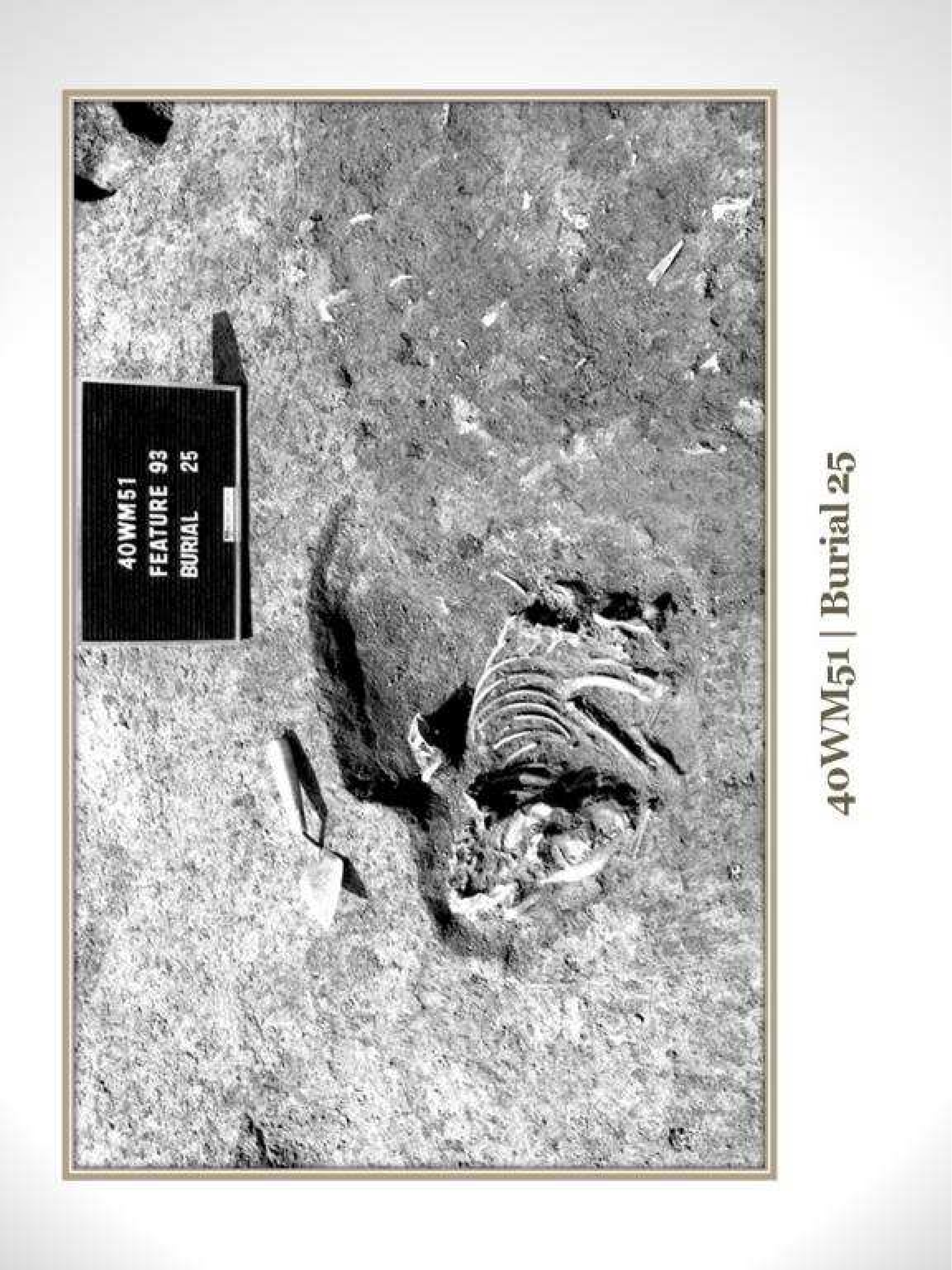


Figure A.29: *Burial 25, 40WM51*

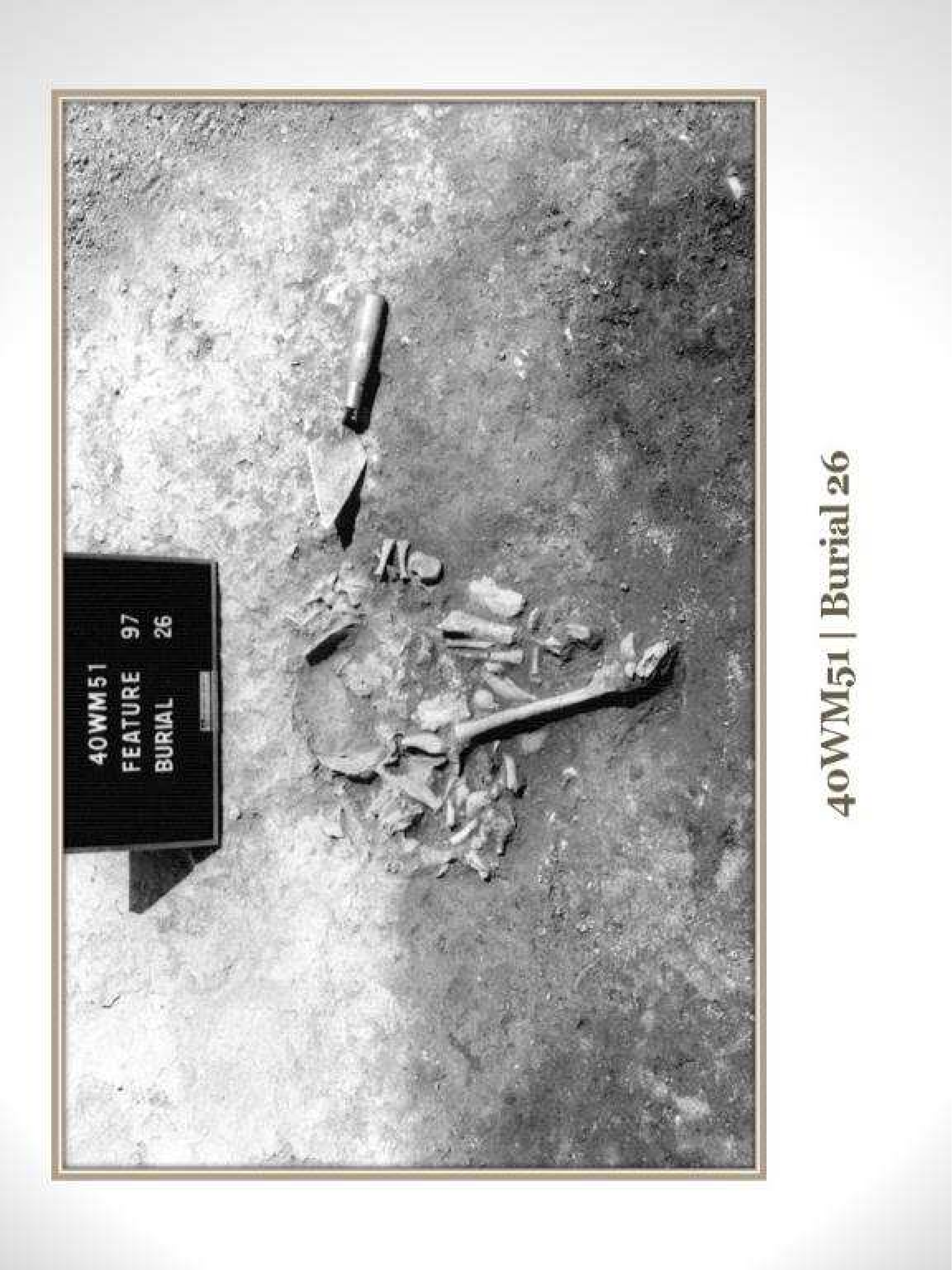


Figure A.30: *Burial 26, 40WM51*

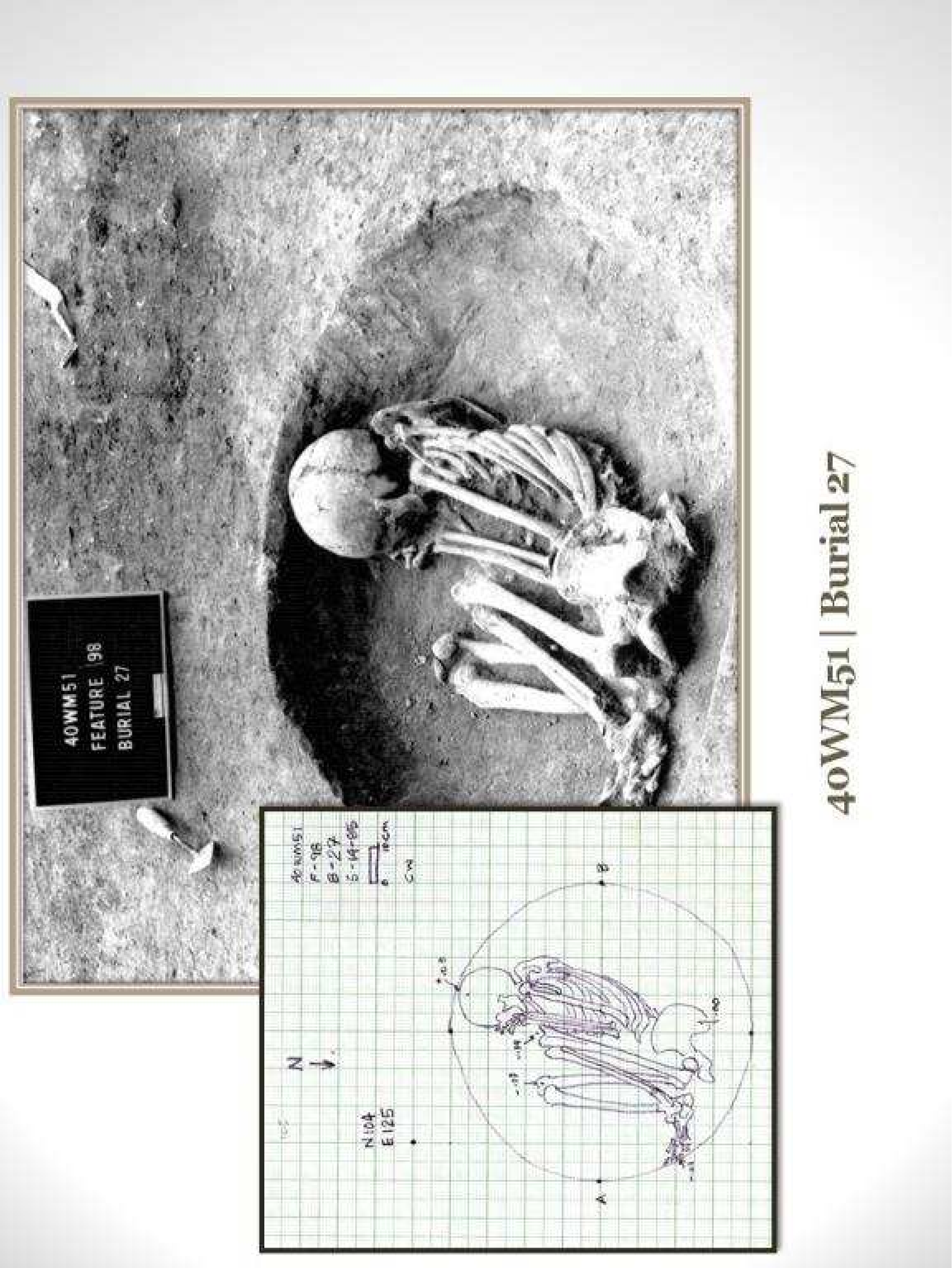


Figure A.31: *Burial 27, 40WM51*

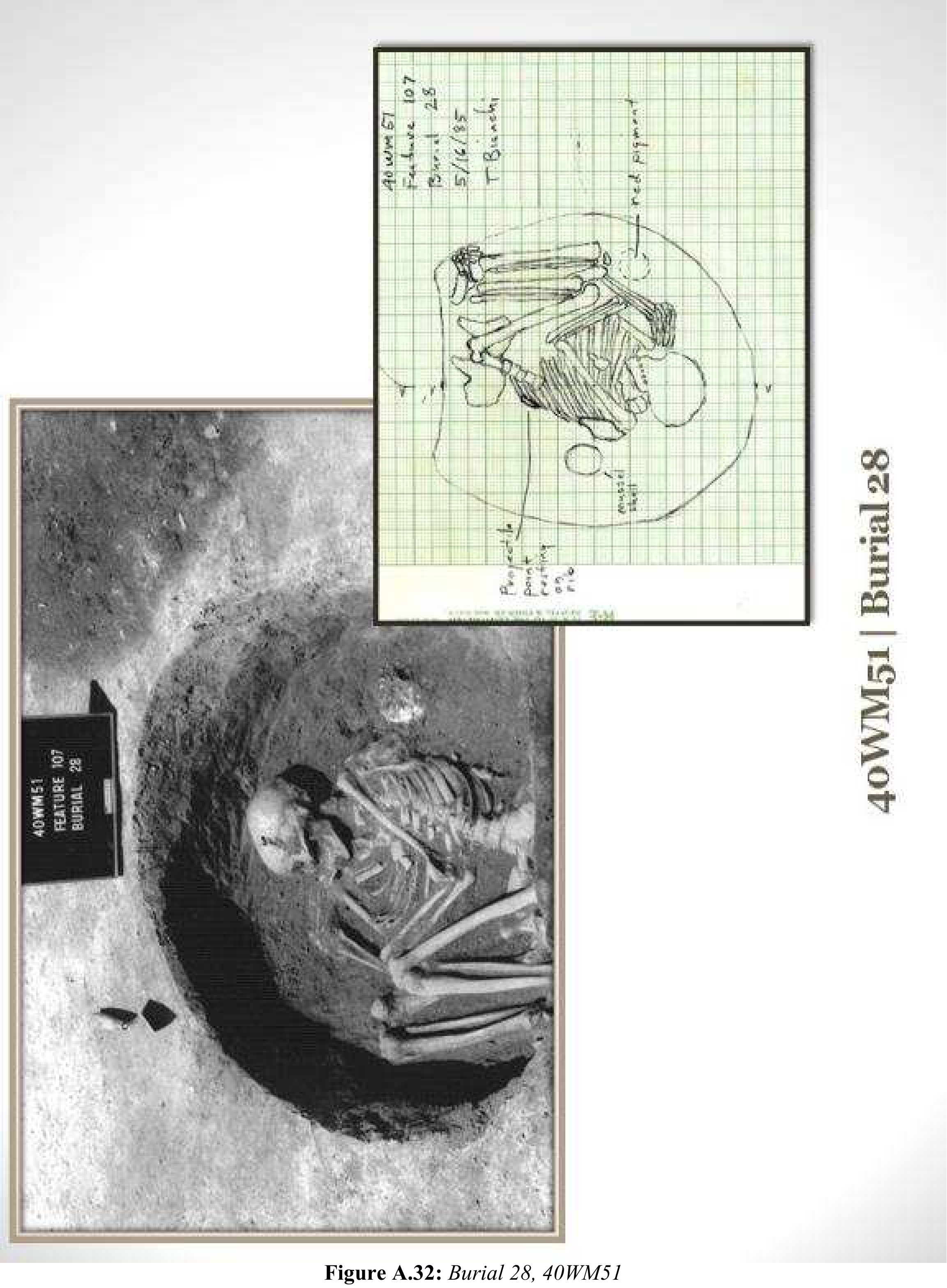


Figure A.32: *Burial 28, 40WM51*

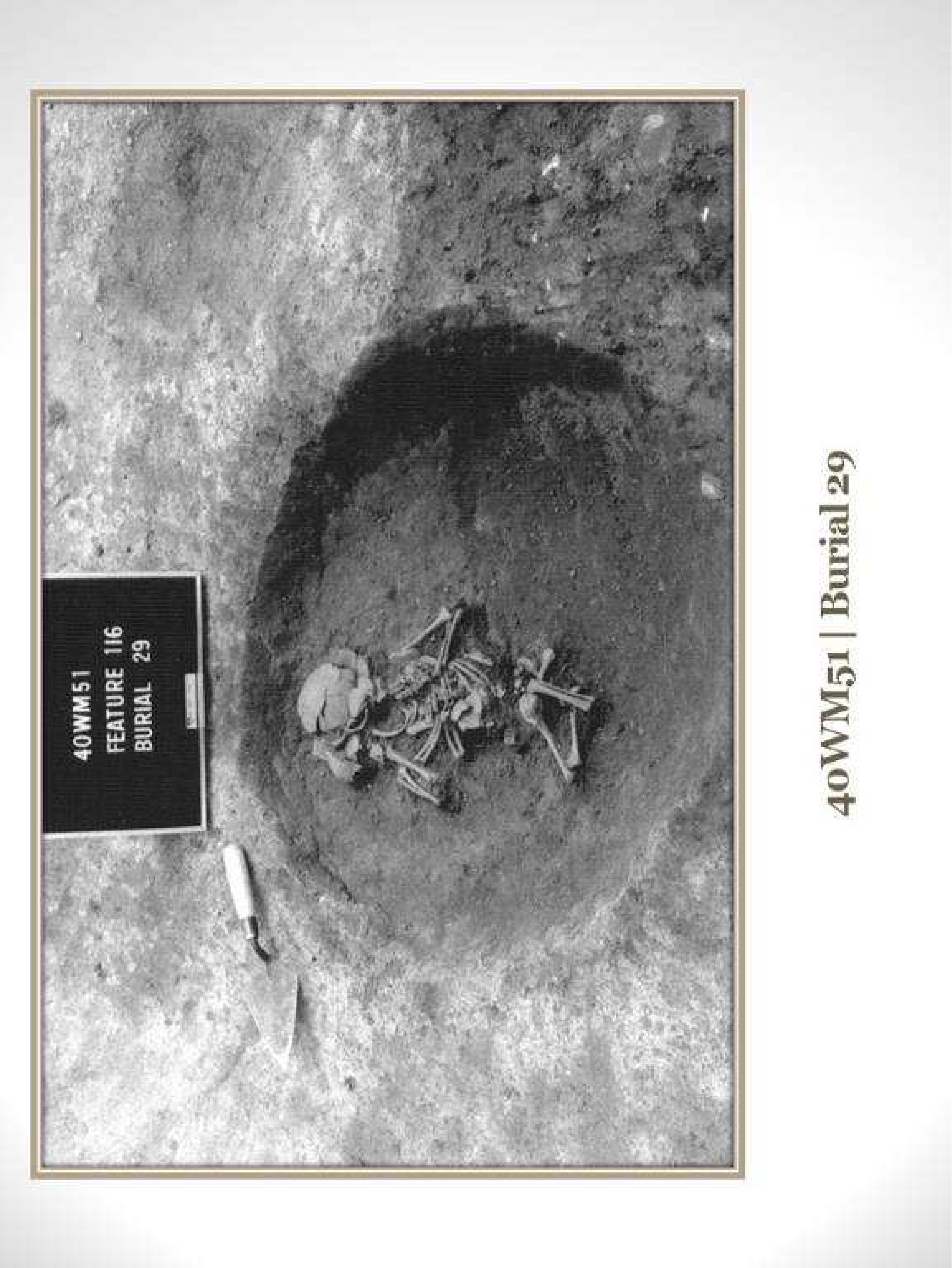


Figure A.33: *Burial 29, 40WM51*

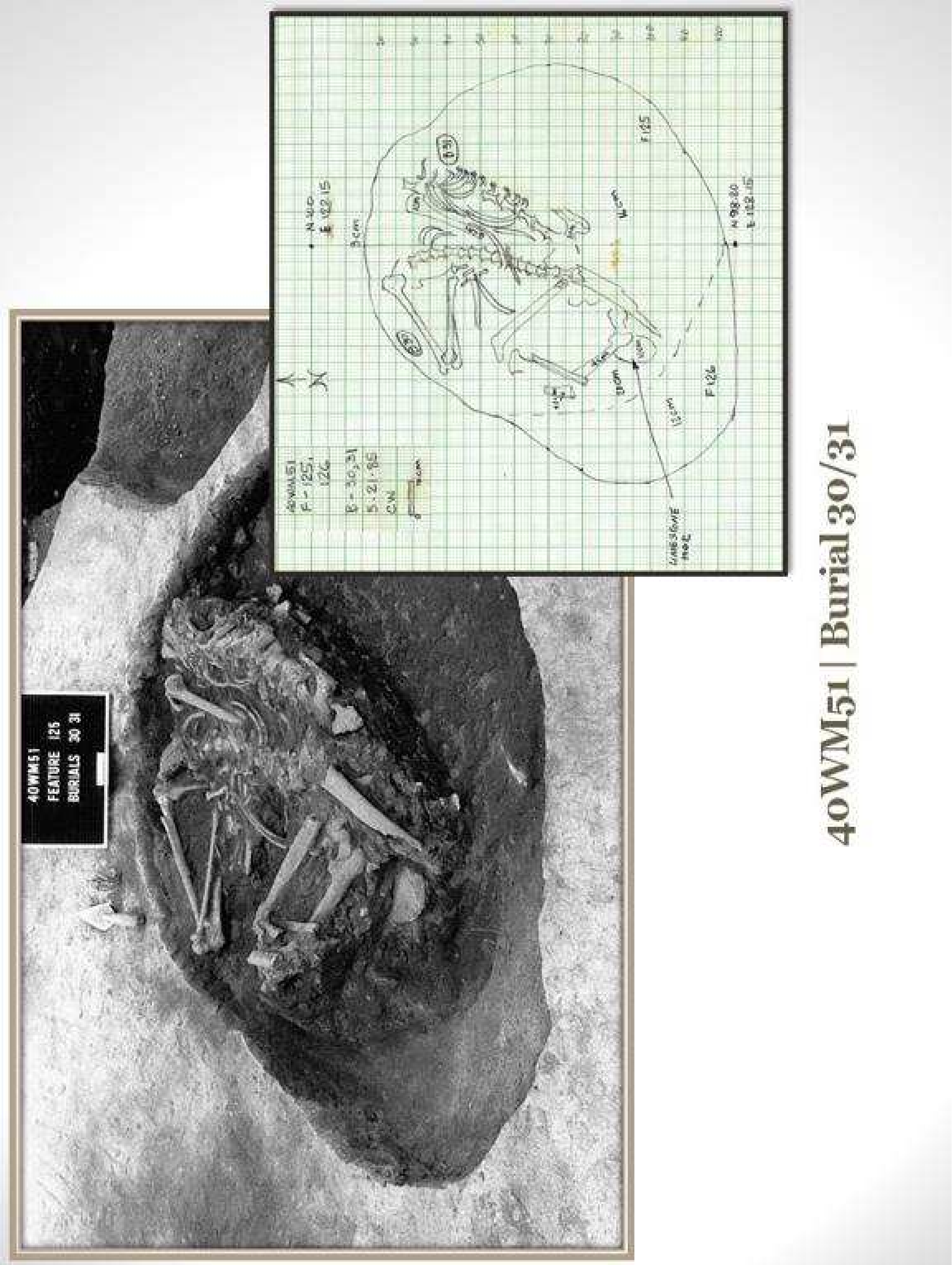


Figure A.34: *Burial 30 and Burial 31, 40WM51*

APPENDIX B: NARRATIVE DESCRIPTIONS AND PATHOLOGICAL ANALYSES OF BURIALS

A complete description of each burial and the findings therein can be found in Deter-Wolf's 2013 reanalysis of the Fernvale site (Hodge and Davis 2013). The following are the results of my pathological analysis of the bones under consideration for this study.

Burial 1a and 1b-40WM51:

Because of the fragmentary nature of the remains of Burial 1 and the age of Burial 1b, these individuals were not included in the sample for this study.

Burial 2-40WM51:

L Humerus-septal aperture; lipping on medial surface of trochlea; porosity; lateral epicondyle almost completely worn away

R Humerus- septal aperture; lipping on medial surface of Trochlea; porosity; eburnation on capitulum

R Ulna- slight eburnation of semilunar notch; indentation posterior to radial notch on coronoid process; porosity; degeneration at triceps insertion (severe)

R Radius-eburnation of radial head

L Ulna- slight lipping and porosity; indentation posterior to radial notch on coronoid process; eburnation on semilunar surface

Burial 3-40WM51:

Burial 3 was heavily impacted by plowing and topsoil removal during excavation; therefore, this individual was not included in the sample for this study.

R Ulna- degeneration at triceps insertion (mild); porosity; lipping; eburnation on semilunar surface

Burial 4-40WM51:

Burial 4 is the remains of a young adult female between 20-25 years of age. Burial 4b is an unborn infant of 24-28 weeks gestation, based on measurements of skeletal elements (Scheuer and Black 2000). Because of the age of the individual, Burial 4b was not included in this study.

R Humerus- septal aperture; eburnation on capitulum; lipping on medial surface of Trochlea; indentation of lateral epicondyle; porosity

R Ulna- eburnation on semilunar surface; porosity along medial surface of triceps insertion

L Humerus- indentation of lateral epicondyle; porosity; eburnation on capitulum

L Ulna- porosity; indentation posterior to radial notch on coronoid process

Burial 5-40WM51:

Burial 5 is a child aged approximately 18 months (± 6 months) to 2 years (± 8 months), based on patterns of dental eruption. For these reasons, this individual was not included in the sample for this study.

Burial 6-40WM51:

Burial 6 is the well-preserved but fragmentary skeleton of an adult female, aged 25 to 40. The right elbow exhibits evidence of chronic hyperflexion of the joint (Hodge and Davis 2013).

R Humerus- septal aperture; eburnation on medial epicondyle; lipping on medial surface of Trochlea; porosity

L Humerus- no septal aperture; eburnation on medial epicondyle with indentation; lipping and porosity on Trochlea; indentation of lateral epicondyle; osteophyte formation in olecranon process

L Ulna- indentation posterior to radial notch on coronoid process (severe); degeneration at triceps insertion; porosity; arthritic lipping

R Ulna- arthritic lipping; eburnation

R Radius- eburnation of radial head and tuberosity

Burial 7-40WM51:

Burial 7 is the remains of an older adult male who exhibited a significant degree of osteoarthritis and degeneration throughout the skeleton.

R Ulna- arthritic lipping; porosity; indentation posterior to radial notch on coronoid process

R Radius- eburnation of radial head

L Radius- eburnation of radial head; ankylosis

R Humerus- eburnation; lipping on medial surface of Trochlea; eburnation on capitulum; indentation of lateral epicondyle; osteophyte formation in olecranon process

L Ulna-slight porosity (on what is observable)

L Humerus- eburnation on capitulum; arthritic lipping; lipping on medial surface of Trochlea; osteophyte formation in olecranon process

Burial 8-40WM51:

Burial 8 is an extremely fragmented cremation burial. For this reason, this individual was not included in the sample for this study.

Burials 9 and 10-40WM51:

Burials 9 and 10 were the remains of a double-interment. Burial 9 is a moderately well-preserved adult probable male, based on sexually dimorphic nonmetric traits of the skull and postcranial skeleton. Age is estimated as an adult aged 35 to 50. Burial 10 is a highly fragmented middle adult female. This woman's age is estimated to be between 20 and 44 years.

Burial 9-40WM51:

L Humerus- indentation of lateral epicondyle; lipping on medial surface of Trochlea; very sharp ridge on capitulum; porosity

R Humerus- lipping on medial surface of Trochlea; lipping on medial surface of Trochlea; porosity

R Ulna- degeneration and osteophyte formation at triceps insertion

Burial 10-40WM51:

L Humerus-no septal aperture; no visible arthritis on distal end

R Humerus- septal aperture; porosity

Burial 11-40WM51:

Burial 11 is a subadult aged between 3 months and 1 year. Because of the age of this individual, Burial 11 was not included in the sample for this study.

Burial 12-40WM51:

Burial 12 is extremely fragmentary, with less than 25% of the skeleton present. Sex is estimated to be probable female. She was aged 18-24 at death, based on dental eruption (Buikstra and Ubelaker 1994) and rib phase analysis (İşcan et al. 1993).

R Humerus- septal aperture; porosity; lipping on medial surface of trochlea

L Ulna- porosity

Burial 13-40WM51:

Burial 13 is an extremely well-preserved young probable female, with sex estimates based on nonmetric cranial and postcranial traits.

L Humerus- indentation of lateral epicondyle; oddly shaped olecranon fossa; medical epicondyle very worn down; porosity

R Humerus- septal aperture; indentation of lateral epicondyle; lipping on medial surface of Trochlea; porosity

Burial 14-40WM51:

Burial 14 is a well-preserved and nearly complete skeleton of a subadult. Because of the relatively young age of this individual, Burial 14 was not included in the sample for this study.

Burial 15-40WM51:

Burial 15 contained the highly fragmented remains of an older adult male.

L Humerus- septal aperture; porosity; eburnation on capitulum; foramen in olecranon fossa

R Ulna- degeneration at triceps insertion; extension of interosseous crest to radial notch; arthritic lipping; porosity

L Ulna- osteophyte formation on coronoid process; extension of interosseous crest to radial notch; arthritic lipping

Burial 16-40WM51:

Burial 16 is a well-preserved extremely robust middle adult male with a calculated age at death between 40 and 60 years (Buikstra and Ubelaker 1994).

L Humerus- very robust; porosity; arthritic lipping

L Ulna- indentation posterior to radial notch on coronoid process; arthritic lipping; porosity; extension of interosseous crest to radial notch

L Radius- porosity; arthritic lipping

R Humerus- indentation of lateral epicondyle

Burial 17-40WM51:

Burial 17 is highly fragmented, with less than fifty percent of the skeleton present. This individual is an adult, but no more specific age estimation can be made. This individual is a probable female, based on nonmetric cranial characteristics (Buikstra and Ubelaker 1994). No metrics were possible on the ulnae due to the poor preservation of the remains.

L Humerus- septal aperture; arthritic lipping; porosity; foramen in olecranon fossa; indentation of lateral epicondyle

R Humerus- septal aperture; arthritic lipping; porosity

Burial 18-40WM51:

Burial 18 is extremely fragmented and poorly preserved. This individual is estimated to be an adult, but because of the fragmentary nature of the remains, age could not be more precisely estimated. Assessment of pathology is incomplete, given the poor preservation of the remains; therefore, this individual was not included in the sample for this study.

Burial 19-40WM51:

Burial 19 is estimated to be an adult probable male, also in highly fragmentary condition. Because of poor preservation, long bones could not be measured accurately. However, enough of the left ulna was present to observe the proximal radioulnar joint .

L Humerus- no septal aperture; eburnation; porosity; indentation of lateral epicondyle; arthritic lipping

L Ulna- indentation posterior to radial notch on coronoid process; foramen in olecranon process; osteophyte formation in middle of semilunar notch; porosity

R Humerus- arthritic lipping; porosity; indentation of lateral epicondyle; osteophyte formation on medial epicondyle

R Ulna- arthritic lipping; indentation posterior to radial notch on coronoid process; missing most of olecranon process

Burial 20-40WM51:

Burial 20 is the highly fragmented remains of an adult probable male. Due Because of to the fragmentary and incomplete nature of this burial's remains, this individual was not included in the sample for this study.

Burial 21-40WM51:

Burial 21 is the fragmentary but very complete remains of a subadult. Because of the age of this individual, this burial was not included in the sample for this study.

Burial 22-40WM51:

Burial 22 is the remains an extremely fragmented adult of indeterminate sex. Age could not be more precisely estimated.

R Humerus- indentation of lateral epicondyle; arthritic lipping; porosity

R Ulna- indentation posterior to radial notch on coronoid process; arthritic lipping; osteophyte formation in center of semilunar notch

Burial 23-40WM51:

Burial 23 is the highly fragmentary remains of a perinatal infant with an age at death estimated to be between 40 weeks gestation and three months of life. For the aforementioned reasons, this individual was not included in the sample for this study.

Burial 24-40WM51:

Burial 24 is a mostly complete adult probable male.

L Humerus- porosity; eburnation; septal aperture; indentation of lateral and medial epicondyles; arthritic lipping

R Ulna- osteophyte formation in center of semilunar notch; arthritic lipping; porosity

R Radius- slight lipping and porosity on head

R Humerus- worn down medial epicondyle with spicule formation; porosity; eburnation on capitulum

L Ulna- extension of interosseous crest to radial notch; porosity; arthritic lipping

L Radius- foramen in radial tuberosity

Burial 26-40WM51:

Burial 26 is the fragmentary though well-preserved remains of a subadult between 8 and 14 years of age. This individual was not included in the sample for this study.

Burial 27-40WM51:

Burial 27 is the poorly preserved and fragmentary remains of an adult female. There is osteoarthritic pitting and lipping of the articular surfaces at the left elbow, left and right acromial-clavicular joints, and left glenoid fossa of the scapula.

postero-lateral edges of L humerus, L radius, and L ulna burned

L Humerus- indentation of lateral epicondyle; arthritic lipping; porosity

L Ulna- osteophyte formation in center of semilunar notch; degeneration at triceps insertion; arthritic lipping; porosity; indentation posterior to radial notch on coronoid process

L Radius- slight porosity; bone is mostly charred

R Humerus- indentation of lateral epicondyle; eburnation; porosity

R Ulna- osteophyte formation in center of semilunar notch; indentation posterior to radial notch on coronoid process; extension of interosseous crest to radial notch; degeneration at triceps insertion; foramen in center of semilunar notch surface (closer to olecranon process); arthritic lipping; porosity

R Radius- no evidence of arthritis on proximal end; missing distal end

Burial 28-40WM51:

Burial 28 is a moderately preserved young female, aged 18 to 24. Estimation of sex was based on cranial and postcranial morphology.

L Ulna- unfused epiphyses; indentation posterior to radial notch on coronoid process; porosity; extension of interosseous crest to radial notch; arthritic lipping

L Humerus- indentation of lateral and medial epicondyles; porosity

R Ulna- extension of interosseous crest to radial notch

L Radius- no evidence of arthritis

Burial 29-40WM51:

Burial 29 is a well-preserved and complete skeleton of a perinatal infant, aged 38 weeks gestation to 3 months of life (± 8 weeks). Because of the age of this individual, Burial 29 was not included in the sample for this study.

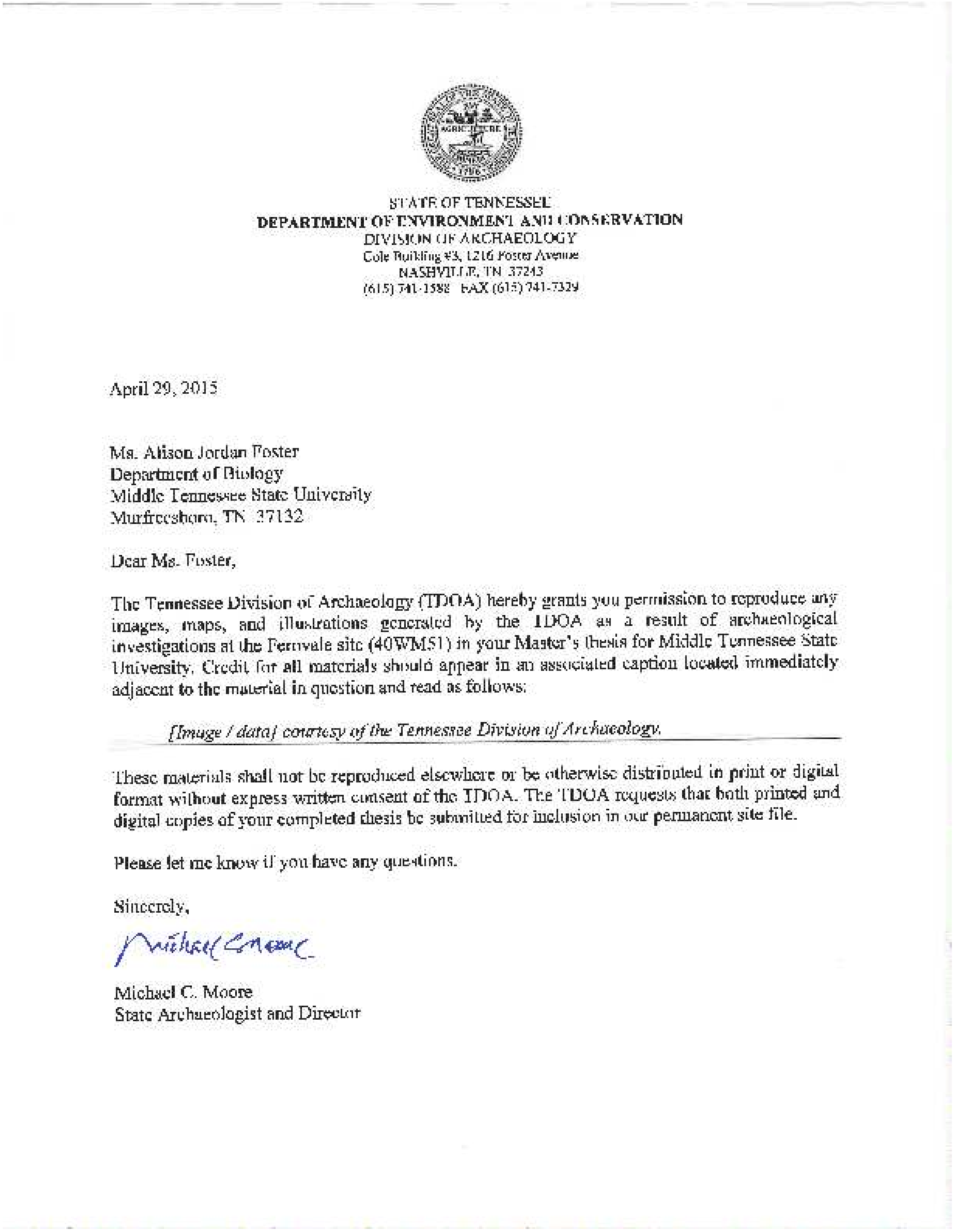
Burials 30 and 31-40WM51:

Burials 30 and 31 were interred together in Feature 125. Because of the incomplete and fragmentary nature of the remains of these individuals, Burials 30 and 31 were not included in the sample for this study.

APPENDIX C: COPYRIGHT AUTHORIZATION

Attached is a copyright authorization letter from Mr. Michael Moore, Tennessee State Archaeologist and Director of the Tennessee Division of Archaeology, Nashville. This letter pertains to the use of data, images, and illustrations published in the Fernvale site information file:

Deter-Wolf A, editor. 2013. Fernvale (40WM51): A Late Archaic occupation along the South Harpeth River in Williamson County, Tennessee. Tennessee Department of Environment and Conservation, Division of Archaeology, Research Series No. 19. 363 pp.



STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF ARCHAEOLOGY
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April 29, 2015

Ms. Alison Jordan Foster
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Dear Ms. Foster,

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Please let me know if you have any questions.

Sincerely,

Michael C. Moore
State Archaeologist and Director