

3D Fossil Visualization and Mapping of the La Brea Tar Pits, Los Angeles, California

by

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To my thesis advisor, Dr. Jennifer Swift.

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## List of Abbreviations

2D	Two-dimensional
3D	Three-dimensional
3MF	3D Manufacturing Format
COLLADA	COLLABorative Design Activity
DPI	Dots per inch
DEM	Digital elevation model
DSM	Digital surface model
GIS	Geographic Information System
GIST	Geographic Information Science and Technology
JPG	Joint Photographic Experts Group
OBJ	Wavefront OBJ
P23	Project 23
PDF	Portable Document Format
SSI	Spatial Sciences Institute
VRML	Virtual Reality Modeling Language

## Abstract

The La Brea Tar Pits and Museum in the middle of Los Angeles, California is a paleontological marvel containing numerous fossil-rich asphalt deposits. Until very recently, the museum only recorded their findings in non-spatial databases. As a continuation of work completed by a former USC Geographic Information Science and Technology student to develop spatial databases documenting artifacts for the museum, the main objective of this thesis project was to create a methodology for visualizing fossils as high-resolution 3D objects on a 3D map in their pre-excavation, *in-situ* locations. Museum scientists selected nineteen fossils from one asphalt deposit for mapping. The fossils were laser scanned by museum scientists, and the resulting 3D objects were provided for this project with accompanying locality data gathered in the manner of a traditional paleontological dig. The data required extensive processing prior to importing the 3D objects into a GIS, including image file conversion, location and orientation diagramming and steps for coordinate transformation from paleontological location measurements to real-world, geographic coordinates. The 3D objects were then imported and manually positioned in a 3D GIS map beneath the earth's surface. The resulting 3D model provides an interactive, GIS-enabled visualization of the nineteen fossils in their original locations and orientations prior to excavation. It is intended that this project support future research efforts of the museum scientists in spatial analysis and modeling of fossils and substrate (tar pits), ultimately to improve our understanding of Ice Age animals and the environments in which they lived and died. In addition, the results of this project serve as an example application of 3D GIS capabilities that can support forensic archaeology, an important tool in intelligence and criminal investigations. Lastly, it is anticipated that the georeferenced 3D objects, as well as this 3D fossil visualization, may become part of an interactive museum exhibit in the future.

## Chapter 1 Introduction

The La Brea Tar Pits and Museum is home to over three million Ice Age fossils. Located in Los Angeles, California, it is a unique onsite museum surrounded by active, urban excavation sites. The museum displays fossil specimens extracted from 10,000 to 40,000-year-old asphalt seeps or “tar pits” that include a variety of plants and animals from saber-toothed cats to mammoths (La Brea Tar Pits and Museum 2017a). Until recently, the location of the tar pits had not been recorded beyond a single hand-drawn, paper map maintained since 1913. In 2015, University of Southern California Geographic Information Science and Technology (GIST) graduate student, Kacey Pham, digitally georeferenced the paper map of the tar pits and created fossil geodatabases as part of her Master’s thesis (Pham 2015, xiv). As a continuation of Pham’s research, the main objective of this thesis project was to develop a methodology to visualize fossils as digital high-resolution 3D objects displayed on a 3D map using Geographic Information System (GIS) technology in their pre-excitation, *in-situ* locations beneath the earth’s surface. It is anticipated that a spatial visualization methodology using GIS will support the museum scientists’ research regarding the interaction between Ice Age animals, humans and environments (Lindsey, pers. comm.).

This chapter describes this thesis project’s scope, motivation and methodology for developing a 3D fossil visualization in a GIS environment for the La Brea Tar Pits and Museum. Section 1.1 provides an overview of the project and section 1.2 discusses the motivation for creating the 3D visualization. Section 1.3 outlines the methodology for developing the 3D model, while section 1.4 summarizes the subsequent chapters in this manuscript.

## **1.1. Project Overview**

This thesis study consisted of the development of a methodology for mapping high-resolution 3D objects of fossils excavated from the La Brea Tar Pits (La Brea Tar Pits and Museum 2017a). Museum scientists selected nineteen fossils for this project from the asphalt deposit named Box 13a in the excavation site known as Project 23 (Figure 1). The fossils were manually laser scanned and shared with the author, including the resulting 3D digital objects and textures as well as supporting documentation regarding the location of the fossils at the time of extraction (La Brea Tar Pits and Museum 2017b). A texture is herein defined as “an image used to define the characteristics of a surface” (Graham 2003). With additional data from Pham’s Master’s thesis, the geodatabase created for this project includes GIS feature classes representing the fossils, their location coordinates, Box 13a and its grids. In its current stage of development, the geodatabase can be utilized in Esri ArcGIS Pro version 2.1 (Esri ArcGIS Pro 2.1 2018) and in other GIS software which includes the capability of reading or importing Esri’s native geodatabase format (Esri ArcGIS Desktop 2018).



Figure 1. La Brea Tarpits Location Map (Pham 2015, 1)

## 1.2. Motivation

The main motivation for the development of the 3D fossil visualization in a GIS environment is to support the research conducted by the La Brea Tar Pits and Museum scientists. Mapping the fossils in 3D will allow the scientists to perform spatial analysis that may inform how Ice Age animals, humans and environments interacted and impacted each other (Lindsey, pers. comm., Howard and Farrell, pers. comm.). Spatial patterns found in the fossil distribution within an asphalt deposit may also provide insight regarding the fluid dynamics of the substrate or even the cause of death of a given animal.

The secondary motivation for this project is to provide museum scientists with a 3D fossil visualization that may eventually be exported to another software to be viewed interactively in the museum. An interactive display would include a touchscreen with the 3D model that can be zoomed and rotated. Ideally, viewers would be able to tap on a fossil on the screen and see its attribute information such as species and body part (Lindsey, pers. comm.). This style of interactive viewing would help guests better visualize where and in what orientation the fossils are found prior to excavation.

### **1.3. Methodological Overview**

The Esri geodatabase containing the 3D model was created using Esri ArcGIS Pro version 2.1 (Esri ArcGIS Pro 2.1 2018). ArcGIS Pro was chosen for this project because of its widespread use in industry and its advanced 3D visualization capabilities (G2 Crowd 2018). Extensive data preparation outside of ArcGIS Pro was performed using Microsoft 3D Builder, Microsoft PowerPoint 2016, Microsoft Excel 2016 and Adobe Reader XI (Microsoft 3D Builder 2013, Microsoft PowerPoint 2016 2016, Microsoft Excel 2016 2016, Adobe Reader XI 2018).

Prior to constructing the 3D model in ArcGIS Pro, the author created hand-drawn diagrams to better understand the placement and orientation of the fossils, provided in Appendix B. The 3D objects representing the fossils were then incorporated into similar diagrams created in PowerPoint to provide a digital 3D visual. This intermediate visual allowed museum scientists to validate the spatial location and orientation of each 3D object before proceeding with import into a GIS (Howard and Farrell, pers. comm.). With this back-to-basics approach, the author was able to confidently move forward with transforming the location information of the fossils provided by the museum scientists into geographically referenced coordinates using a combination of Excel and ArcGIS Pro. Next using ArcGIS Pro, empty 3D feature classes

representing Box13a and the grids within it were created and placed in a 3D map. The fossil 3D objects were then imported for manual placement (location and orientation) in their pre-excavation, *in-situ* locations beneath the ground surface.

#### **1.4. Thesis Structure**

The remainder of this thesis manuscript is divided into four chapters. Chapter 2, Background and Related Work, discusses background information regarding the La Brea Tar Pits and Museum history, current excavation procedures and previous GIS work completed for Pham's Master's thesis (Pham 2015). Chapter 2 also describes existing 3D modeling and visualization techniques used in archaeology as well as excavation techniques used in forensic archaeology. Chapter 3, Methodology, outlines the steps to develop the methodology for the 3D fossil visualization including data preparation, coordinate transformation, and 3D modeling. Chapter 4, Results, presents the experiences testing alternative methodologies and software to build the 3D visualization as part of this thesis work as well as the outcomes of the developed methodology. Chapter 5, Discussion and Conclusion, summarizes the successes and challenges of the project and proposes future work regarding further development of the 3D model.

## **Chapter 2 Background and Related Work**

This chapter provides an overview of the background of the La Brea Tar Pits and Museum and describes the related work reviewed prior to developing a methodology for constructing the 3D fossil visualization. Section 2.1 gives an overview of the history of the La Brea Tar Pits and Museum, its fossil collection protocol and Pham's previous Master's thesis work. Section 2.2 describes the related 3D modeling and visualization case studies in GIS that were reviewed to inform this project's methodology. Section 2.3 describes excavation practices in the field of forensic archaeology, which employs investigative field and laboratory practices analogous to techniques at the La Brea Tar Pits and Museum.

### **2.1. La Brea Tar Pits Background**

This section provides background information on the La Brea Tar Pits and Museum, current fossil collection procedures and previous GIS Master's thesis work completed by Kacey Pham (2015). Section 2.1.1 describes the history of the La Brea Tar Pits including Project 23, of which Box 13a is a part. Section 2.1.2 reviews current tar pit excavation methods practiced by museum scientists. Section 2.1.3 summarizes information from Kacey Pham's Master's thesis relevant to this study (Pham 2015).

#### *2.1.1. La Brea Tar Pits Background*

The first major excavations at the La Brea Tar Pits and Museum occurred from 1913 to 1915 and resulted in more than 750,000 Ice Age plant and animal specimens of various sizes, including saber-toothed cats, mammoths and dire wolves. Since initial excavations, the La Brea Tar Pits and Museum collection has grown extensively as museum scientists continue to excavate fossils unearthed as recently as 2006 (La Brea Tar Pits and Museum 2017). Known

collectively as Project 23, the 23 fossil-rich asphalt deposits unearthed in 2006 were discovered during the construction of an underground parking lot for the nearby Los Angeles County Museum of Art. The deposits were boxed up in wooden crates, labeled and relocated to the La Brea Tar Pits and Museum grounds to be processed by the museum scientists (Figure 2). Latitude, longitude and depth measurements were recorded prior to deposit extraction (Pham 2015, 11). This thesis project utilized data from Project 23's deposit Box 13a which is currently undergoing excavation (Howard and Farrell, pers. comm.).

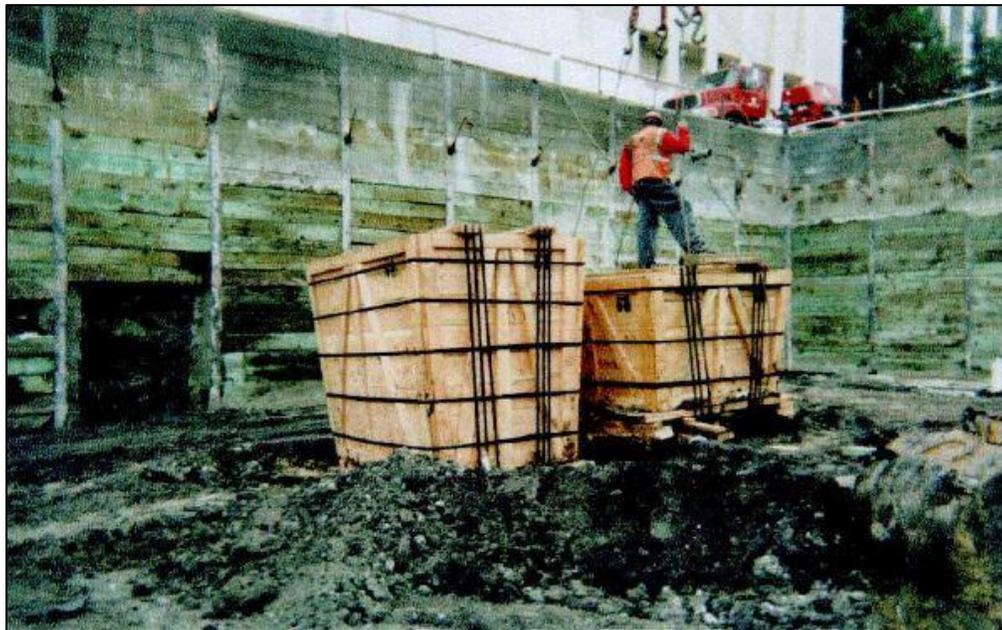


Figure 2. Project 23 fossil deposits being crated and lifted from the excavation site (Turner 2006, 9)

### *2.1.2. Fossil Collection Procedures*

From 1913 to the present, fossil locations at the La Brea Tar Pits and Museum have been recorded manually with pencil and paper. A meter-by-meter grid pattern made of string is spread across the asphalt deposit and multiple x, y and z locations are recorded for each fossil using a ruler (Figure 3). This style of data collection may lead to small (cm) errors due to the fact that

locations are measured and recorded by hand. The string may also be placed improperly or loosen over time, further impacting data collection accuracy (Pham 2015, 14-15).



Figure 3. String laid across grid in early excavation of a single pit at the La Brea Tar Pits (Pham 2015, 14, Shaw 1982, 71)

### *2.1.3. Kacey Pham's Thesis*

As mentioned in Chapter 1, the inspiration for this thesis was derived from previous work completed by former GIST program student Kacey Pham in 2015. In her thesis entitled “GIS Data Curation and Web Map Application for La Brea Tar Pits Fossil Occurrences in Los Angeles, California,” Pham developed a fossil excavation spatial database by digitizing a manually maintained historical paper map into a GIS-friendly spatial dataset, also joining data from the museum’s existing, non-spatial KE EMu database to this to create a feature-rich geodatabase. She then published the newly created geodatabase to a unique web GIS application that she customized for the museum as a proof of concept for future GIS work, such as data sharing in real-time (Pham 2015, xiv-2). As part of the future recommendations, Pham suggested

the development of a 3D fossil visualization so that museum visitors could better comprehend the vast collection of fossils contained in the tar pits (Pham 2015, 67). Pham's project and recommendations laid the groundwork for this thesis project.

## **2.2. Review of Existing 3D Modeling and Visualization Techniques in Archaeology**

Prior to developing the methodology for this study, a thorough literature review of existing 3D modeling and visualization techniques related to archaeology revealed GIS to be an up-and-coming software for documenting and representing excavation sites in 3D. In the context of this thesis, 3D modeling refers to the construction of a 3D visualization and, thus, the terms "3D model" and "3D visualization" are used interchangeably throughout this document. At the Pompeii Archaeological area in Italy, researchers from the University of Bologna created a pipeline for the Superintendence of Pompeii to follow when generating and managing 3D models of artifacts prior to import into a 3D GIS environment (Apollonio, Gaiani, and Benedetti 2012, 1271). As a case study, they used a combination of close-range photogrammetry and laser scanning to 3D model 13 artifacts from the area that had been previously excavated (discovered) but remained *in-situ*. They then performed quality control testing on their results as well as post-collection data processing in OpenSceneGraph. Their efforts resulted in a methodology for the generation of 3D base elements required to develop a large archaeological site like Pompeii in a 3D GIS (Apollonio, Gaiani, and Benedetti 2012, 1271-1275). Their work is similar to this thesis project through the use of laser scanning to digitally capture and visualize (build a 3D model of) their artifacts but differs in that they did not attempt to bring their 3D models into a GIS environment.

In the same region but separate from the University of Bologna, researchers from Lund University working under the Swedish Pompeii Project also performed a case study with the goal of designing a digital 3D model of the North House of Caecilius Iucundus in Pompeii (Campanaro, Landeschi, Dell'Unto, and Touati 2016, 321). The artifacts retrieved from this archeological site were laser scanned, then the resulting 3D model was processed using AutoDesk 3D Studio Max and split into architectural sub-elements. For example, sub-elements consisted of planes or façades, which represent structure walls. The researchers then created horizontal clones, or base maps, of the vertical facades and imported them into Esri ArcMap to generate 2D thematic maps, analyzing factors such as decay and tilting. Using reference planes for each façade, the researchers were also able to successfully import vertical façades into Esri ArcScene while projecting the newly created thematic maps onto the maps vertically (in 3D). Ultimately, they successfully created a digital 3D visualization of the North House of Caecilius Iucundus in ArcScene (Figure 4) (Campanaro, Landeschi, Dell'Unto, and Touati 2016, 323-331). This work is similar to this thesis project because the researchers sought to create a 3D model of a portion of an excavation site and they used laser scanning to record the 3D artifacts excavated from the site. However, their work differs in that they focused on 3D modeling and visualizing larger archaeological, man-made building or construction elements (i.e., structures, walls) up to 3 m tall, while this project focuses on smaller-scale natural, non-human fossils ranging from 10-20 cm in length.

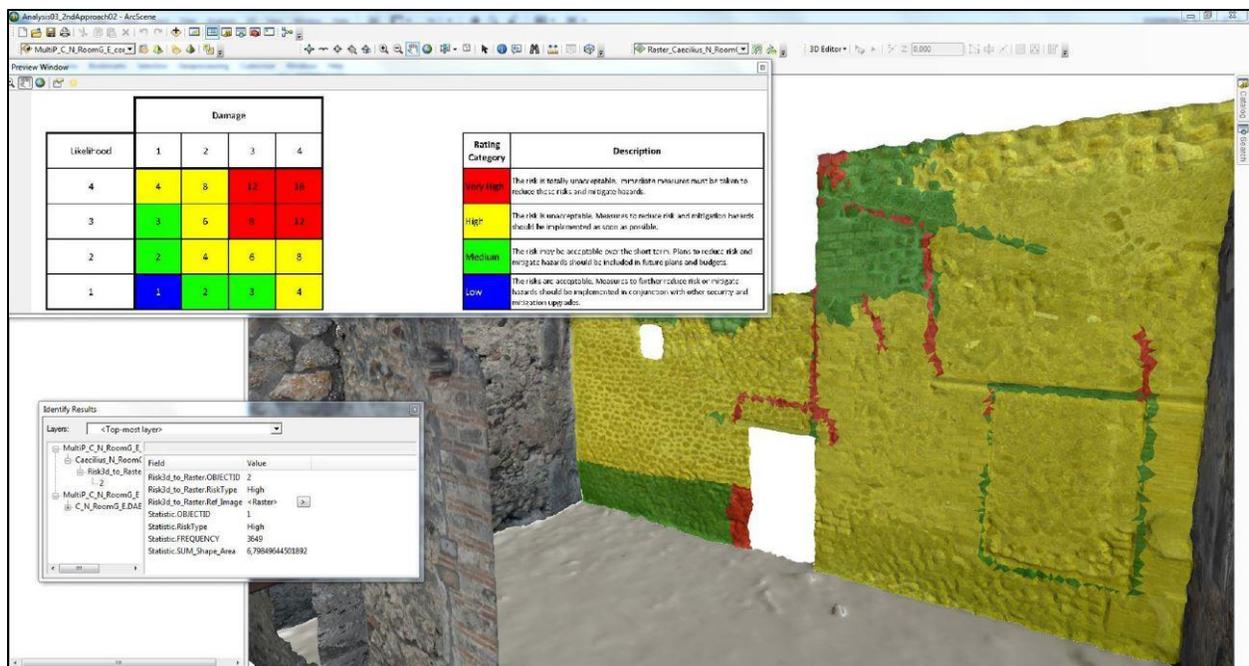


Figure 4. North House of Caecilius Iucundus 3D modeled in Esri ArcScene for analysis (Campanaro, Landeschi, Dell’Unto, and Touati 2016, 330)

In another large-scale archaeological effort, researchers at Ghent University, Belgium applied image-based 3D modeling in the recording of the Boudelo-2 excavation site as a case study in recording an entire excavation site in 3D (De Reu, De Smedt, Herremans, Van Meirvenne, Laloo, and De Clercq 2014, 251-252). Traditional excavation methods were adapted to accommodate the 3D data collection. High-quality photographs were taken along with ground control points on site at various times during the excavation. The 3D data were then processed in Photoscan 0.9.0 and exported in various formats including both horizontal and vertical ortho-images, digital surface models (DSMs) and Virtual Reality Modeling Language (VRML) files (De Reu, De Smedt, Herremans, Van Meirvenne, Laloo, and De Clercq 2014, 253-254). Researchers analyzed ortho-images and DSMs in ArcMap but were unable to import the VRML files containing the 3D models into ArcScene because the software did not support it. They were only able to import low-resolution versions of the 3D models which resulted in the loss of the

high-resolution information present in the ortho-images and DSMs. The researchers concluded that image-based 3D modeling could transform archaeological excavation practices in the future, but that 3D GIS technology limitations at the time of the study would not allow the full digital potential of 3D models to be realized (De Reu, De Smedt, Herremans, Van Meirvenne, Laloo, and De Clercq 2014, 260-261). This thesis project mirrors their work in that they attempted to import VRML 3D object files into Esri ArcGIS software. In fact, one of the major challenges of this thesis project which still remains is the importing of the fossil 3D objects in VRML format into ArcGIS Pro at version 2.1, which is covered in detail in Chapters 3 and 4. Their work differs from this thesis project in that their excavation site was much larger and they collected 3D data *in-situ* during excavation. 3D data was not collected as the fossils were excavated from Project 23.

In a separate effort to visualize artifacts both large-scale (m-sized) and small-scale (cm-sized), researchers from the Aristotle University of Thessaloniki, Greece chose Esri ArcGIS software to develop a 3D model due to its functional 3D environment, customization abilities, ability to communicate with external programs (i.e. CAD, SketchUp) and its support of object-oriented data with linked attribute information at the prehistoric site of Paliambela Kolindros, Greece (Katsianis, Tsipidis, Kotsakis, and Kousoulakou 2008, 655-658). A combination of point data collection and photogrammetry was used to create a digital elevation model (DEM) of their study area with imagery draped over it. In order to represent each archaeologically significant feature as a single digital object within the GIS environment, SketchUp was used to create complex 3D objects of artifacts that were then imported into the Esri geodatabase. For smaller finds such as rocks and fossils, simple 3D point markers (i.e. spheres, tetrahedrons) were used as symbols while researchers acknowledged that more advanced 3D symbology could be created in

other software and then imported to the 3D model (Figure 5) (Katsianis, Tsipidis, Kotsakis, and Kousoulakou 2008, 659-663). Their creation of complex 3D objects outside of the ArcGIS software is similar to work done as part of this thesis project in that the fossils from the museum were laser scanned and processed prior to import into Esri software.



Figure 5. 3D model of Paliambela Kolindros in Esri ArcScene (Katsianis, Tsipidis, Kotsakis, and Kousoulakou 2008, 663)

The Katsianis, Tsipidis, Kotsakis and Kousoulakou (2008, 659-663) researchers also programmed several tools in ArcGIS to facilitate archaeological analysis, the most relevant to this thesis work being a 3D point-to-point distance tool that can calculate the distance between objects in 3D space, forming the basis for the implementation of spatial statistics. However, the study in Paliambela Kolindros differs greatly from this thesis project given that future 3D modeling was taken into consideration in their study when the archaeological data was recorded. In this thesis project, deposit Box 13a was removed from its original location which has been

built over. These circumstances limited the development of this project's 3D model to the data that was collected prior to the asphalt deposit's removal, which only included a single geographic coordinate (x, y) taken at the center of Box 13a with accompanying depth measurements.

Also considering small-scale objects, researchers at Queen's University in Ontario, Canada used Esri ArcGIS Online, Esri Web App Builder for ArcGIS Developer Edition version 1.3 and ArcGIS API Javascript version 3.15 to incorporate laser scanned hand samples of mesoscale rocks, minerals and fossils into a GIS (Harvey, Fotopoulos, Hall, and Amolins 2017, 152-162). The researchers built a widget for an ArcGIS Web App that facilitated the 3D visualization of mesoscale rocks, minerals and fossils in the geographical context of their 2D macro-scale environment. First, a prototype geological database with samples as georeferenced point features on a 2D map was developed. Then a widget was customized that allowed the user to click on a sample on the 2D map to view its attributes as well as the 3D model of the sample in a pop-up window. The 3D model could be rotated, zoomed in and zoomed out from (Figure 6) (Harvey, Fotopoulos, Hall, and Amolins 2017, 154-158). The objective of this work was similar to this thesis project as both studies sought to georeference small-scale samples that were laser scanned by hand with linked attribute information and included 3D visualization. The study differed from this thesis project because the widget limits the user to viewing each sample in 3D individually. The proximity and orientation between samples cannot be viewed, restricting visual interpretation of spatial patterns between samples to what can be viewed on the 2D map. This thesis project sought to develop a 3D visualization in which multiple artifacts could be visualized simultaneously in 3D and at varying scales.

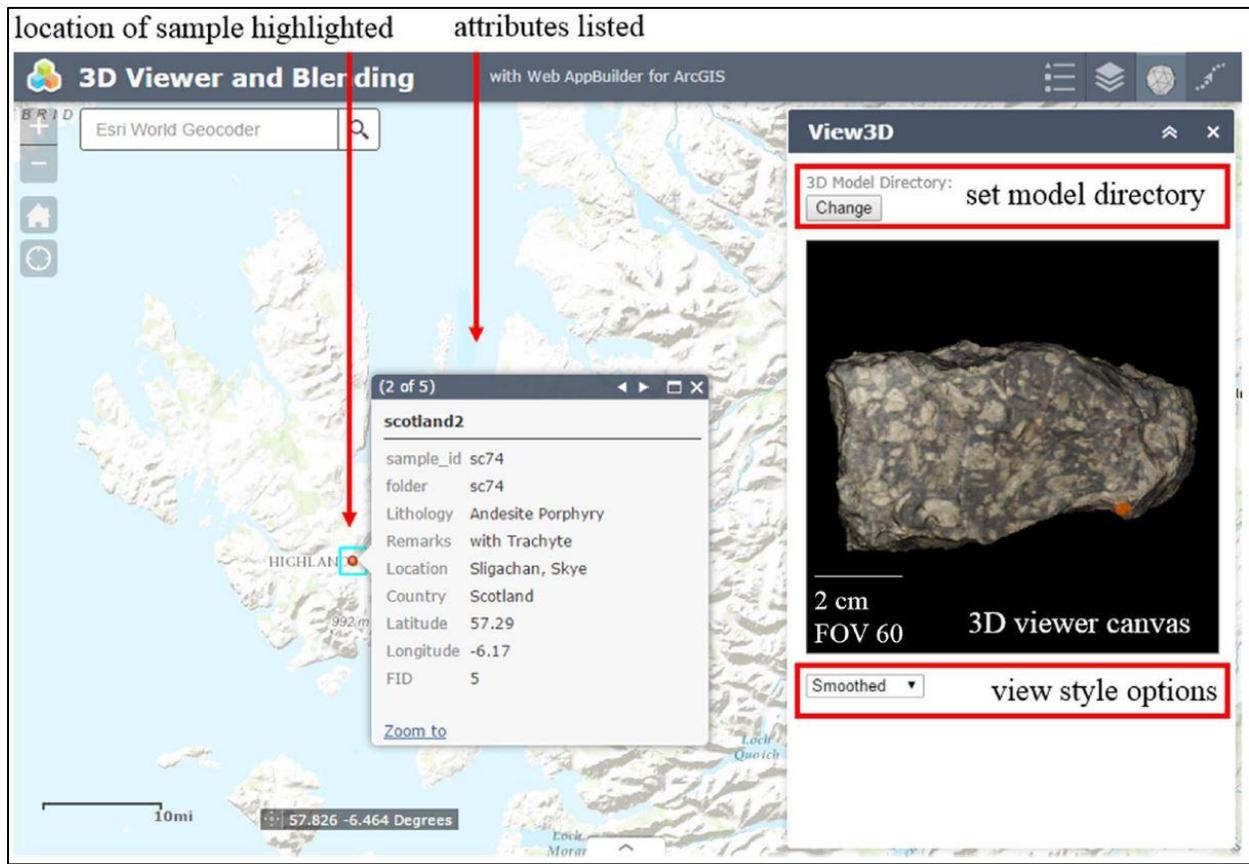


Figure 6. Widget for viewing 3D models of samples in ArcGIS Web App (Harvey, Fotopoulos, Hall, and Amolins 2017, 155)

The review of these studies provided useful insights into the development of the methodology to construct a 3D fossil visualization, which is described in detail in the next chapter of this thesis.

### 2.3. Forensics Background

Forensic archaeology is defined as “the controlled recovery of human remains and other evidence at forensic scenes (Nawrocki 1996, 1).” In some cases, prior to excavation, a datum or fixed point is established along with a subdatum at a known distance from the datum near the site. A reference grid of meter-by-meter grids using materials such as string is then constructed and assigned Cartesian coordinates based on the relative position of the subdatum. This allows

for the recording of “provenience” of remains or evidence from the excavation site. Provenience refers to the x, y and z coordinate location of an item (Nawrocki 1996, 5-6). Although this is just one of many methods for recording data in forensic archaeology, the process of establishing grids with Cartesian coordinates is similar to the excavation practices performed by the La Brea Tar Pits and Museum. Thus, the methodology outlined in the following chapter for visualizing excavated fossils may have implications beyond that of paleontology.

Additionally, a lesser-known field referred to as forensic paleontology is newly emerging as a useful tool in intelligence and criminal investigations. Although the term itself is currently under debate, forensic paleontology is defined as “the use of paleontology as a scientific tool available both to law enforcement officers and to judges and defending counsels (Sacchi and Nicosia 2013, 652).” It appears to overlap with other branches of science such as forensic archaeology, forensic geosciences and forensic biology, making it less frequently emphasized in criminal cases and its specific applications less distinct (Sacchi and Nicosia 2013, 651). At present, it is unclear if the methodology described in the following chapter will have implications in the field of forensic paleontology.

## Chapter 3 Methodology

This chapter describes the methodology for the development of the 3D GIS fossil visualization for the La Brea Tar Pits and Museum. Section 3.1 provides an overview of the methodology and section 3.2 describes the data sources for this project. Section 3.3 presents additional relevant background information about the project data and section 3.4 outlines the development of the 3D GIS fossil visualization and potential sources of error.

### 3.1. Method Overview

As previously stated, the main objective of this methodology was to find a way to visualize fossils as high-resolution 3D objects displayed on a 3D map in their pre-excavation, *in-situ* locations beneath the earth's surface utilizing 3D GIS technology. The methodology reported in this thesis is unique in the fields of paleontology and archeology, as well as in the forensic branch of archaeology, at the time of this writing. Initial steps toward developing this 3D visualization included significant data preparation outside of the GIS environment including diagramming of fossil orientations, fossil location coordinate transformations and various file conversion activities. These initial data preparation steps were followed by 3D object creation, import and placement into 3D maps in ArcGIS Pro. Since access to advanced 3D functionality within GIS software is relatively new in the field of spatial science, the following sections in this chapter contain a summary of instructions on utilizing specific tools in GIS software to manually handle the placement of small-scale (cm-sized) 3D objects below ground surface. Detailed instructions of the steps performed in ArcGIS Pro are available in Appendix A. At this time, tools for automatic placement of 3D objects were not available in ArcGIS Pro, and other GIS software packages with 3D functionality such as Esri CityEngine were not tested due to the objective of testing ArcGIS Pro as it is heavily used in industry and government, as well as due

to thesis project time constraints. Future enhancements in handling high-resolution 3D objects in ArcGIS Pro are currently under consideration by Esri and solutions are even now being developed by Safe Software, Inc., all of which are discussed in Chapter 5 in the Future Work section (Sims, pers. comm., Bagh, pers. comm.).

## **3.2. Data Sources**

Museum scientists provided the author with data from Project 23's deposit Box 13a from Grid B-3 Levels 1 and 2. This included nineteen high-resolution 3D objects of the fossils in VRML format with corresponding imagery (96 dpi) and attribute information (Lindsey, pers. comm.). Museum scientists also provided images, tables and reports clarifying the locations and sizes of Box 13a, Grid B-3 Levels 1 and 2 and the locations and orientations of the fossils within (La Brea Tar Pits and Museum 2018). Pham (2015) provided the author with her thesis manuscript and an Esri geodatabase that includes a feature class with the location of Box 13a.

## **3.3. Data Background**

This section covers background information regarding the box, grid and fossil data provided by the museum. Section 3.3.1 describes Box 13a's grid levels, and section 3.3.2 discusses the nineteen fossils and their corresponding images (textures).

### *3.3.1. Box and Grid Data*

Box 13a was comprised of seven partial or complete 1 x 1 meter grids (Figure 7). The fossils selected for this project were excavated in Grid B-3 and ranged from Levels 1 to 2. Grid B-3 Level 1 was located 0 to 25 centimeters below the top of Box 13a, while Grid B-3 Level 2 was located underneath Level 1 at 25 to 50 centimeters below the top of the box. The origin of each grid was located at its southeastern corner. When the fossils were excavated, three sets of

local coordinates were recorded in centimeters for each fossil including northing (x-direction), westing (y-direction) and below depth (z-direction) with respect to the origin of the grid (Figure 8). Each fossil was marked with three small paint dots representing the three sets of local coordinates (i.e. Px, MC, LC in Figure 9) (Howard and Farrell, pers. comm.). This information served as the location and orientation information for the fossils used in this project.

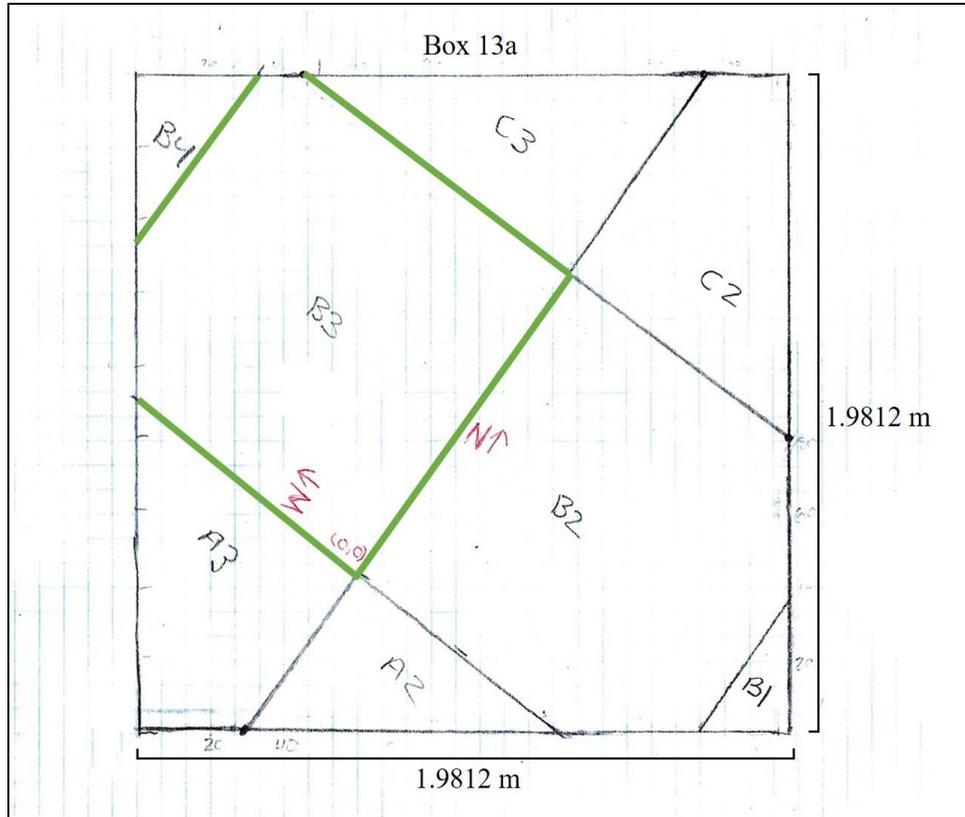


Figure 7. The grid layout of Box 13a with Grid B-3 highlighted in green (La Brea Tar Pits and Museum 2018)

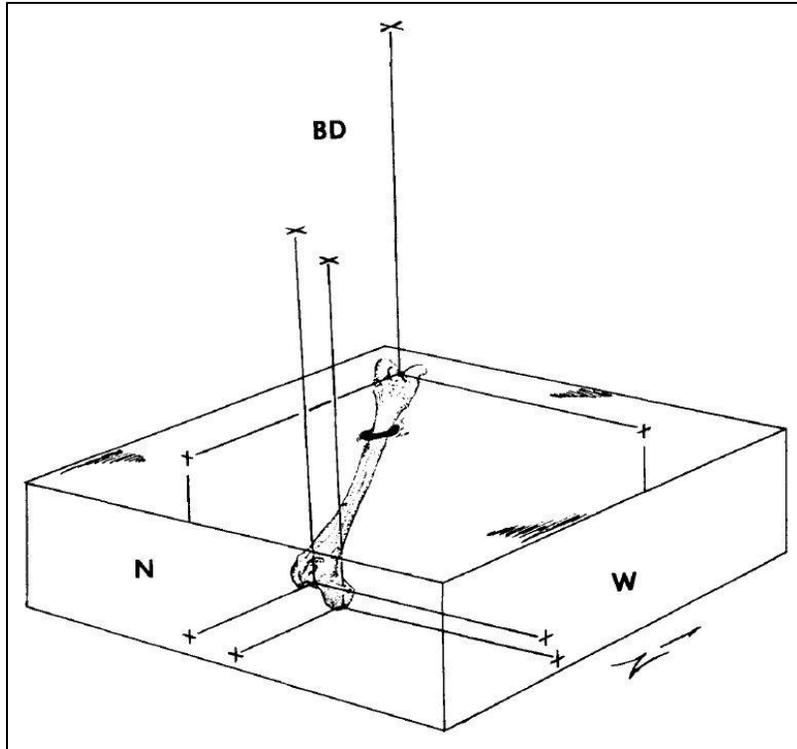


Figure 8. Northing (N), Westing (W), and Below Depth (BD) measurements (Pham 2015, 32, Shaw 1982, 66)

### 3.3.2. Fossil Data

Nineteen fossils from Box 13a Grid B-3 Levels 1 and 2 were selected by museum scientists to be included in the 3D visualization. The fossils included bird (*Aves*), ancient bison (*Bison antiquus*), dire wolf (*Canis dirus*), coyote (*Canis latrans*), Western horse (*Equus occidentalis*) and saber-toothed cat (*Smilodon fatalis*) specimens ranging in length from 10 to 20 cm. The fossils were manually laser scanned by museum scientists using an Artec Space Spider scanner and processed in Artec Studio 12 (Artec Space Spider 2015, Artec Studio 12 2017). The resulting 3D objects were exported into VRML format files. Museum scientists then provided attribute information in an Excel table format, including species, location and orientation information within Grid B-3, both levels. This data was also accompanied with imagery indicating where the local coordinates were taken during excavation on each fossil, as

shown in an example in Figure 9. Human error relating to paleontological excavation measurement methods mentioned in the previous chapter may have impacted the spatial data accuracy of the fossils. A summary of errors which should be taken into account is provided at the end of Chapter 3, in section 3.4.5.

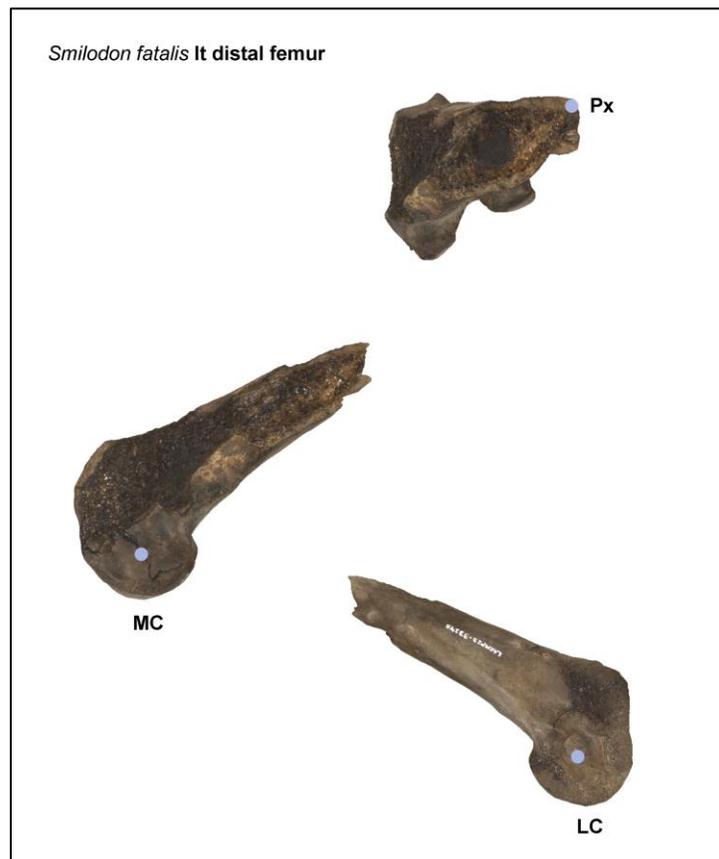


Figure 9. Fossil P23 33245 saber-toothed cat coordinate locations (La Brea Tar Pits and Museum 2018)

### 3.4. 3D Visualization Development Approach

This section outlines the methodology developed to construct the 3D visualization. Section 3.4.1 describes the fossil scanned image data processing steps taken prior to import into the GIS in order to understand and validate the orientation of each fossil. Section 3.4.2 describes the coordinate transformation required to generate geographically referenced coordinates for the

fossils using Excel, to support the subsequent required georeferencing steps in ArcGIS Pro. Section 3.4.3 describes how Box 13a and Grid B-3 Levels 1 and 2 were created in 3D using Excel and ArcGIS Pro. Section 3.4.4 details how the 3D objects - the scanned images of the fossils - were imported into ArcGIS Pro and then placed in their pre-excavation, *in-situ* locations. See Appendix A for more detailed instructions regarding steps performed in ArcGIS Pro.

#### *3.4.1. Fossil Diagramming*

The first step to developing the 3D model of the fossils in Box 13a was to understand and validate where the fossils were located and how they were oriented within Grid B-3. Hand-drawn diagrams were made with graph paper and pencil of the top view and north-facing side view of each fossil within the grid. An example drawing is provided in Figure 10. These simple visualizations were a tremendous aid in the creation of 3D diagrams of each fossil in PowerPoint. Although any diagramming software could have been used, PowerPoint was a readily available tool suitable for this purpose. This second step of producing diagrams in PowerPoint was deemed necessary in order to produce images clearly depicting the location and orientation of each fossil for validation by museum scientists (Howard and Farrell, pers. comm.). This step served as an intermediate check on the validity of the coordinate transformations described in the following section before moving on to build the visualization in ArcGIS Pro. Real-world, geographic coordinates were not used in PowerPoint.

Prior to importing the fossil scans into PowerPoint, each 3D object was converted to 3D Manufacturing Format (3MF) using Microsoft 3D Builder in order to preserve its texture. Using the 3D model tool, the fossil scans were imported into PowerPoint and manually rotated to their proper orientation with respect to the grid (Figure 10). Learning how to manually rotate the 3D objects in PowerPoint inspired later steps in the methodology when building the final 3D

visualization in ArcGIS Pro. Diagramming also revealed that some of the fossils' coordinates occurred just outside of Grid B-3 Levels 1 and 2 to the east. See Appendix B for the hand-drawn and PowerPoint diagrams of the 19 fossils.

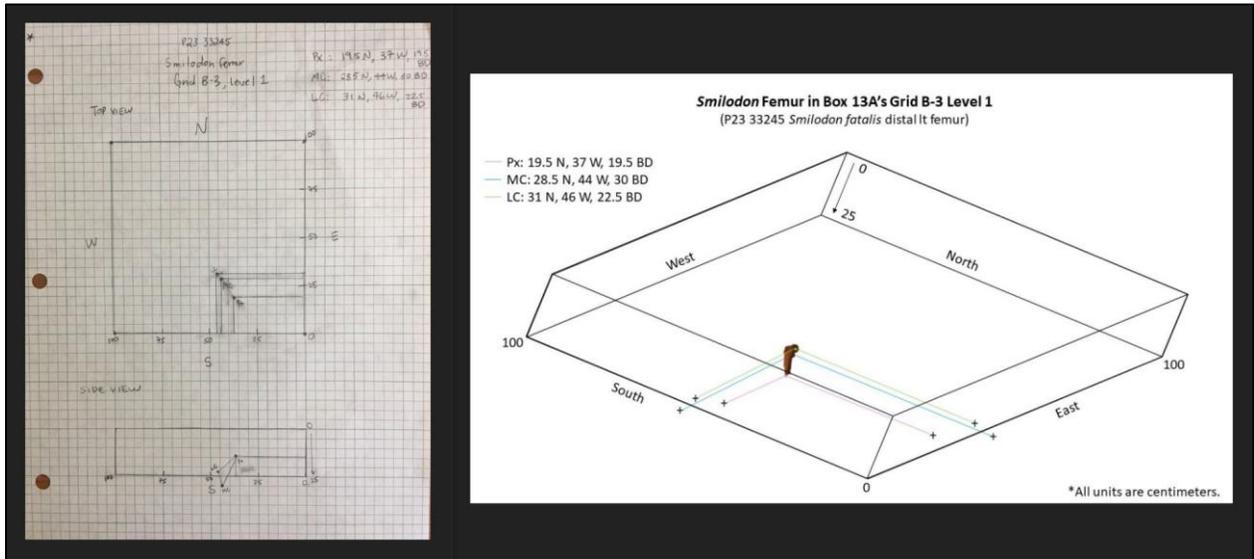


Figure 10. Example of a hand-drawn diagram and the corresponding PowerPoint diagram of fossil P23 33245

### 3.4.2. Coordinate Transformation in Excel and ArcGIS Pro

Before the fossil scans could be imported into ArcGIS Pro, significant coordinate transformation steps were required in Excel and ArcGIS Pro. The only georeferenced data provided to the author was the central coordinate of Box 13a, also found in Pham's geodatabase (Howard and Farrell, pers. comm., Pham 2015). The grid coordinates accompanying the fossils were not previously georeferenced, thus, they had to be transformed into real-world, geographic coordinates. Knowing the central coordinate of Box 13a was taken at the center of the box, a point was placed at the approximate center of the Box 13a schematic (Figure 11). This point, representing the central coordinate of Box 13a, landed at 0 cm W, 50 cm N in Grid B-3. This information was used in conjunction with the fossil coordinates to perform relative distance (eq 1) and bearing (eq 2) calculations between the central coordinate of Box 13a and the fossil

coordinates. Bearing and distance values were required for the subsequent coordinate transformation steps performed in ArcGIS Pro using the Bearing Distance to Line tool.

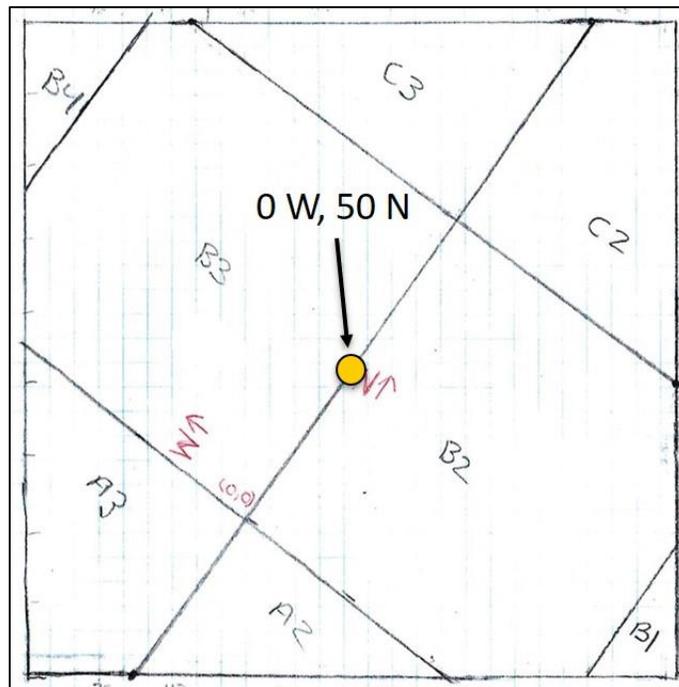


Figure 11. Box 13a central coordinate at 0 cm W, 50 cm N on Grid B-3

First, the distance (eq 1) equation was written based on principle of the Pythagorean theorem, which states “if  $a$  and  $b$  are lengths of the legs of a right triangle, and  $c$  is the length of the hypotenuse, then  $a^2 + b^2 = c^2$ ” (Gelfand and Saul 2001, 7, Figure 12).

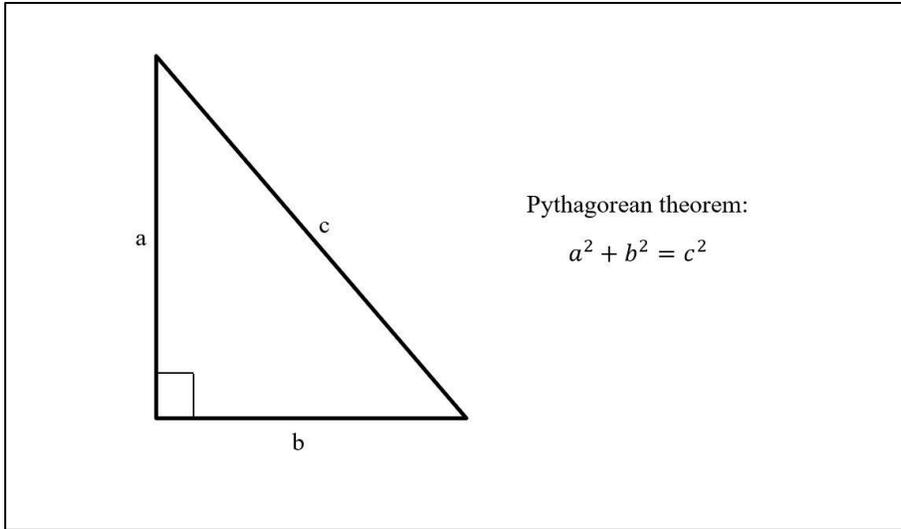


Figure 12. Pythagorean theorem diagram

In the case of this thesis project, the diagram in Figure 13 is representative of any given coordinate in centimeters west (*W*) and north (*N*) of the Grid B-3 origin at 0 west, 0 north. Find the distance (*D*) from the central coordinate of Box 13a at 0 west, 50 north to any given coordinate.

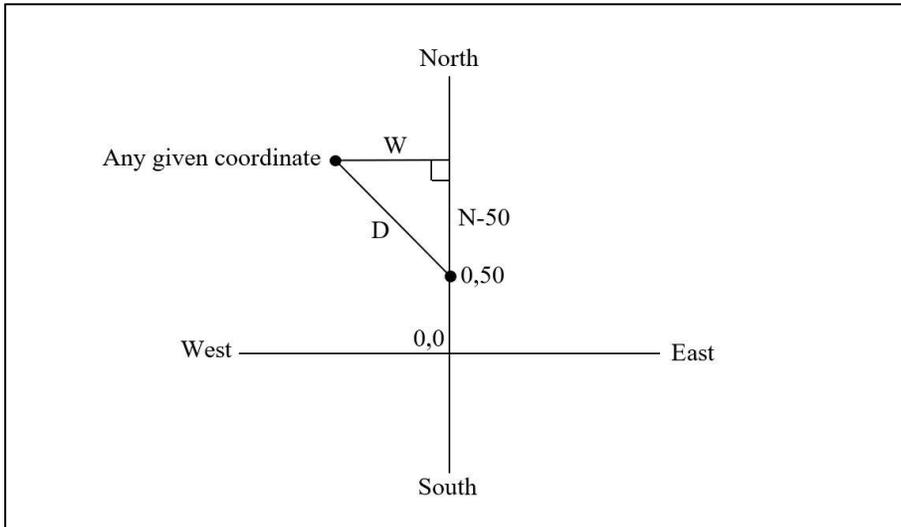


Figure 13. Distance equation example

For the right triangle in Figure 13, this means:

$$D^2 = (N - 50)^2 + W^2$$

After square rooting both sides of the equation above:

$$D = \pm\sqrt{(N - 50)^2 + W^2}$$

Negative distances do not exist, therefore:

$$D = \sqrt{(N - 50)^2 + W^2}$$

Since the coordinates were given in centimeters but ArcGIS Pro's Bearing Distance to Line tool required meter units, the final distance equation was adjusted for meters as follows:

$$Distance (m) = \sqrt{(N - 50)^2 + W^2} * \frac{1 m}{100 cm} \quad (eq 1)$$

Next, the bearing (eq 2) equation was developed based on the principles of the arctangent function. In a right triangle, the tangent of an angle is equal to the length of the opposite side divided by the length of the adjacent side. While the tangent returns only a ratio, the arctangent is the inverse function of the tangent and returns an angle (Gelfand and Saul 2001, 35). An example right triangle with these relationships is shown in Figure 14.

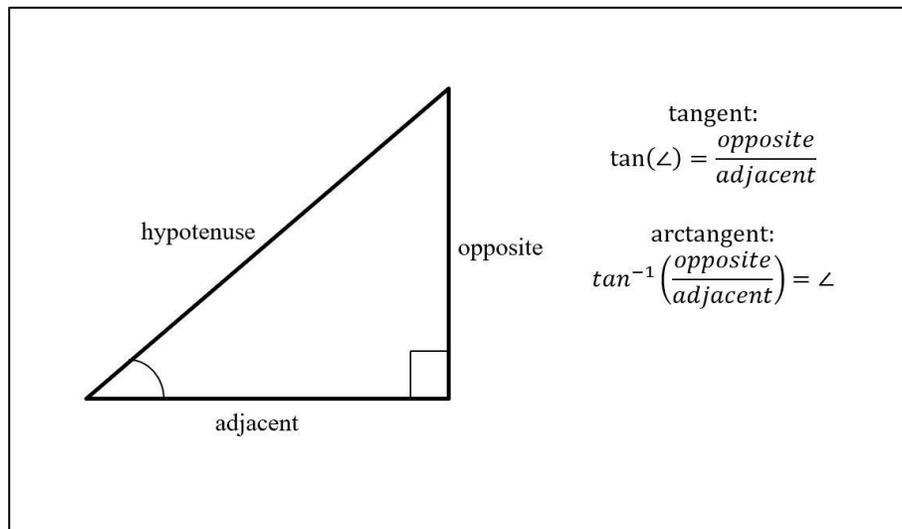


Figure 14. Tangent and arctangent diagram

The arctangent function only returns values between  $-90^\circ$  and  $90^\circ$  (Microsoft Office 2018a). For this project, an arctangent function that returns values for angles greater than  $90^\circ$  was desired. The Excel function known as *atan2*, a variation of the arctangent function, returns values between  $-180^\circ$  and  $180^\circ$  expressed in radians. As shown in the right triangle in Figure 15, the inputs of *atan2* are the adjacent side followed by the opposite side, referred to as  $(x\_num, y\_num)$  respectively in the Excel syntax (Microsoft Office 2018b).

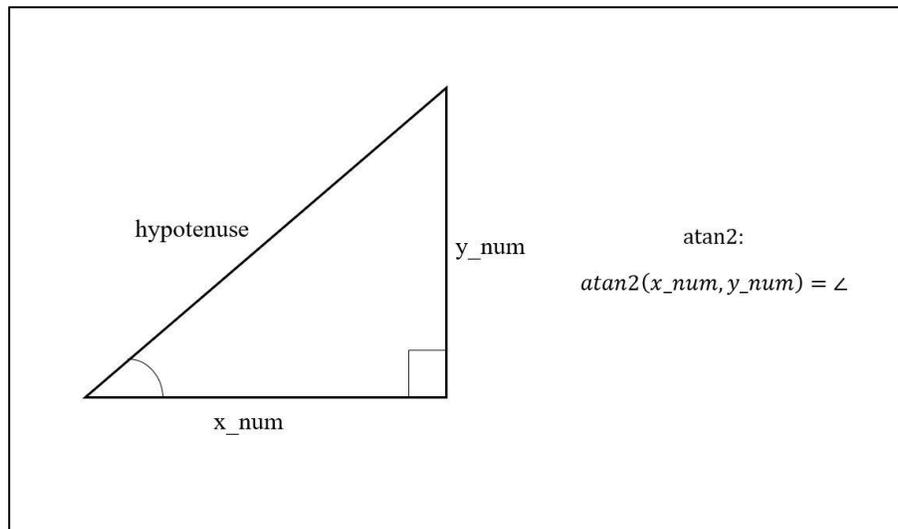


Figure 15. Atan2 diagram

In the case of this thesis project, Figure 16 illustrates an example of an angle or bearing ( $B$ ) that needs to be found. Bearings, like those on a compass, are measured clockwise from north ( $0^\circ$ ) (United States Marine Corps 2001, 20). This shows the bearing as negative because the example bearing is counter-clockwise from north. The majority of the fossils' local coordinates occurred within Grid B-3, located in the northwest quadrant of the local  $x, y$  grid shown in the example in Figure 16.

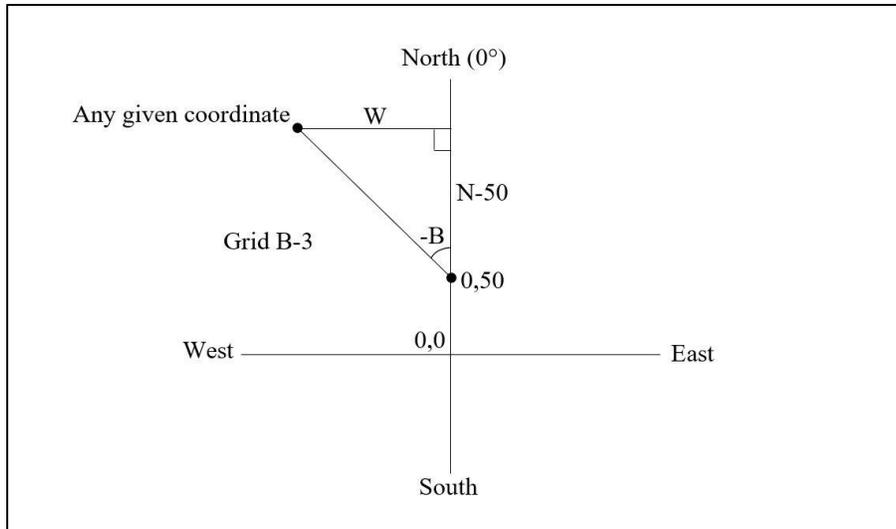


Figure 16. Bearing equation example

For the right triangle in Figure 16, this means:

$$-B = \text{atan2}(N - 50, W)$$

To solve for  $B$ , multiply both sides of the equation by  $-1$ , therefore:

$$B = -\text{atan2}(N - 50, W)$$

As previously stated, *atan2* returns values in radians. ArcGIS Pro's Bearing Distance to Line tool required bearing units in degrees. The conversion factor is  $180^\circ$  per  $\pi$  radians, therefore (Microsoft Office 2018b):

$$B = -\text{atan2}(N - 50, W) * \frac{180^\circ}{\pi}$$

The equation above returns values between  $-180^\circ$  and  $180^\circ$ . However, bearings between  $0^\circ$  and  $360^\circ$  were preferred for this project for clarity as bearings are conventionally reported as positive values. When the variable  $W$  is negative, the equation produces a positive bearing. Conversely, when the variable  $W$  is positive, the equation produces a negative bearing. In this instance, it is necessary to add a full  $360^\circ$  rotation to the equation to generate an equivalent

positive bearing (Gelfand and Saul 2001, 90-95). To generate the final bearing equation, let  $i = 1$  when  $W$  is greater than 0 and let  $i = 0$  when  $W$  is less than or equal to 0:

$$Bearing (^{\circ}) = -\text{atan2}(N - 50, W) * \frac{180^{\circ}}{\pi} + 360^{\circ}i \quad (\text{eq 2})$$

As previously mentioned, the majority of the fossils' local coordinates occurred in Grid B-3, west of the Box 13a central coordinate. Coordinates in Grid B-3 had positive  $W$  values and required that  $i = 1$ . However, a few of the fossil coordinates occurred slightly outside of Grid B-3 to the east of the central coordinate of Box 13a in the northeast quadrant of the x, y grid. These coordinates had negative  $W$  values and required that  $i = 0$ . The example diagram in Figure 17 demonstrates the result of adding a full  $360^{\circ}$  rotation to a negative bearing to generate an equivalent positive bearing. All distance and bearing values were calculated in an Excel table called *CoordinateTransformation.xlsx* which also contained the fossils' attribute information (Table 1).

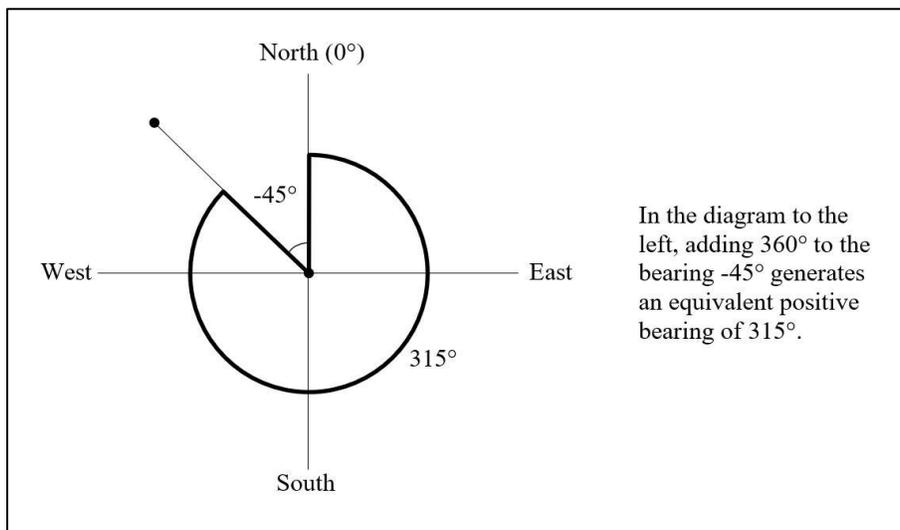


Figure 17. Example of  $360^{\circ}$  rotation added to negative bearing

Table 1. Example data for fossil P23 33245 from CoordinateTransformation.xlsx

<b>Specimen Number</b>	<b>Point</b>	<b>Taxon</b>	<b>Element</b>	<b>Deposit</b>	<b>Level</b>	<b>Grid</b>	<b>BD_cm</b>	<b>N_cm</b>	<b>W_cm</b>	<b>i</b>	<b>Bearing_deg</b>	<b>Distance_m</b>	<b>Box 13a Origin X_m</b>	<b>Box 13a Origin Y_m</b>	<b>Elevation_m</b>
P23 33245	Px	<i>Smilodon fatalis</i>	Femur	13	1	B-3	19.5	19.5	37	1	230.5004115	0.479504953	-13175742.2139	4037373.0874	47.244
P23 33245	MC	<i>Smilodon fatalis</i>	Femur	13	1	B-3	30	28.5	44	1	243.9581834	0.489719307	-13175742.2139	4037373.0874	47.139
P23 33245	LC	<i>Smilodon fatalis</i>	Femur	13	1	B-3	22.5	31	46	1	247.5572466	0.497694686	-13175742.2139	4037373.0874	47.214

Next, in ArcGIS Pro, the Box 13a central coordinate from Pham's (2015) geodatabase was exported to a new geodatabase called LaBreaTarPits\_P23Box13a\_FossilsModel.gdb as a point feature class named P23\_Box13a.fc. Pham's data and geodatabase were projected into the WGS 1984 Web Mercator Auxiliary Sphere. Thus the same projection was used for the new geodatabase created for this thesis project to best support the existing or current museum geodatabases. The author used the Esri basemap named 'Imagery' as an elevation source in meters. The Add Geometry Tool was run on point feature class P23\_Box13a.fc to generate x and y coordinates in the associated attribute table. The x and y coordinates were then added to a table named CoordinateTransformation.xlsx. The correct elevation for each coordinate was then calculated in the Excel table based on the elevation attribute information found in P23\_Box13a.fc for the top of Box 13a. The fossils' attribute information included depth below the top of the box (BD) values in centimeters. Thus, the BD values were subtracted from the elevation of the top of Box 13a to generate z values in meters. Another Excel table called AllBones\_DataForCoordinateTransformation.xlsx was then created including only information from CoordinateTransformation.xlsx required for the next step of importing the information into ArcGIS Pro (Table 2).

Table 2. Example data for fossil P23 33245 from AllBone\_DataForCoordinateTransformation.xlsx to be imported into ArcGIS Pro

<b>ID</b>	<b>Spec_Num</b>	<b>Point</b>	<b>Taxon</b>	<b>Element</b>	<b>Level</b>	<b>Bearing_deg</b>	<b>Distance_m</b>	<b>Box13a_OriginX_m</b>	<b>Box13a_OriginY_m</b>	<b>Elevation_m</b>
31	P23 33245	Px	<i>Smilodon fatalis</i>	Femur	1	230.5004115	0.479504953	-13175742.21386	4037373.087427	47.244
32	P23 33245	MC	<i>Smilodon fatalis</i>	Femur	1	243.9581834	0.489719307	-13175742.21386	4037373.087427	47.139
33	P23 33245	LC	<i>Smilodon fatalis</i>	Femur	1	247.5572466	0.497694686	-13175742.21386	4037373.087427	47.214

The AllBones\_DataForCoordinateTransformation.xlsx was then imported into the LaBreaTarPits\_P23Box13a\_FossilsModel.gdb as a table. With the table as input, the Bearing Distance to Line tool was used to create lines running from the central coordinate of Box 13a to the fossils' coordinates. The Feature Vertices to Points tool was then used with the newly created polyline feature class to generate vertices at the ends each line (Figure 18). The Join Field tool was then run using the vertices feature class and the imported table as input to add any attribute fields to the vertices feature class that were lost in the previous step. The vertices opposite of the Box 13a central coordinate were then selected according to fossil using the attribute table and exported into 19 individual point feature classes with z values enabled in the LaBreaTarPits\_P23Box13a\_FossilsModel.gdb.

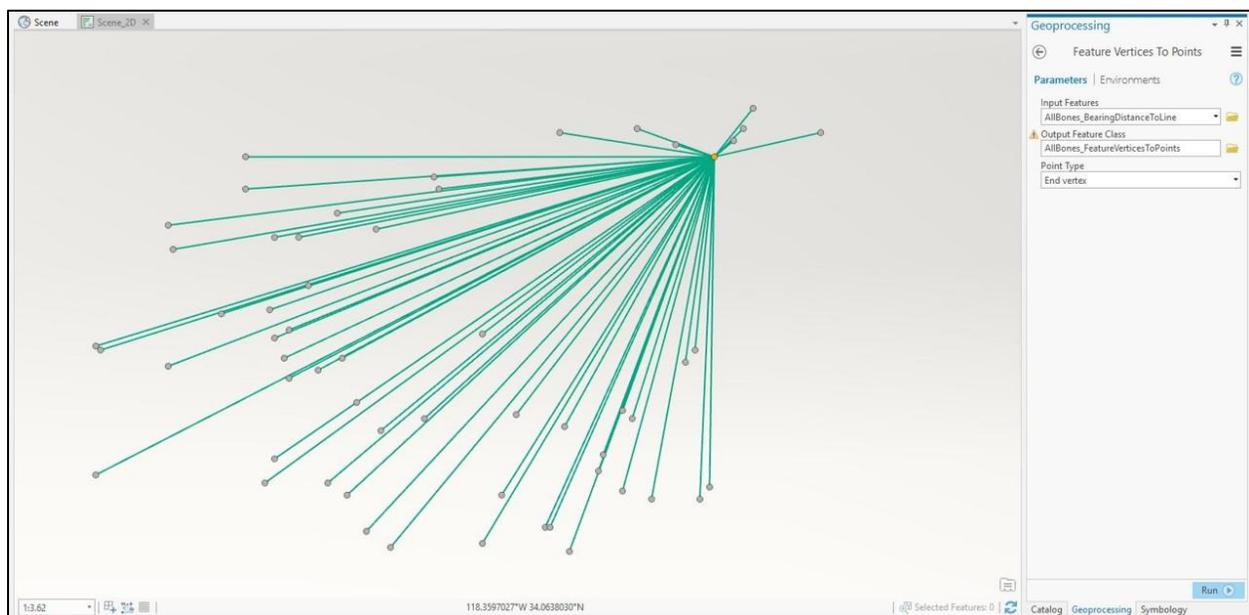


Figure 18. Bearing Distance to Line and Feature Vertices to Points tools results in ArcGIS Pro

Since the transformed coordinates did not have built-in z values, the Move To tool was utilized to select each coordinate and move it to its exact elevation indicated in its attribute table (Figure 19). The Add Geometry Attribute tool was then used to generate x, y and z values for

each coordinate in the attribute table as well as to crosscheck the z field with the elevation field for accuracy.

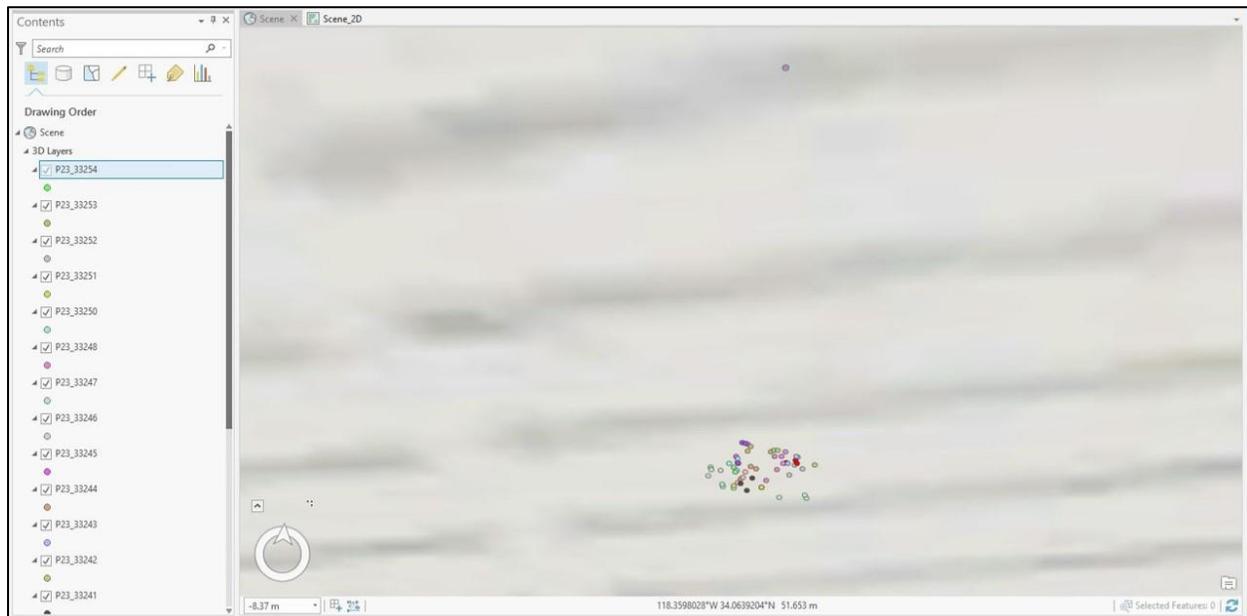


Figure 19. Transformed coordinates below ground surface in ArcGIS Pro

### 3.4.3. Box 13a and Grid B-3 Creation using Excel, Adobe Reader and ArcGIS Pro

The next step in building the 3D visualization was to create digital representations of Box 13a and Grid B-3 Levels 1 and 2. Using Excel, the height of Box 13a was subtracted from the known elevation of the top of the boxed substrate prior to extraction in order to determine Box 13a's elevation below ground. The height of Grid B-3 Level 1 was also subtracted from the known elevation of the top of the box to determine Level 1's elevation, while Level 2's elevation was determined by subtracting both Level 1 and 2's total height from the known elevation of the top of the box. This elevation information was then used later in ArcGIS Pro to position the box and grids underground accurately.

In Adobe Reader, a hand-drawn vicinity map of Project 23 provided by the museum in PDF was cropped and converted to JPG format (Figure 20) (La Brea Tar Pits and Museum

2018). Next, the image was imported into the LaBreaTarPits\_P23Box13a\_FossilsModel.gdb in ArcGIS Pro. The Georeference tool was used to approximately align the map with the point feature class P23\_Box13a.fc as well as with the imagery in the 2D Scene. From there, a new multipatch feature class named P23\_Box13a\_obj.fc was created in the geodatabase LaBreaTarPits\_P23Box13a\_FossilsModel.gdb. Using the Create tool and selecting the “Cube” model, the dimensions of Box 13a (width: 1.9812 m, depth: 1.9812 m, height: 1.40208 m) were entered into the Parameters tab. Prior to digitizing Box 13a, the cube was manually dragged or hovered over the Project 23 vicinity map and the Rotation was adjusted using the Parameters tab to match that of the map. The cube was then digitized in the 3D Scene to create Box 13a and the transparency was adjusted to 75%. The Move To tool was then used to center the box over its centroid, P23\_Box13a.fc (Figure 21). The box symbol was then colored “Electron Gold.”

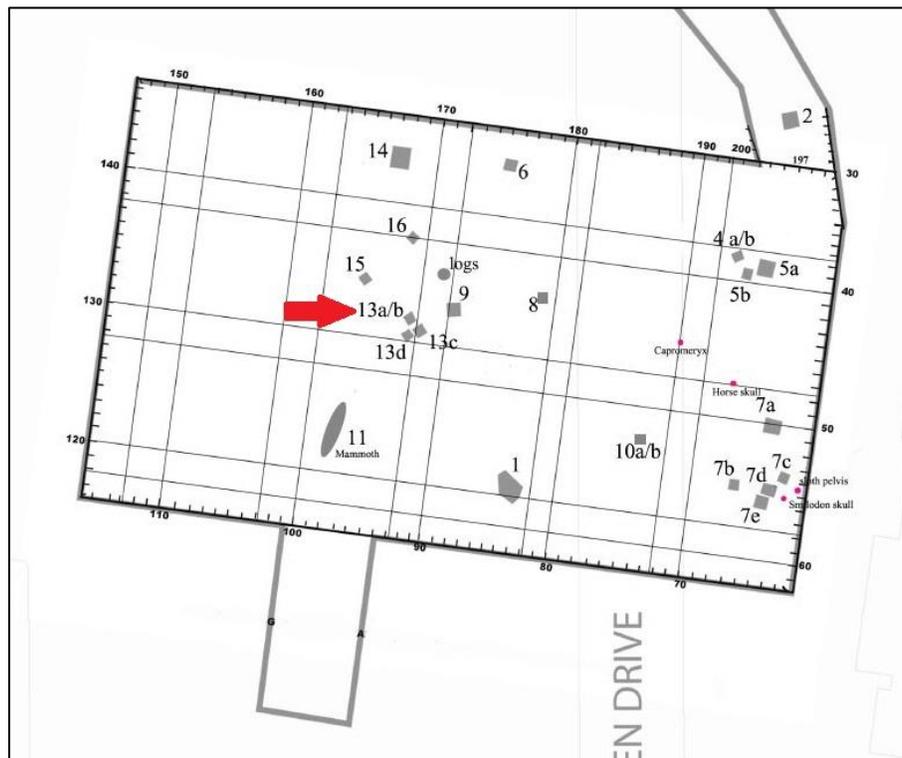


Figure 20. Project 23 locality map with an arrow indicating Box 13a (La Brea Tar Pits and Museum 2018)

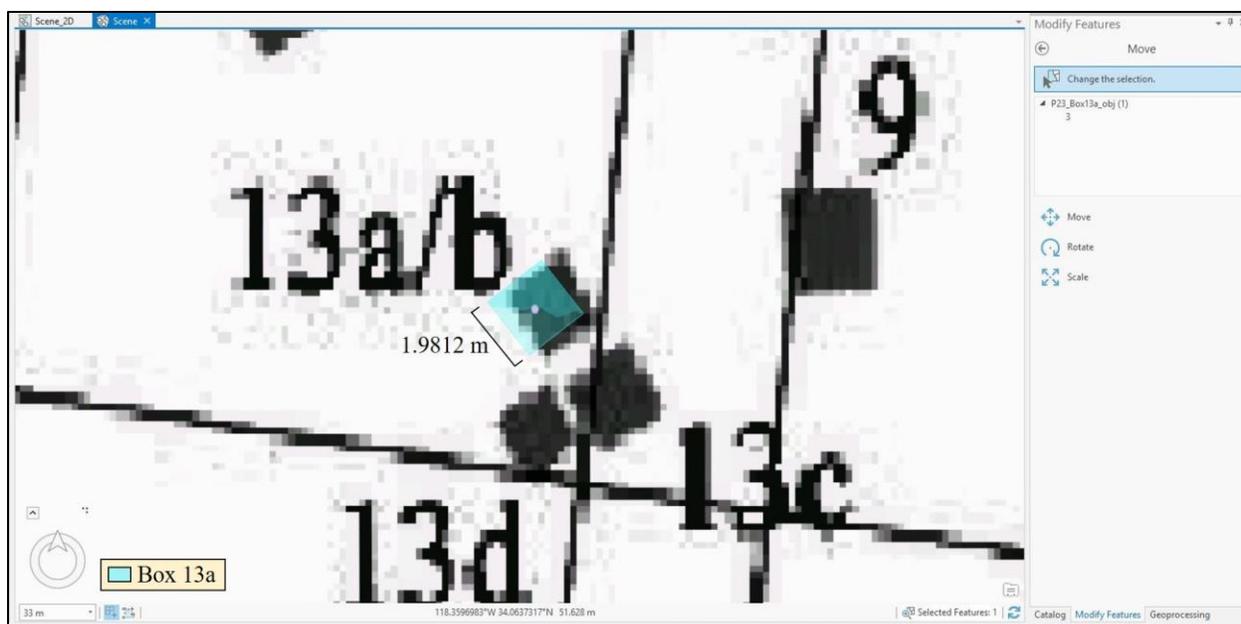


Figure 21. Box 13a rotated and centered over Box 13a’s central coordinate

The next step was to create two new multipatch feature classes to represent Grid B3 Levels 1 and 2. First, a multipatch feature class named P23\_GridB3\_Level2.fc was created in the LaBreaTarPits\_P23Box13a\_FossilsModel.gdb. Using the Create tool and selecting the “Cube” model, the dimensions for Grid B-3 Level 2 (width: 1 m, depth: 1 m, height: 0.25 m) were entered in the Parameters tab. The grid was then manually digitized approximately over Box 13a’s central coordinate at the grid’s 0 cm W, 50 cm N location (Figure 22). The grid did not need to be rotated since its eastern side runs directly north. A copy of P23\_GridB3\_Level2.fc was then made and renamed to P23\_GridB3\_Level1.fc in order to create Grid B-3 Level 1. Grid B-3 Levels 1 and 2 have identical dimensions.

The final step in creating the 3D representations of the box and grids was to use the Move To tool to place each of them at their correct elevations below the ground surface. The color of the symbols for Level 1 and 2 were set to “Mars Red” and “Big Sky Blue,” respectively. The transparency was set at 50-75% for each level to maximize visualization (Figure 23). Attribute

fields including height, width and elevation were then added and manually filled out for P23\_Box13a\_obj.fc, GridB3\_Level1.fc and GridB3\_Level2.fc.

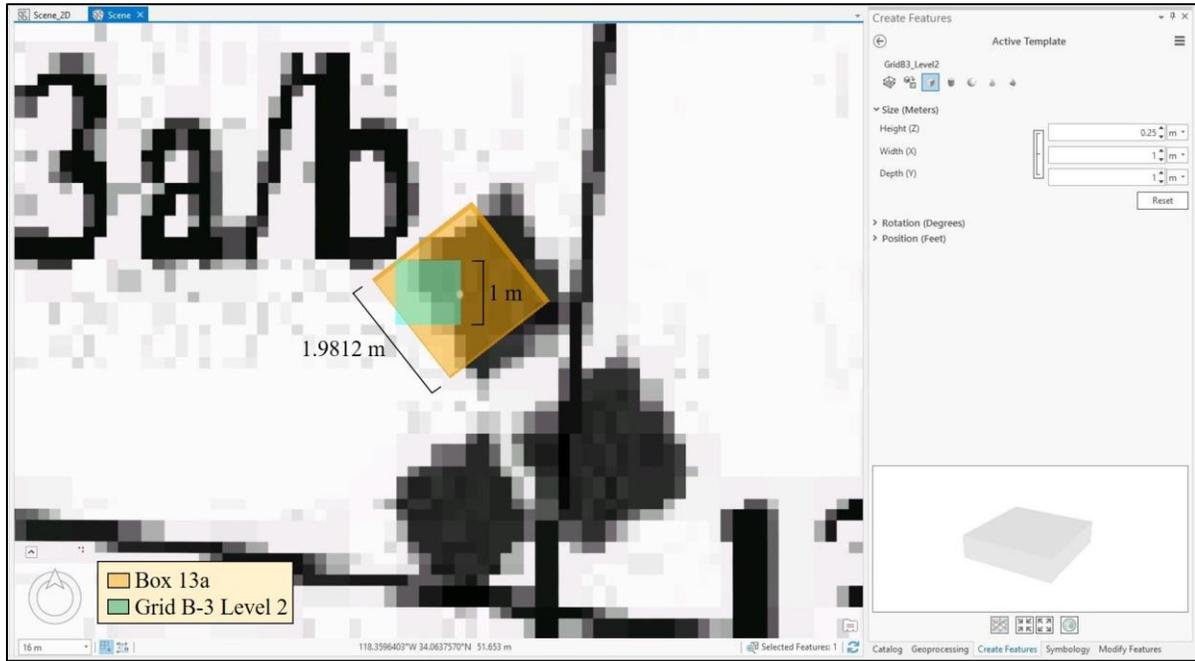


Figure 22. Grid B-3 Level 2 digitized over Box 13a's central coordinate at 0 cm W, 50 cm N on the grid

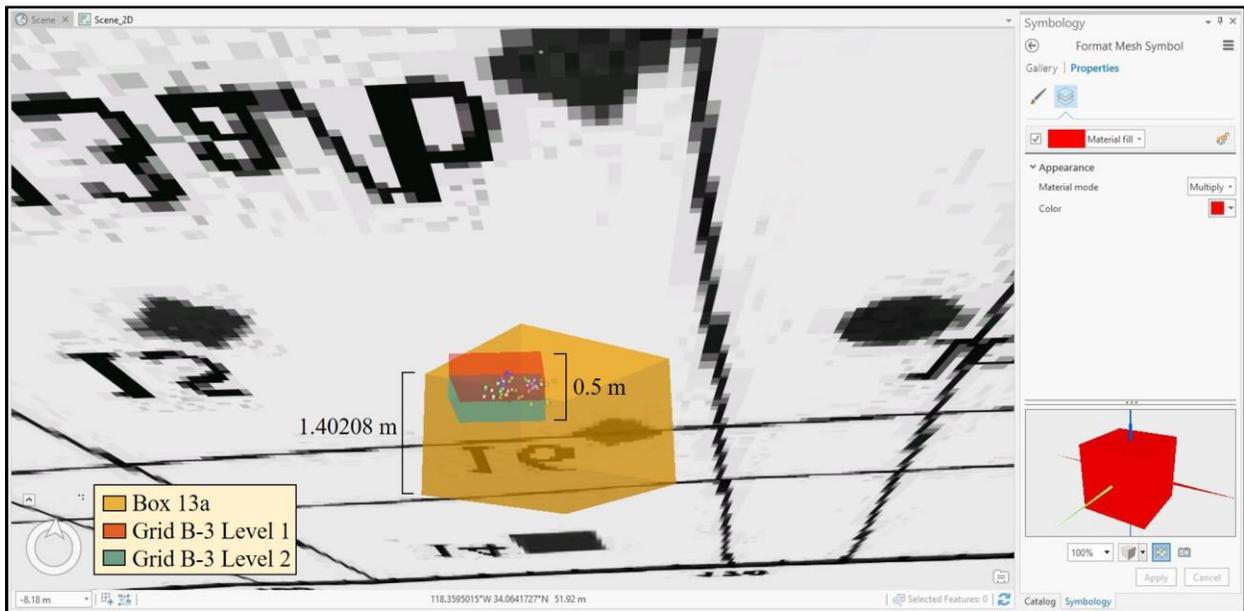


Figure 23. Box 13a and Grid B-3 Levels 1 and 2 below ground surface

#### 3.4.4. Fossil Digitization in ArcGIS Pro

Given the fossils' coordinates were in the proper location in ArcGIS Pro, the fossil scans were ready to be imported and manually scaled, rotated and placed in their pre-excavation, *in-situ* locations. The 3D objects were first converted from VRML format to Wavefront OBJ (OBJ) format using Microsoft 3D Builder in order to upload them to ArcGIS Pro. During this process, the textures of the 3D objects were lost, leaving the fossils white in color. Many solutions and workarounds were tested throughout this thesis work to solve this issue, such as importing using different 3D GIS software and imagery formats, as well as trying a variety of ArcGIS Pro tools. At the time of this writing, however, ArcGIS Pro version 2.1 did not support the import of high-resolution 3D objects in VRML format (Sims, pers. comm.). Current efforts underway to solve this deficiency are described in Chapter 5, in section 5.2.1. (Bagh, pers. comm.).

Next, the 3D objects in OBJ format were imported into ArcGIS Pro by first creating a new multipatch feature class for each fossil in the LaBreaTarPits\_P23Box13a\_FossilsModel.gdb. Then the Create tool was utilized to upload the 3D objects as Esri Model Files, which were then manually digitized in the 3D Scene above the ground surface. Using the Symbology template, the color of each fossil was changed to "Leather Brown" to appear as similar as possible to the original high-resolution fossil image textures that were lost during file format conversion (Figure 24). Each fossil was then manually positioned using a combination of the Move, Scale and Rotate tools to align them with their corresponding coordinates as close as possible (Figure 25- Figure 26). The Join Field tool was then used to link relevant attributes from the fossils' coordinate point feature classes to their respective multipatch feature classes. Finally, the origin and function of each dataset were added to each of the feature class' metadata by right-clicking on each feature class and selecting "Edit Metadata."

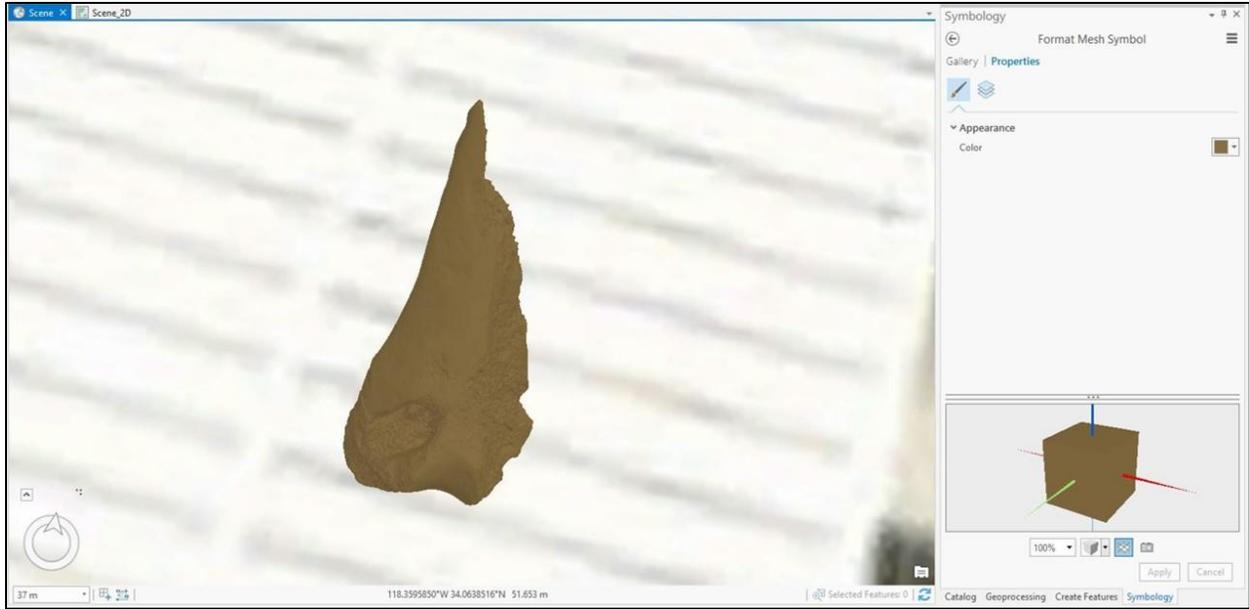


Figure 24. Fossil P23 33245 manually added to the 3D Scene

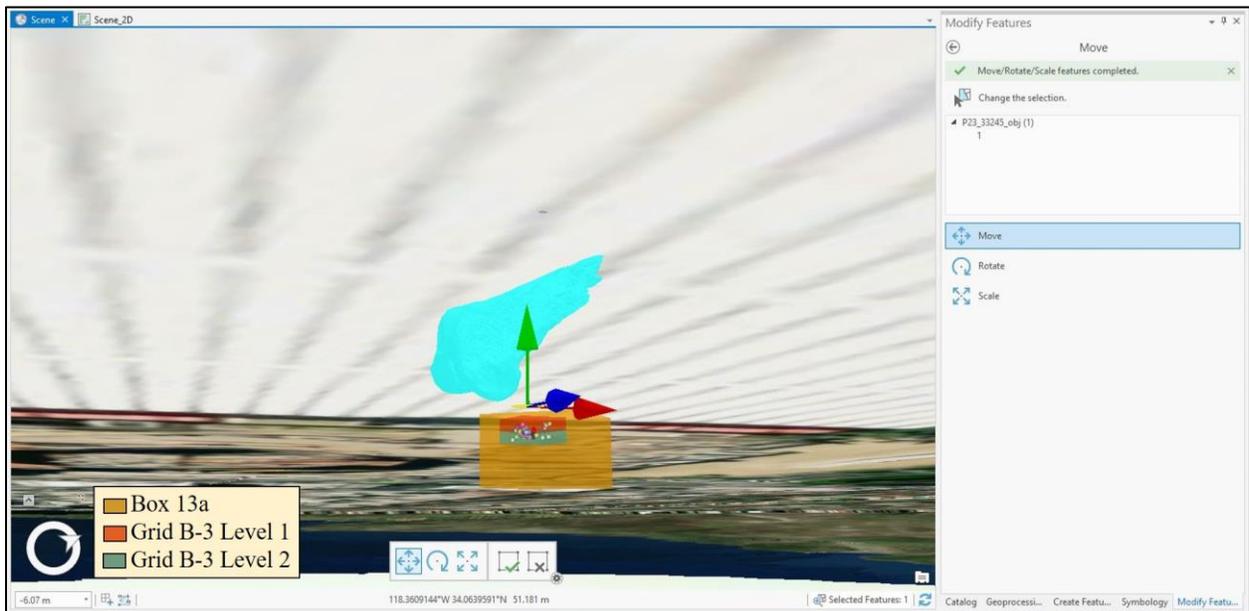


Figure 25. Fossil P23 33245 manually placed below ground surface using the Move tool prior to the Scale and Rotate tools

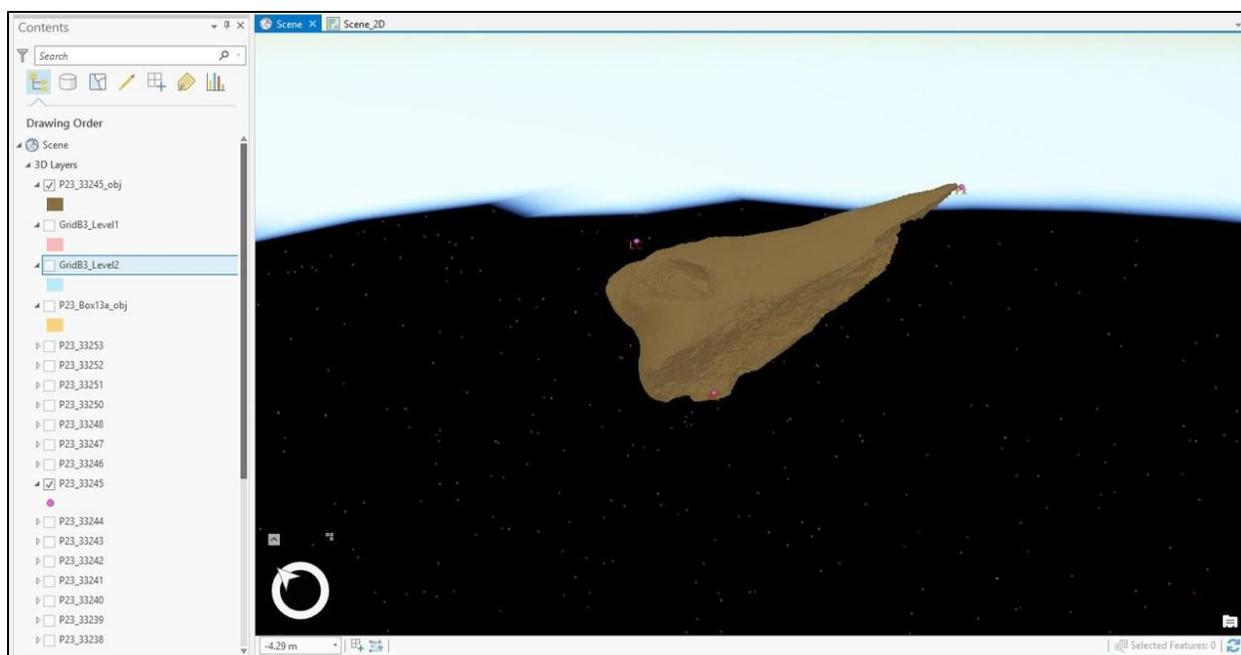


Figure 26. Fossil P23 33245 manually aligned with corresponding coordinates

### 3.4.5. Sources of Error

Beyond the human error inherent in the excavation process, other sources of error exist in this methodology. It was approximated that the central coordinate of Box 13a occurred at 0 cm W, 50 cm N in Grid B-3 based on the grid's hand-drawn schematic (Figure 7). For this reason, the fossils' geographic coordinates relative to the central coordinate of Box 13a may have been impacted by a few centimeters. It is important to mention, however, that the fossils' positions relative to each other were not affected by that approximation. Additionally, GridB3\_Level2.fc was digitized at approximately 0 cm W, 50 cm N on Grid B-3 in ArcGIS Pro and then copied to create GridB3\_Level1.fc. This may have led to error of up to a few centimeters when digitizing the grids. Lastly, Box 13a was digitized approximately over its central coordinate and rotated to match its orientation depicted on the georeferenced locality map, creating more potential for error in the 3D model.

### **3.5. Chapter Summary**

The methodology described above includes hand-drawn graphing of the fossils in Box 13a, coordinate transformation of local grid coordinates to real-world, geographic coordinates, file conversion of 3D objects from VRML to OBJ format and building an Esri geodatabase of 3D objects representing fossils. Although the main objective of the thesis project was met, due to limitations in the 3D functionality of the GIS software chosen for this project, the methodology developed is manual, rather than automated, and the results fell short of the museum scientists' expectations that the 3D representations of the fossils in the visualization would include the textures of each individual fossil. The 3D fossil visualization resulting from this methodology is outlined in the next chapter, Chapter 4 Results. Current efforts are underway to improve upon both the process of building the visualization as well as retaining the original fossil imagery are described in Chapter 5 under Future Work.

## Chapter 4 Results

This chapter describes the results of the development of the methodology for the 3D fossil visualization for the La Brea Tar Pits and Museum. Section 4.1 discusses the alternative methodologies and software that were tested during the thesis work as well as the overall methodology developed, and section 4.2 presents the final 3D model results.

### 4.1. Alternative 3D Modeling Testing and Results

Several methodologies and software were tested to develop the methodology for the 3D visualization, including ArcGIS Pro, SketchUp Pro 2017, Microsoft 3D Builder and Microsoft 3D Paint (SketchUp Pro 2017 2017, Microsoft 3D Paint 2016). Section 4.1.1 documents the results of these efforts in ArcGIS Pro and section 4.1.2 describes the results of testing the other software.

#### 4.1.1. ArcGIS Pro Testing

The primary approach to building the 3D model in ArcGIS Pro was to utilize the Import 3D Files tool to upload the fossil P23 33245 3D object in VRML format as a test. This step was the first attempt at importing the 3D object into ArcGIS Pro. The tool was initially run without indicating a coordinate system, which resulted in distortion of the 3D object in the 3D Scene such that fragments comprising the object spread across the globe. Prior to running the tool for a second time, a coordinate system matching that of the 3D Scene was chosen and, although the tool ran successfully, the object could not be located in the 3D Scene. When zooming to the generated output feature class, the 3D Scene panned over Africa. It is important to note that the coordinate system chosen for testing was the same as that used successfully throughout the rest of the project work and that the x, y (longitude, latitude) were correctly assigned when using the

tool. The tool was then run a third time using a selected Placement Points feature class. This feature class was generated in advance by creating a point feature class in the same coordinate system as the 3D Scene, digitizing a point in the vicinity of Box 13a, extruding the point below ground with the Adjust 3D Z tool, and then running the Add Geometry Attributes tool to create x, y and z values in the feature class' attribute table. Although a placement point was provided and the Import 3D Files tool claimed to have run successfully, the imported 3D object could not be located in the 3D Scene. Again, when zooming to the generated output feature class, the 3D Scene panned over Africa.

Another approach taken to import the 3D object was to first convert the fossil P23 33245 VRML file into a COLLABorative Design Activity (COLLADA) file. Using the Data Interoperability Extension FME Workbench 2017.1 in ArcGIS Pro, the P23 33245 VRML file was converted to a COLLADA file (FME Workbench 2017.1 2017, Bagh, pers. comm.). The Import 3D Files tool was then run again with the newly created P23 33245 COLLADA file, which caused ArcGIS Pro to close unexpectedly. Next, a multipatch feature class was created, and the Create tool was selected. The COLLADA file was selected as the Model File to be digitized at this stage, and ArcGIS Pro crashed again. It was determined that the combination of ArcGIS Pro version 2.1 and the USC SSI ONLINE system resources could not support the import of even a single COLLADA file of such high resolution (Sims, pers. comm.).

This led the author to convert the VRML files into a supported OBJ format using Microsoft 3D Builder for further testing. In ArcGIS Pro, the OBJ format was not supported by the Import 3D Files tool, so the author repeated the process above of creating a new multipatch feature class and using the Create tool to then select the Model File fossil P23 33245 in OBJ format. The fossil was then manually positioned within the 3D Scene. After testing both the

Georeference tool and the Data Interoperability Extension FME Workbench, it became clear that the P23 33245 3D object could not be georeferenced numerically or automatically to its set of three location coordinates (FME Workbench 2017.1 2017). This led the author to next test ArcGIS Pro's Move, Scale and Rotate tools to manually align the P23 33245 3D object with its respective coordinates. An additional limitation of ArcGIS Pro discovered during this testing process was that the Add Geometry Attributes tool did not work with the P23 33245 3D object. Thus, the multipatch feature classes representing the fossils in the final 3D model do not have finalized x, y and z coordinates in their attribute tables which could be used to validate placement within the 3D visualization.

#### *4.1.2. SketchUp Pro, Microsoft 3D Builder and Microsoft 3D Paint Testing*

Other software that were tested for 3D visualization capabilities including SketchUp Pro, Microsoft 3D Builder and Microsoft 3D Paint (SketchUp Pro 2017 2017, Microsoft 3D Builder 2013, Microsoft 3D Paint 2016). The author considered building the 3D visualization in a GIS other than Esri and then importing it into ArcGIS Pro as a single entity. SketchUp Pro was the first software that was tested but could not be used because the free version of the software required the user to publish the museum's 3D objects to the software's 3D Warehouse, thus potentially releasing the fossil images to the public. This would have violated the current Memorandum of Understanding between the author and the museum (La Brea Tar Pits and Museum 2017b). The next software tested was Microsoft, including 3D Builder and 3D Paint, both of which proved to have insufficient capabilities for building the 3D visualization because they lacked the option to make 3D objects transparent. The lack of transparency would not have worked for this project for viewing the fossils inside of Box 13a. 3D Builder and 3D Paint also

lacked all georeferencing tools making it impossible to recreate the 3D model with any spatial accuracy.

## **4.2. 3D Modeling Results**

The 3D visualization produced for this project consists of an Esri geodatabase containing multipatch feature classes representing Box 13a, Grid B3 Levels 1 and 2 and the nineteen fossils' simplified 3D scanned imagery. The geodatabase also includes point feature classes representing the three sets of transformed coordinates associated with each fossil. Additionally, the geodatabase contains the table that was imported for the coordinate transformation as well as two feature classes produced by the Bearing Distance to Line tool and the Feature Vertices to Points tool. And finally, three visual, image mensuration feature classes were autogenerated while building the 3D model. These image mensuration point, line, and polygon feature classes allow the user to measure ground features from georeferenced imagery but were not utilized in this project.

Overall, the 3D visualization adequately displays the fossils underground in the position and orientation in which they were originally excavated (Figure 27-Figure 30). When viewed in ArcGIS Pro, the user can zoom and rotate the 3D Scene to view the fossils from all angles within their grids in Box 13a. Transparency of all objects including the fossils, grids and box can be controlled by the user. The user can also click on the fossils, box and grids to view their basic attribute information (Figure 31). For more information, the user can view the attribute tables of the point feature classes containing the fossils' coordinates (x, y and z) to obtain precise location information. The origin and function of each dataset were also added to the feature class' metadata to provide clarity for museum scientists when viewing the 3D model.



Figure 27. All fossils aligned with their respective coordinates

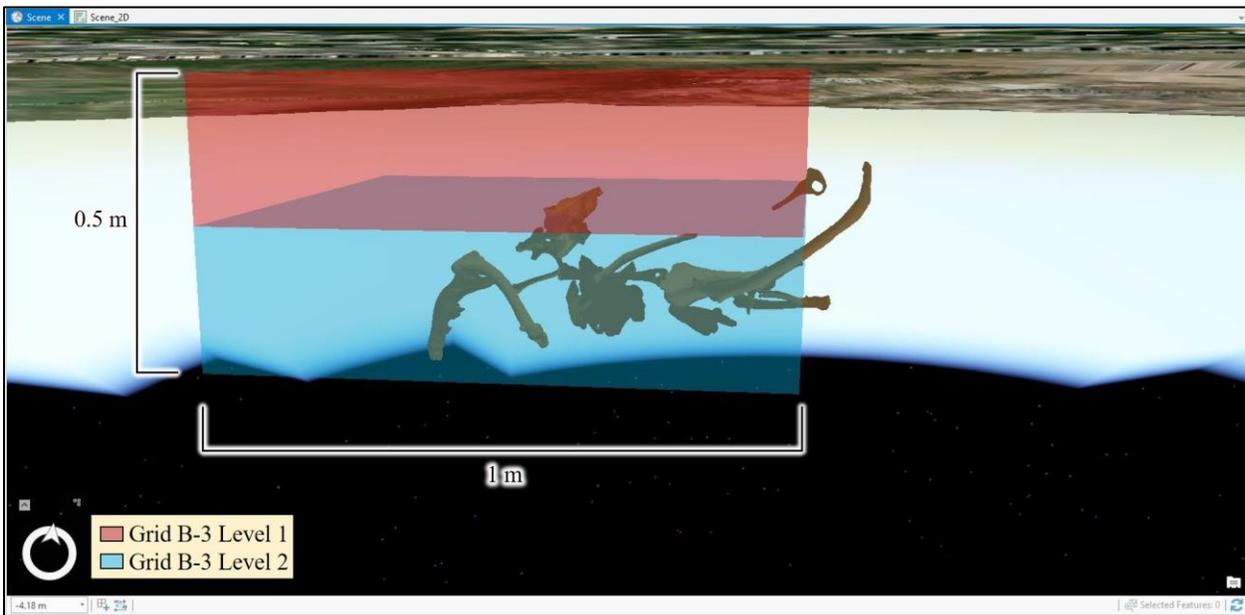


Figure 28. North-facing view of all fossils in Grid B-3 Levels 1 and 2

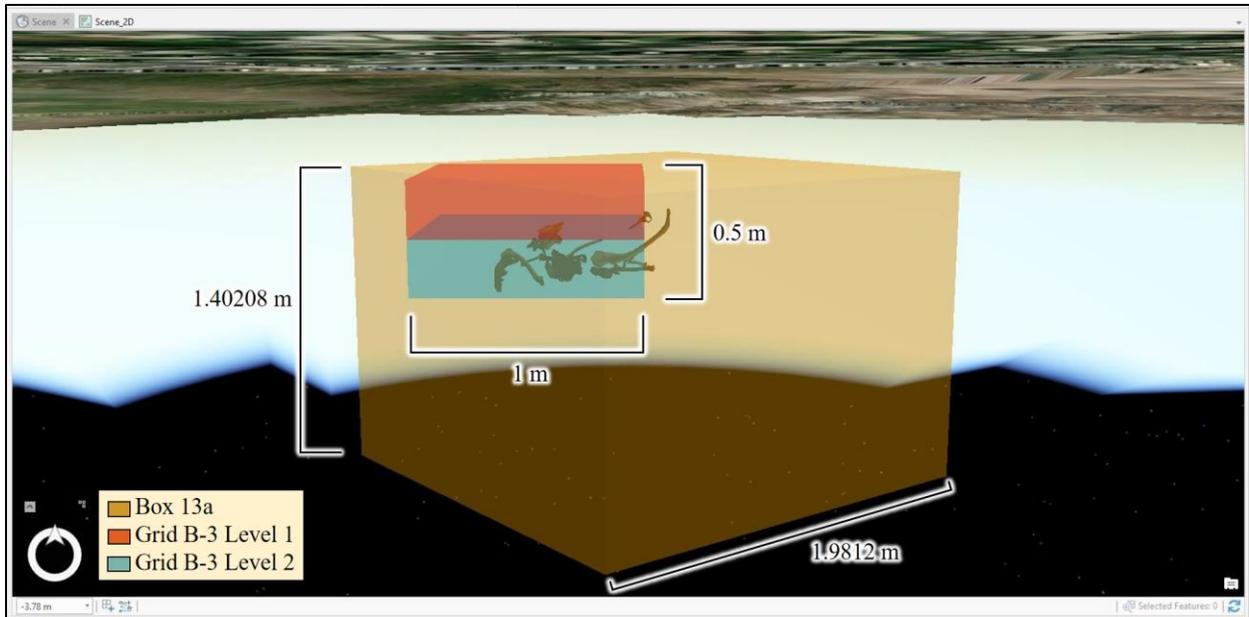


Figure 29. North-facing view of all fossils in Box 13a

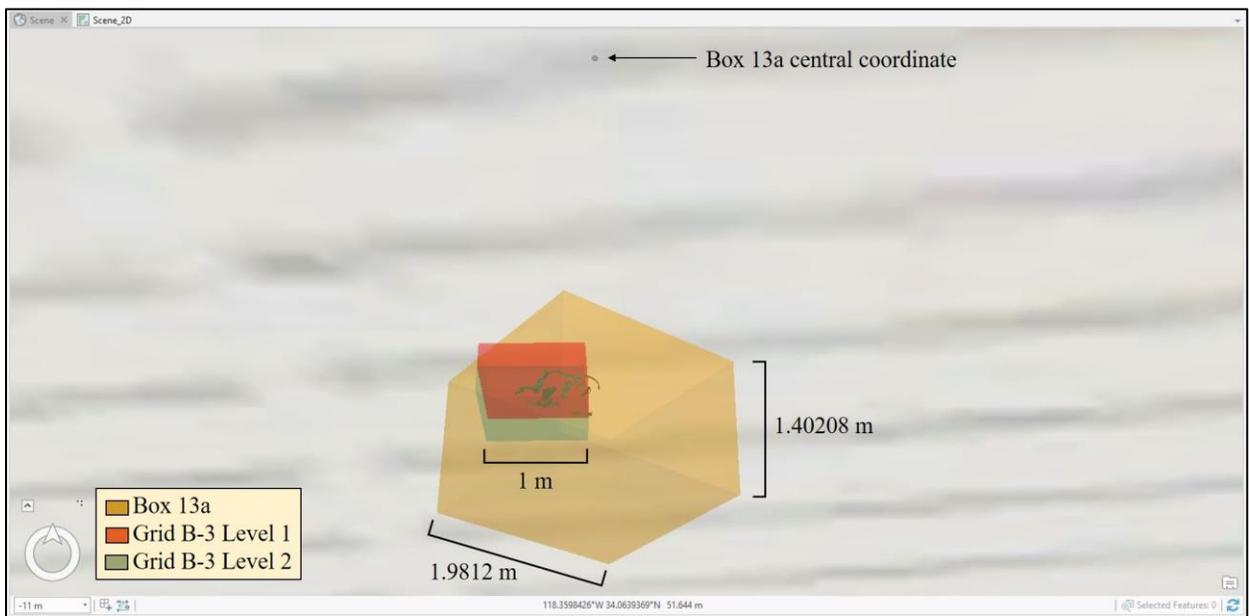


Figure 30. View from below of the fossils in Box 13a beneath its central coordinate

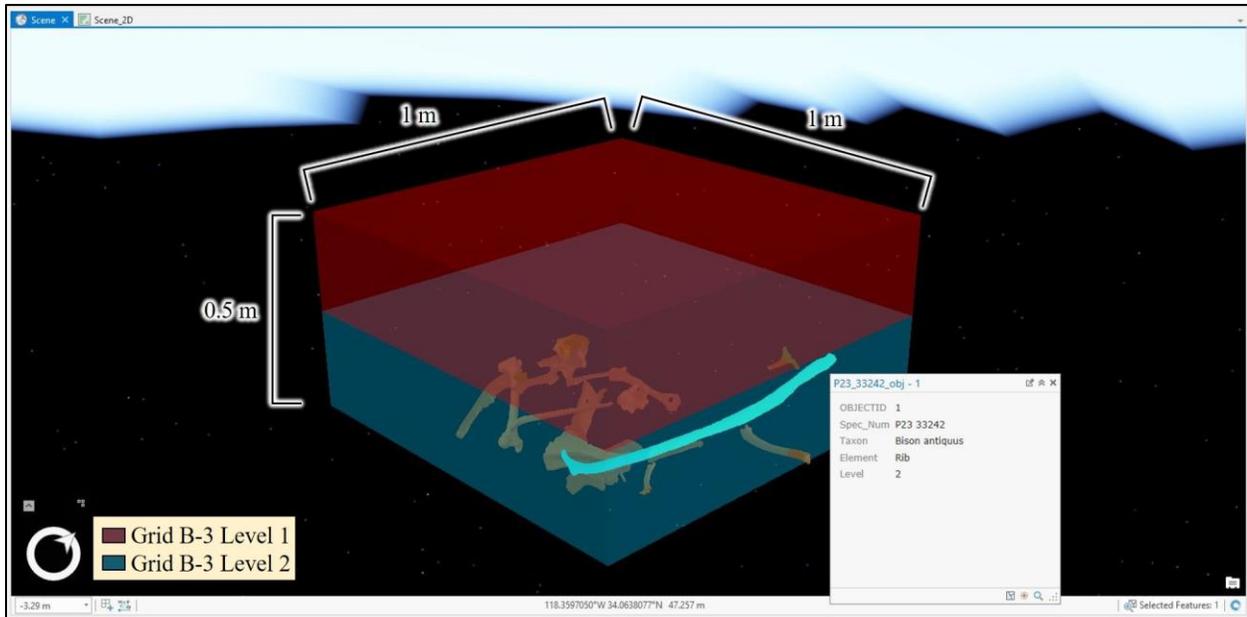


Figure 31. Fossil P23 33242 clicked on to view attribute information

Unfortunately, the 3D objects of the fossils lost their original textures due to the lack of support of functionality for import of VRML files into ArcGIS Pro version 2.1. The fossil 3D objects had to be converted into a file type that ArcGIS Pro could handle, OBJ format. During this process, the connection or link between the 3D objects and their respective textures was broken. To mitigate the visual impact of the texture loss, the author symbolized the fossils with a brown color that was similar to the texture.

Although the fossils were manually aligned with their respective coordinates to the best of the author's ability within the constraints of the Move, Scale and Rotate tools in ArcGIS Pro, the fossils did not always fit their anticipated locations (Figure 32). This is partly due to the limitations of the ArcGIS Pro toolset but may also be due to error in the marking and cataloging of each fossil's local coordinates during excavation. While the scale of the fossils was adjusted to align with their respective coordinates within this visualization, the proportions of the fossils were not altered by the author in any way in an attempt to preserve their original shape. For these

reasons, the fossils were aligned with their coordinates with errors up to +/-1 cm in the x, y or z direction.



Figure 32. Fossil P23 33252 coordinate alignment error

As anticipated in the previous chapter, evidence of error regarding the location of the grids also occurred in the final 3D model. Although three of the fossils were expected to extend outside of Grid B-3, Figure 33 shows one additional fossil (P23 33243) unexpectedly extending outside the grid, demonstrating the predicted error of up to a few centimeters when digitizing the grids.

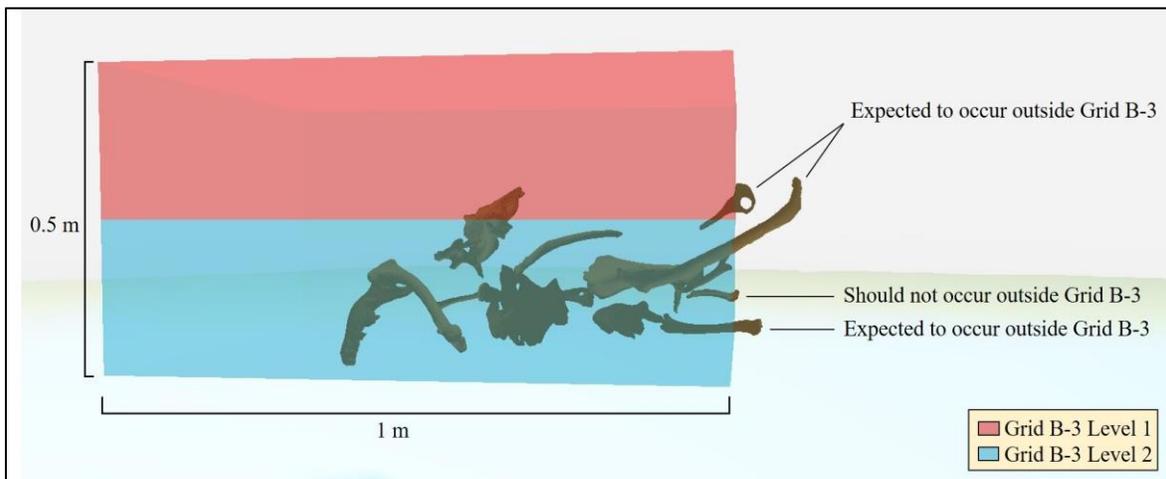


Figure 33. Fossils extending outside Grid B-3 Levels 1 and 2

### **4.3. Chapter Summary**

In summary, substantial testing was performed both inside and outside of ArcGIS Pro to develop a viable methodology for building a 3D visualization of small-scale (cm-sized) objects beneath the ground. These efforts resulted in an Esri geodatabase containing 2D and 3D spatial and non-spatial data sets and feature classes, including well-documented visualization issues and spatial accuracy concerns. The following chapter, Chapter 5 Discussion and Conclusion, describes the successes and challenges of this thesis project and suggestions about how this work can be further developed in the future.

## Chapter 5 Discussion and Conclusion

This chapter describes the successes and failures of the 3D fossil visualization for the La Brea Tar Pits and Museum and provides recommendations for future work to improve the methodology. Section 5.1 discusses the limitations of the 3D visualization. Section 5.2 describes potential future work including improvements in GIS tools for importing 3D objects, creating an interactive museum exhibit and building an archive of high-resolution scanned images of fossils as 3D objects. Section 5.3 prioritizes recommendations and provides final thoughts on furthering this thesis work. Section 5.4 describes potential applications of the developed methodology to forensic archaeology.

### 5.1. Discussion

This thesis project achieved its objective to develop a methodology to create a 3D visualization of fossils in their pre-excavation, *in-situ* locations at the La Brea Tar Pits and Museum. The author was successful in developing a methodology for converting traditionally collected paleontological or archeological artifact coordinates into real-world, geographic coordinates, making this procedure available and sharable with other researchers as well as the museum in Microsoft Excel format. The author was also successful in developing the 3D model in an Esri geodatabase in ArcGIS Pro but was limited to the constraints of the software at version 2.1. ArcGIS Pro could not import the 3D objects of the fossils in their original VRML format, so the author had to convert the files to a supported OBJ format at the expense of the object textures. The latter meant that the texture was lost. This, in combination with the fact that the 3D objects themselves could not be georeferenced in ArcGIS Pro, produced a somewhat slow, clunky visualization with 3D objects that had to be manually aligned with their respective coordinates. ArcGIS Pro's Move, Scale and Rotate tools were limited when making small-scale

adjustments to the fossils positions, thus, the fossils were aligned with their coordinates with errors up to +/- 1 cm. This style of manual placement limited the entire 3D visualization in its spatial accuracy.

The time-consuming nature of manually digitizing the 3D objects makes the process of building the 3D fossil visualization far from streamlined. Due to limitations in the 3D functionality of the GIS software chosen for this project, this thesis project did not meet its primary purpose of producing a 3D model that could be spatially analyzed using GIS by museum scientists. However, the resulting 3D visualization fulfilled the secondary purpose of this thesis project to create a 3D model that could be interactively displayed in the museum using software and hardware that can support the visualization. While the possibilities for improving the 3D model are vast, the following section provides some ideas for ongoing work.

## **5.2. Future Work**

This section describes long-term ambitions for the continuation of this project. Section 5.2.1 describes ongoing work being done and proposes future work to improve the process of importing 3D objects into ArcGIS Pro. Section 5.2.2 discusses the future development of an interactive display for the 3D visualization at the museum. Section 5.2.3 discusses the potential for archiving 3D objects that could be used in many different types of projects by the museum. Lastly, section 5.2.4 discusses the potential applications of this thesis work in the field of forensic archaeology.

### *5.2.1. Improving the Import Process of 3D Objects to ArcGIS Pro*

The first step to improving the methodology will be to improve the import process of complex 3D objects into ArcGIS Pro. In July 2018 at the Esri User Conference, the author began collaborating with developers from Safe Software, Inc., the company that developed the Data

Interoperability Extension FME Workbench (Bagh, pers. comm.). They are currently working on a process to import VRML 3D objects into ArcGIS Pro that would allow automatic georeferencing with real-world, geographic coordinates using FME Workbench. If successful, this procedure would eliminate the need to manually position the 3D objects in ArcGIS Pro and, thus, could radically streamline and improve the efficiency of the 3D fossil visualization methodology. This procedure could be applied not only to the complex 3D objects like the fossils but also to the simpler 3D objects such as Box 13a and Grid B-3 Levels 1 and 2. Currently, ArcGIS Pro version 2.1 cannot georeference complex 3D objects or generate x, y and z values for multipatch feature classes. Advanced georeferencing techniques developed in FME Workbench may provide a workaround in the future while ArcGIS Pro continues to improve its own software (FME Workbench 2017.1 2017).

### *5.2.2. Museum Exhibit*

The 3D visualization created in this project could be displayed interactively in the museum, but its viewing platform has yet to be determined. In line with the visions of the museum scientists, future work will need to be done to set up a durable touchscreen display that visitors can use to view fossil deposits interactively. The museum scientists envisioned that visitors could click on various features on the 3D map to view information and better understand the complexity of the tar pits (Lindsey, pers. comm.). This will require a software to be chosen that both displays the 3D model and tolerates the interactive nature and heavy-handed use of the exhibit anticipated.

### *5.2.3. 3D Data Generation and Archive*

Another step to further the development of the 3D fossil visualization would be to create and store an archive of the high-resolution scanned fossils readily accessible to the museum's

research teams, such as in a secured private Google Drive. In addition, it is recommended that the museum scientists begin laser scanning the fossils by hand immediately after excavation, and even *in-situ* immediately after being marked (3 points). It would also be ideal if at least one real-world, geographic coordinate marked on the fossil was recorded during excavation. This could lead to the semi-automated generation of a 3D Data Archive that could be used to continue to build and expand the 3D fossil visualization methodology documented in this thesis. As 3D GIS functionality improves and usage becomes more commonplace, this archive could be a valuable asset for the La Brea Tar Pits and Museum when it comes to both visualization and spatial analysis.

#### *5.2.4. Potential Application for Forensic Archaeology*

The methodology developed for this 3D fossil visualization may have an application in forensic archaeological practices in the future. As previously mentioned in Chapter 2, one method of recording the locations of remains and evidence at excavation sites involves the establishment of grids and a local Cartesian coordinate system based off a fixed point. This practice produces x, y and z field data recordings similar to those taken in the La Brea Tar Pits and Museum excavations. By applying this methodology developed for the fossil 3D visualization to data recorded by forensic archaeologists, this thesis project could inform the process of reconstructing crime scenes. For example, one benefit of having a crime scene mapped in a GIS would be the access to spatial analysis and modeling tools to support solving criminal investigations.

### **5.3. Next Steps**

It is recommended that this project is continued through student interns with the same or similar qualifications as the author and through funded research. In this way, the 3D fossil

visualization methodology could continue to evolve and contribute to the proposed 3D artifacts digital archive, and the La Brea Tar Pits and Museum could move forward more quickly toward new interactive 3D displays of fossils *in-situ* for the public to enjoy.

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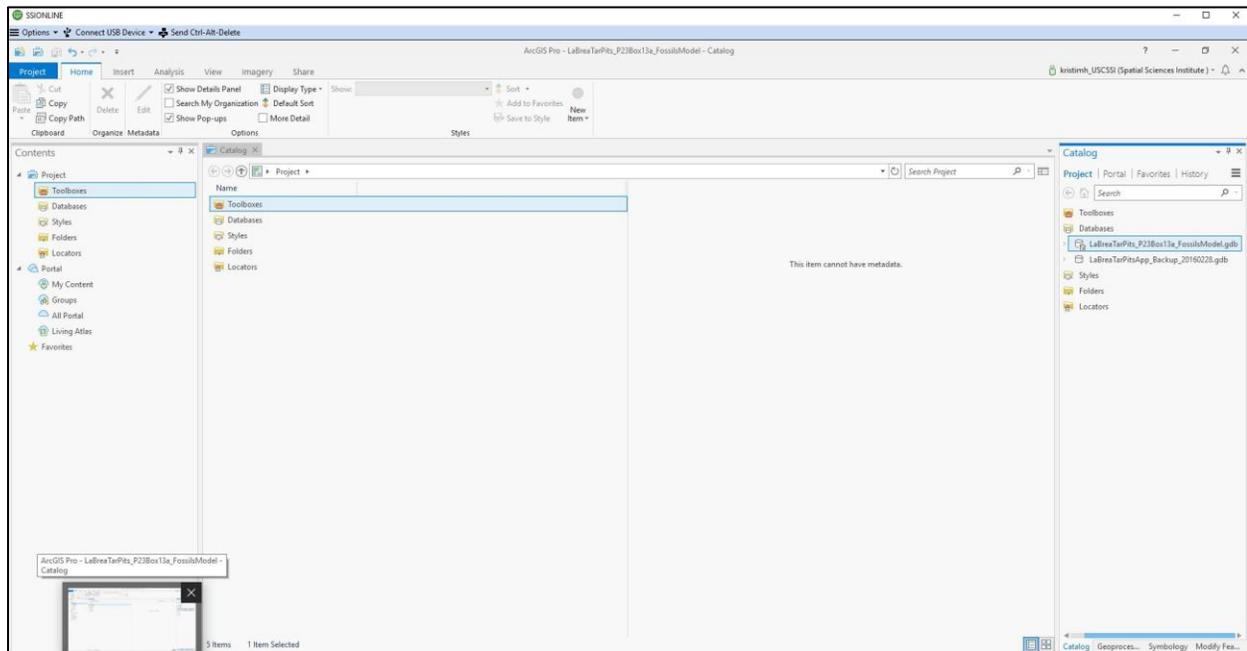
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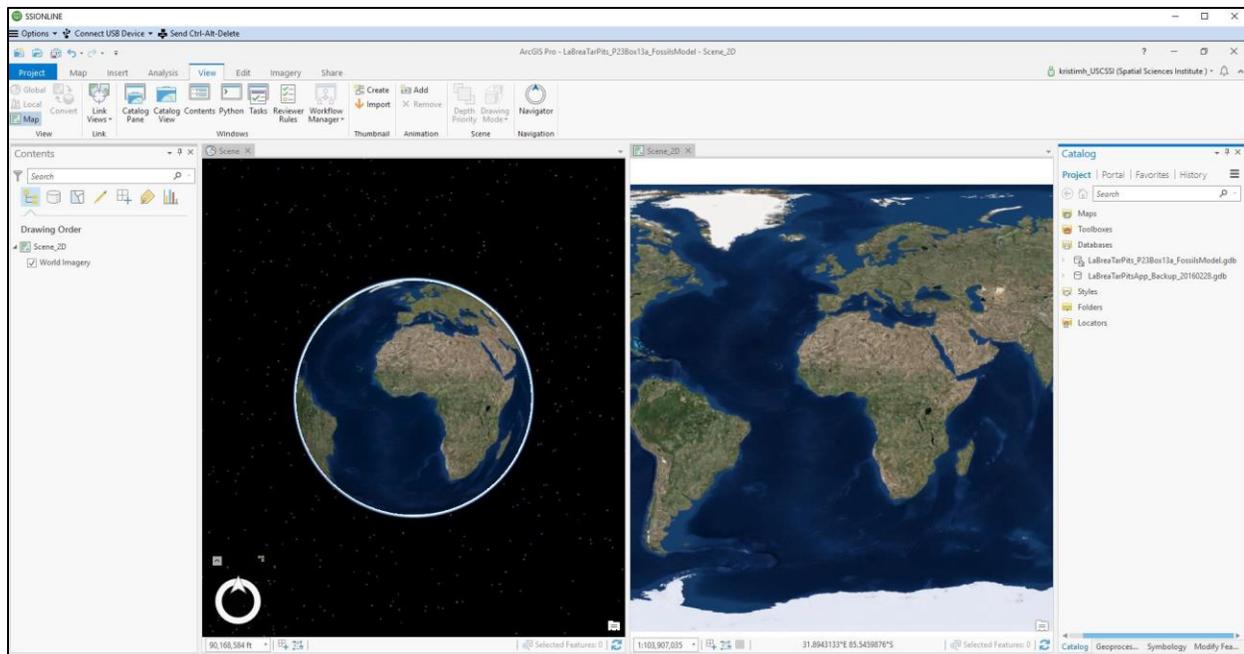
## Appendix A ArcGIS Pro Version 2.1. Steps

### INITIAL STEPS:

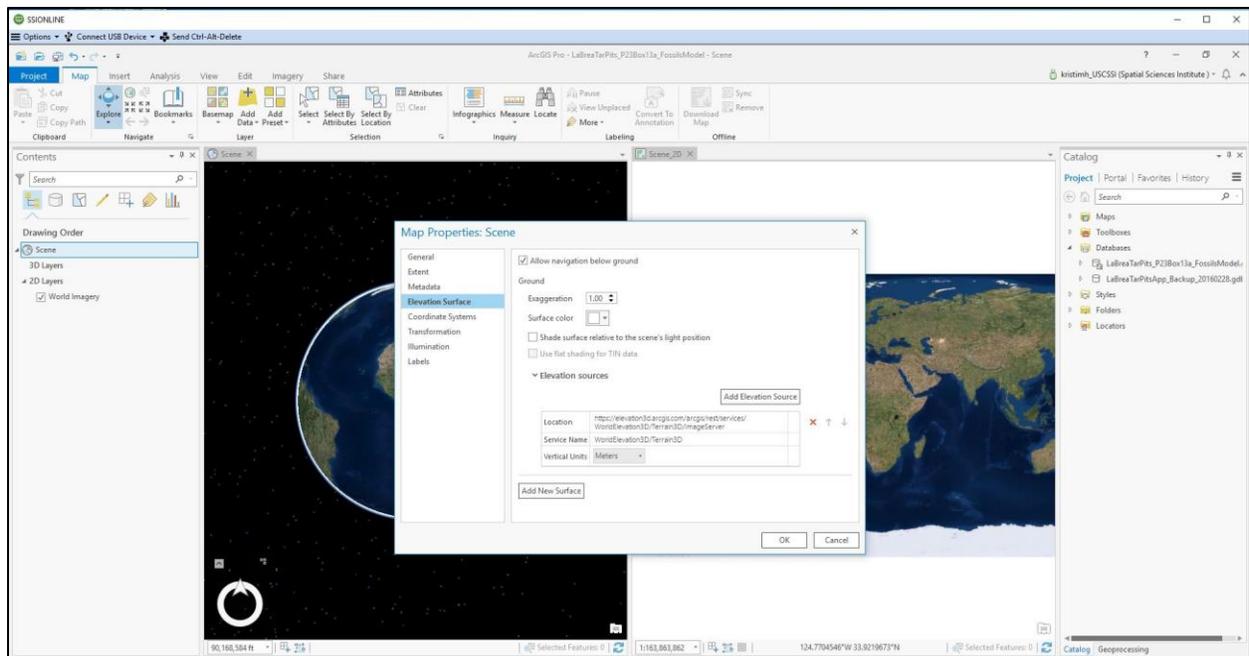
1. Open ArcGIS Pro. Under Create a New Project, select Blank. Name project LaBreaTarPits\_P23Box13a\_FossilsModel.aprx. This step creates a default file geodatabase in the Catalog called LaBreaTarPits\_P23Box13a\_FossilModel.gdb. Add Pham's geodatabase LaBreaTarPitsApp\_Backup\_20160228.gdb to Databases in Catalog tab.



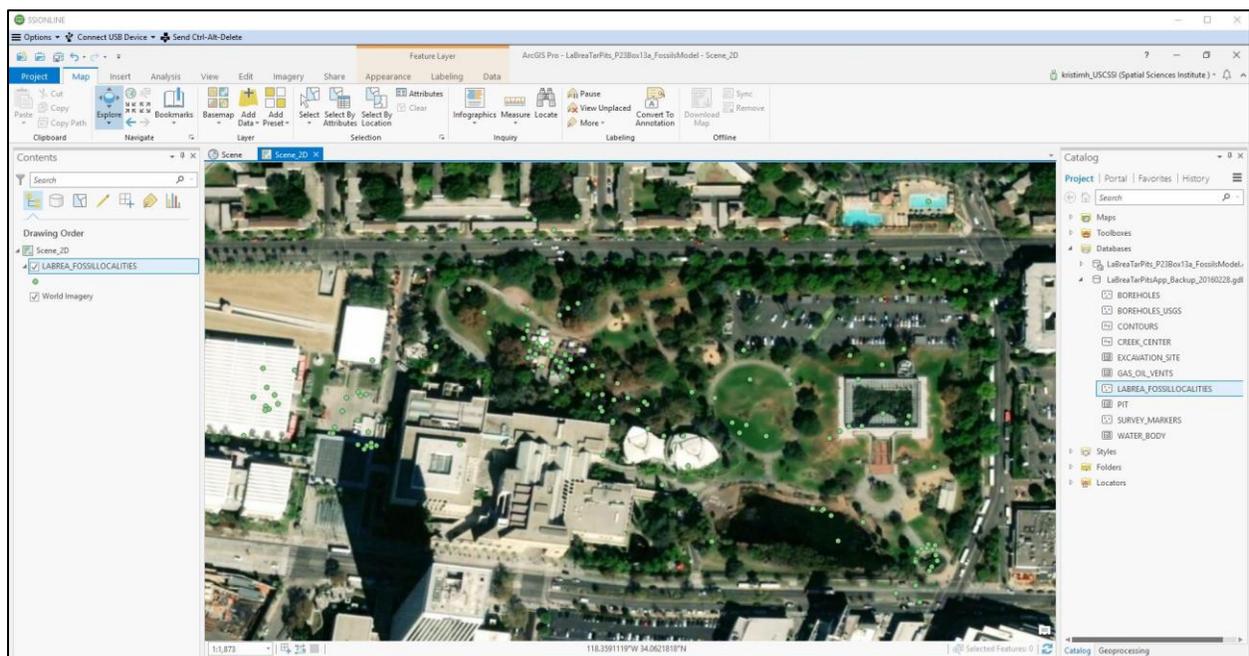
2. Under Insert tab, select New Map and clicked New Scene. Under Map tab, select Basemap and clicked Imagery. Under View tab, click Convert to view a 2D Scene (Scene\_2D) as well as a 3D Scene (Scene).



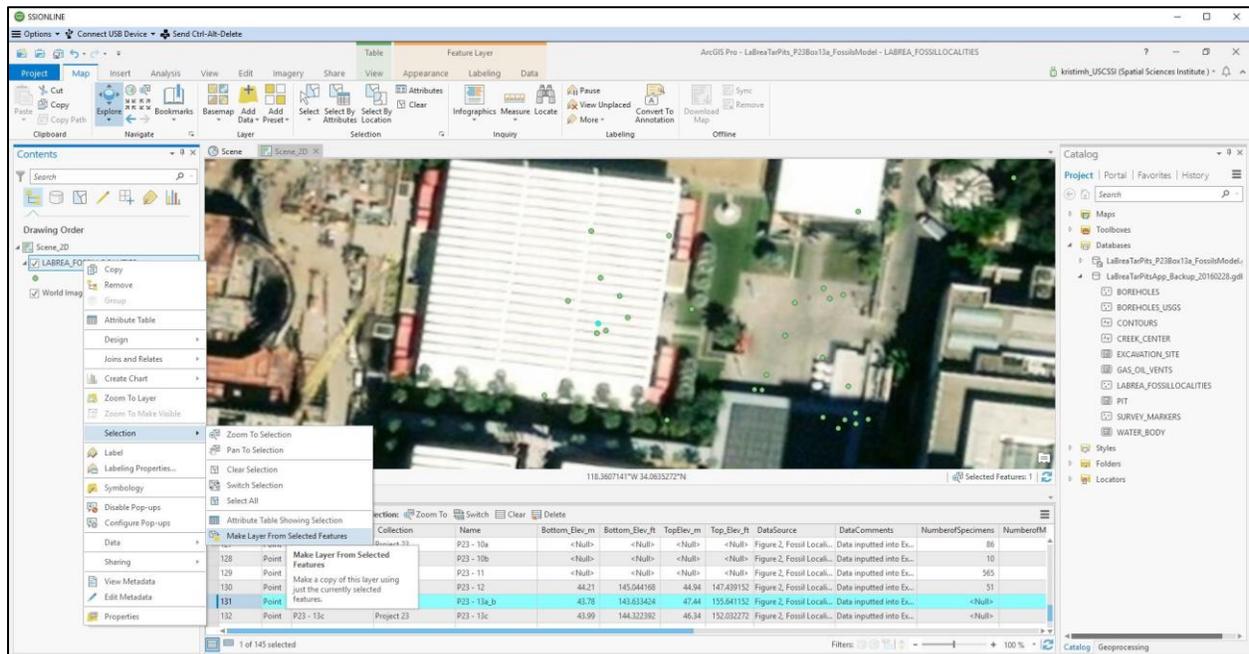
3. Right click on Scene under Contents, click Properties, select Elevation Surface, and check box “Allow Navigation below ground” and verify that Elevation source is Imagery basemap (Location: <https://elevation3d.arcgis.com/arcgis/rest/services/WorldElevation3D/Terrain3D/ImageServer>. Service Name: WorldElevation3D/Terrain3D. Vertical Units: Meters). Then select Coordinate Systems and verify Coordinate System is geographic CGS\_WGS\_1984.



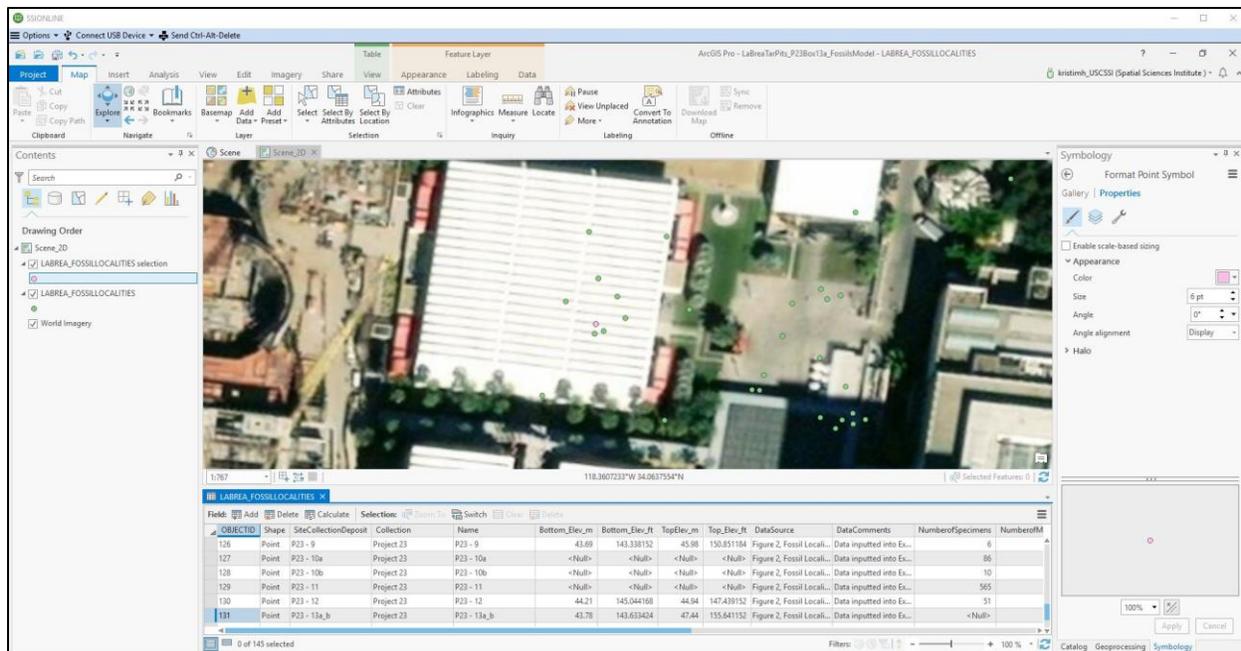
- In Scene\_2D, add LABREA\_FOSSILOCALITIES feature class (projection: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere) from LaBreaTarPitsApp\_Backup\_20160228.gdb.



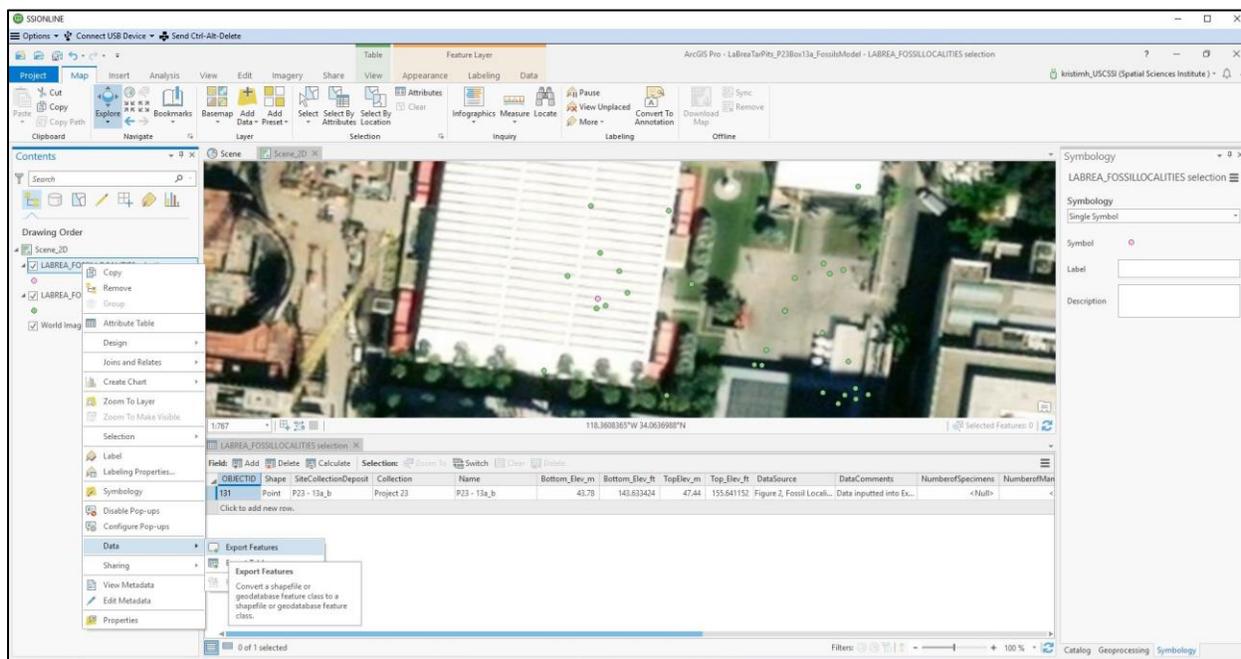
- Open LABREA\_FOSSILOCALITIES attribute table and select Box 13a feature. Right click on the feature class, select Selection and click Make Layer From Selected Features.



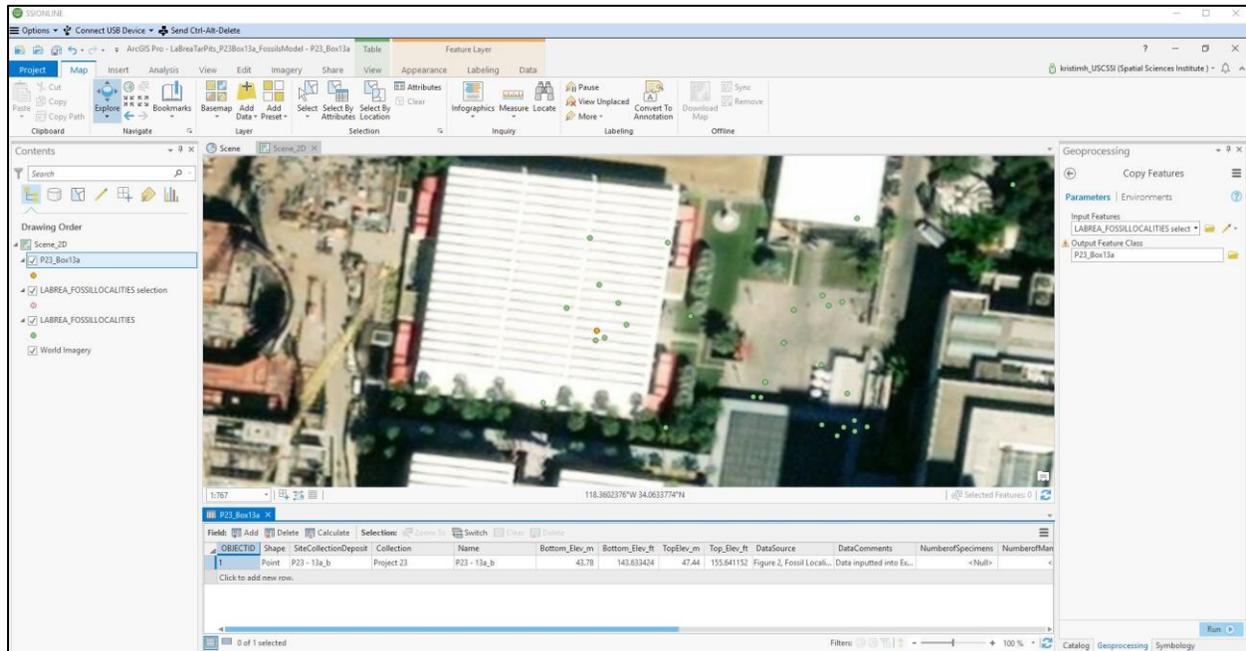
- Right click on the symbol below newly created layer, LABREA\_FOSSILLOCATIES selection, to open the Symbology template. Select Properties and change the symbol color.



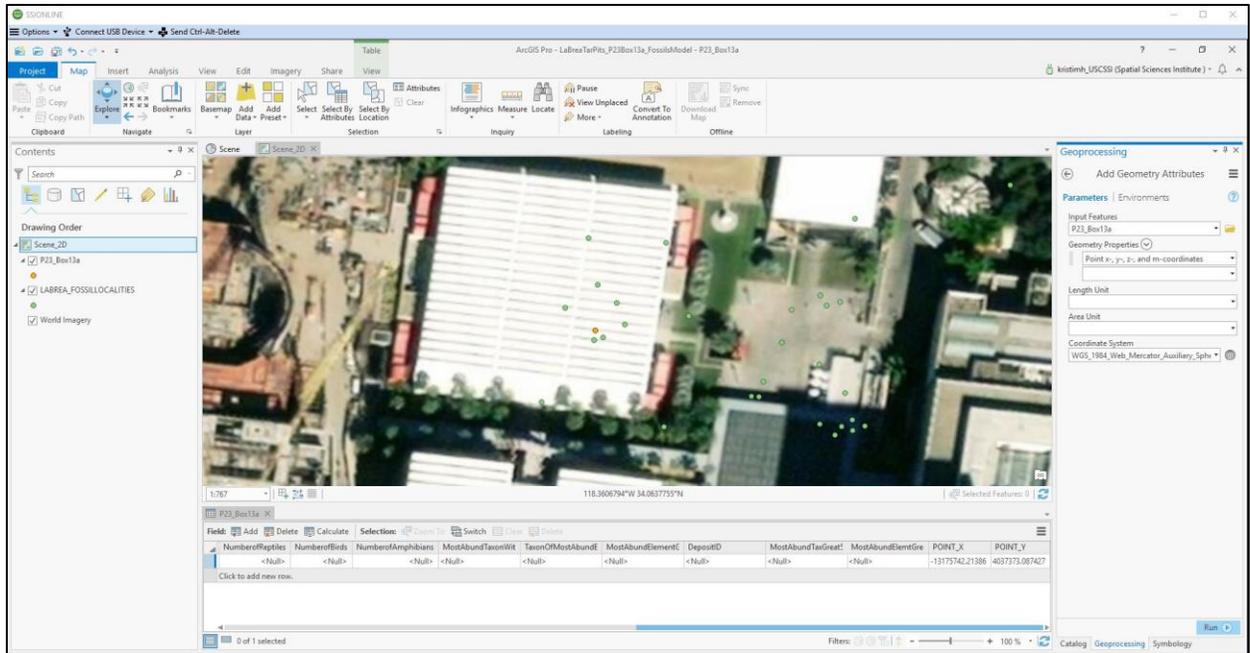
7. Then right click LABREAFOSSILOLOCALITIES selection, select Data and click Export Features.



- Open Copy Features template and under Parameters tab, name Output Feature Class: P23\_Box13a under LaBreaTarPits\_P23Box13a\_FossilsModel.gdb. Under Environments tab, indicate Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and indicate Output has Z Values: Same as Input. Click symbol under P23\_Box13a and change color in Symbology template.

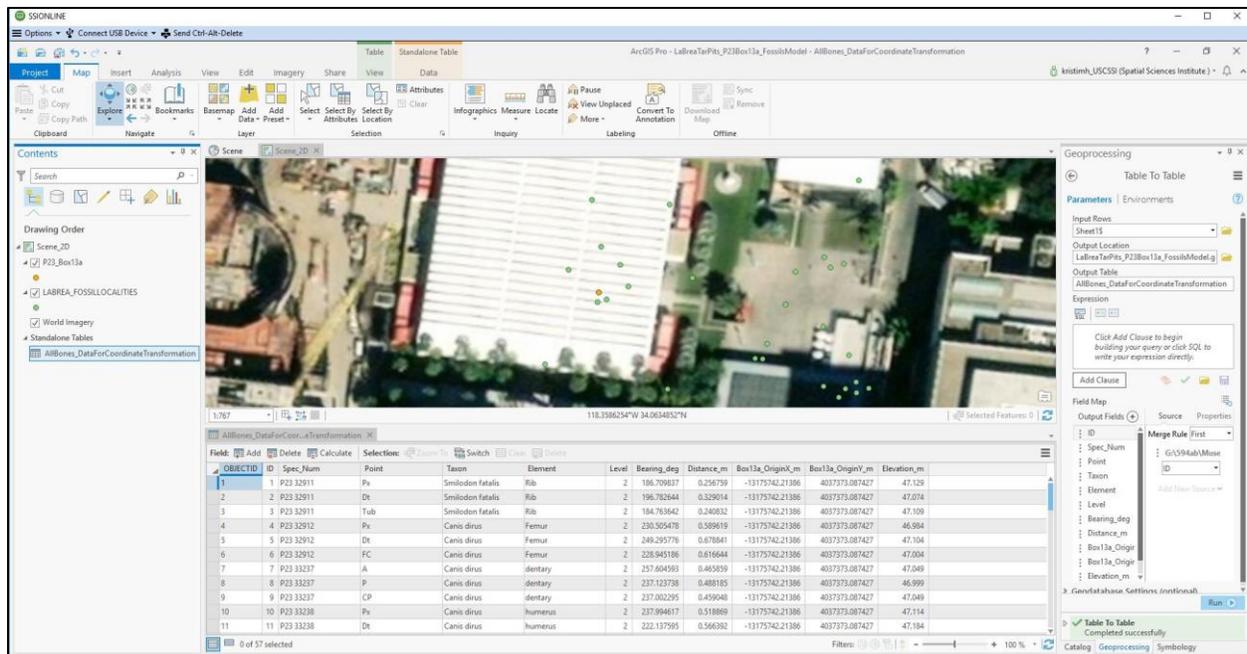


- Remove LABREA\_FOSSILLOCALITIES selection layer. Run Add Geometry Attributes tool on P23\_Box13a to calculate x and y in meters. Under Add Geometry Attributes template click on Parameters tab and indicate Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Then click on Environments tab and indicate Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Add the x and y data to the Excel table CoordinateTransformation.xlsx for coordinate transformation step.



## COORDINATE TRANSFORMATION:

10. Right click on LaBreaTarPits\_P23Box13a\_FossilsModel.gdb, select Import and click Table. Under Table to Table template under Parameters tab, indicate Input Rows: Sheet1\$ of AllBones\_DataForCoordinateTransformation.xlsx, Output Location: LaBreaTarPits\_P23Box13a\_FossilsModel.gdb and Output Table: AllBones\_DataForCoordinateTransformation. Then run Table to Table tool.

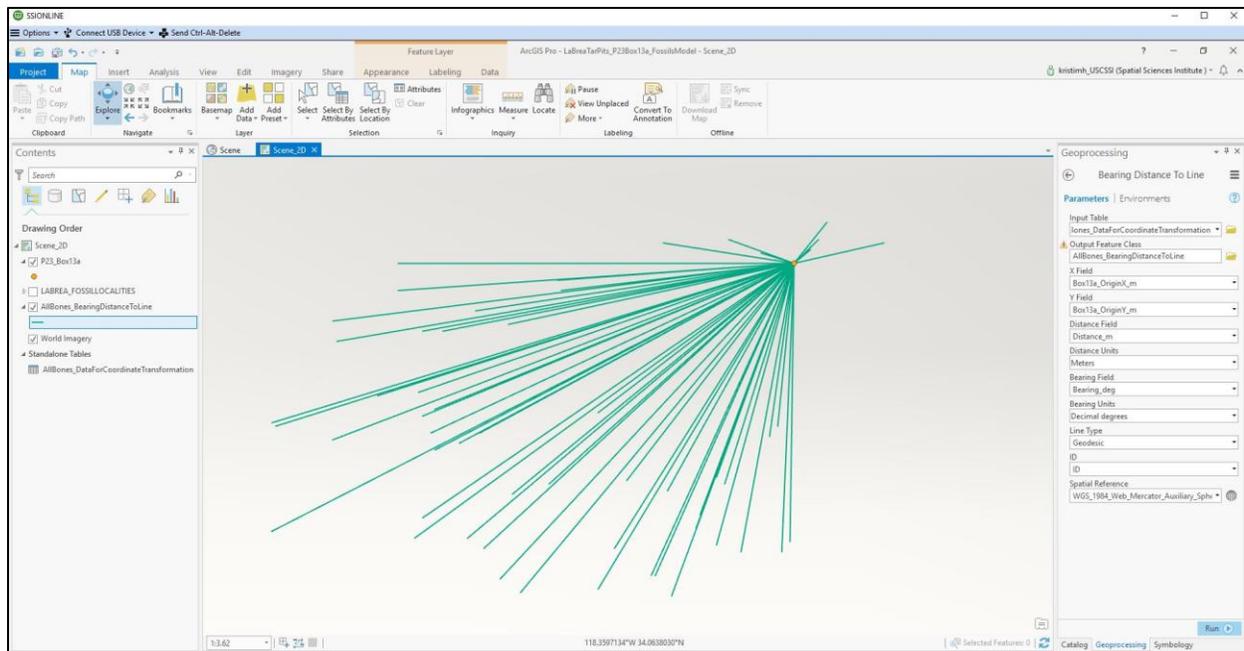


11. Run the Bearing Distance to Line tool with Input Table:

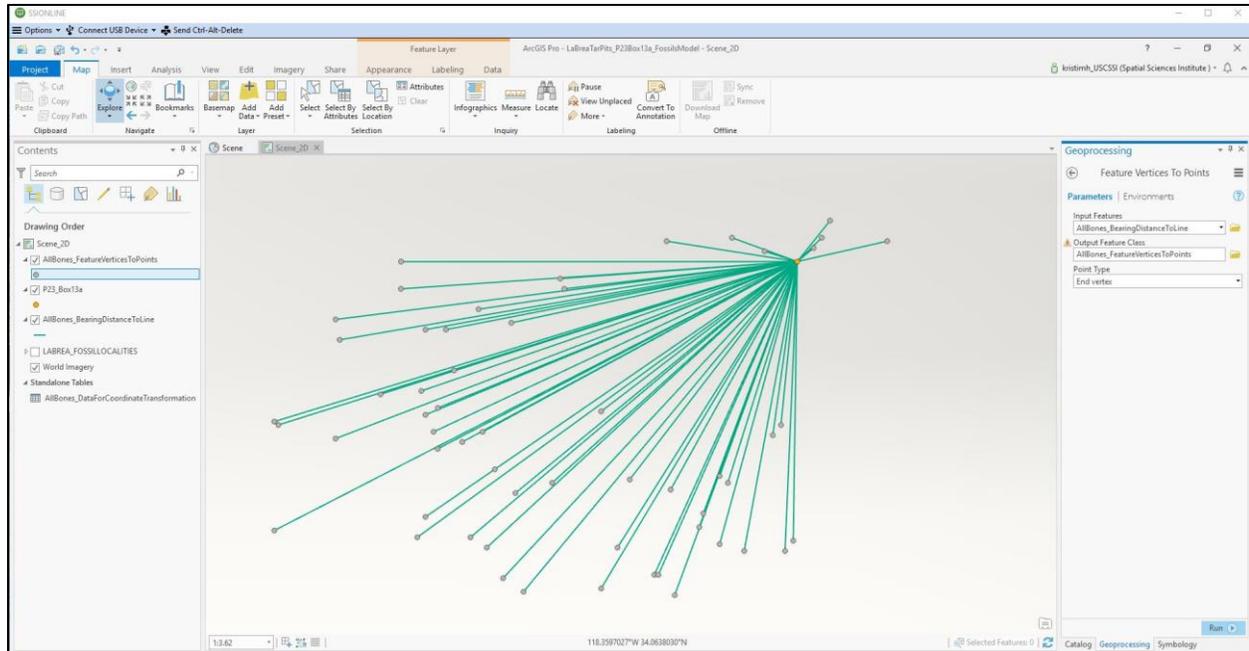
AllBones\_DataForCoordinateTransformation and Output Feature Class:

AllBones\_BearingDistancetoLine under LaBreaTarPits\_P23Box13a\_FossilsModel.gdb.

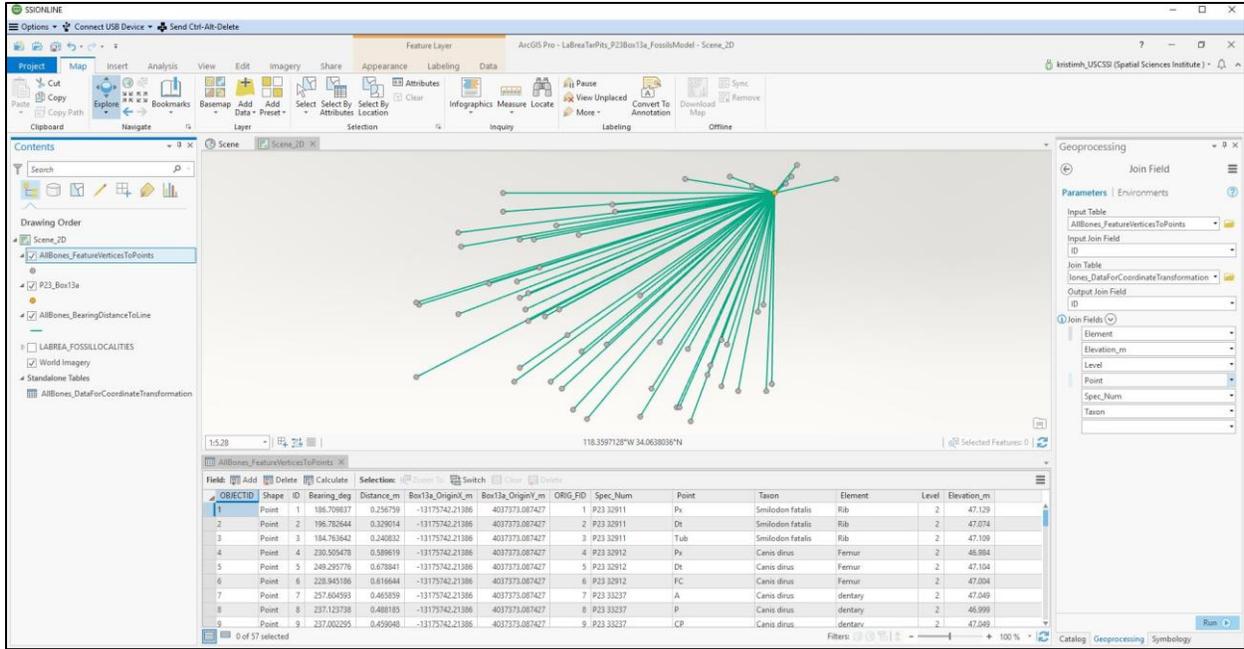
In the Bearing Distance to Line template under Parameters tab, match X and Y fields to origin fields, match bearing and distance fields, indicate Distance Units: meters and Bearing Units: decimal degrees, match ID to ID field and indicate Spatial Reference: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere.



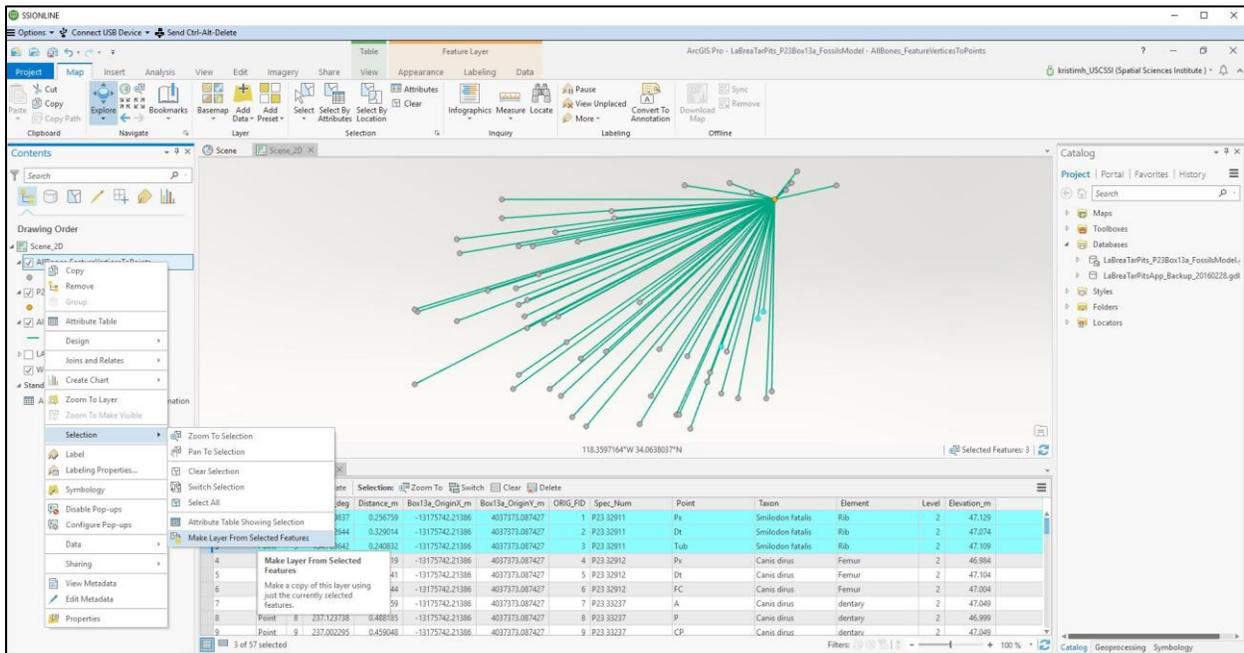
12. Run Feature Vertices to Points tool: in template under Parameters tab, indicate Input Features: AllBones\_BearingDistanceToLine, name Output Feature Class: AllBones\_FeatureVerticesToPoints under LaBreaTarPits\_P23Box13a\_FossilsModel.gdb and indicate Point Type: End vertex. Under Environments tab, indicate Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and left Output has Z Values: Same as input.



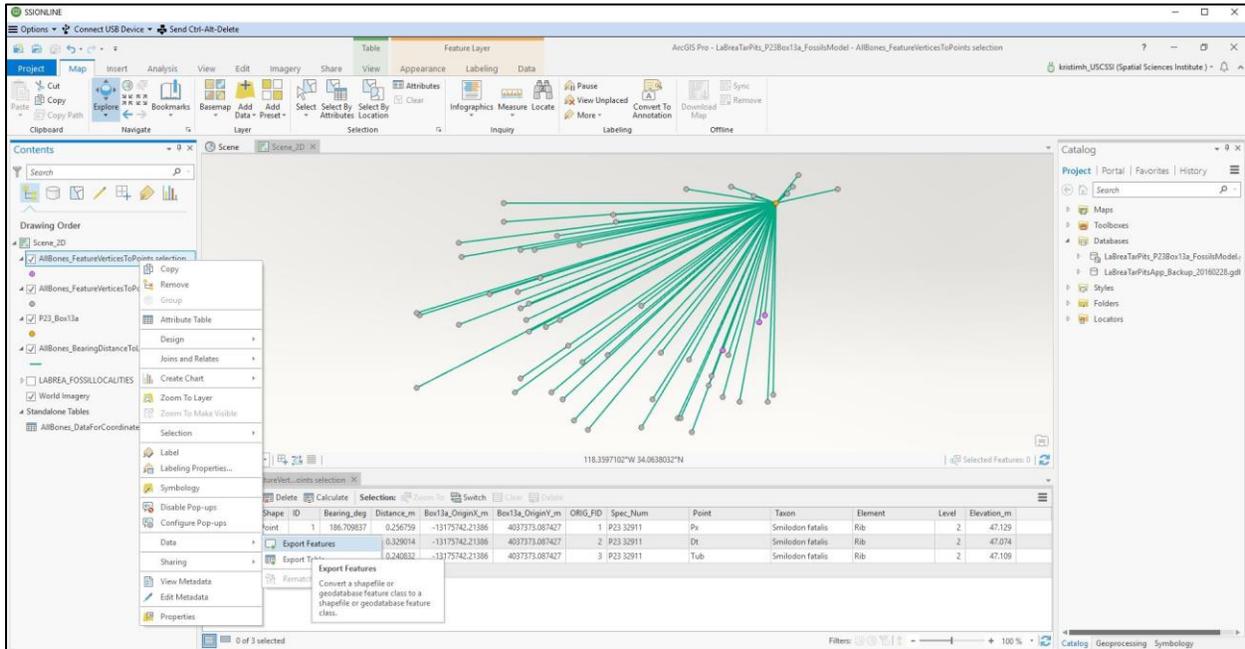
13. Use Join Field tool to add fields to attribute table lost in previous step. Under Join Field template under Parameters tab, indicate Input Table: AllBones\_FeatureVerticesToPoints, Input Join Field: ID, Join Table: AllBones\_DataFor CoordinateTransformation, Output Join Field: ID and Join Fields: Element, Elevation\_m, Level, Point, Spec\_Num, and Taxon.



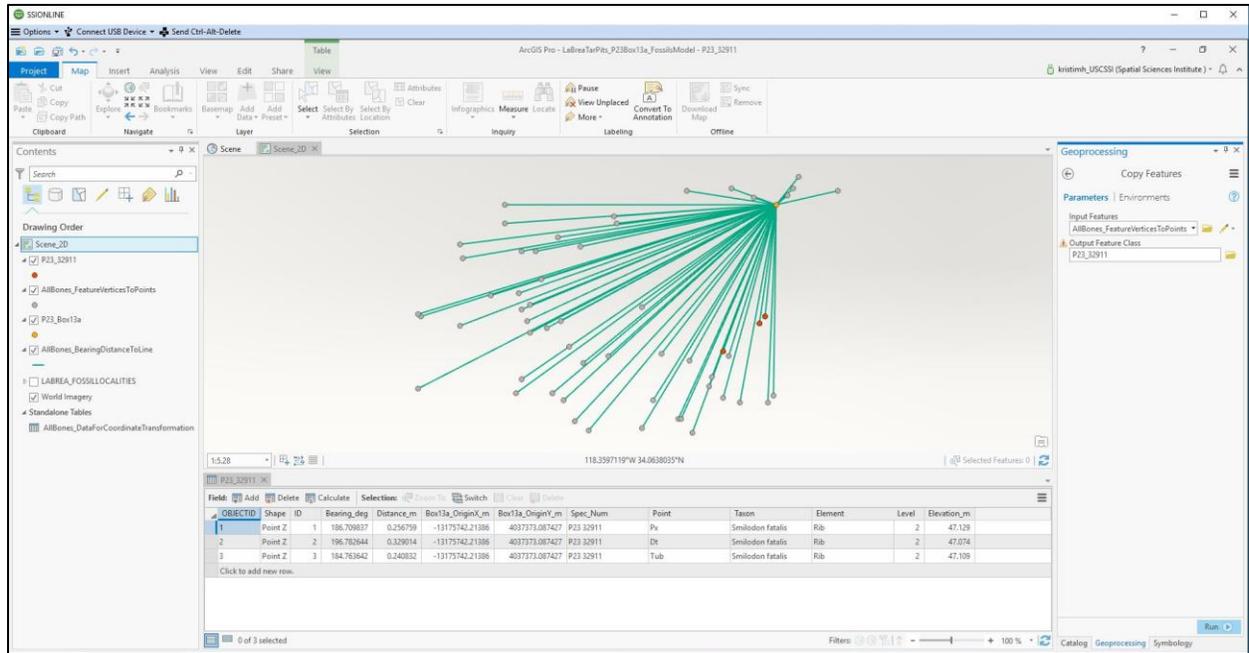
14. Select first set of coordinates (P23\_32911) from AllBones\_FeatureVerticesToPoints attribute table, right click on feature class, select Selection, click Make Layer From Selected Features.



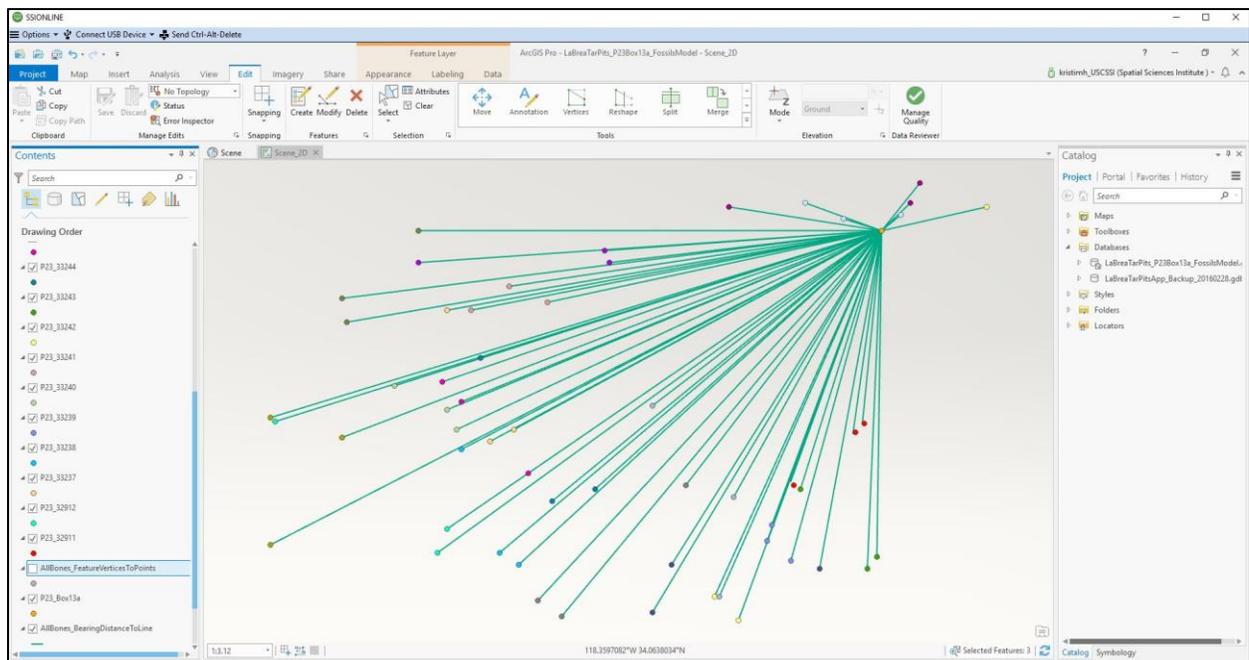
- Right click on symbol below newly created AllBones\_FeatureVerticesToPoints selection layer to change the color in the Symbology template. Right click on AllBones\_FeatureVerticesToPoints selection layer, select Data and click Export Features.



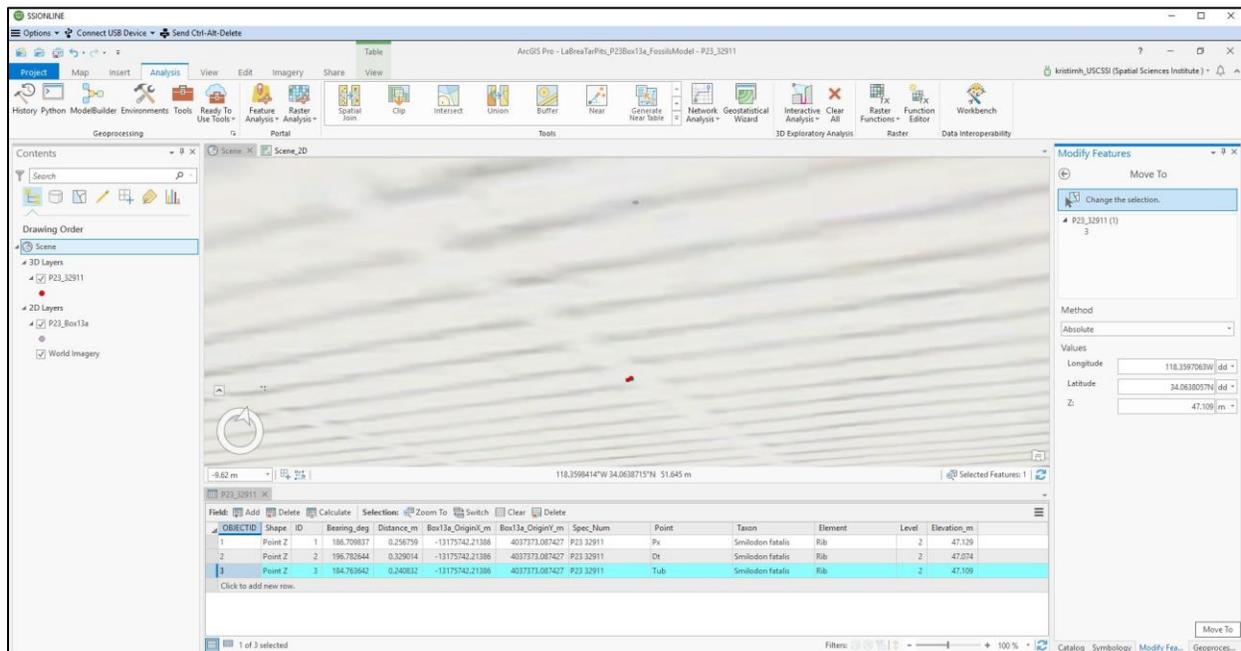
- Under Copy Features Template under Parameters tab, name Output Feature Class: P23\_32911 under LaBreaTarPits\_P23Box13a\_FossilsModel.gdb. Under Environments tab, indicate Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and Output have Z Values: Enabled. Run tool. Right click on symbol below newly created P23\_32911 feature class to change the color in the Symbology template. Remove AllBones\_FeatureVerticesToPoints selection layer from Contents.



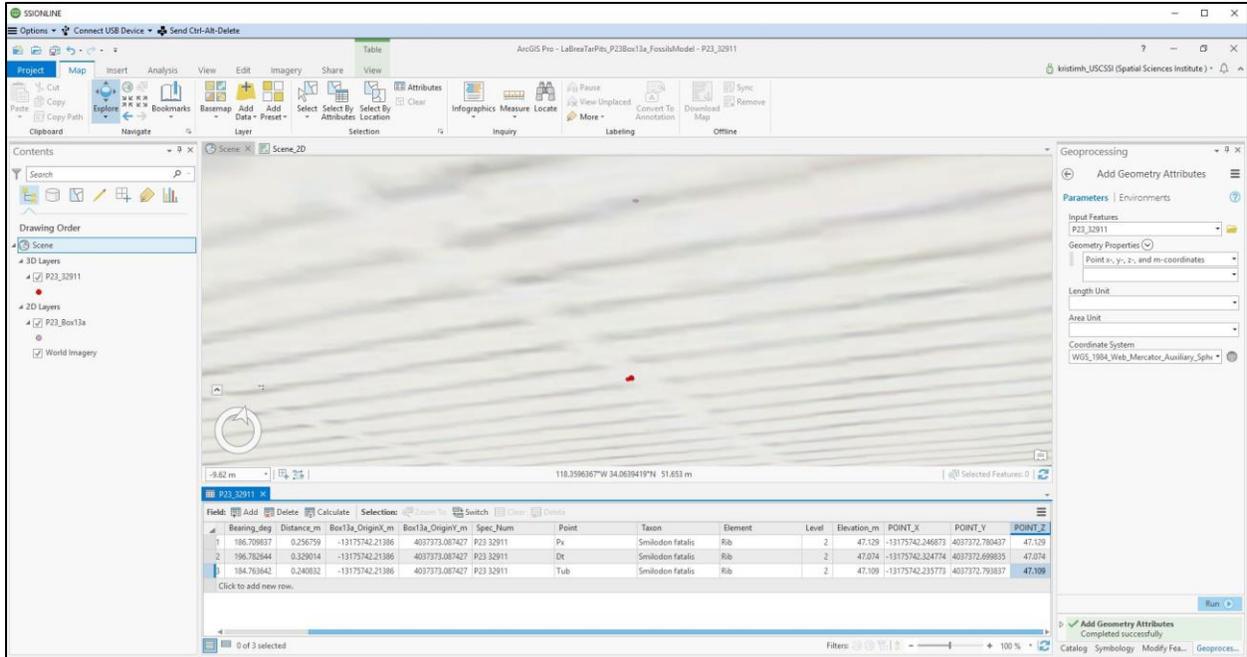
17. Repeat the last three steps for the remaining 18 bones' coordinates.



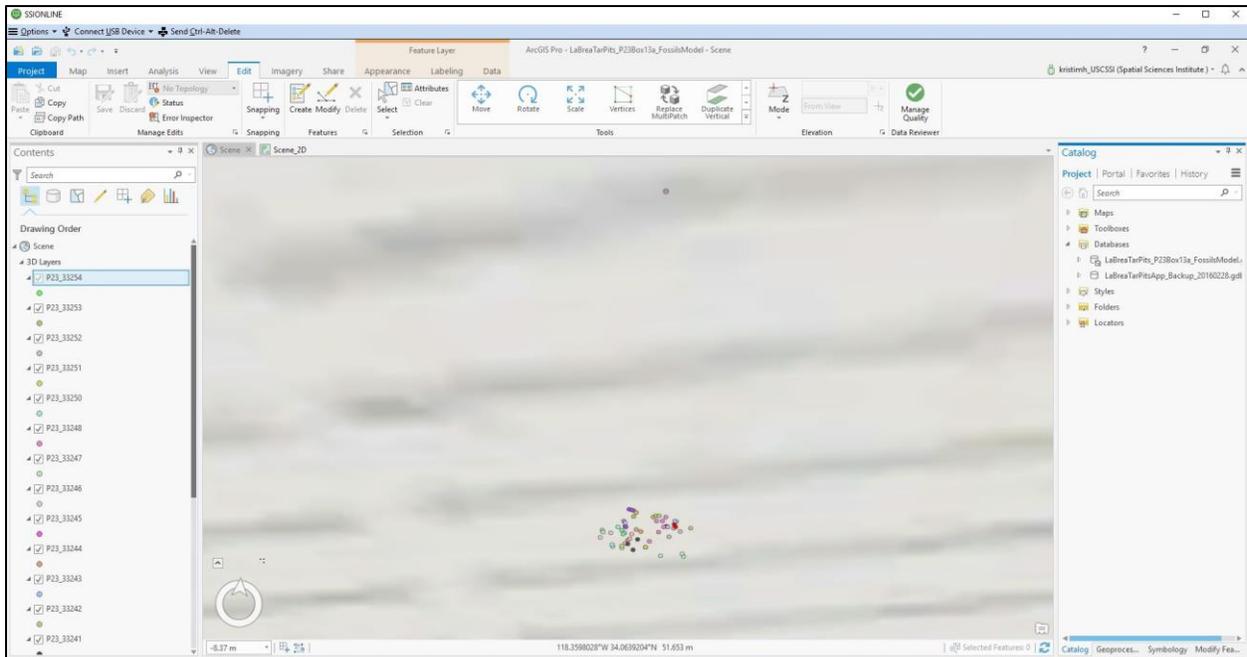
18. In the Scene tab, add P23\_Box13a and P23\_32911 feature classes. Open the P23\_32911 attribute table. Select P23\_32911 under Contents and click the Edit tab and then Modify. Select the three-point features in the attribute table. Click the Move To tool and under Move To template, select Method: Absolute and for Z: enter the elevation in meters for the selected point listed in the attribute table. Complete this step for the remaining two points in the feature class and save edits.



19. Clear the selection and run Add Geometry Attributes tool on P23\_32911. Under the Add Geometry Attributes template, click Parameters tab and indicate Input Features: P23\_32911, Geometry Properties: Point x-, y-, and m- coordinates and Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Click Environments tab and specify Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. This step is to verify the that the Move To tool was executed properly by generating a z value as well as to calculate x and y data for each coordinate.

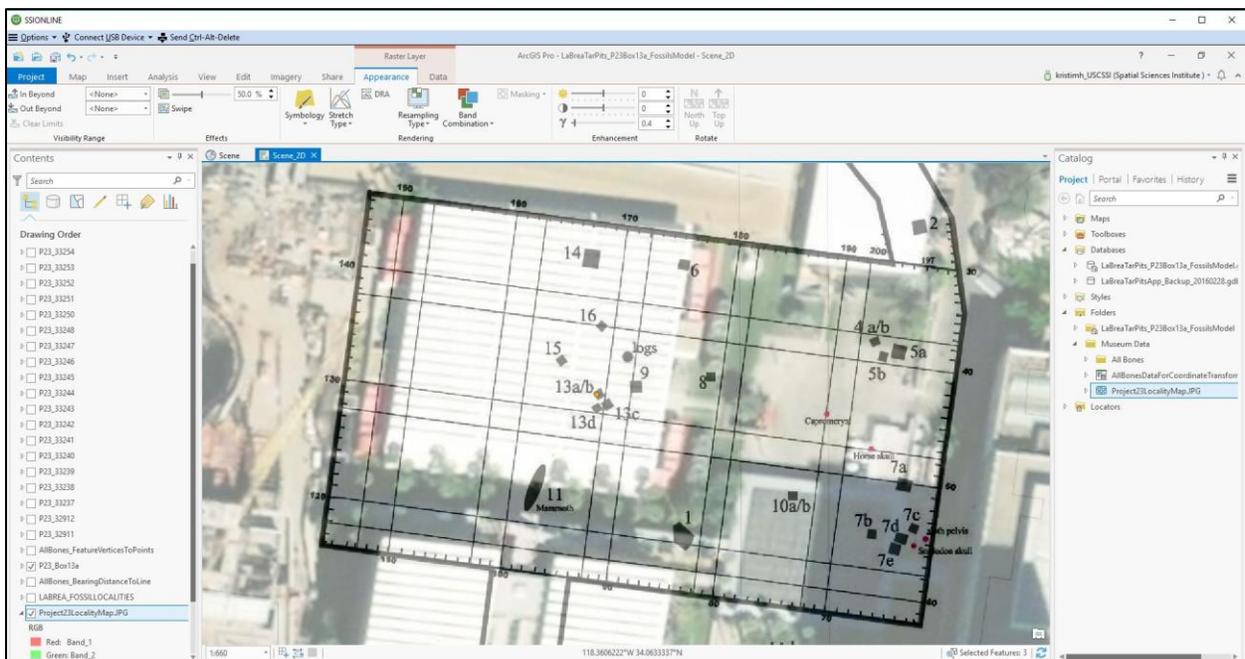


20. Repeat the last two steps for the remaining 18 fossils' sets of coordinates.



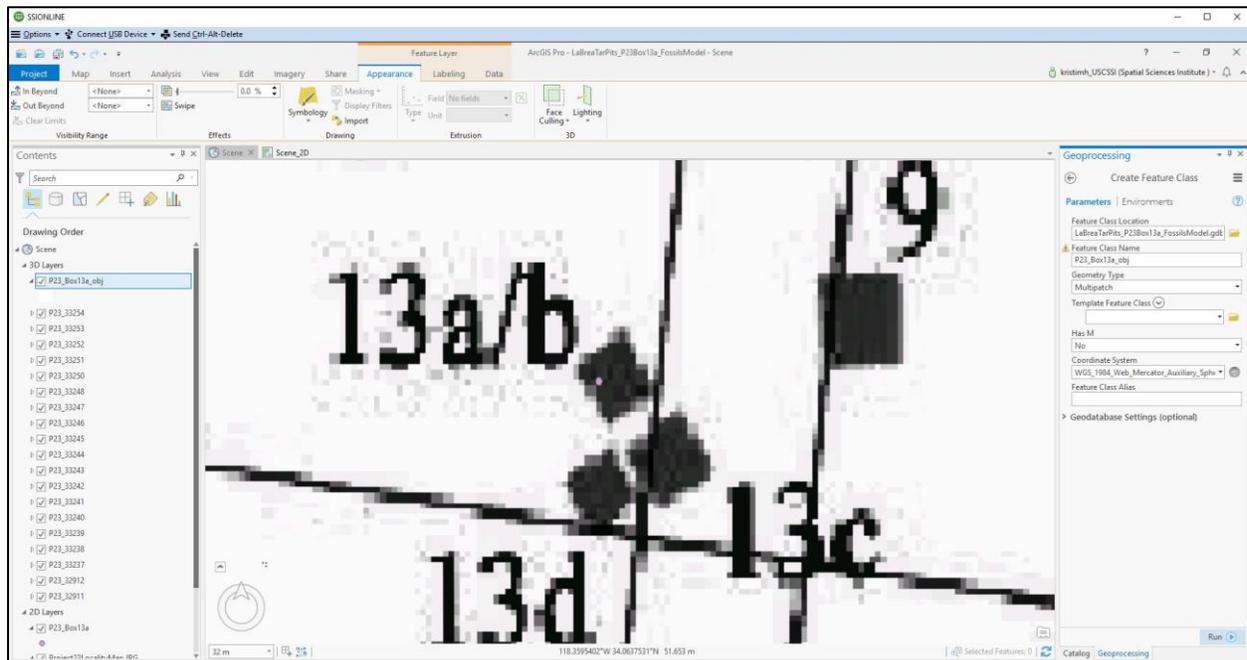
## IMAGE GEOREFERENCING & BOX AND GRIDS CREATION:

21. In ArcGIS Pro in Scene\_2D, right-click Folders under the Catalog tab and click Add Connection to access Museum Data folder. Drag Project23LocalityMap.jpg into Scene\_2D and adjusted Transparency to 50% under the Appearance tab to ensure the imagery is facing north so that Box 13a orientation can be deduced. Use the Georeference tool to approximately scale and align the map with Box 13a and the surrounding property.

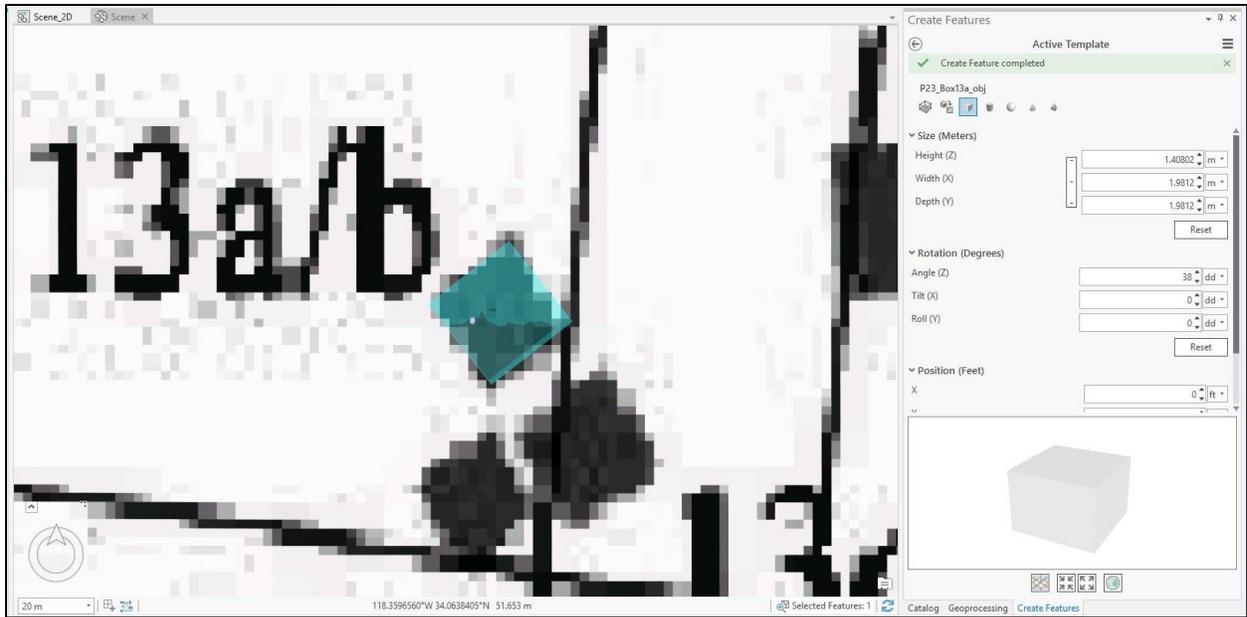


22. Add Project23LocalityMap.jpg to the Scene. Do not adjust transparency. Right click on LaBreaTarPits\_P23Box13a\_FossilsModel.gdb in Catalog, select New and click Feature Class. Under Create Feature Class template under the Parameters tab, indicate Feature Class Name: P23\_Box13a\_obj, Geometry Type: Multipatch and Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Under the Environments tab, specify

Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and Output has Z Values: Enabled.



23. Select P23\_Box13a\_obj in Contents, select Edit tab, click Create and select the Cube in the Active Template. Under Active Template, click the icon to unlink size dimensions together to scale proportionally and indicate Height (Z): 1.40208 m, Width (X): 1.9812 m, Depth (Y): 1.9812 m. and Rotation: 38 dd. Digitize cube in Scene approximately in line with Box 13a on Project23LocalityMap.jpg. Set Transparency to 75% under the Appearance tab.

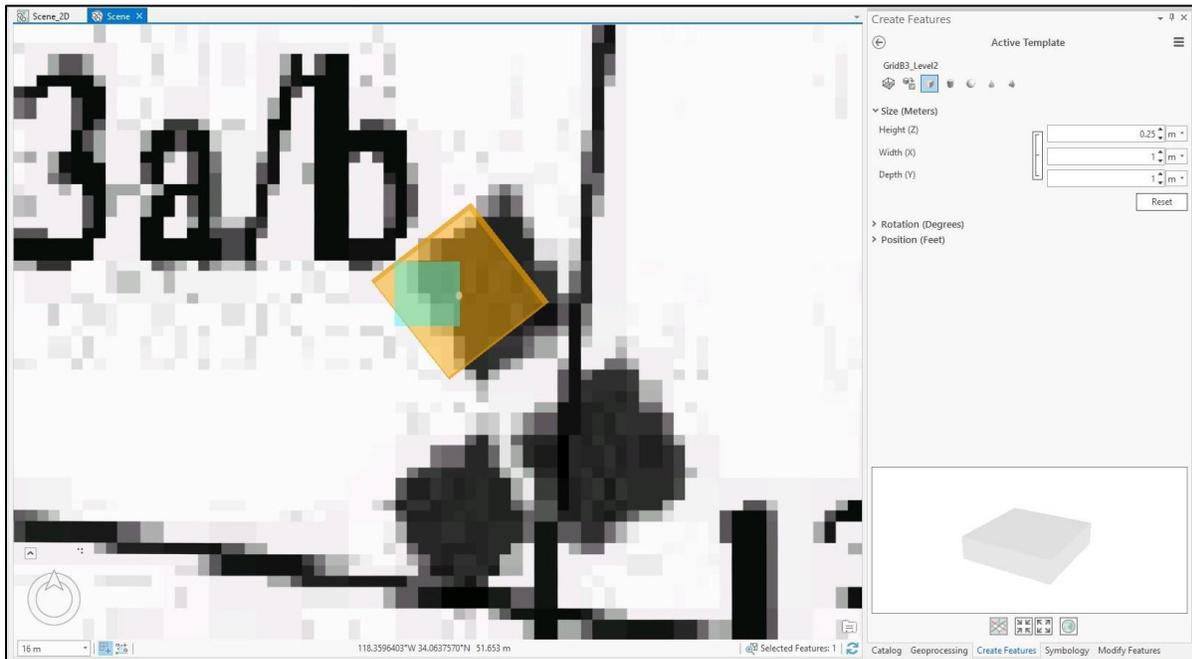


24. Under Edit tab, select Modify and use Move tool to center box over P23\_Box13a point.



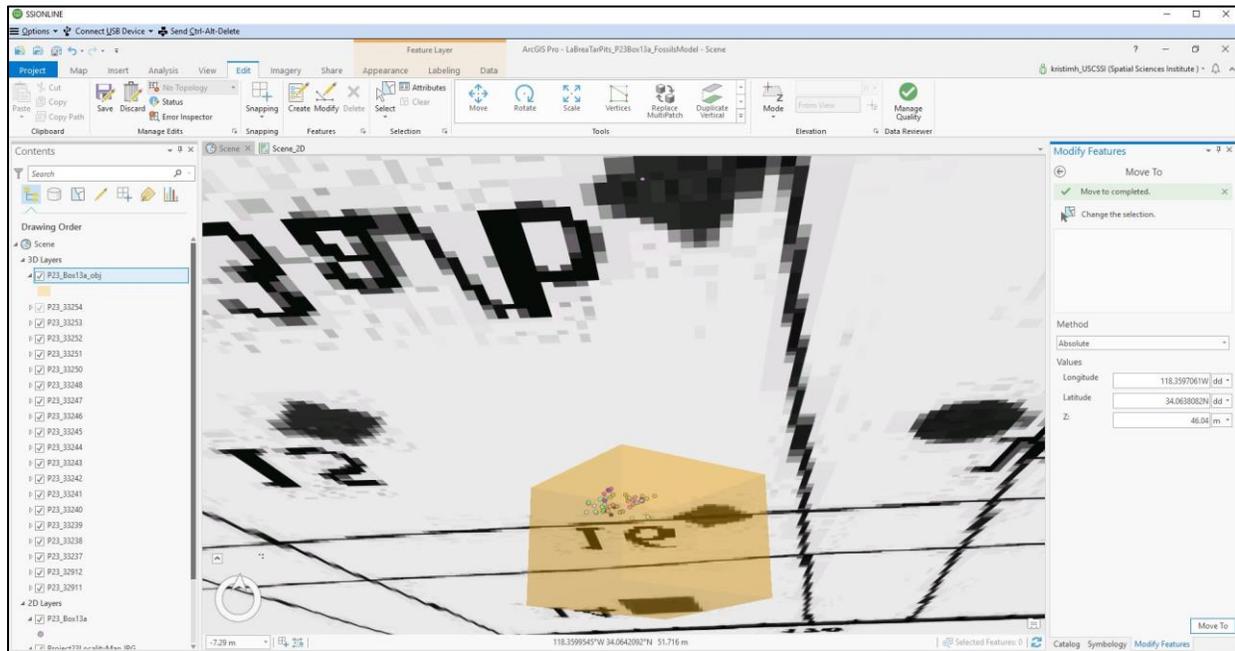
25. Right click on LaBreaTarPits\_P23Box13a\_FossilsModel.gdb in Catalog, select New and click Feature Class. Under Create Feature Class template under the Parameters tab,

indicate Feature Class Name: GridB3\_Level2, Geometry Type: Multipatch and Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Under the Environments tab, specify Output Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and Output has Z Values: Enabled. Selected GridB3\_Level2 in Contents and select Edit tab. Click Create and select the Cube in the Active Template. Under Active Template, click the icon to unlink size dimensions together to scale proportionally and indicate Height (Z): 0.25 m, Width (X): 1 m and Depth (Y): 1 m. Do not adjust the Rotation: 0 dd. Position and digitize cube in Scene on P23\_Box13a at approximately 0 cm W, 50 cm N in Grid B3 Level 2. Set Transparency to 50-75% under the Appearance tab. Save edits. GridB3\_Level 2 is pictured in blue above below.



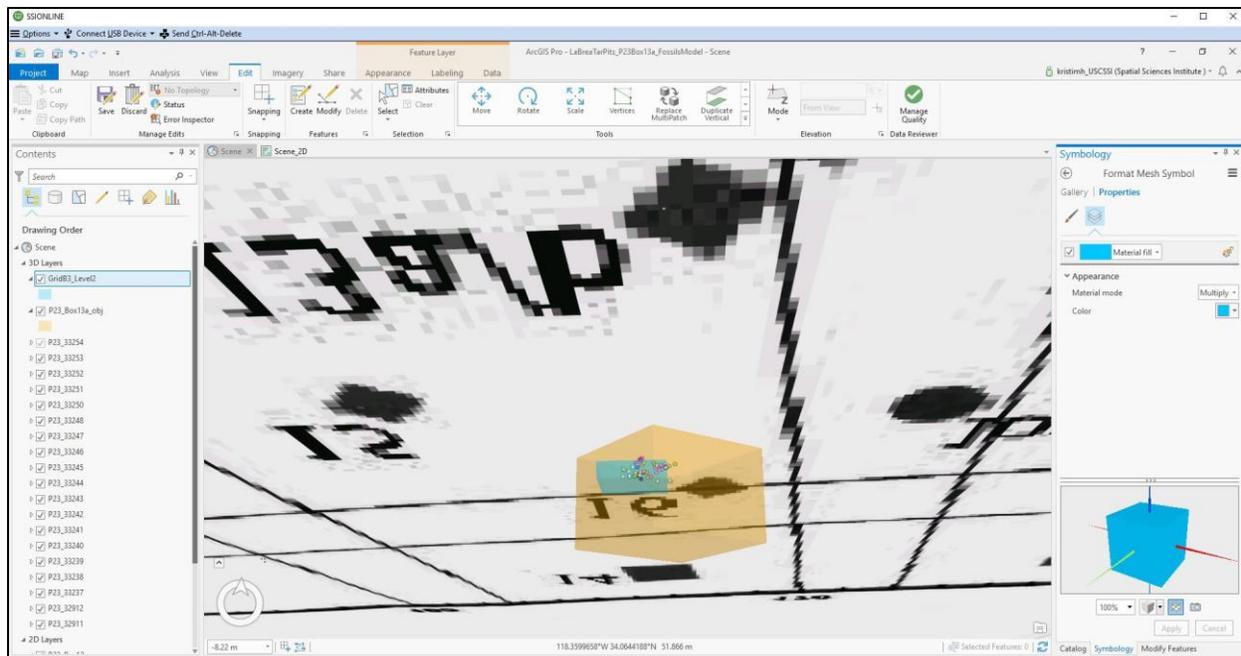
26. Select P23\_Box13a\_obj in Contents and select Edit tab. Click Modify and select Move To tool. Select P23\_Box13a\_obj in Scene. Under Move To template, indicate Method:

Absolute and Z: 46.03792 m. This process moves P23\_Box13a\_obj below ground surface. Select symbol below P23\_Box13a\_obj. Under Format Mesh Symbol template under Symbology, select Properties tab and select Color: Electron Gold.

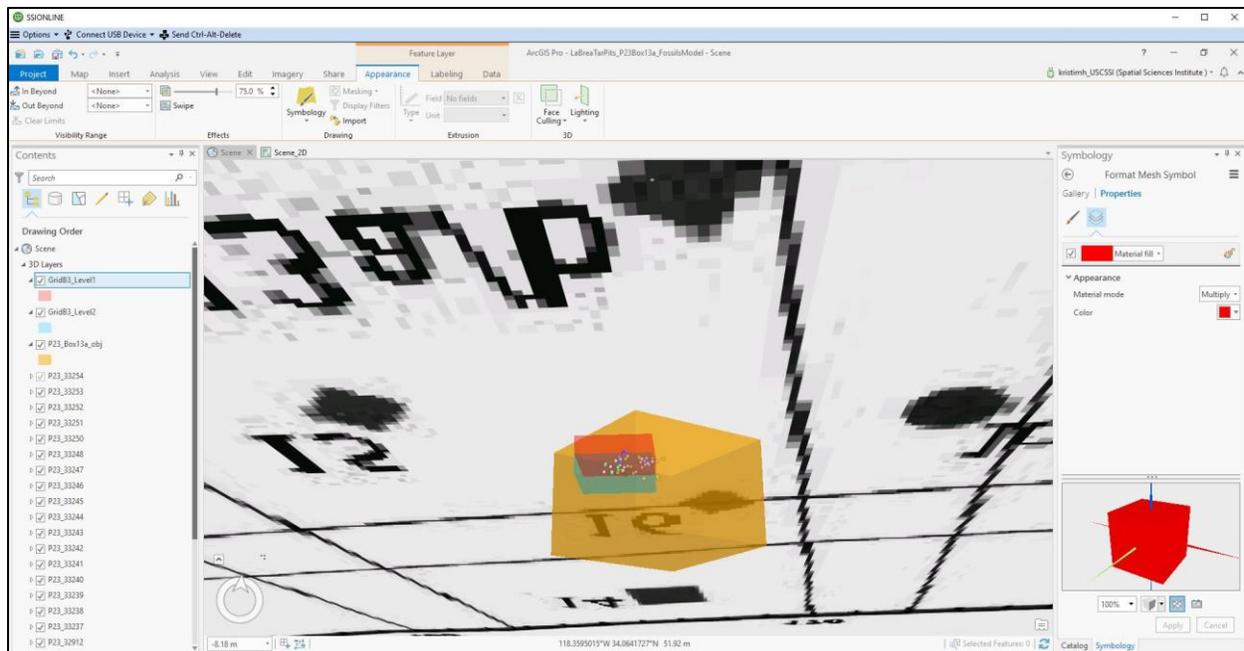


27. Select GridB3\_Level2 in Contents, select Edit tab, click Modify and select Move To tool.

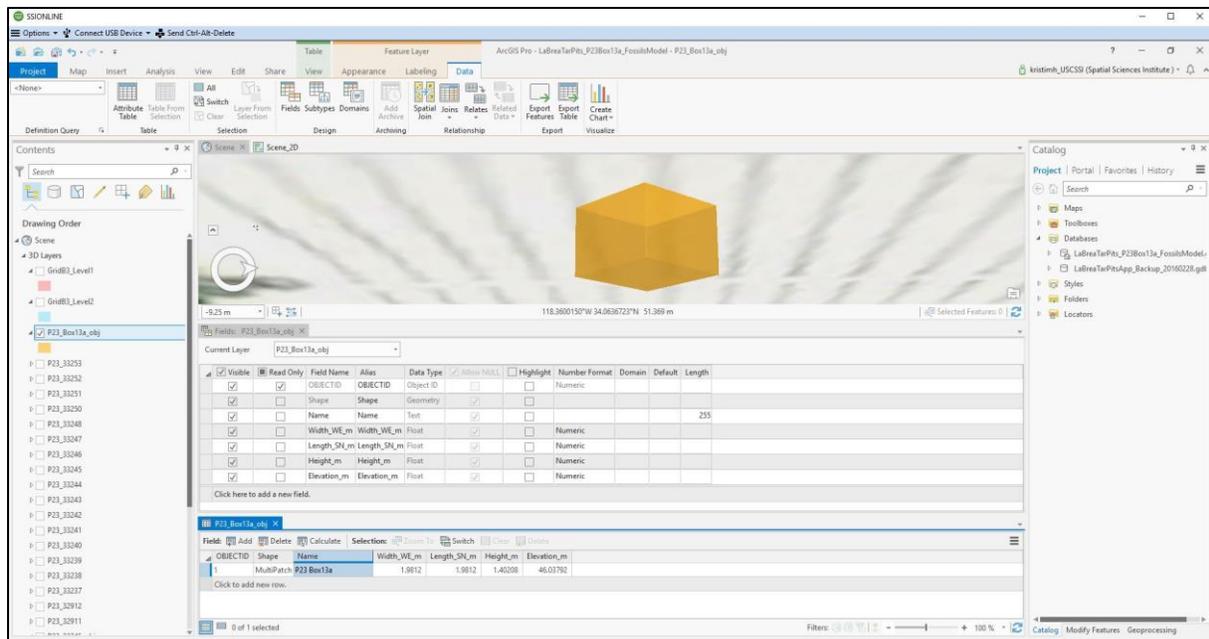
Select GridB3\_Level 2 in Scene. Under Move To template, specify Method: Absolute and Z: 46.94 m. This process moves GridB3\_Level2 below ground surface. Select symbol below GridB3\_Level2 and under Format Mesh Symbol template under Symbology, select Properties tab and select Color: Big Sky Blue.



28. Under LaBreaTarPits\_P23Box13a\_FossilsModel.gdb in Catalog, right click GridB3\_Level2 and click copy. Then right click LaBreaTarPits\_P23Box13a\_FossilsModel.gdb and click Paste. Rename copy of GridB3\_Level2 feature class to GridB3\_Level1 and add GridB\_Level1 to the Scene. Select GridB3\_Level1 in Contents, select Edit tab, click Modify and select Move To tool. Select GridB3\_Level1 in Scene. Under Move To template, indicate Method: Absolute and Z: 47.19 m. This process moves GridB3\_Level1 below ground surface. Select symbol below GridB3\_Level2 and under Format Mesh Symbol template under Symbology, select Properties tab and select Color: Mars Red. Set Transparency to 75% under Appearance tab. Transparencies of Box 13a and grids are set at 50-75% as needed for best viewing below.



29. To add attributes to P23\_Box13a\_obj, GridB3\_Level1 and Grid\_B3 Level2, right click each feature class in the Contents pane and select Attribute Tables. Under Data tab, select Fields and click Add New Field on Fields table. For P23\_Box13a\_obj., add Fields: Name, Width\_WE\_m, Length\_SN\_m, Height\_m and Elevation\_m. For GridB3\_Level1 and GridB3\_Level2, add Fields: Name, Width\_m, Length\_m, Height\_m and Elevation\_m. Save changes in Fields tab and then fill in attribute information in tables.



## FOSSIL 3D OBJECT IMPORT AND PLACEMENT INSTRUCTIONS:

30. Turn off ProjectLocalityMap.jpg layer. Right click

LaBreaTarPits\_P23Box13a\_FossilsModel.gdb in Catalog, select New and select Feature Class. Under Parameters tab, indicate Feature Class Location:

LaBreaTarPits\_P23Box13a\_FossilsModel.gdb, Feature Class Name: P23\_33245\_obj,

Geometry Type: Multipatch and Coordinate System:

WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere. Under Environments tab, specify Output

Coordinate System: WGS\_1984\_Web\_Mercator\_Auxiliary\_Sphere and Output has Z

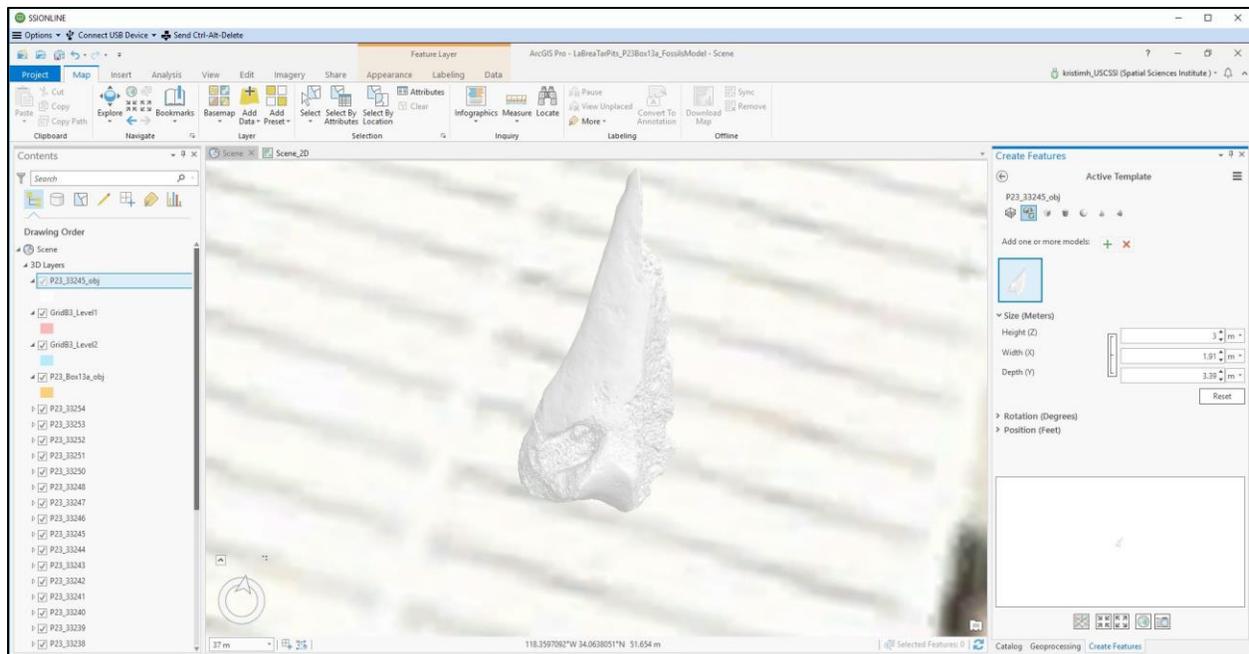
Values: Enabled. Click Run. Click on P23\_33245\_obj in Contents tab and select Edit tab

and then Create. Under Active Template, select Model File icon and add OBJ file of

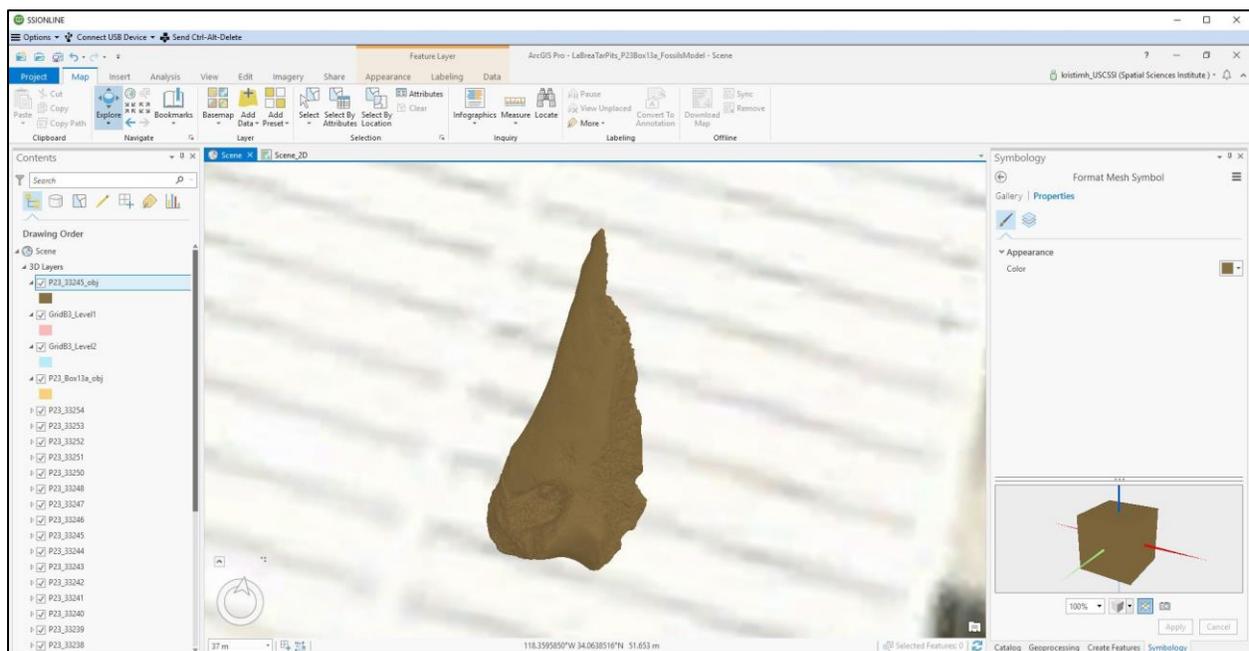
fossil P23 33245, change Size to meters and Reset Height (Z) to 3 m as Width (X) and

Depth (Y) scaled proportionally. Digitize fossil above Box 13a centroid P23\_Box13a.

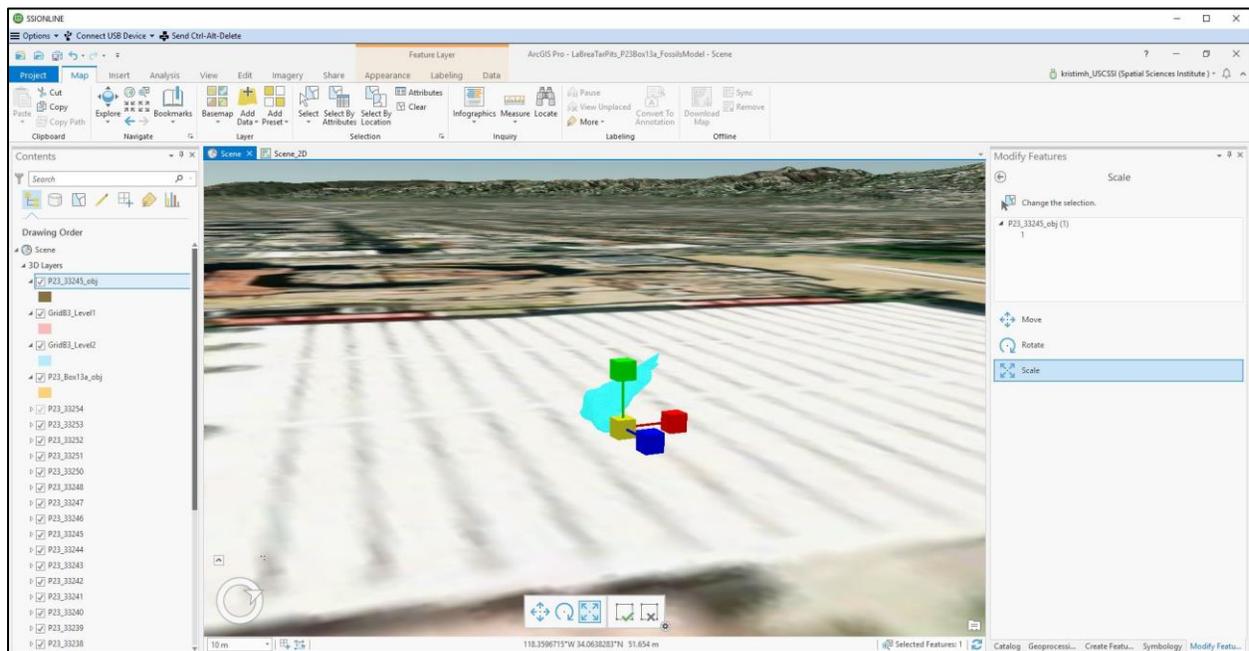
Save edits.



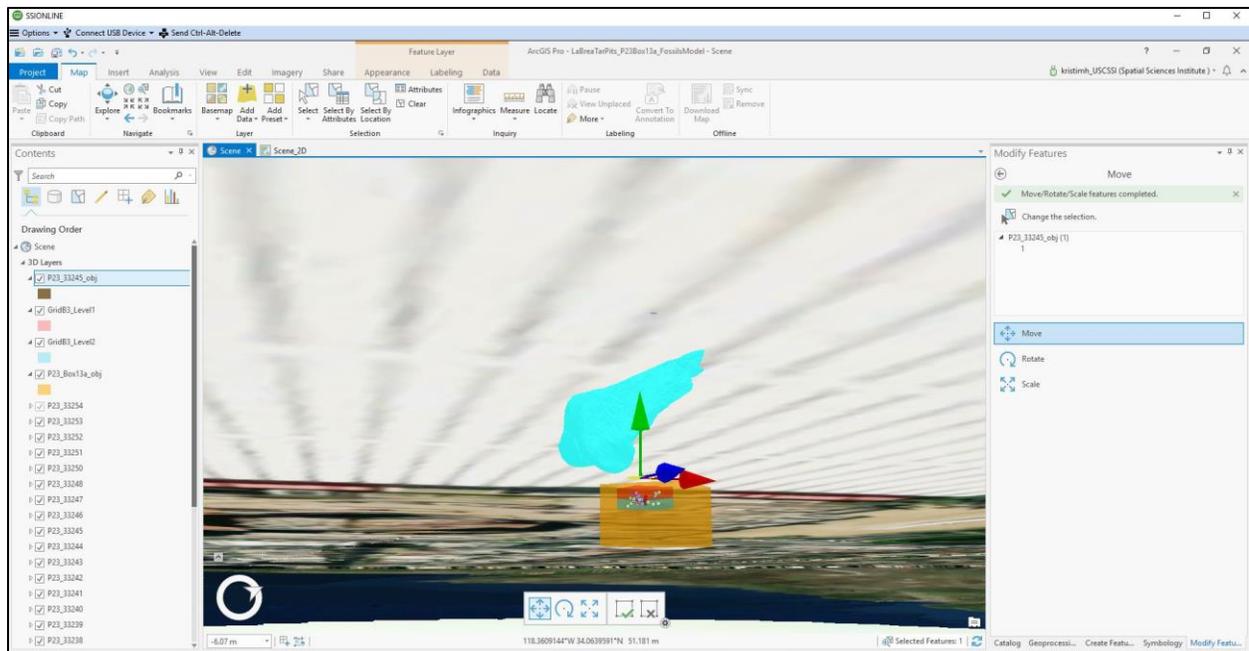
31. With P23\_33245\_obj selected in Scene, click Appearance tab. Under Symbology, select Single Symbol and click on symbol below it. Under Format Mesh Symbol tab, click Properties tab and change color to Leather Brown. Click Apply.



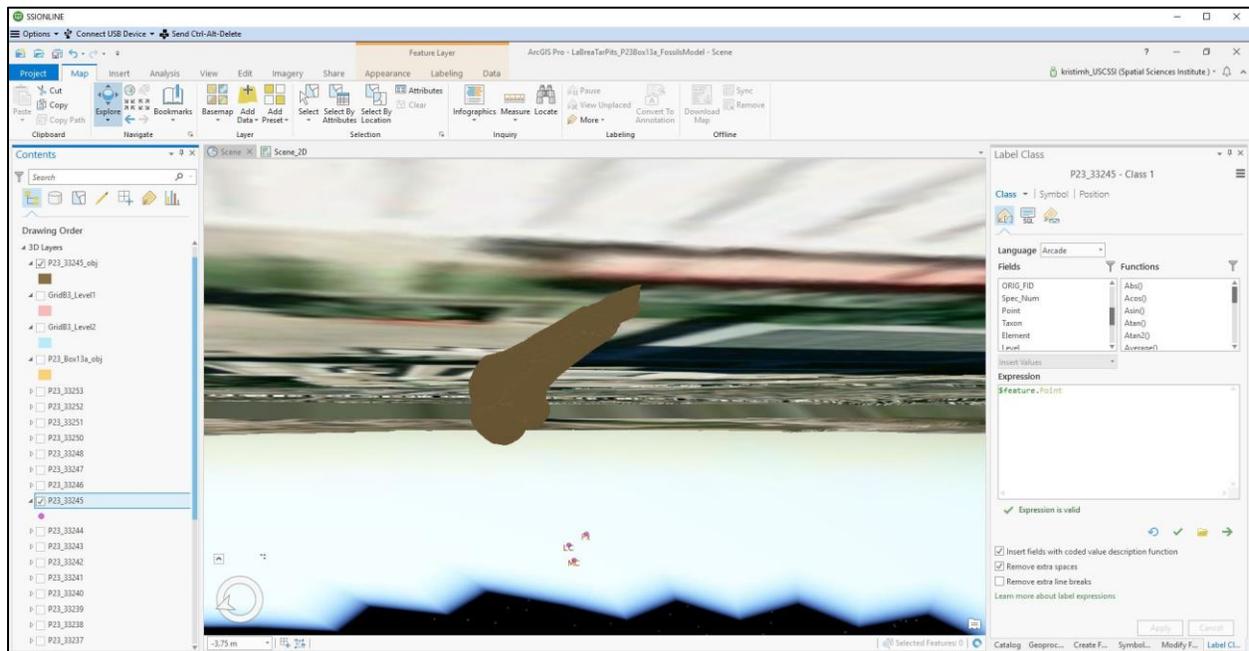
32. Select P23\_33245\_obj in Scene, click Edit tab, click Modify. Under Modify Features, select Scale. Click and hold mouse on yellow box in Scene to manually scale down feature while maintaining proportions. Click box with green check mark to apply changes.



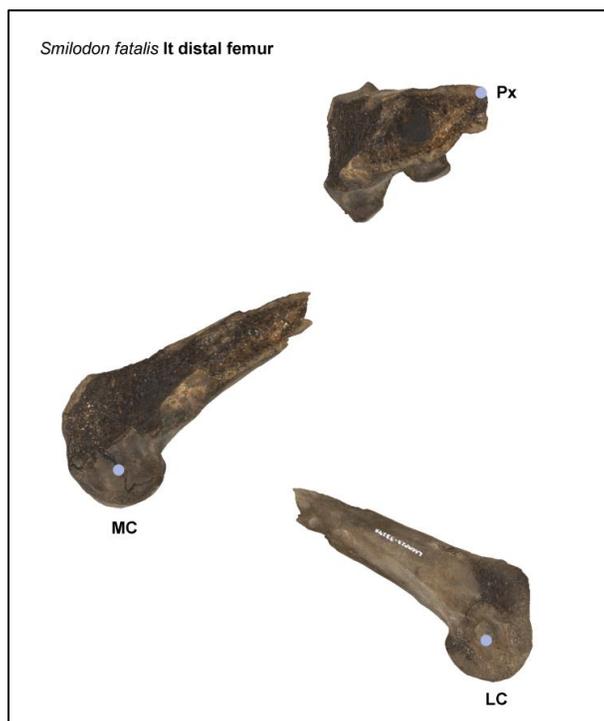
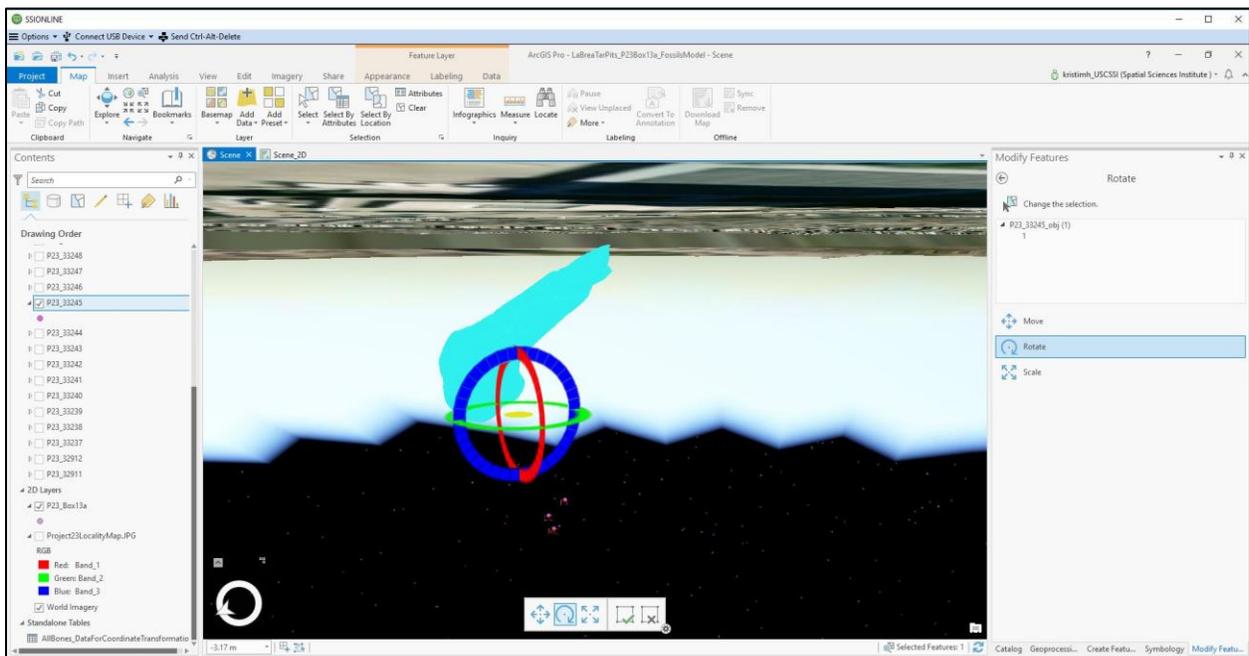
33. Under Modify Features, click Move and click and hold mouse over green arrow to move the feature below the ground surface. Click on red and blue arrows to move the feature side to side.



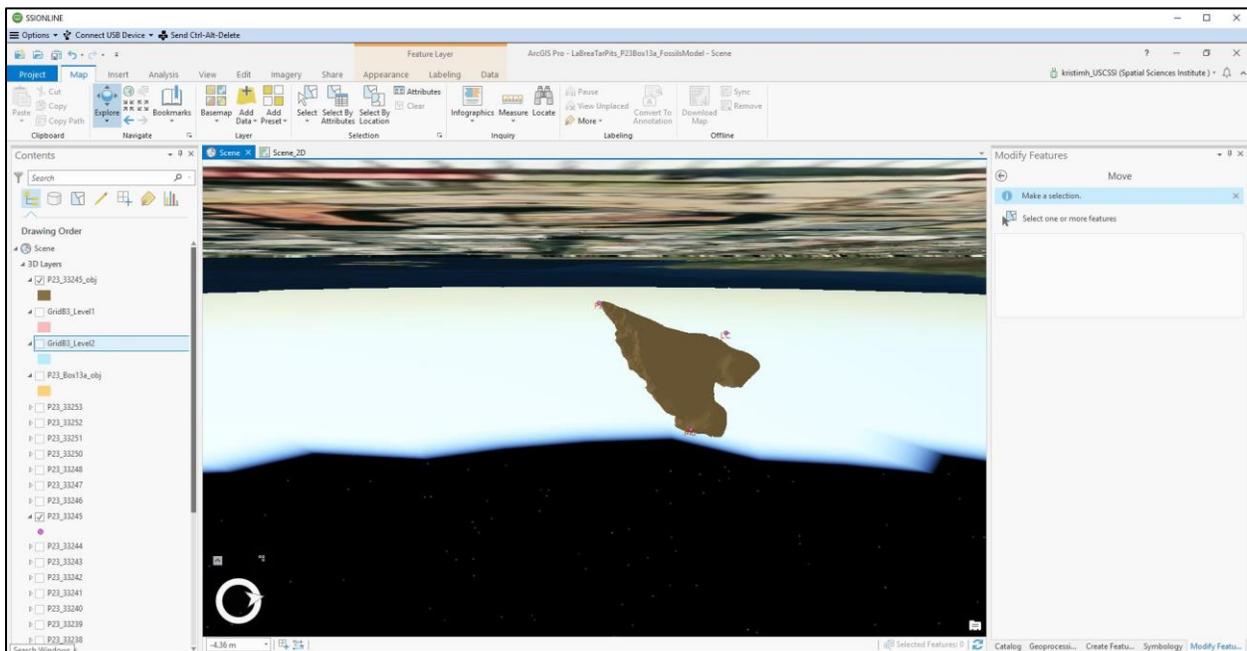
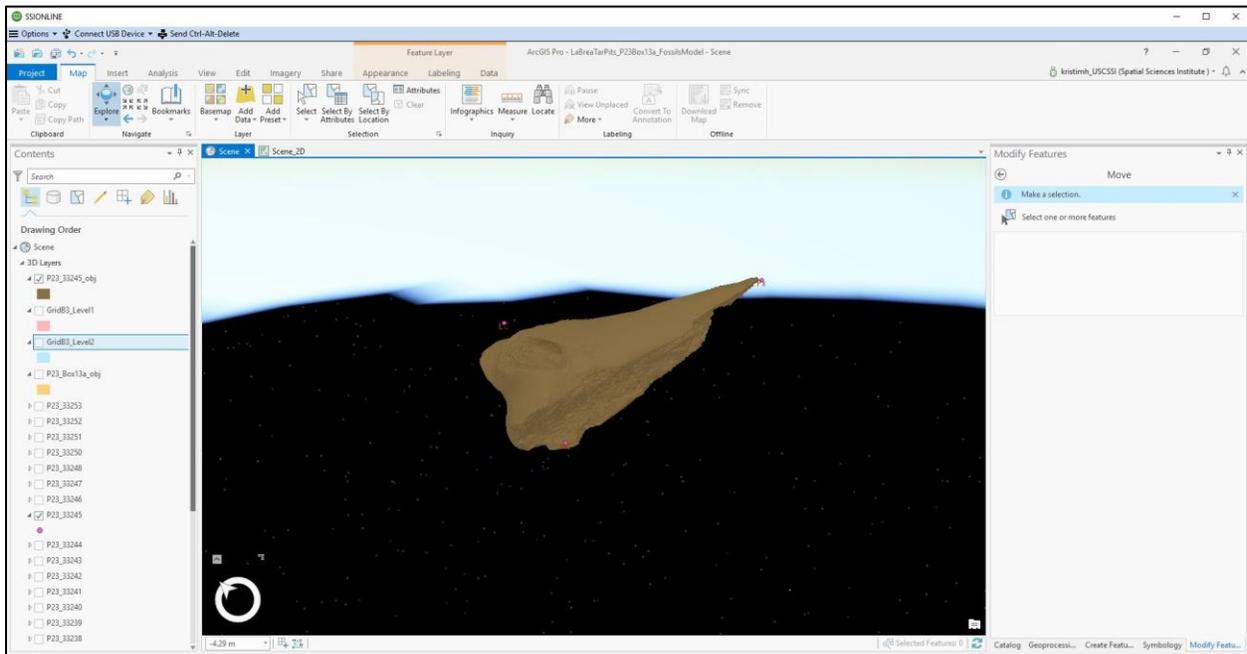
34. Turn off all 3D layers except P23\_33245 and P23\_33245\_obj. Right click on P23\_33245 in Contents and select Labeling Properties and then Class tab. Under Fields, double click Point to add to Expression box. Under Symbol tab, change color to “Fire Red.” Right click on P23\_33245 in Contents and select Label.

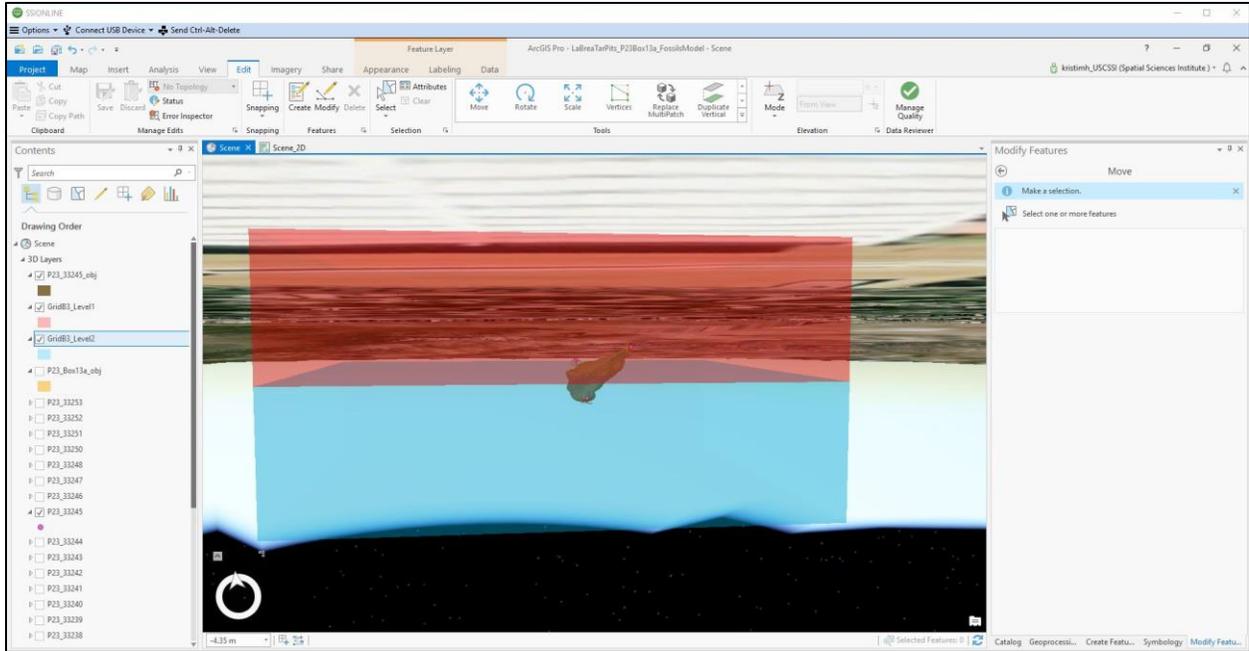


35. Select P23\_33245\_obj. Under Modify Features, select Rotate and use green, red and blue rings to rotate feature to align with its respective coordinates. Use imagery from museum of coordinate locations on fossil as reference for aligning the feature.

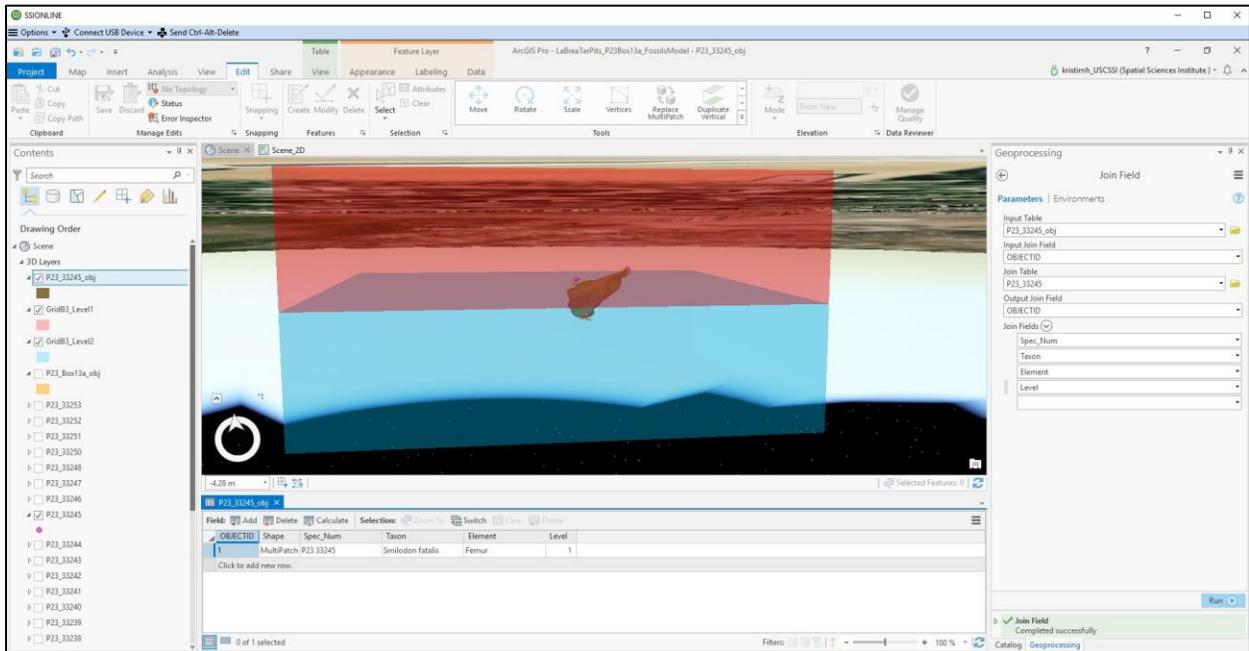


36. Utilize Move, Scale and Rotate tools to adjust the position of P23\_33245 until it aligns with its coordinates as closely as manually possible. Turn on GridB3\_Level1 and GridB3\_Level2 to see placement.

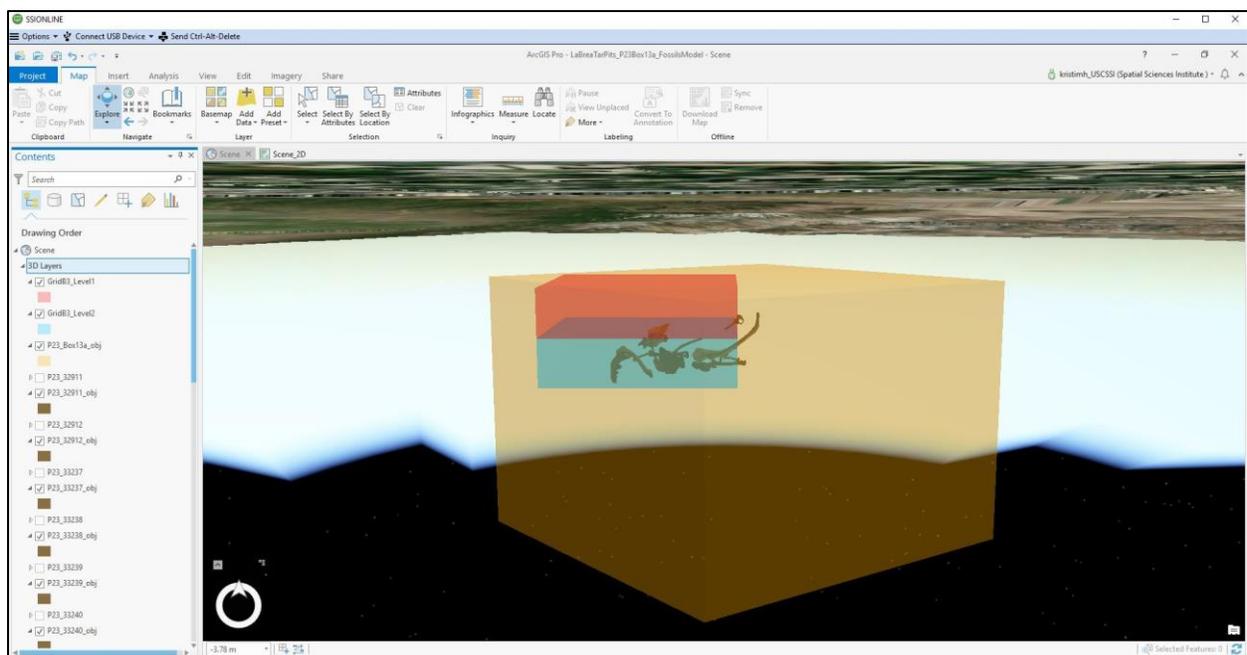
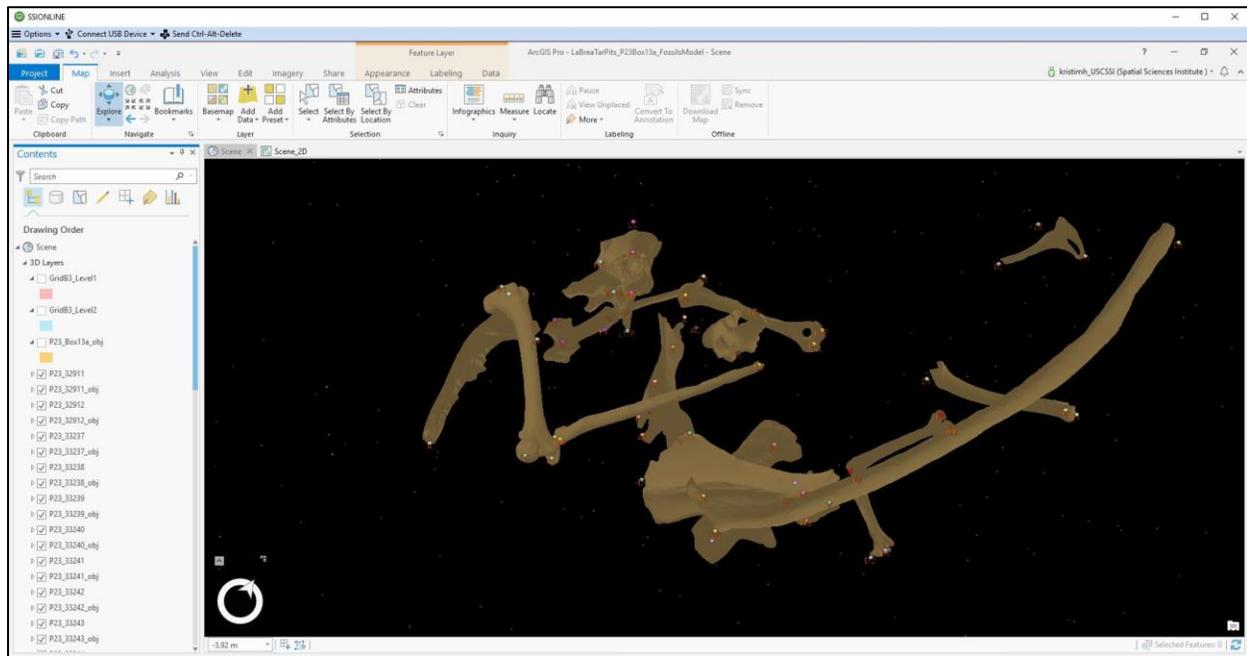




37. To add attributes to P23\_33245\_obj, run Join Field tool with corresponding coordinate feature class. Under Parameters tab, indicate Input table: P23\_33245\_obj, Input Join Field: OBJECTID, Join Table: P23\_33245, Output Join Field: OBJECTID and Join Fields: Spec\_Num, Taxon, Element and Level. Save edits.



38. Repeat steps 30-37 for the remaining 18 fossils.

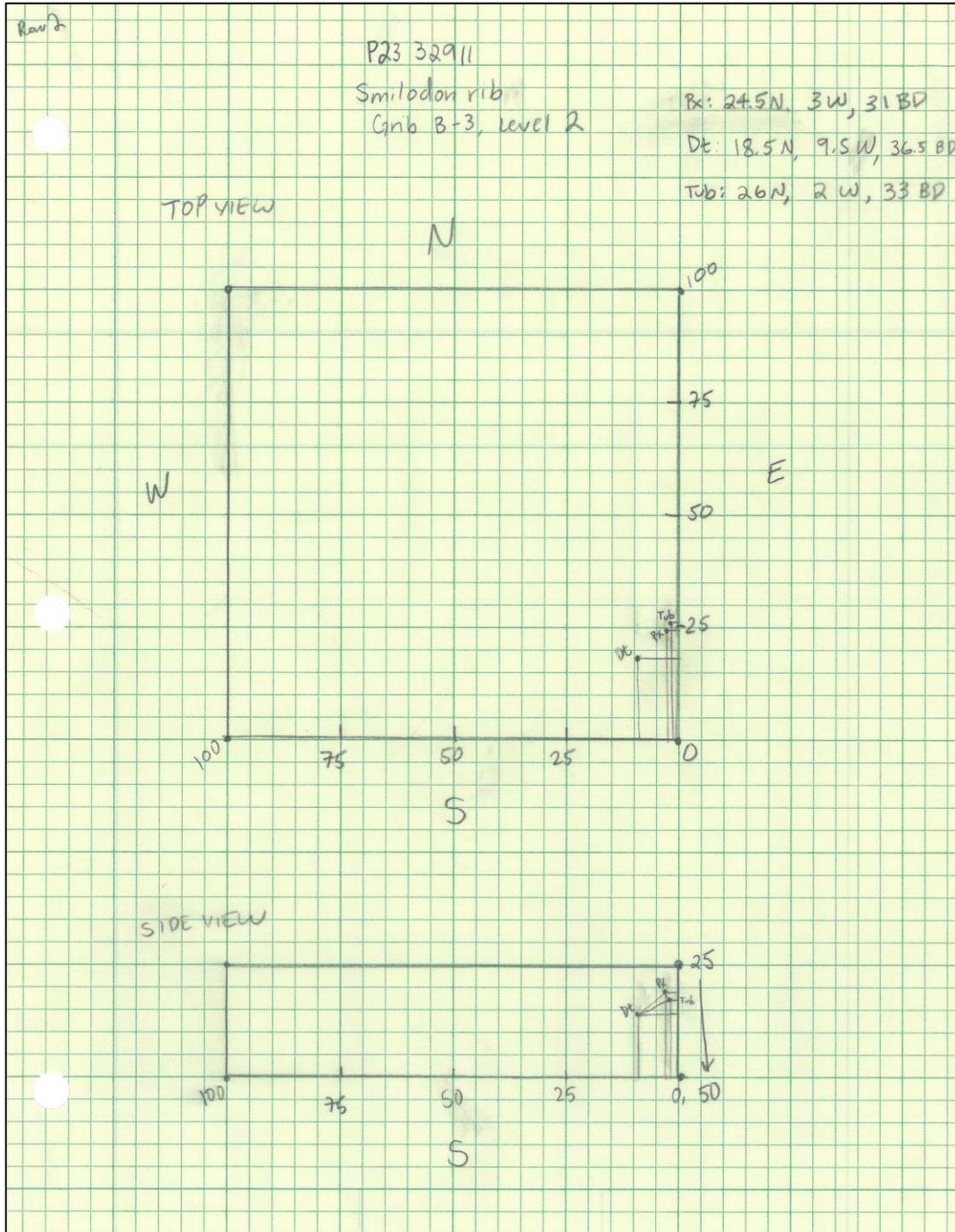


39. Right click on each feature class in the geodatabase, select “Edit Metadata” and add the function and origin of each dataset. Save all edits.

## Appendix B Hand-Drawn and PowerPoint Fossil Diagrams

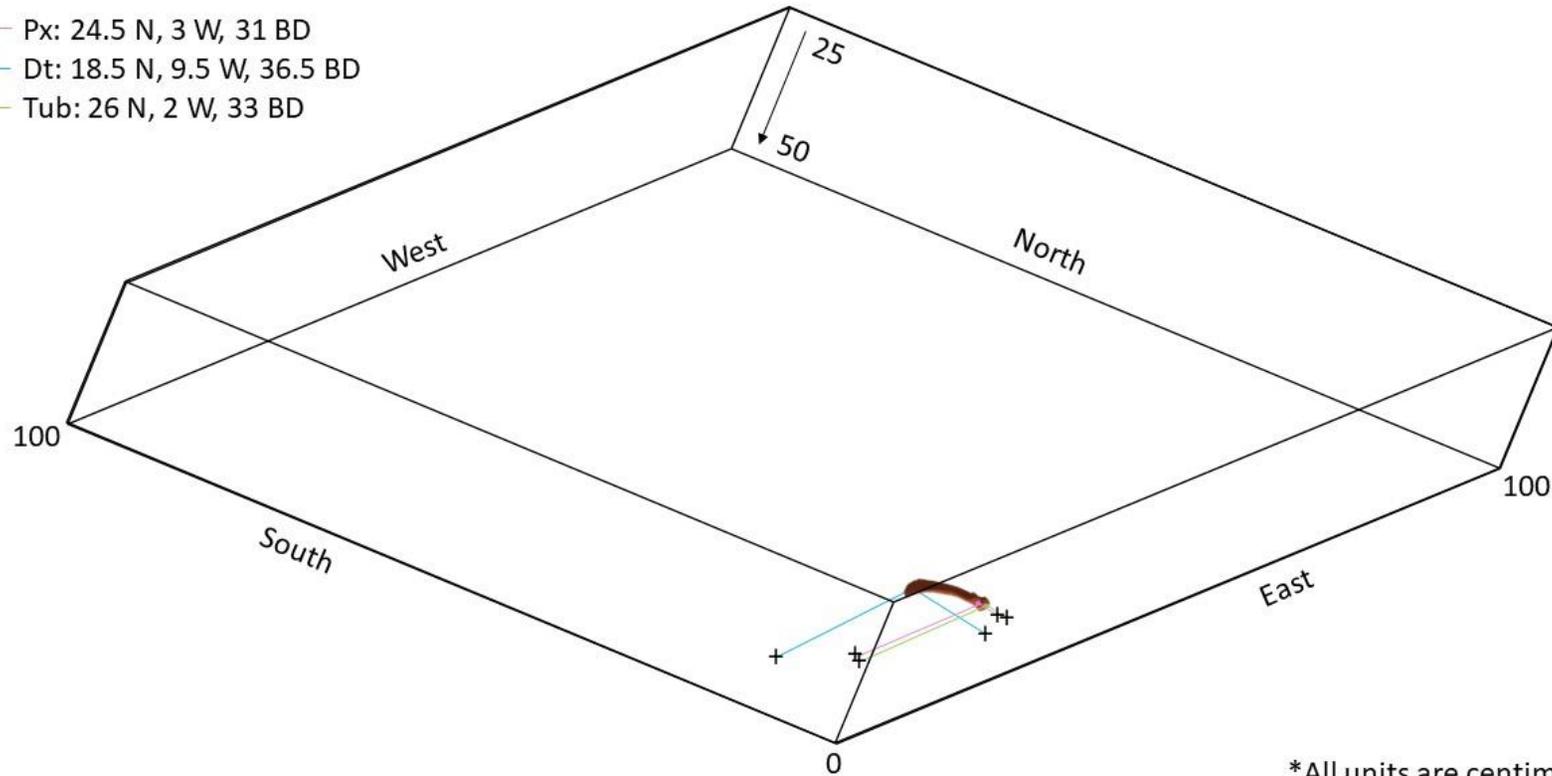
All locations were confirmed by La Brea Tar Pits and Museum scientists (Howard and Farrell, pers. comm.).

### 1. P23 32911 *Smilodon fatalis* rib



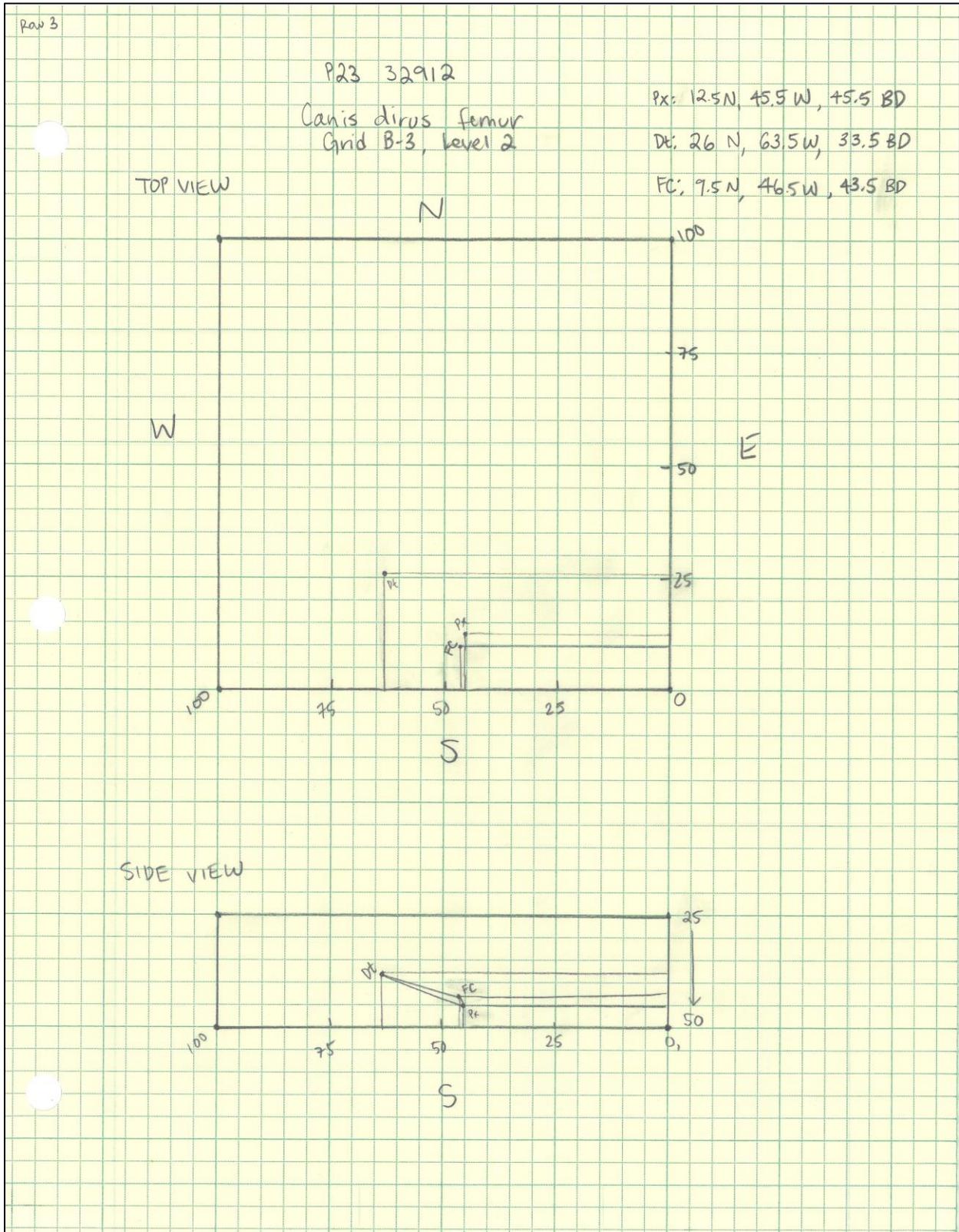
**Smilodon Rib in Box 13A's Grid B-3 Level 2**  
(P23 32911 *Smilodon fatalis* lt rib 1)

- Px: 24.5 N, 3 W, 31 BD
- Dt: 18.5 N, 9.5 W, 36.5 BD
- Tub: 26 N, 2 W, 33 BD



\*All units are centimeters.

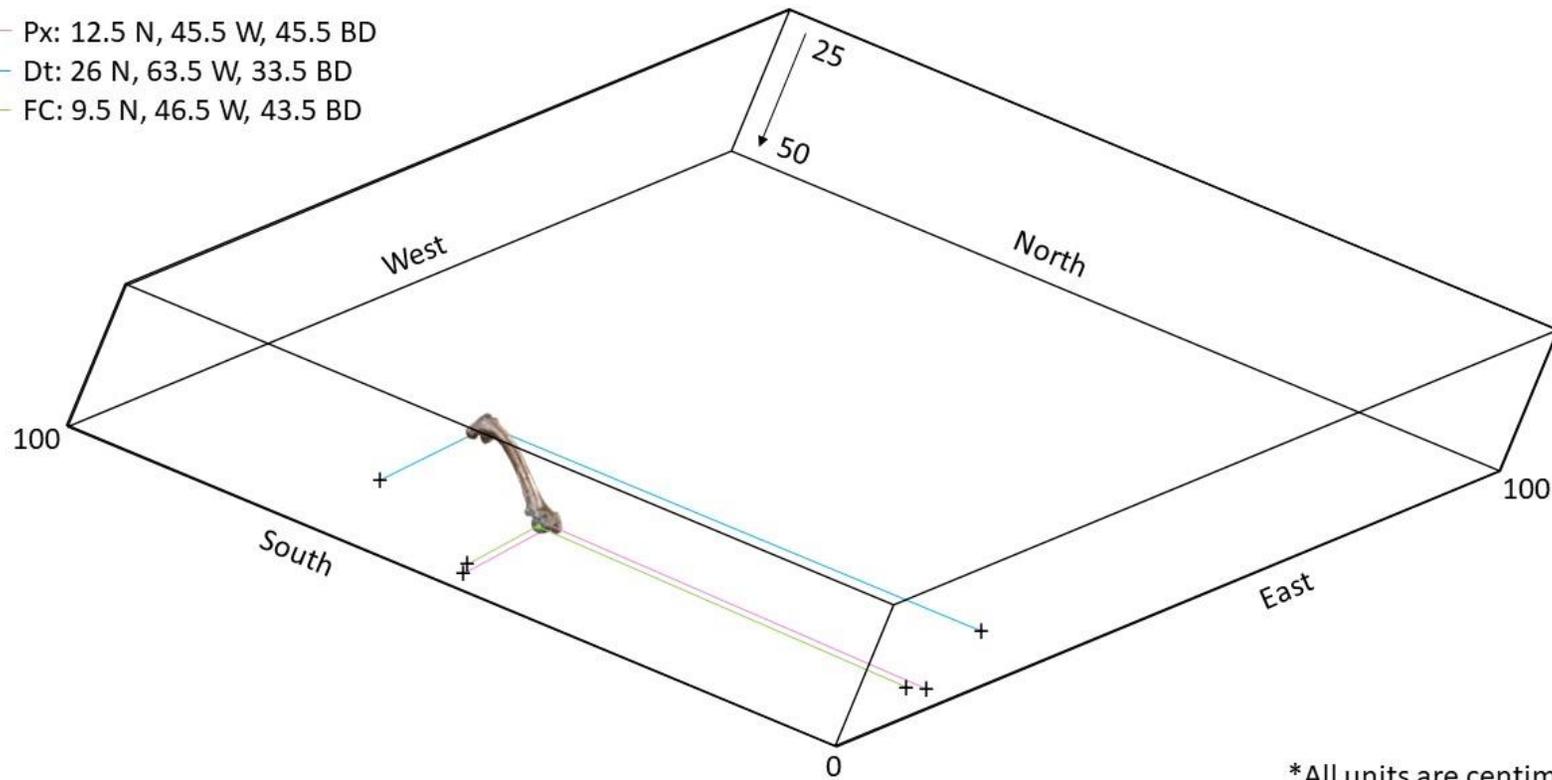
2. P23 32912 *Canis dirus* femur



### Canis Femur in Box 13A's Grid B-3 Level 2

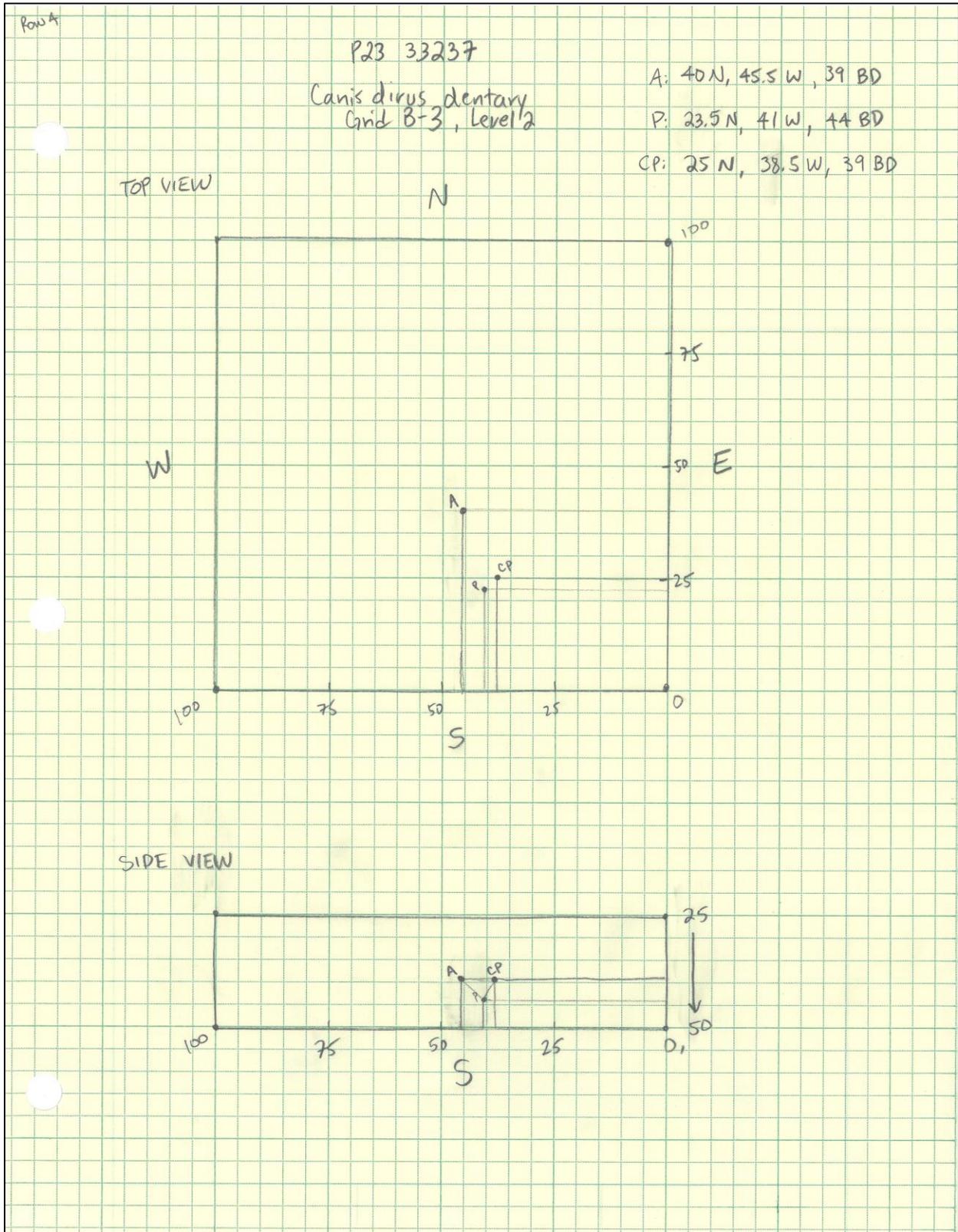
(P23 32912 *Canis dirus* rt femur)

- Px: 12.5 N, 45.5 W, 45.5 BD
- Dt: 26 N, 63.5 W, 33.5 BD
- FC: 9.5 N, 46.5 W, 43.5 BD



\*All units are centimeters.

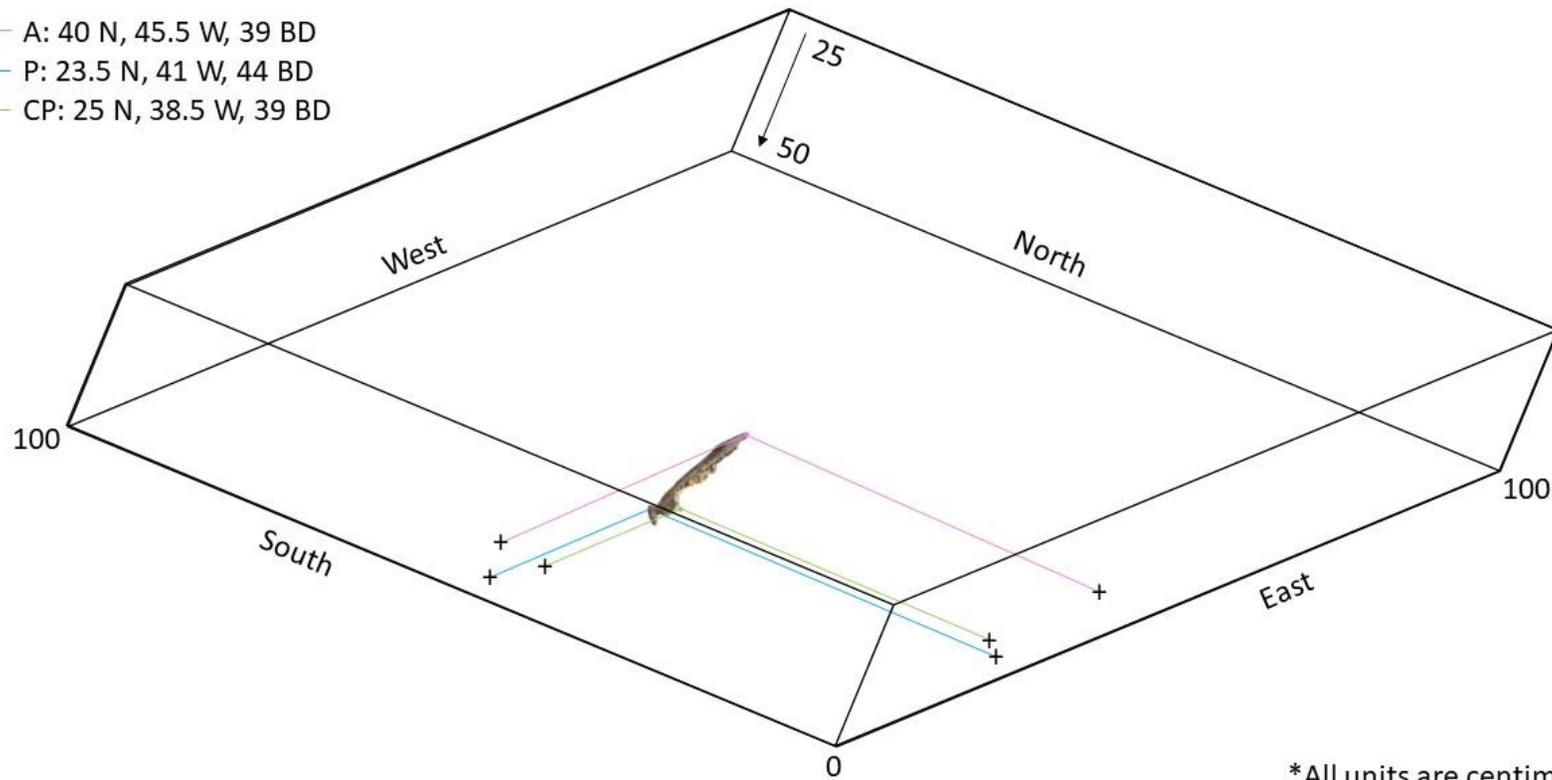
3. P23 33237 *Canis dirus dentary*



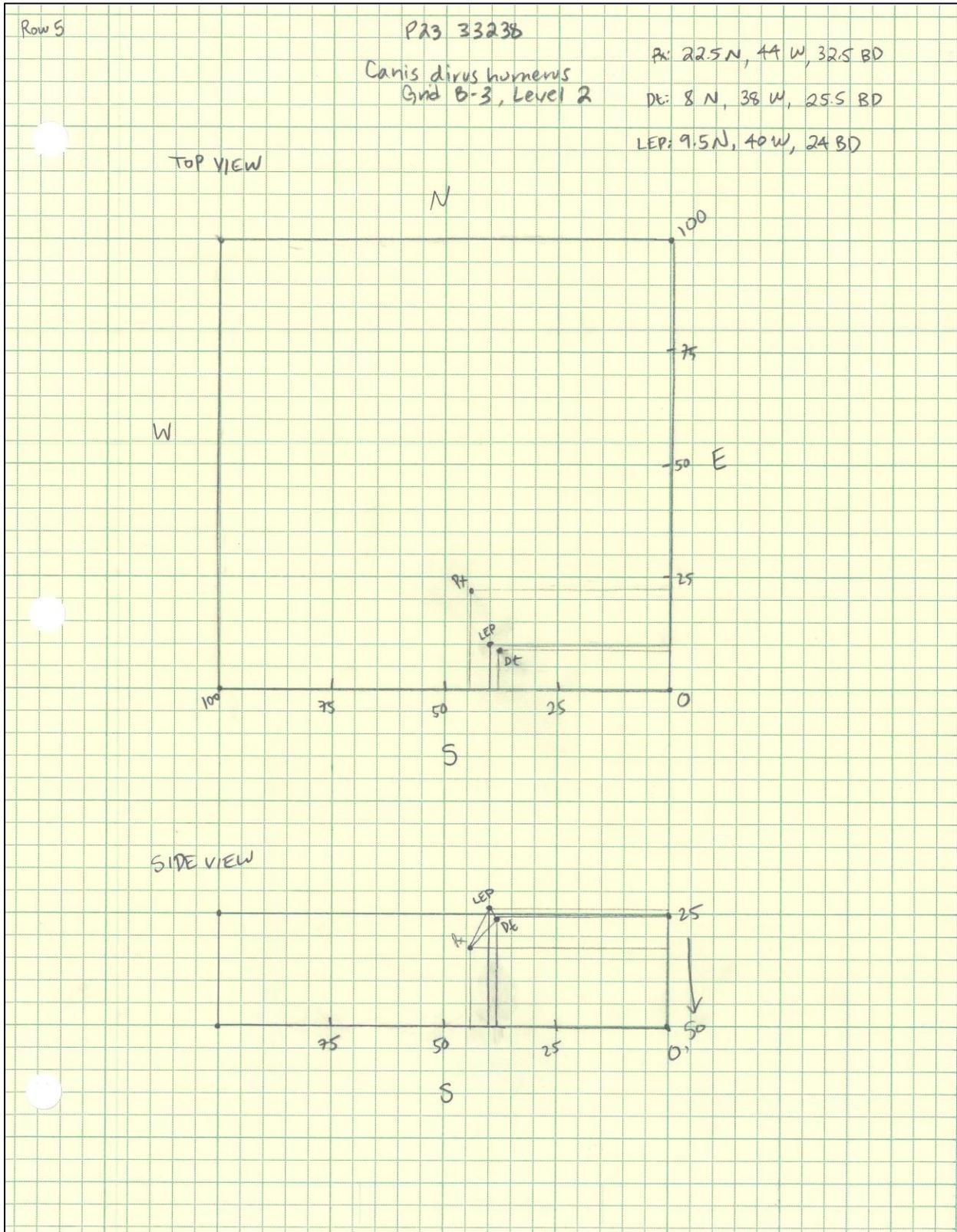
### Canis Dentary in Box 13A's Grid B-3 Level 2

(P23 33237 *Canis dirus* rt dentary)

- A: 40 N, 45.5 W, 39 BD
- P: 23.5 N, 41 W, 44 BD
- CP: 25 N, 38.5 W, 39 BD



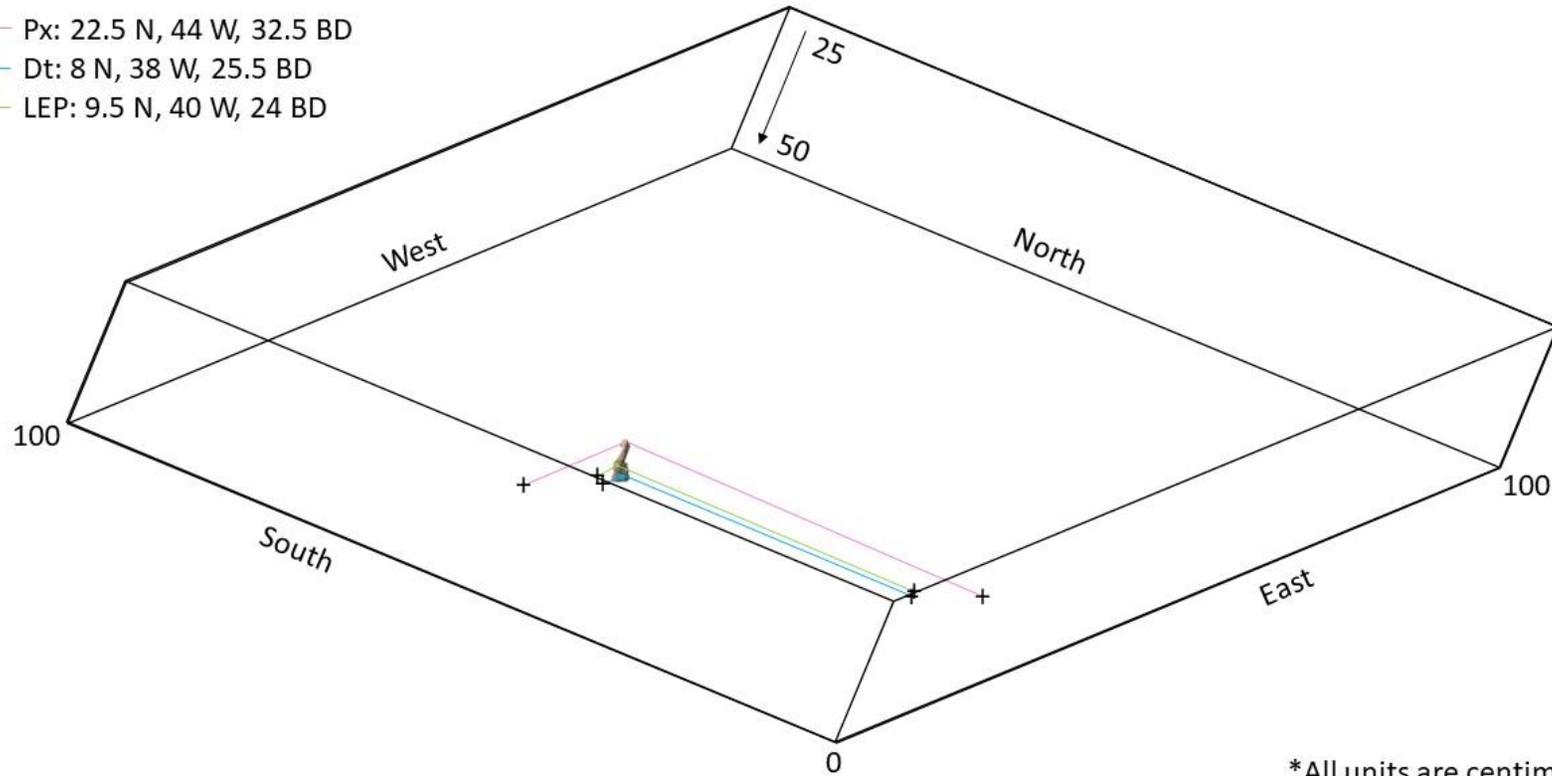
4. P23 33238 *Canis dirus* humerus



### **Canis Humerus in Box 13A's Grid B-3 Level 2**

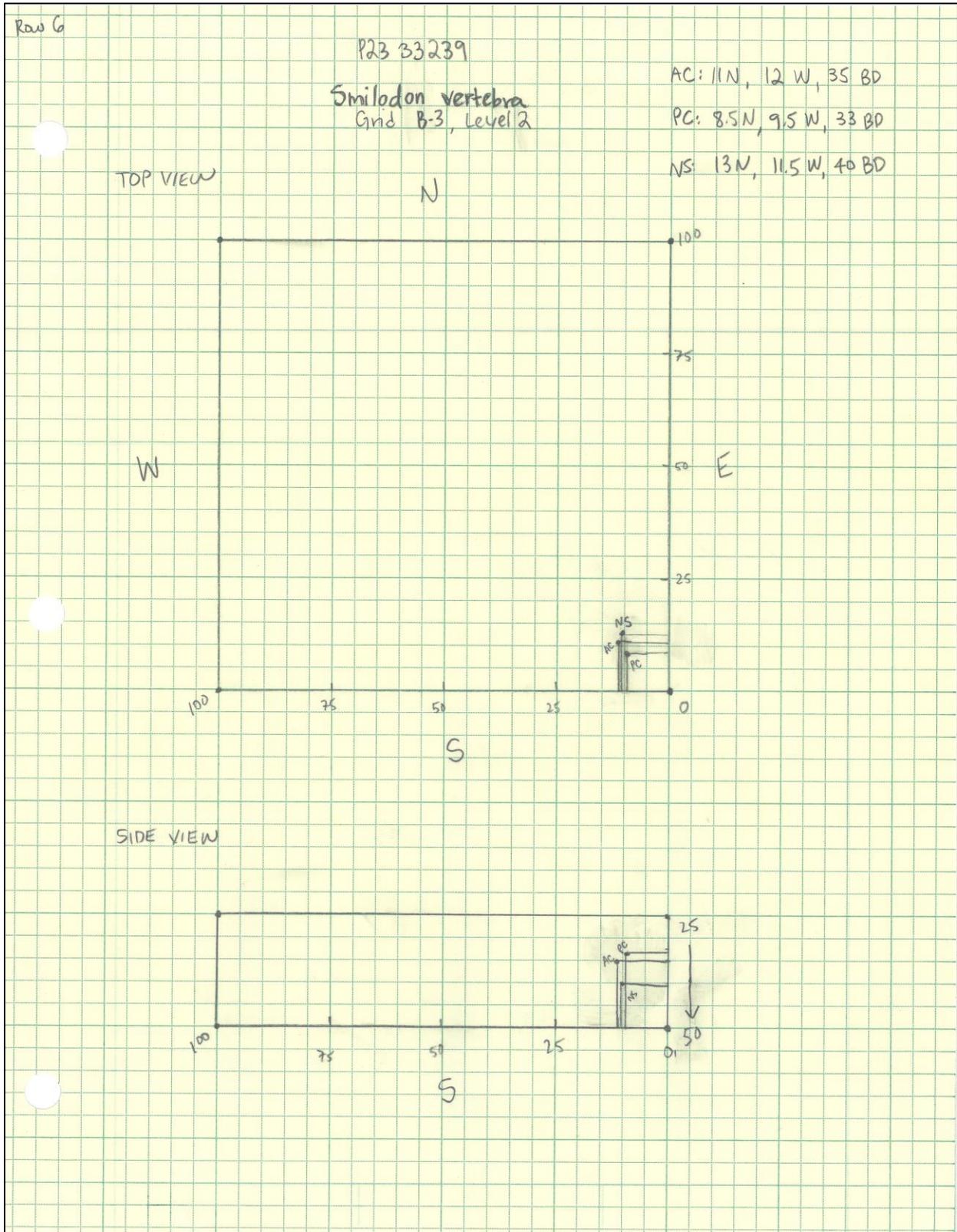
(P23 33238 *Canis dirus* rt humerus)

- Px: 22.5 N, 44 W, 32.5 BD
- Dt: 8 N, 38 W, 25.5 BD
- LEP: 9.5 N, 40 W, 24 BD



\*All units are centimeters.

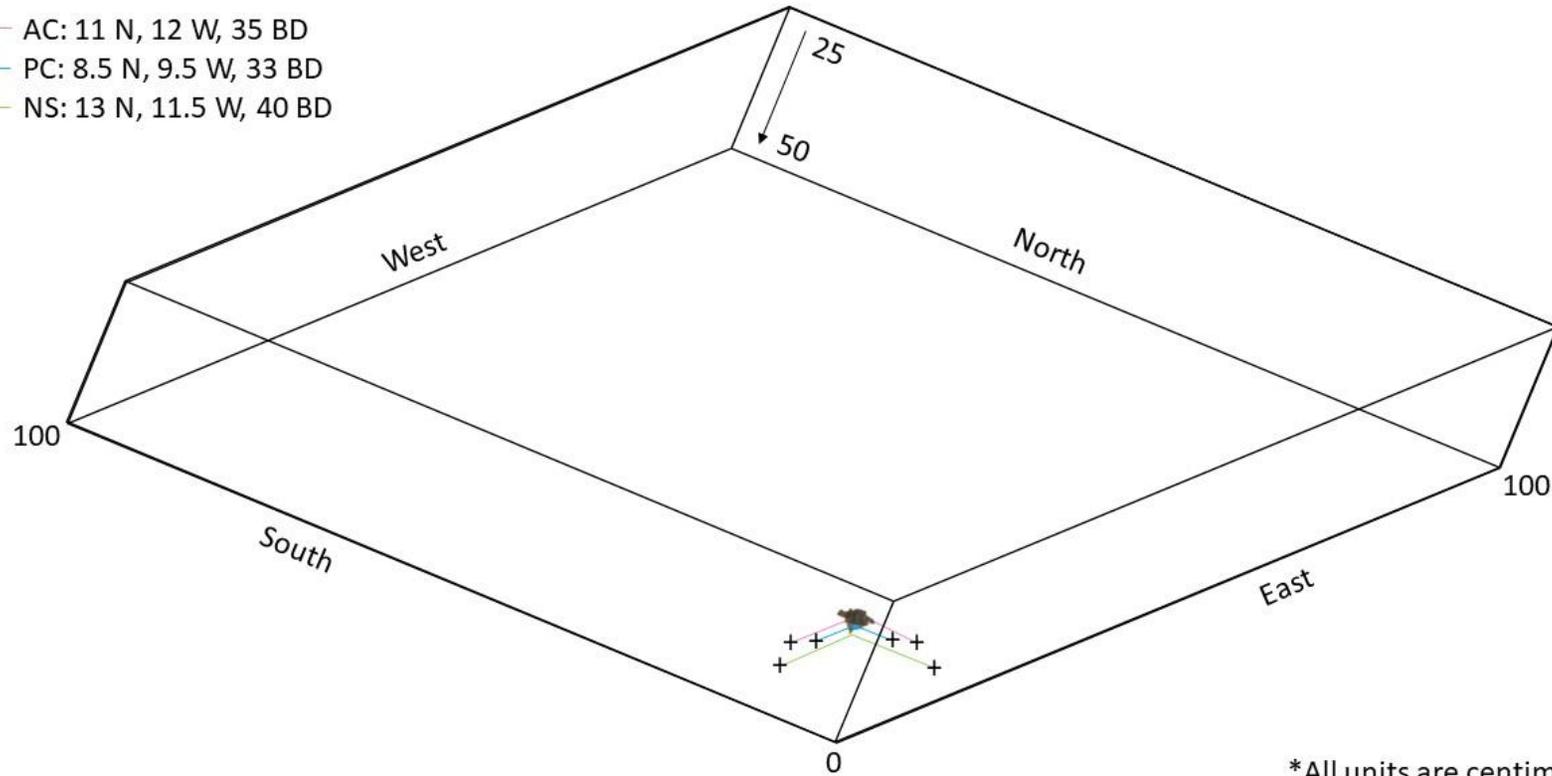
5. P23\_33239 *Smilodon fatalis* vertebra



### Smilodon Vertebra in Box 13A's Grid B-3 Level 2

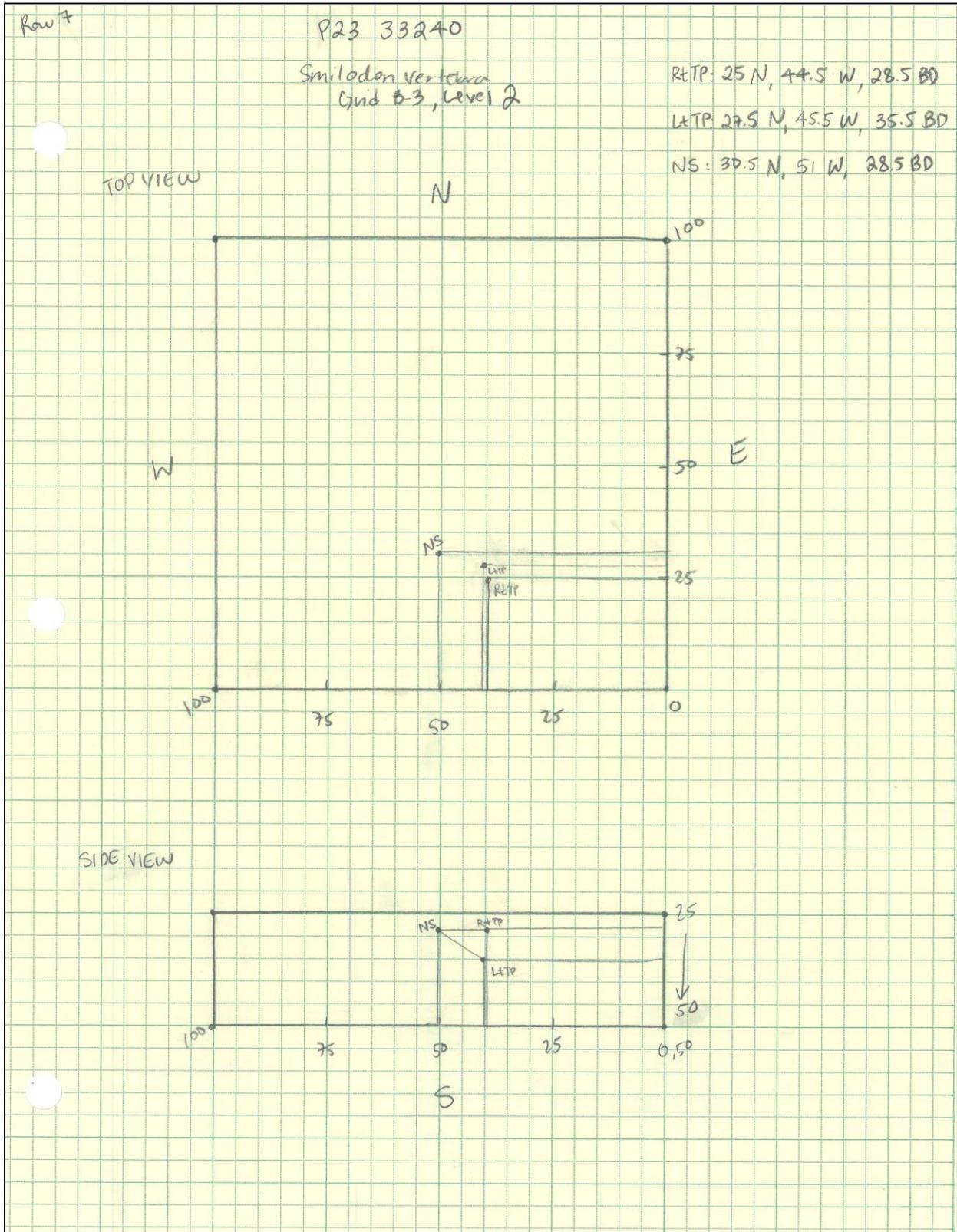
(P23 33239 *Smilodon fatalis* III thoracic vertebra)

- AC: 11 N, 12 W, 35 BD
- PC: 8.5 N, 9.5 W, 33 BD
- NS: 13 N, 11.5 W, 40 BD



\*All units are centimeters.

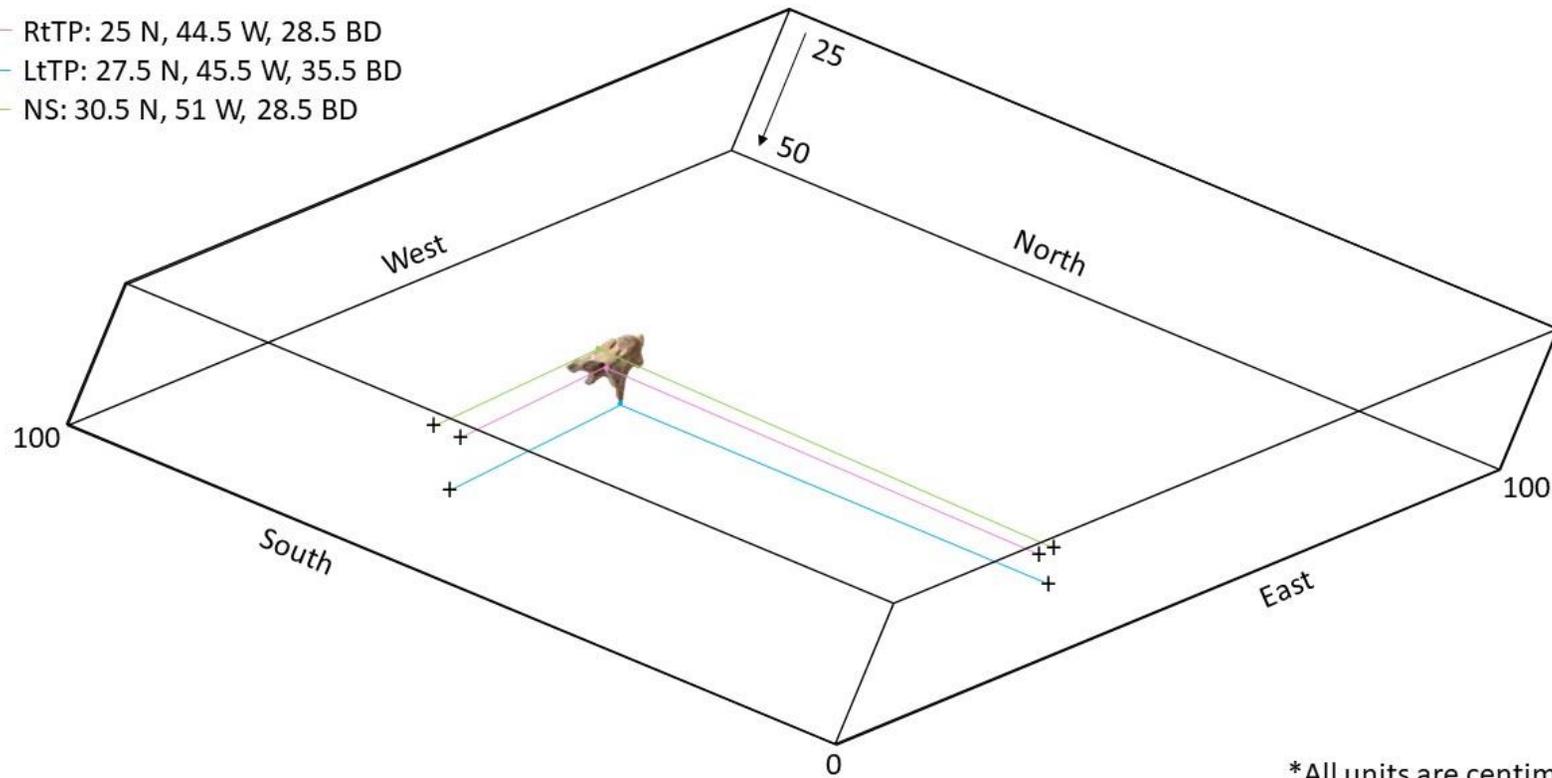
6. P23 33240 *Smilodon fatalis* vertebra



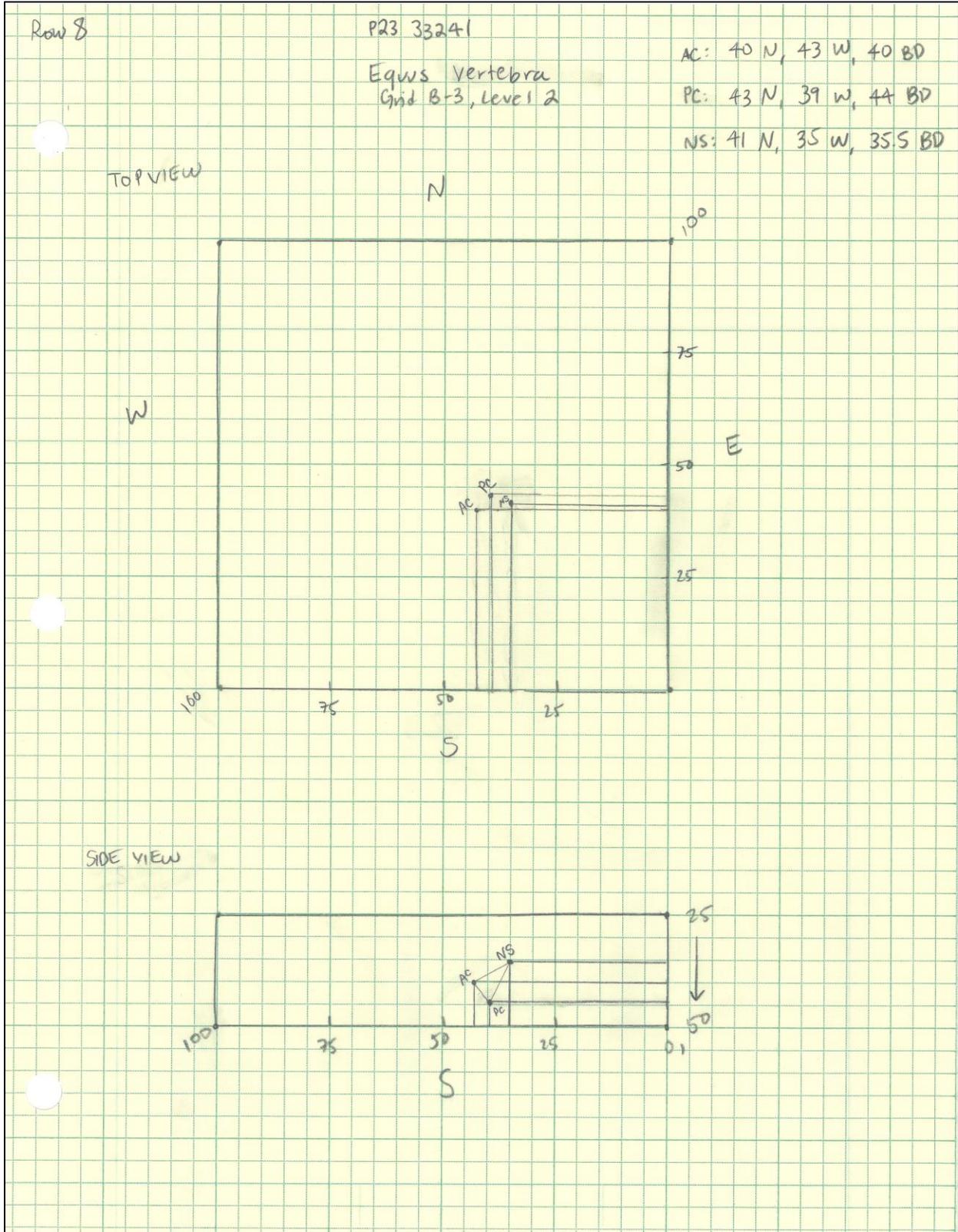
### Smilodon Vertebra in Box 13A's Grid B-3 Level 2

(P23 33240 *Smilodon fatalis* II cervical vertebra)

- RtTP: 25 N, 44.5 W, 28.5 BD
- LtTP: 27.5 N, 45.5 W, 35.5 BD
- NS: 30.5 N, 51 W, 28.5 BD

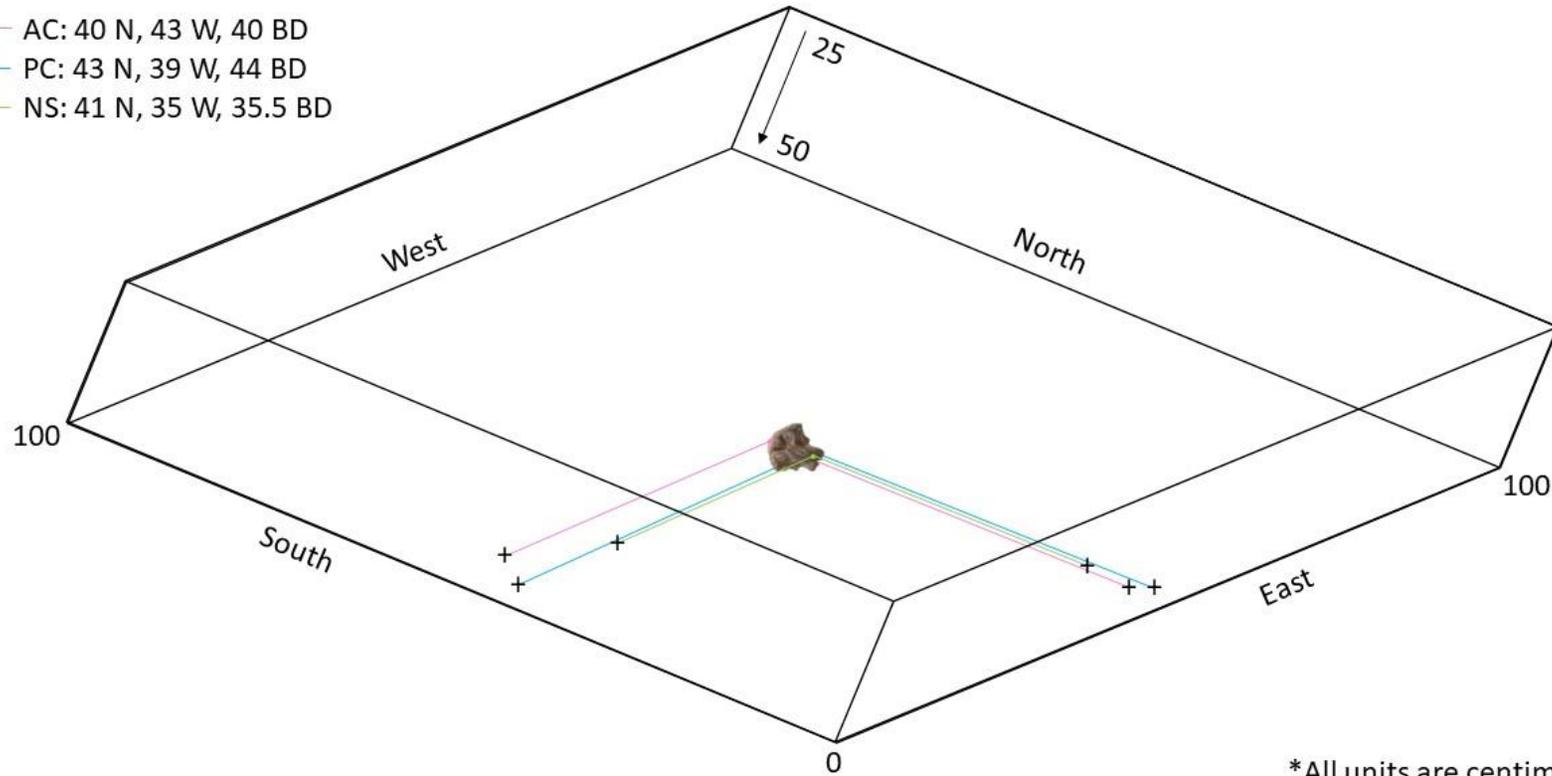


7. P23\_33241 *Equus occidentalis* vertebra



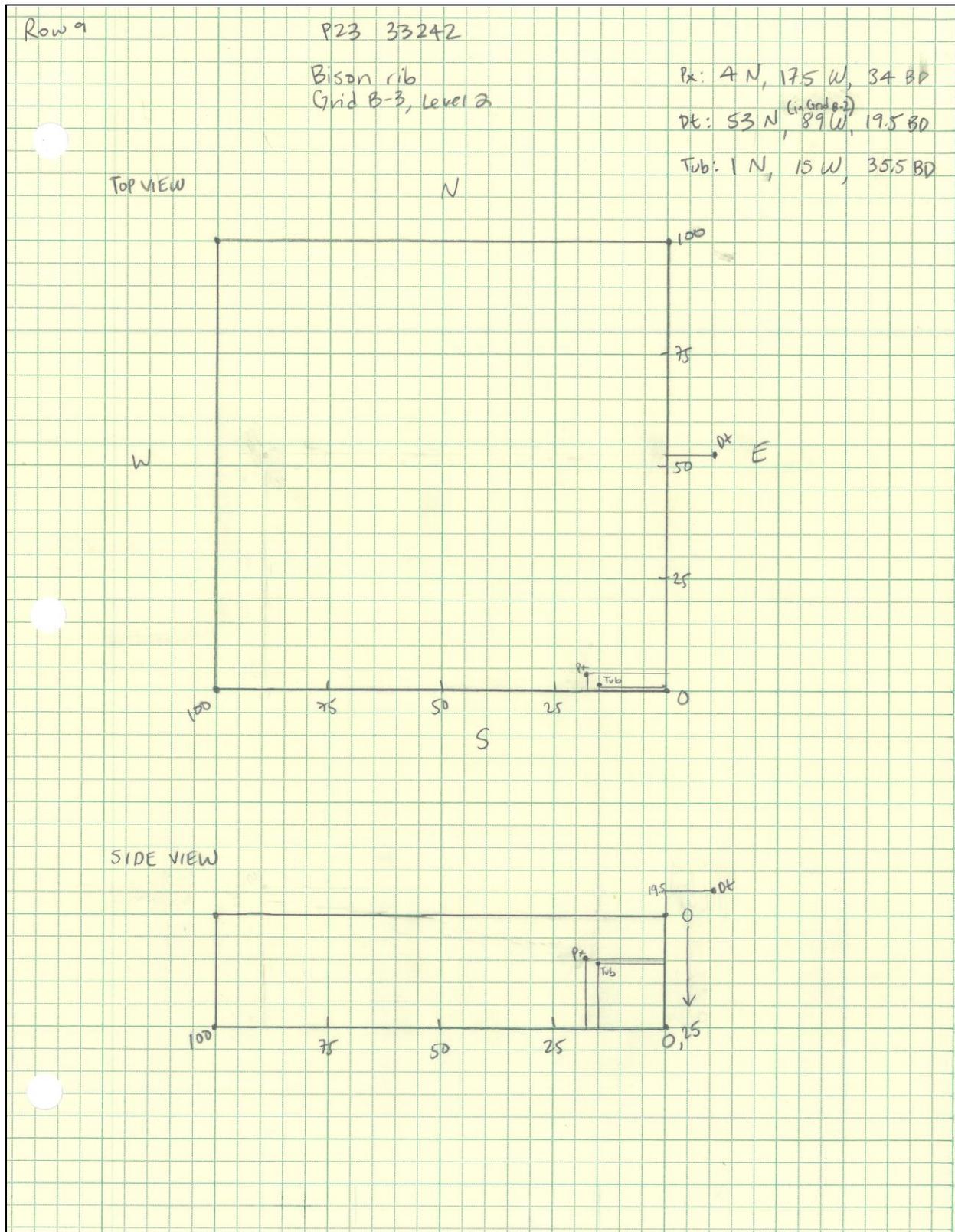
**Equus Vertebra in Box 13A's Grid B-3 Level 2**  
(P23 33241 *Equus occidentalis* I lumbar vertebra)

- AC: 40 N, 43 W, 40 BD
- PC: 43 N, 39 W, 44 BD
- NS: 41 N, 35 W, 35.5 BD



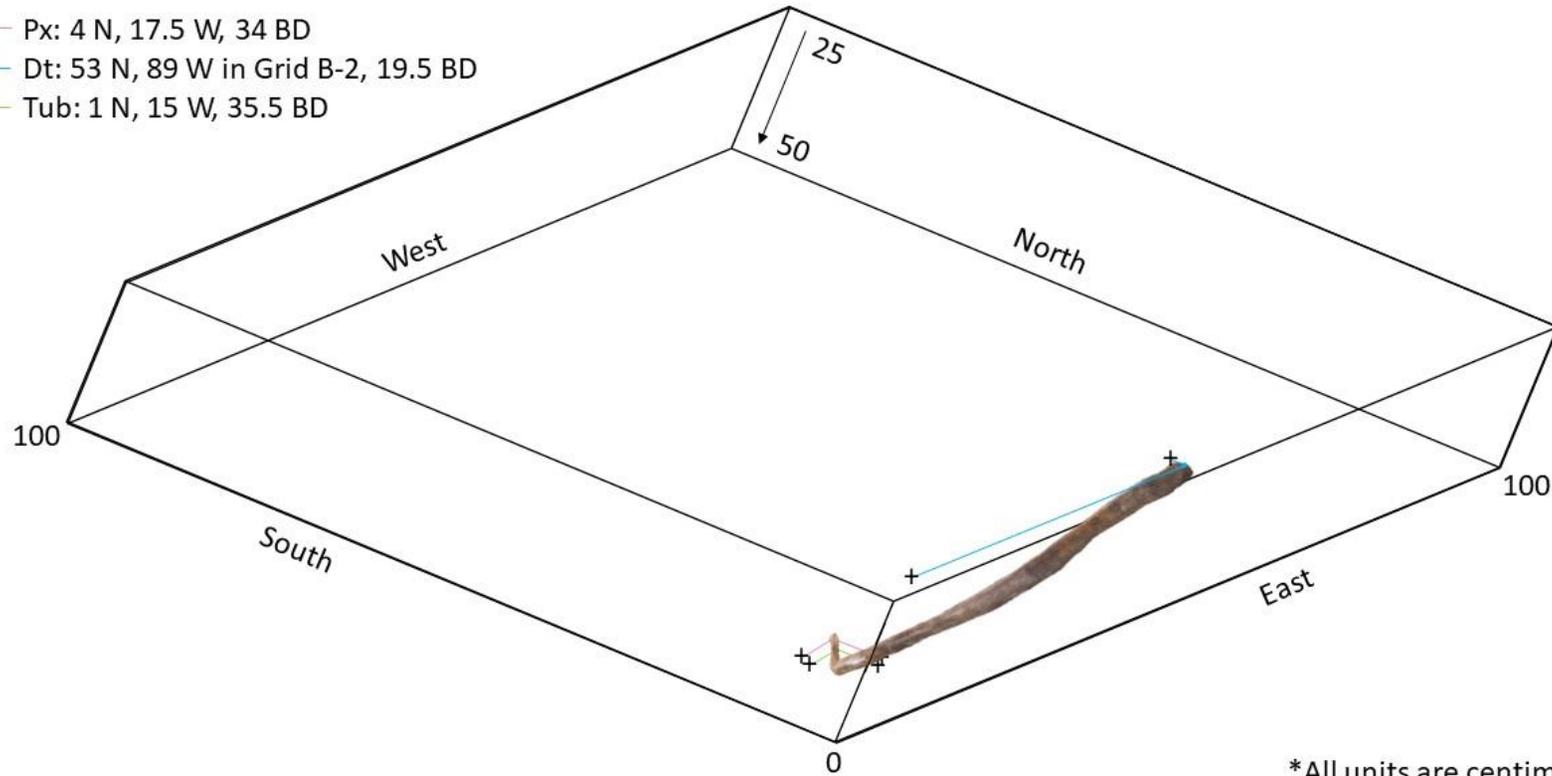
\*All units are centimeters.

8. P23 33242 *Bison antiquus* rib



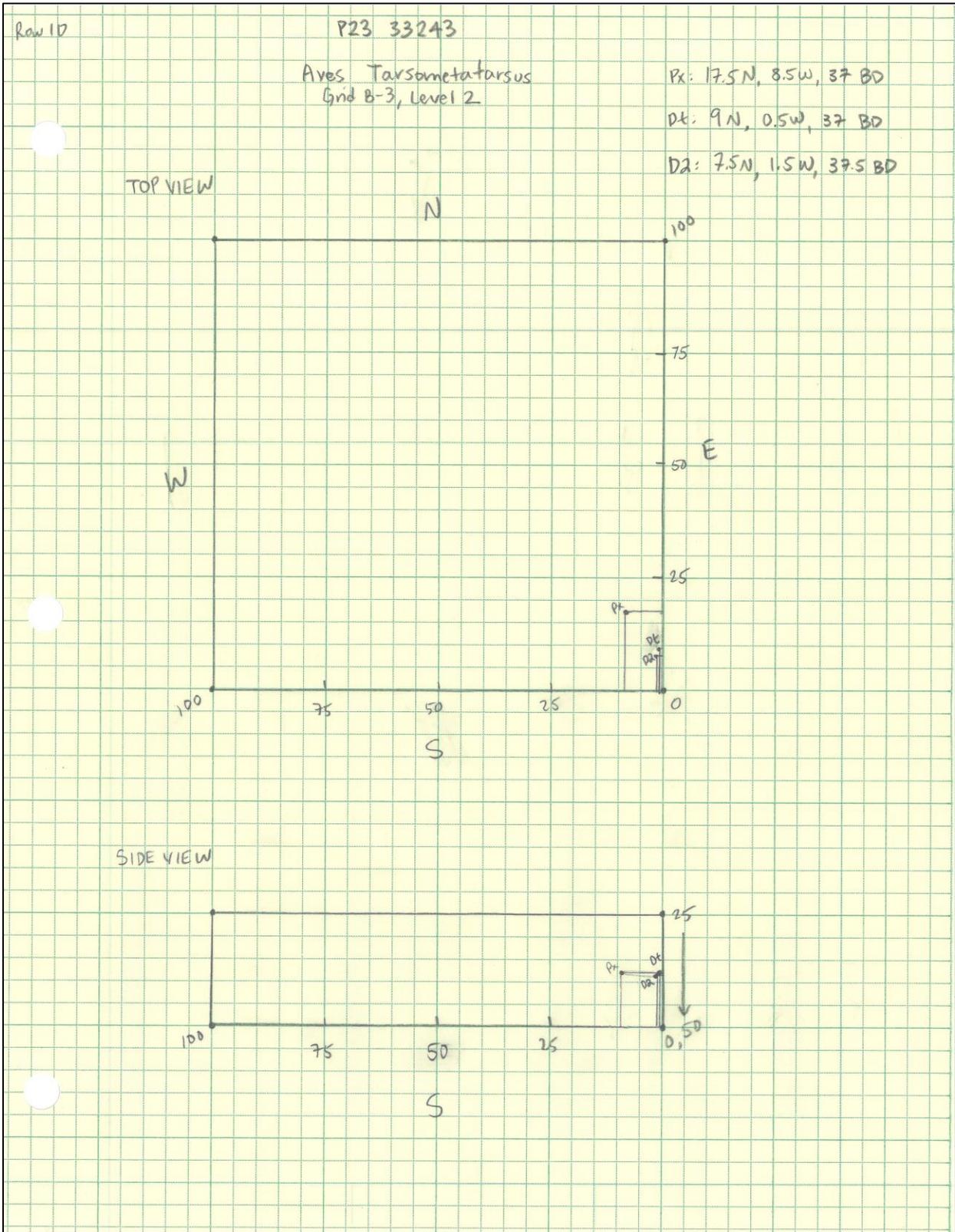
**Bison Rib in Box 13A's Grid B-3 Level 2**  
(P23 33242 *Bison antiquus* rt rib)

- Px: 4 N, 17.5 W, 34 BD
- Dt: 53 N, 89 W in Grid B-2, 19.5 BD
- Tub: 1 N, 15 W, 35.5 BD



\*All units are centimeters.

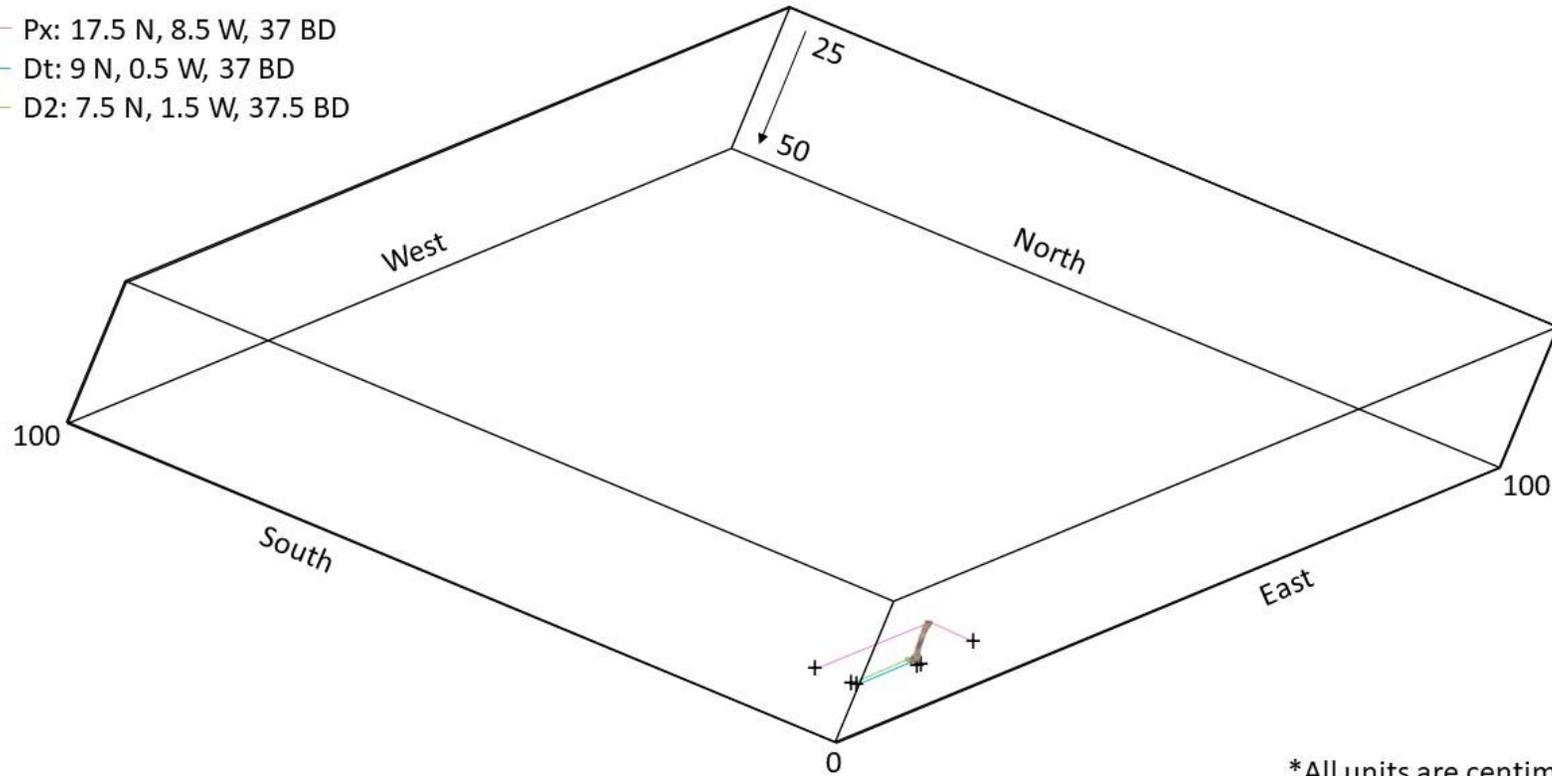
9. P23 33243 *Aves tarsometatarsus*



### Aves Tarsometatarsus in Box 13A's Grid B-3 Level 2

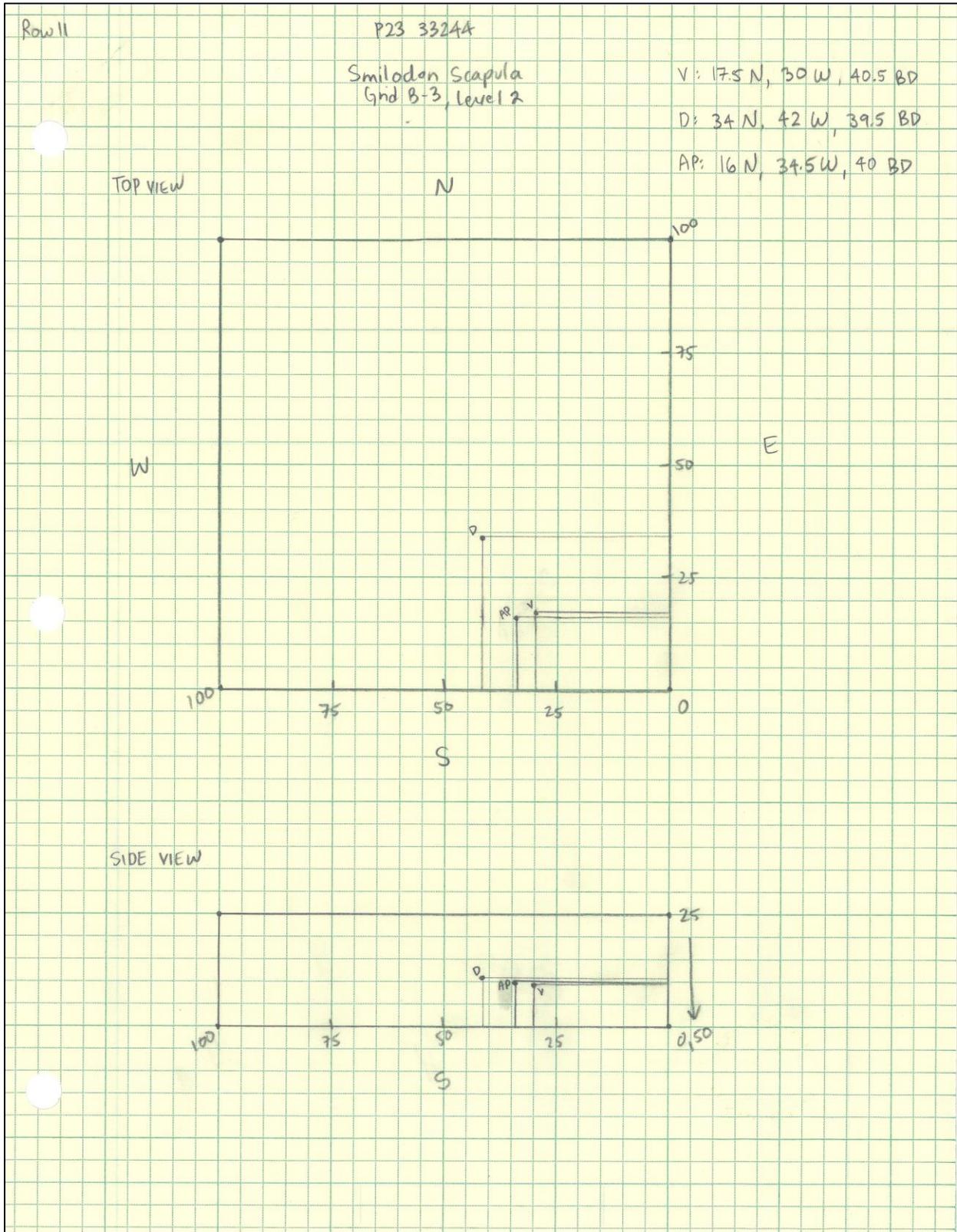
(P23 33243 Aves rt tarsometatarsus)

- Px: 17.5 N, 8.5 W, 37 BD
- Dt: 9 N, 0.5 W, 37 BD
- D2: 7.5 N, 1.5 W, 37.5 BD



\*All units are centimeters.

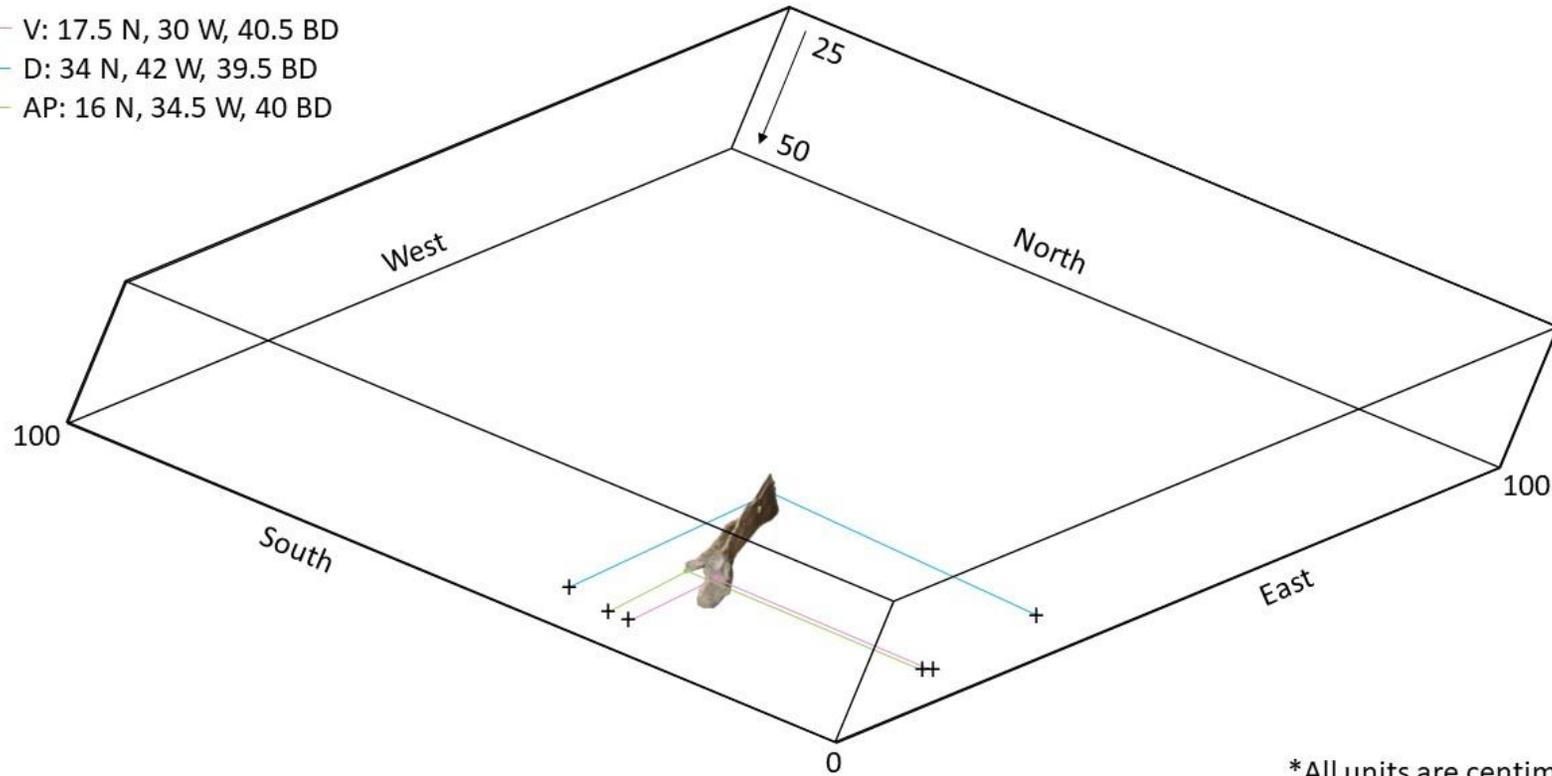
10. P23 33244 *Smilodon fatalis* scapula



**Smilodon Scapula in Box 13A's Grid B-3 Level 2**

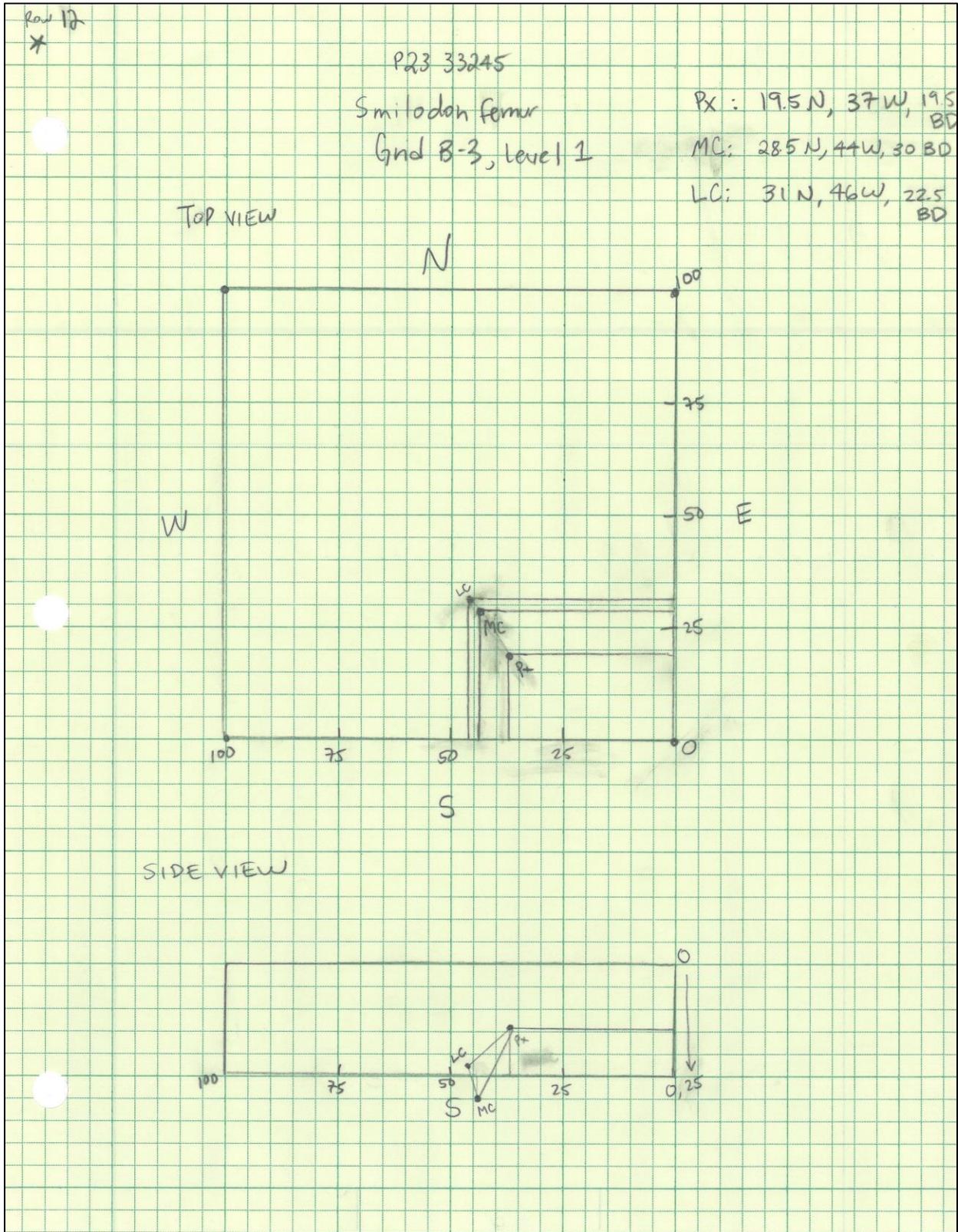
(P23 33244 *Smilodon fatalis* rt scapula)

- V: 17.5 N, 30 W, 40.5 BD
- D: 34 N, 42 W, 39.5 BD
- AP: 16 N, 34.5 W, 40 BD



\*All units are centimeters.

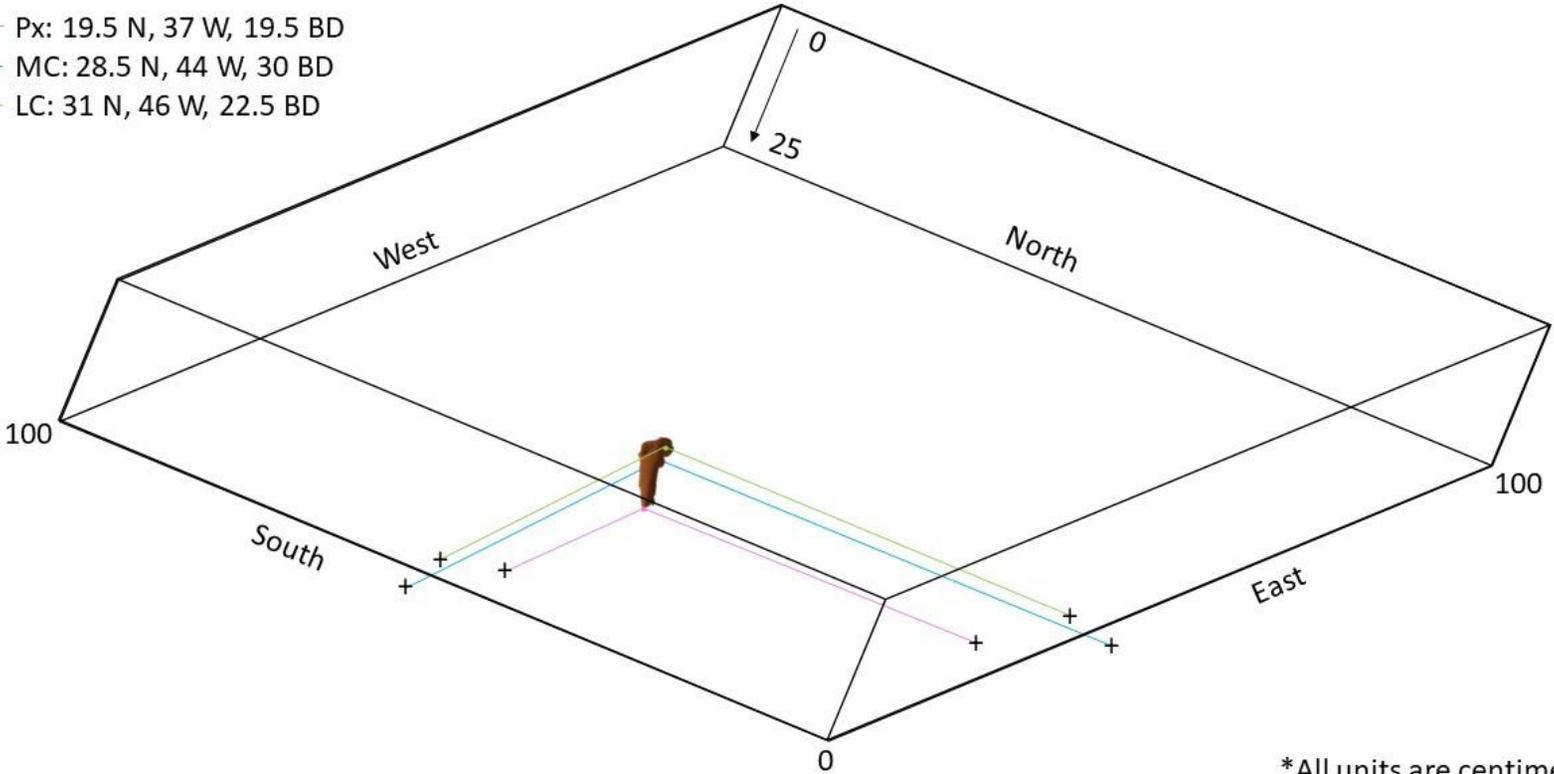
11. P23 33245 *Smilodon fatalis* femur



**Smilodon Femur in Box 13A's Grid B-3 Level 1**

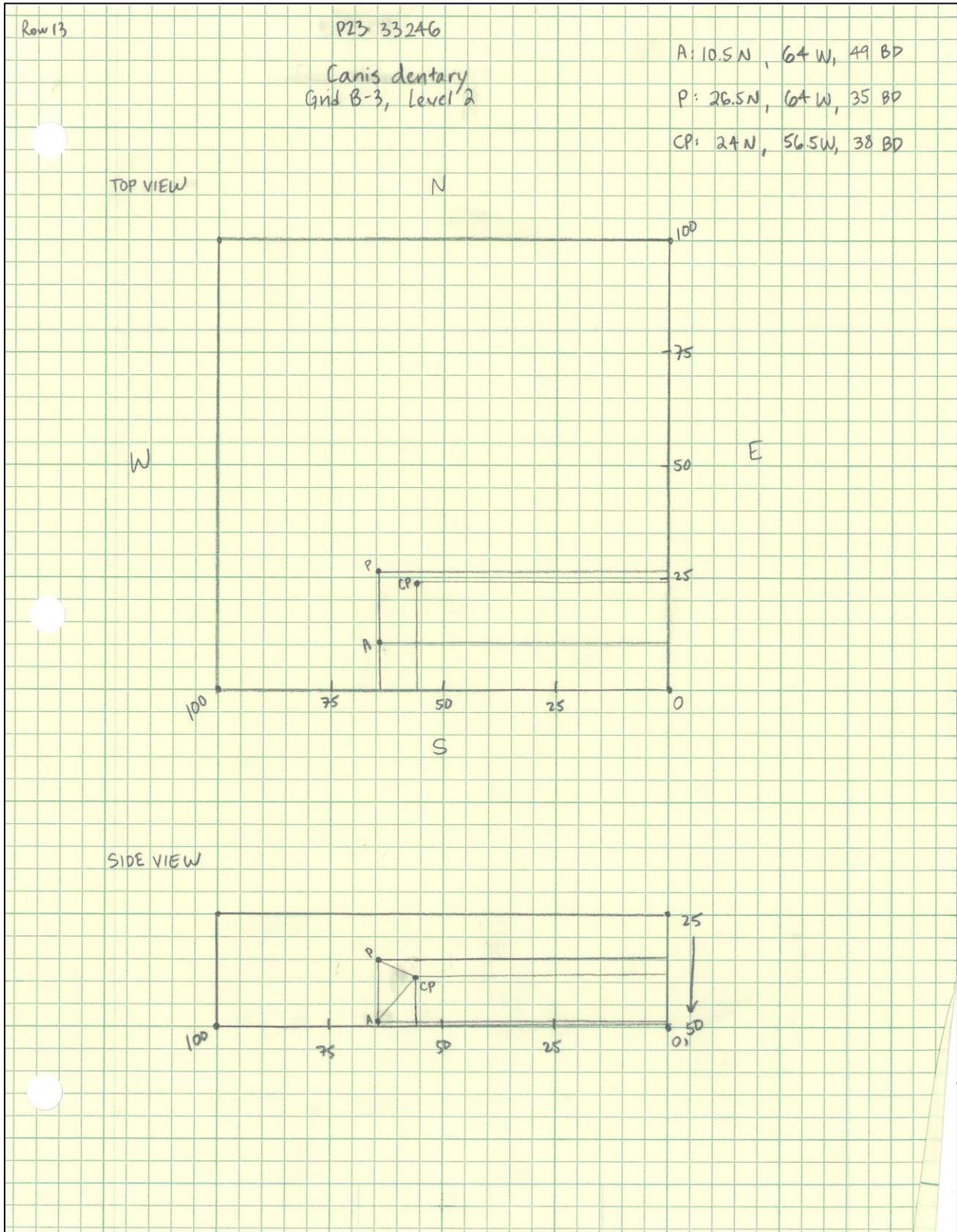
(P23 33245 *Smilodon fatalis* distal lt femur)

- Px: 19.5 N, 37 W, 19.5 BD
- MC: 28.5 N, 44 W, 30 BD
- LC: 31 N, 46 W, 22.5 BD



\*All units are centimeters.

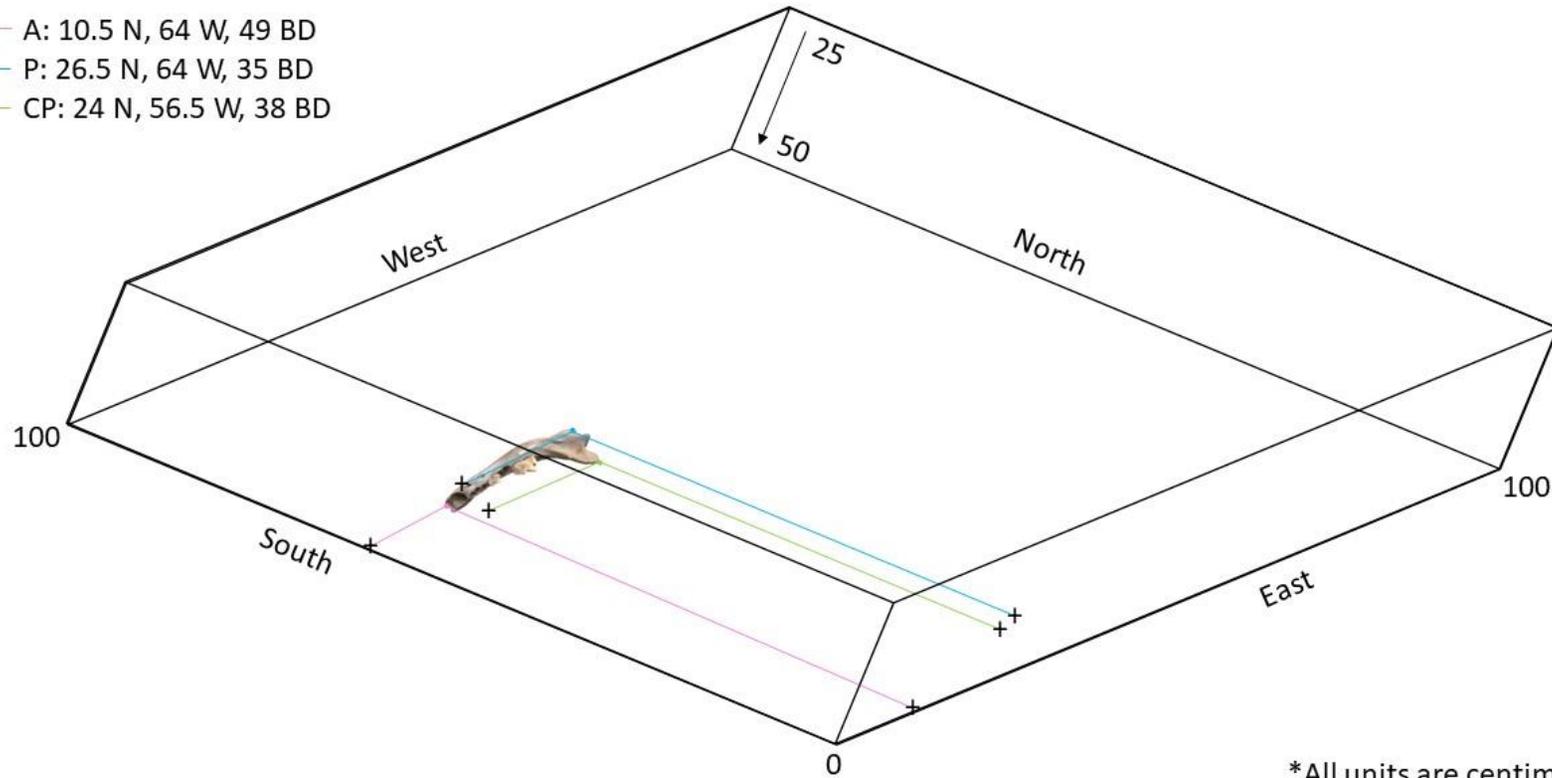
12. P23 33246 *Canis dirus* dentary



### Canis Dentary in Box 13A's Grid B-3 Level 2

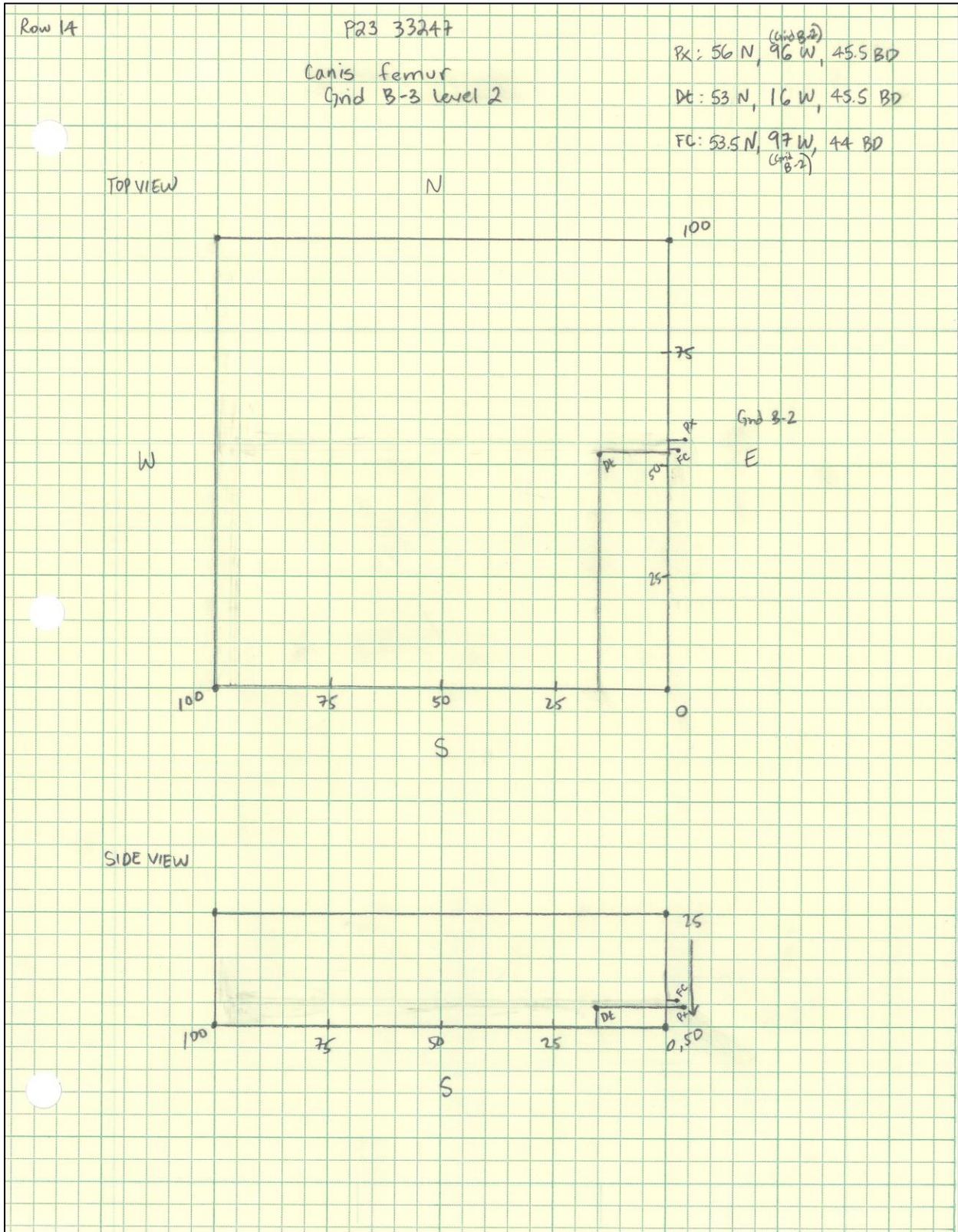
(P23 33246 *Canis dirus* rt dentary)

- A: 10.5 N, 64 W, 49 BD
- P: 26.5 N, 64 W, 35 BD
- CP: 24 N, 56.5 W, 38 BD



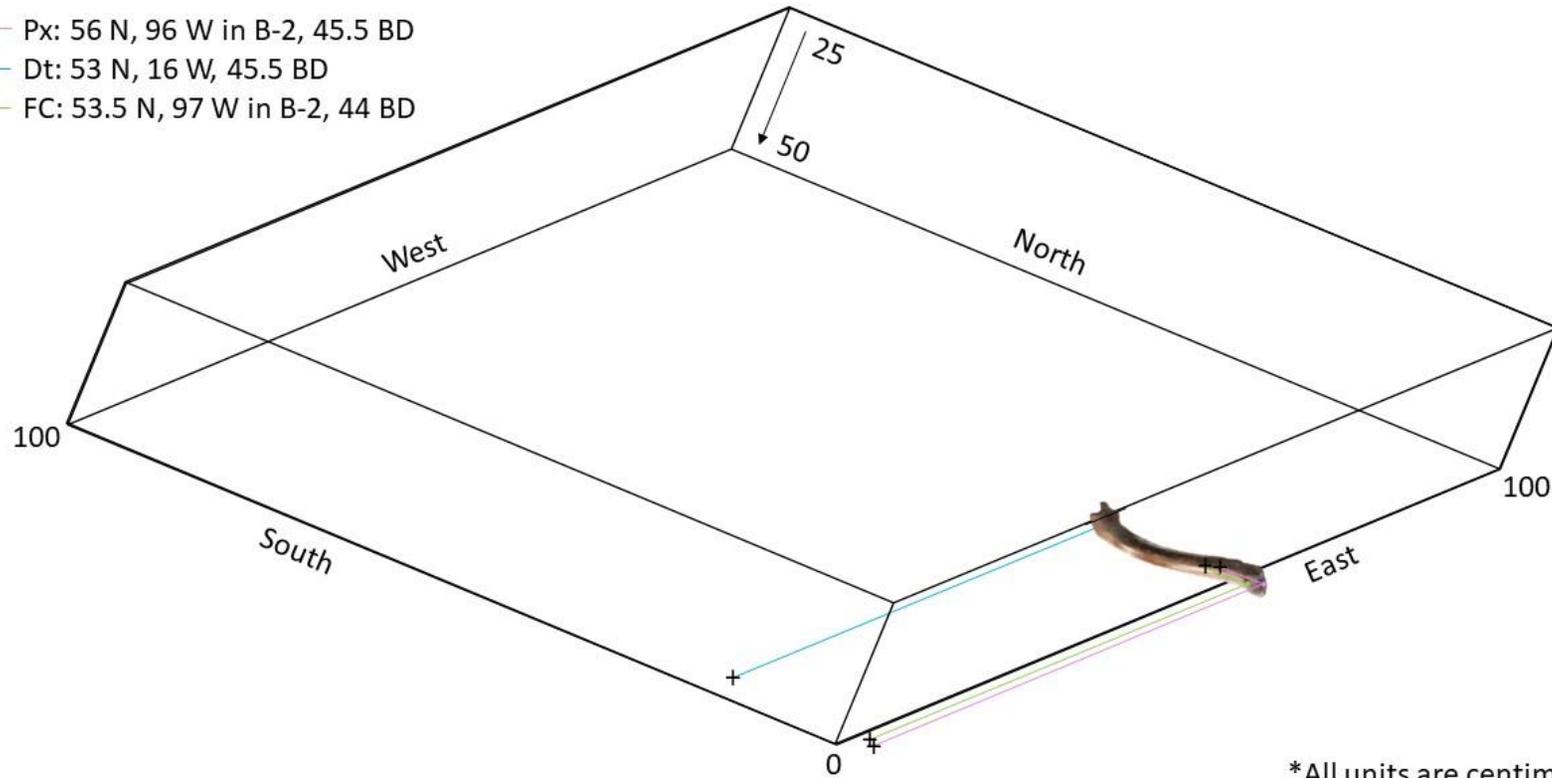
\*All units are centimeters.

13. P23 33247 *Canis dirus* femur



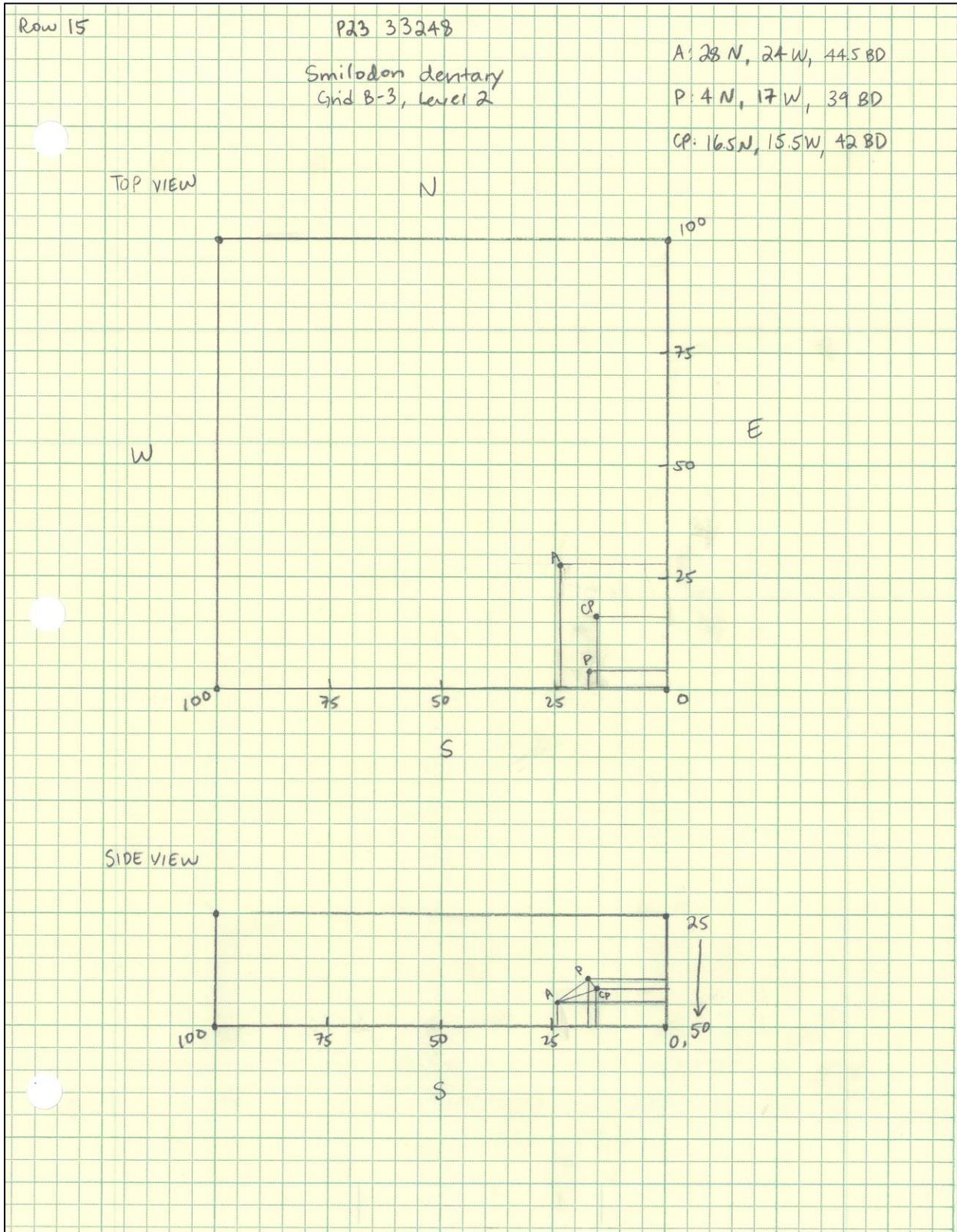
**Canis Femur in Box 13A's Grid B-3 Level 2**  
(P23 33247 *Canis dirus* diaphysis of lt femur)

- Px: 56 N, 96 W in B-2, 45.5 BD
- Dt: 53 N, 16 W, 45.5 BD
- FC: 53.5 N, 97 W in B-2, 44 BD



\*All units are centimeters.

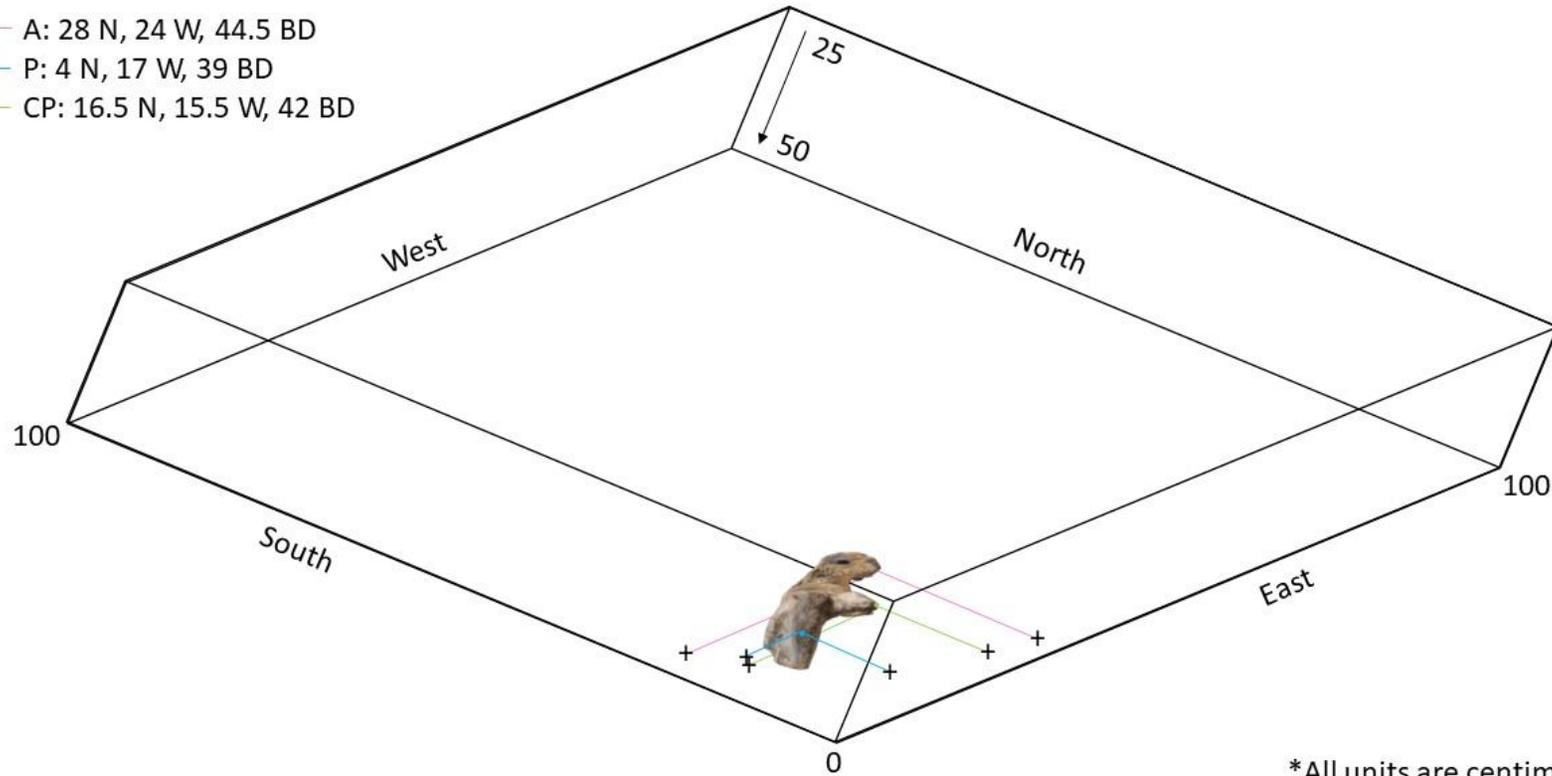
14. P23 33248 *Smilodon fatalis dentary*



### Smilodon Dentary in Box 13A's Grid B-3 Level 2

(P23 33248 *Smilodon fatalis* rt dentary)

- A: 28 N, 24 W, 44.5 BD
- P: 4 N, 17 W, 39 BD
- CP: 16.5 N, 15.5 W, 42 BD

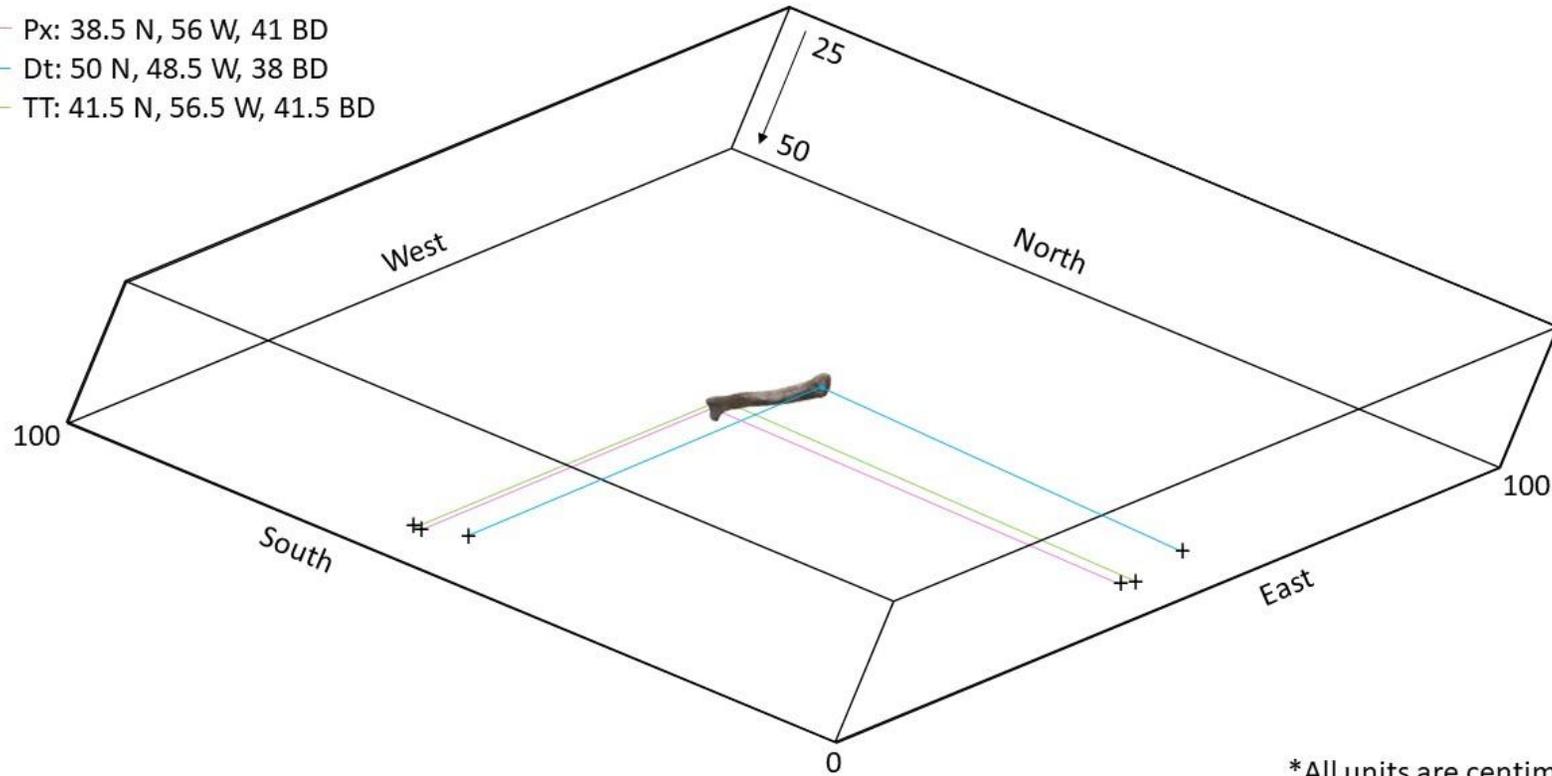


\*All units are centimeters.



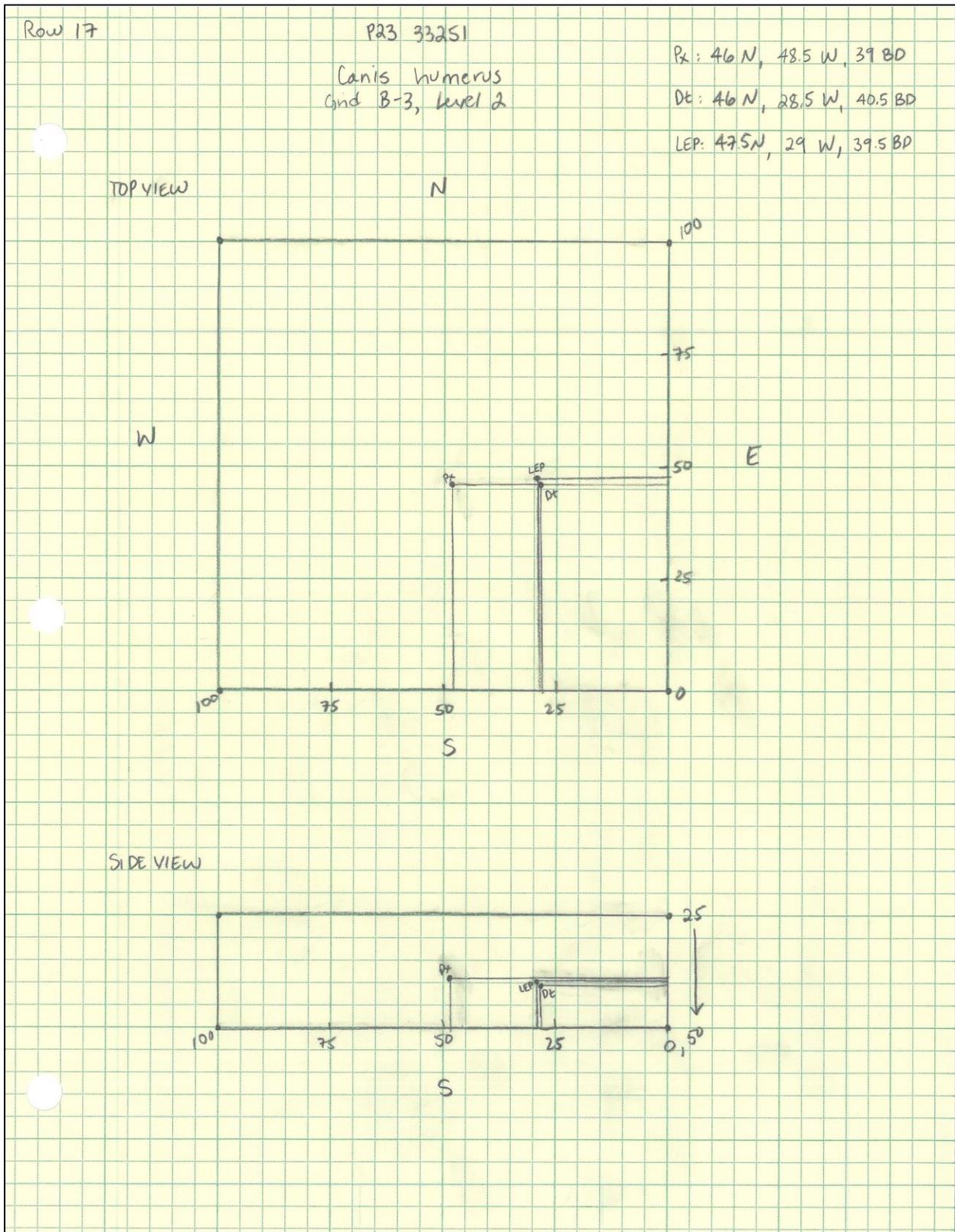
**Canis Tibia in Box 13A's Grid B-3 Level 2**  
(P23 33250 *Canis latrans* diaphysis of Lt tibia)

- Px: 38.5 N, 56 W, 41 BD
- Dt: 50 N, 48.5 W, 38 BD
- TT: 41.5 N, 56.5 W, 41.5 BD



\*All units are centimeters.

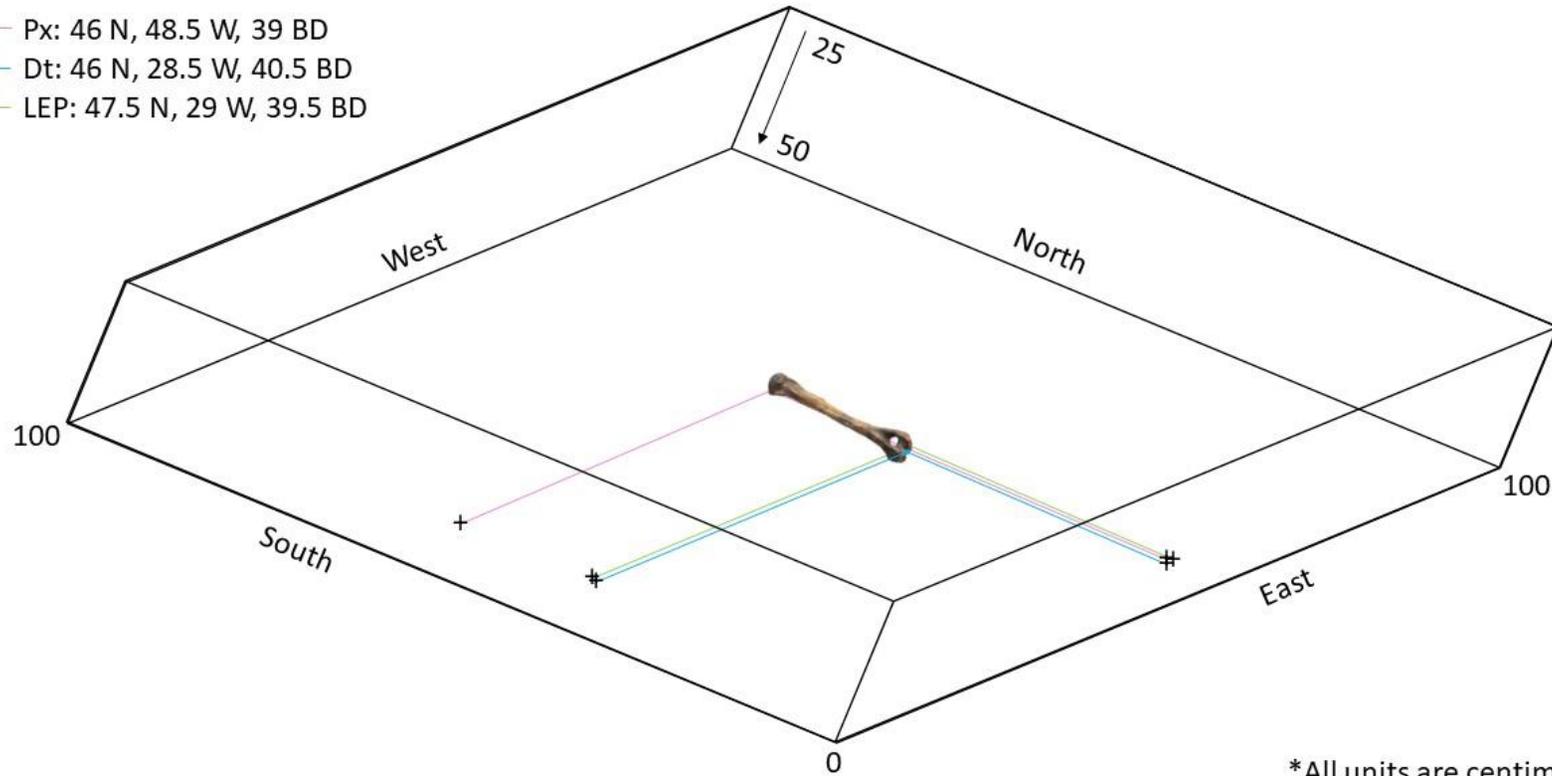
16. P23 33251 *Canis latrans* humerus



### Canis Humerus in Box 13A's Grid B-3 Level 2

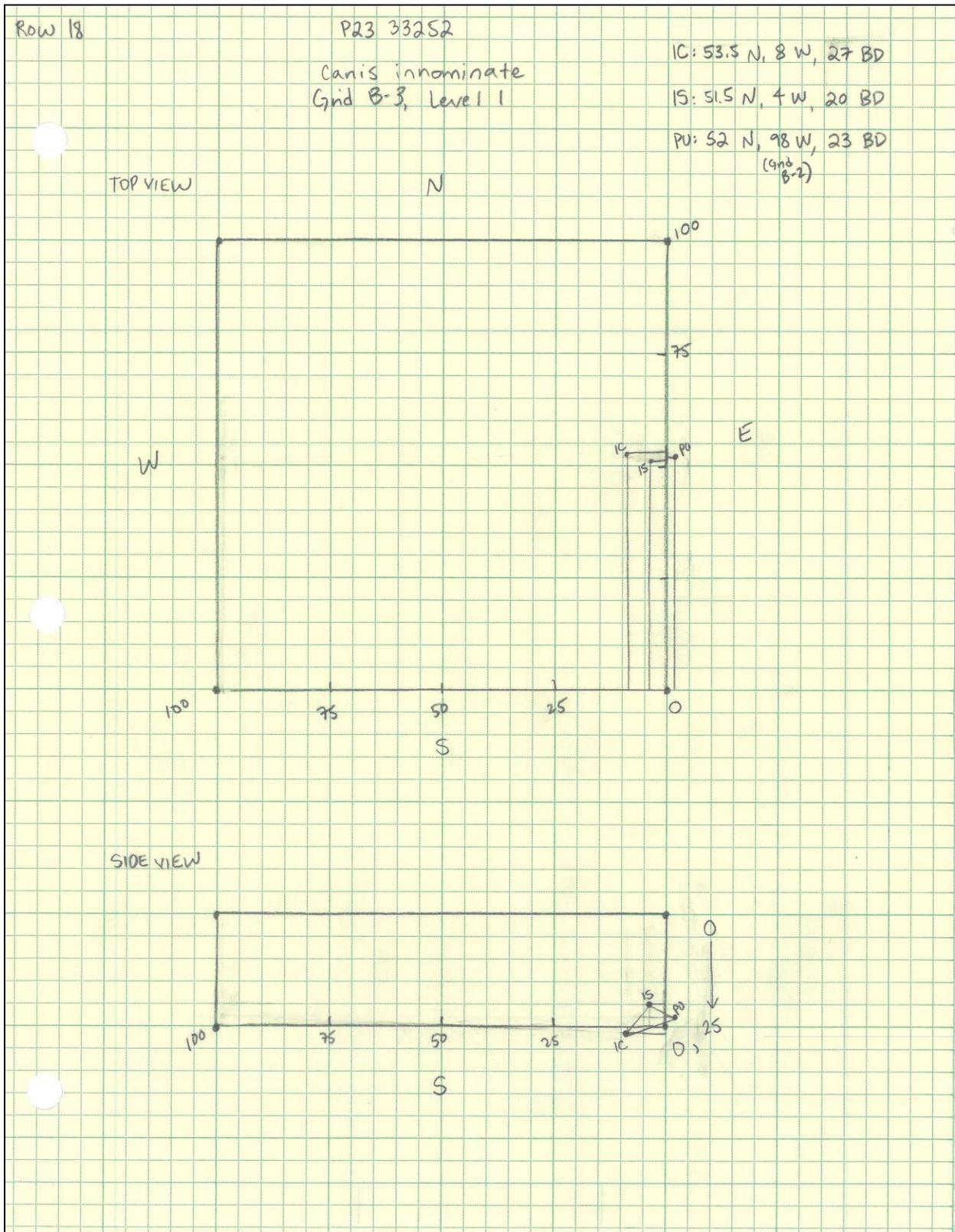
(P23 33251 *Canis latrans* rt humerus)

- Px: 46 N, 48.5 W, 39 BD
- Dt: 46 N, 28.5 W, 40.5 BD
- LEP: 47.5 N, 29 W, 39.5 BD



\*All units are centimeters.

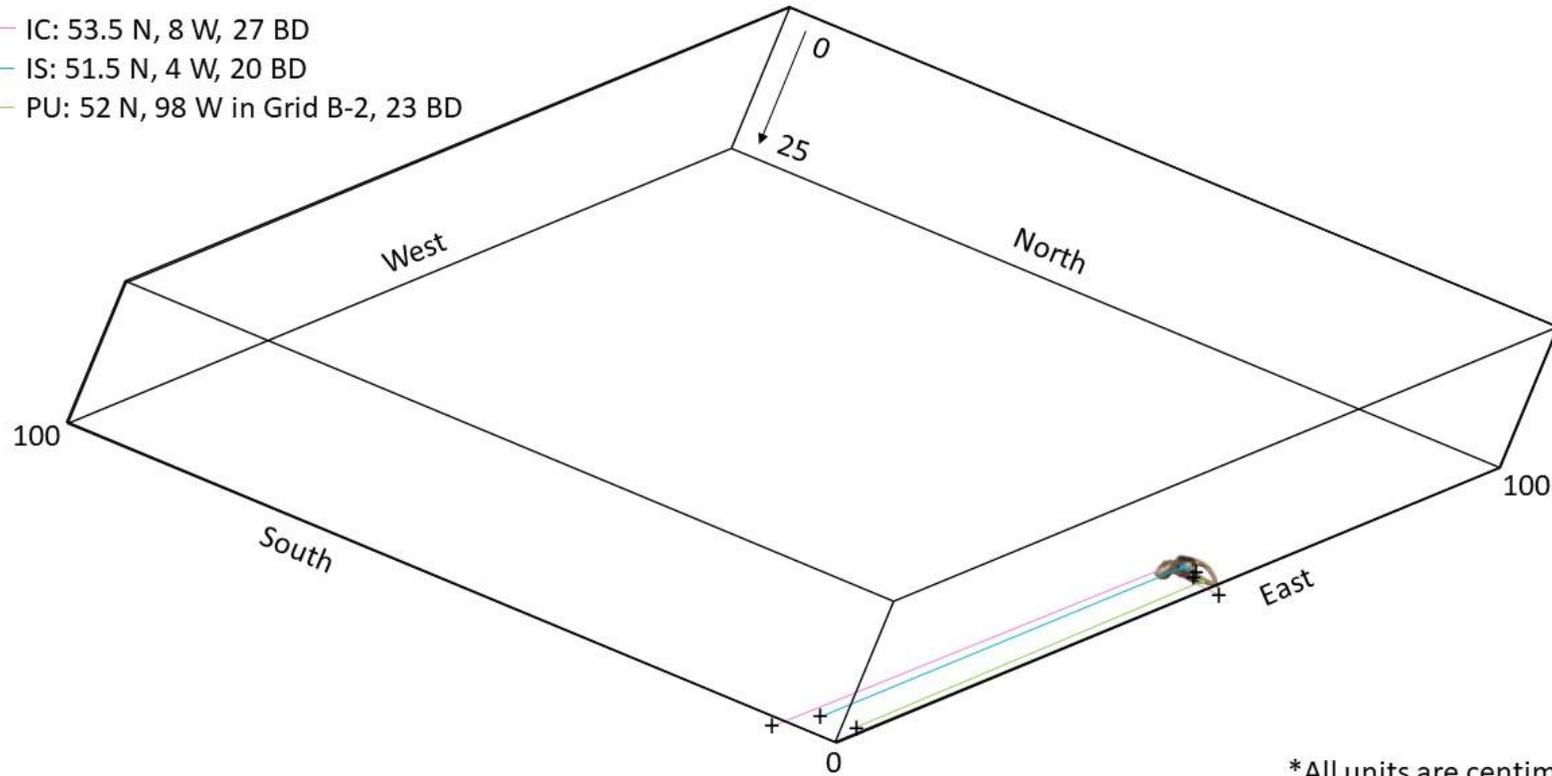
17. P23\_33252 *Canis latrans* innominate



### Canis Innominate in Box 13A's Grid B-3 Level 1

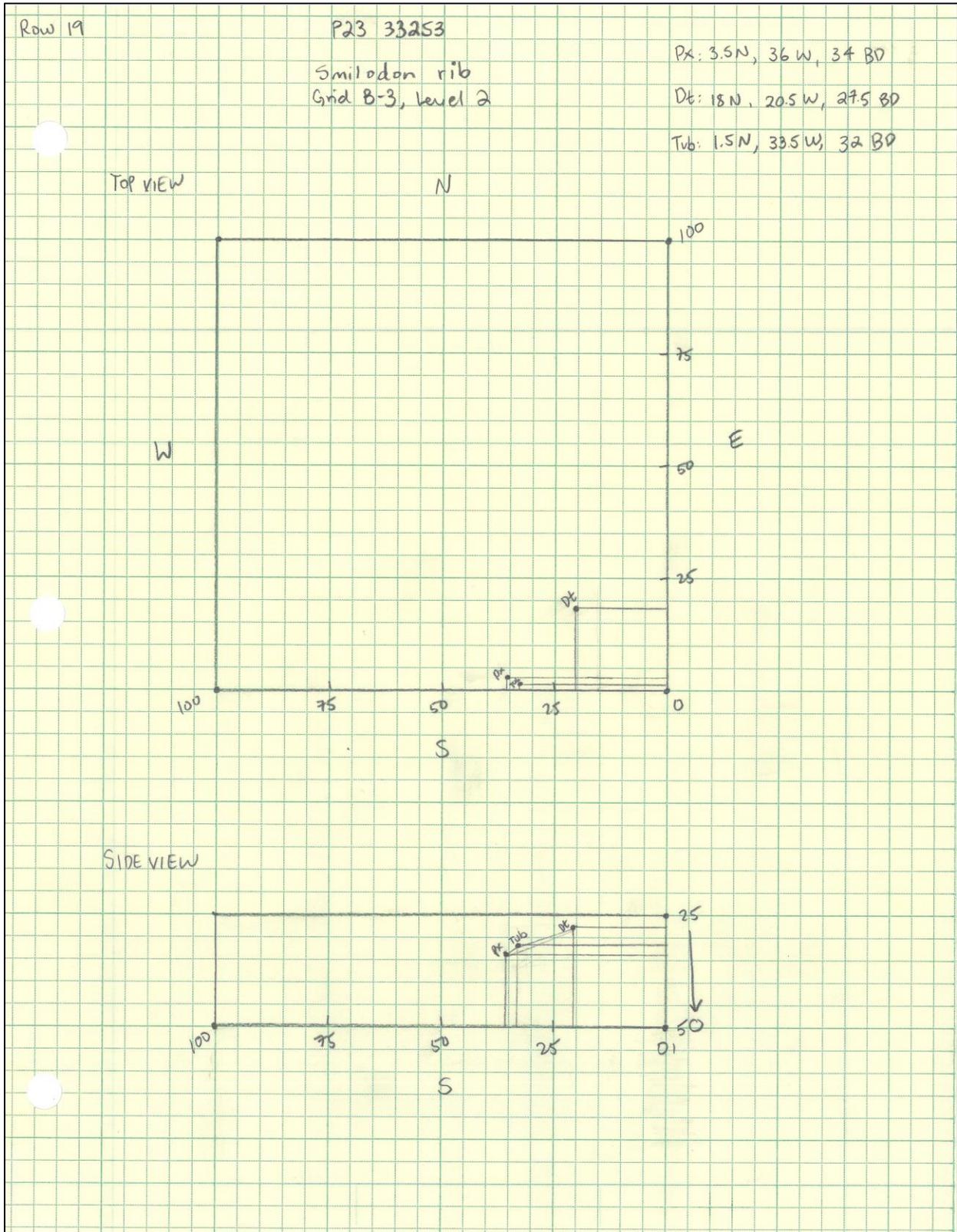
(P23 33252 *Canis latrans* rt innominate)

- IC: 53.5 N, 8 W, 27 BD
- IS: 51.5 N, 4 W, 20 BD
- PU: 52 N, 98 W in Grid B-2, 23 BD



\*All units are centimeters.

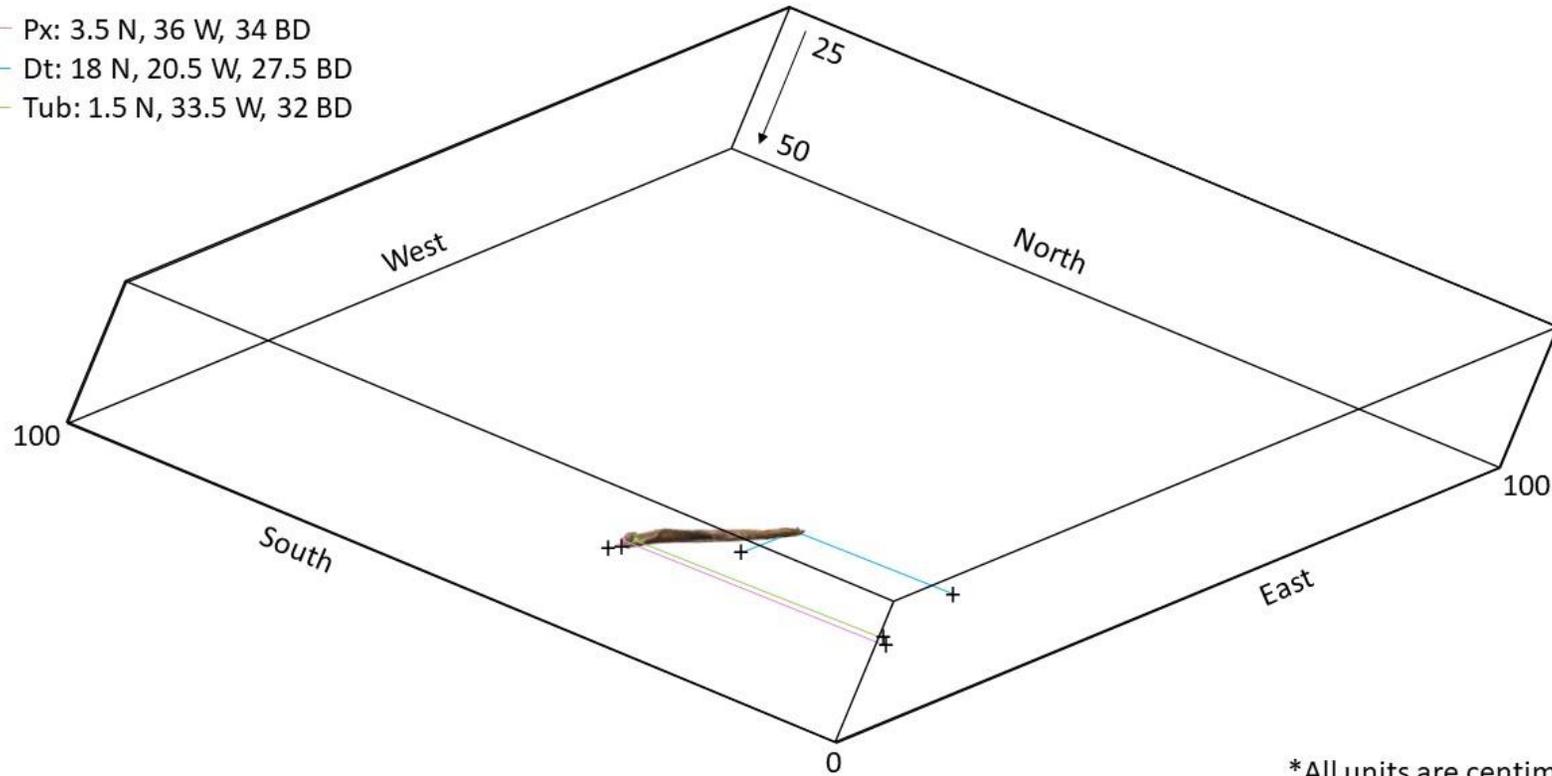
18. P23 33253 *Smilodon fatalis* rib



**Smilodon Rib in Box 13A's Grid B-3 Level 2**

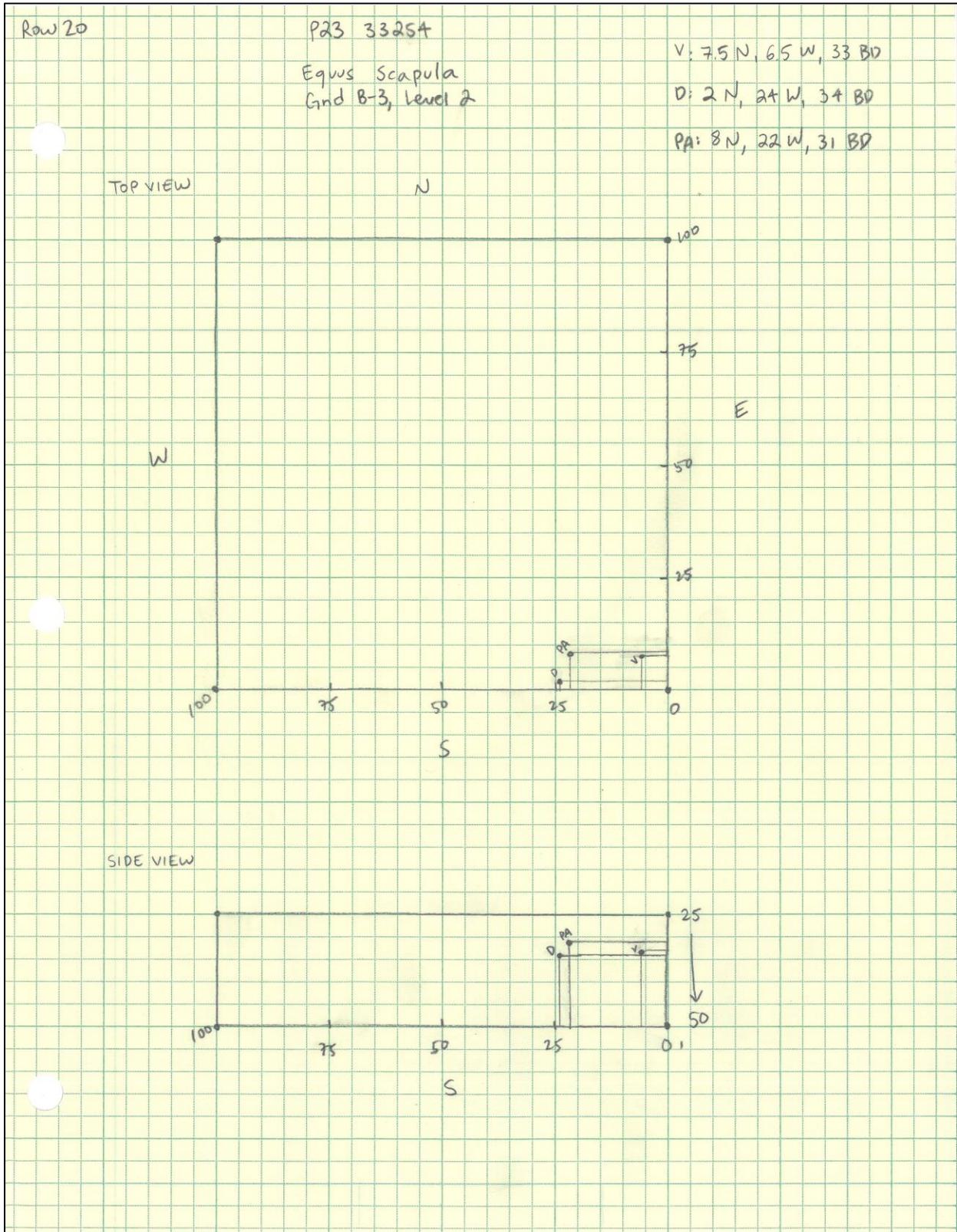
(P23 33253 *Smilodon fatalis* lt XI rib)

- Px: 3.5 N, 36 W, 34 BD
- Dt: 18 N, 20.5 W, 27.5 BD
- Tub: 1.5 N, 33.5 W, 32 BD



\*All units are centimeters.

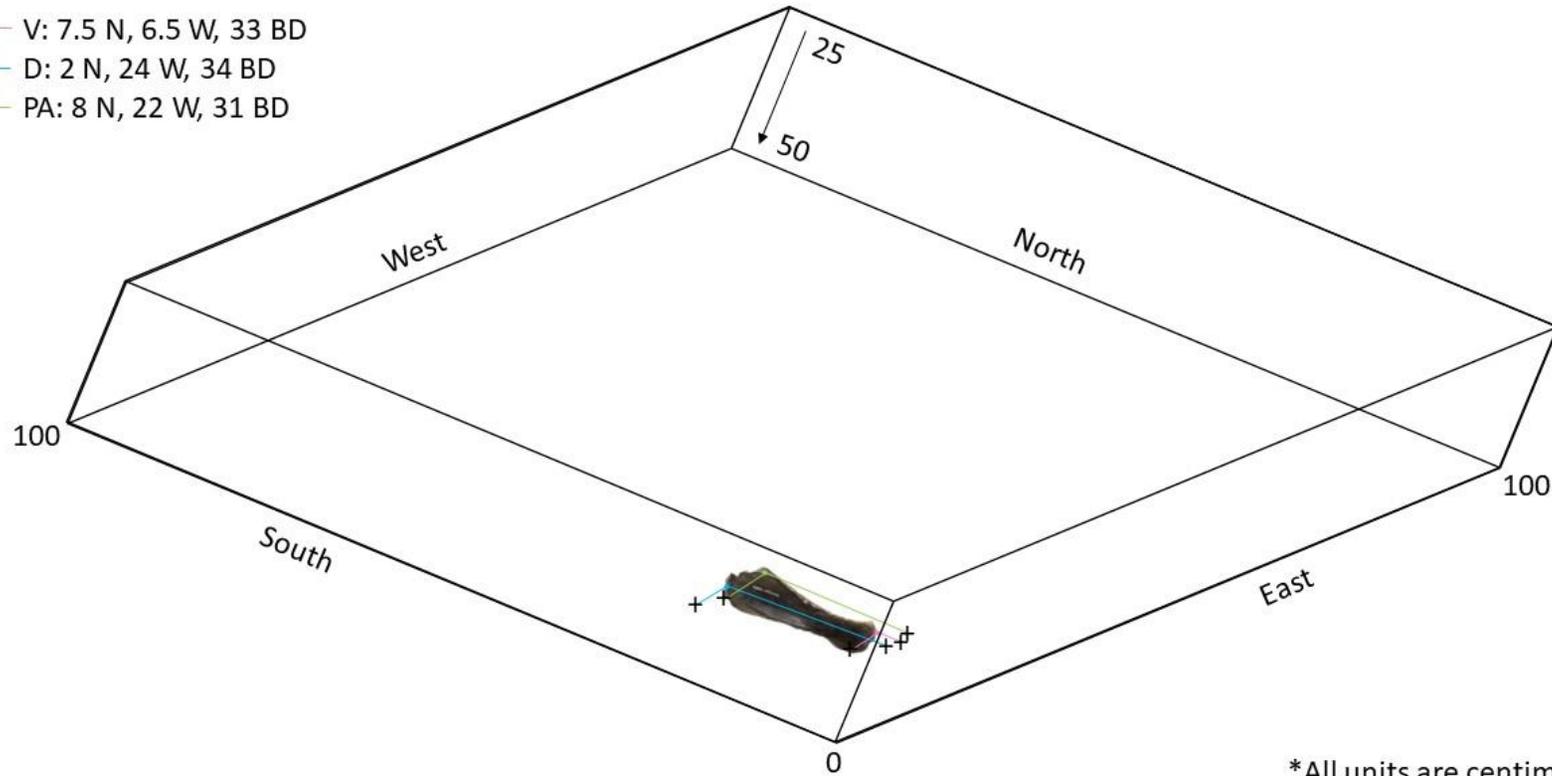
19. P23 33254 *Equus occidentalis* scapula



**Equus Scapula in Box 13A's Grid B-3 Level 2**

(P23 33254 *Equus occidentalis* lt scapula)

- V: 7.5 N, 6.5 W, 33 BD
- D: 2 N, 24 W, 34 BD
- PA: 8 N, 22 W, 31 BD



\*All units are centimeters.