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Digitizing Dinosaur National Monument's Carnegie Quarry

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Master of Science

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ABSTRACT

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The Carnegie Quarry in northeastern Utah is world-renowned for the dinosaur skeletons it has produced and for its *in situ* display of dinosaur bones. The specimens excavated at Carnegie Quarry are displayed and curated in 20 repositories, most in North America. Data on these specimens in the forms of notes, photographs, publications, field maps, and so on, are scattered in an array of formats and institutions. The primary goal of this thesis is to develop a database linking these data with a digital map (GIS system) to make them readily accessible. To this end, a relational database was created using Microsoft Access linked to a vector-based map developed using Avenza MAPublisher running in Adobe Illustrator. Analyzing these data, the Carnegie Quarry produced 4146 specimens representing at least 105 individuals pertaining to 18 genera; 12 dinosaurs, one crocodylomorph, two turtles, *Unio utahensis* (a freshwater clam), and one plant. The map is based on high resolution photographs of the current quarry face merged with historic maps of previously excavated portions of the quarry. Previous attempts to develop a complete map were hindered by the large number of maps primarily from four institutions that excavated at the site, and the lack of an accurate map of the current quarry face (due to substantial relief, the 67° dip of strata, and the lack of a permanent grid). The new maps will provide invaluable insights into the depositional setting, taphonomy and paleoecology of the site. The map and database provide a single access point for data on specimens from 20 widely dispersed repositories linking them their original quarry positions. This expandable tool will be invaluable to scientists and the caretakers of Dinosaur National Monument and is recommended for adoption at other quarries.

Keywords: Dinosaur National Monument, Carnegie Quarry, database, taphonomy, quantitative analysis, GIS, Carnegie Museum

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INTRODUCTION

Dinosaur National Monument is a popular unit of the National Park Service in northeastern Utah with around 300,000 visitors every year (Johnson, 2017). Its primary attraction is the Carnegie Quarry (hereafter, simply quarry). With over 300 scientific papers referencing the quarry it is significant to both lay and scientific audiences. It was opened in 1909 following the discovery of a string of eight *Apatosaurus* vertebrae (Neel, 2015). Since then, four institutions worked the quarry intermittently over a period of several decades. Changes in management of the excavations and the number of institutions working at the quarry over almost 50 years complicates documentation of the quarry. This is exacerbated by the lack of a complete quarry map, the friable nature of some of the original maps, and the distribution of the bones to 16 repositories throughout the United States of America, two in Europe, one in Canada, and one in South Africa (Appendix A). Below is the documentation for the digitization of the Carnegie Quarry maps, the input of records into a database and the linkage between map and database. The consolidated taxonomic, taphonomic, and locational information will then be more readily available to scientists, the staff of Dinosaur National Monument, and ultimately the general public. It will facilitate curation of the specimens and future studies.

Abbreviations

CM, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania; DINO, Dinosaur National Monument, Uintah County, Utah; ROM, Royal Ontario Museum, Ontario, Canada; UU, University of Utah, Salt Lake City, Utah; USNM, United States National Museum of Natural History, Washington, D, C.

BACKGROUND

History of Dinosaur National Monument

On August 17, 1909 Earl Douglass, a paleontologist prospecting for the Carnegie Museum of Pittsburgh, Pennsylvania, discovered eight articulated *Apatosaurus* caudal vertebrae (Douglass, 1909) on public land open to homesteading north of Jensen, Utah (Holland, 1911). This marked the beginning of a monumental undertaking to uncover a paleontological treasure trove.

Earl Douglass supervised a Carnegie Museum crew at the site for more than a decade (1909-1922) (Neel, 2015). During the first several years of excavation the specimens were shipped to the Carnegie Museum (Neel, 2015). By 1922, the museum's storage had reached capacity (Chure, personal commun., 2017). In addition, Andrew Carnegie had died and with that his funding for the quarry operations dried up (Chure, personal commun., 2017). Subsequently some of the bones already at the Carnegie were shipped to institutions across North America, often still in their original crates (Chure, personal commun., 2017). In October of 1915, the quarry and surrounding land was designated by President Woodrow Wilson as Dinosaur National Monument (Boyle, 1938). Several years later, in late 1922, the Carnegie Museum stopped applying for excavation permits for the site (Neel, 2015).

Then a team from the National Museum of Natural History (USNM) led by Charles Gilmore quickly stepped in and began excavating in May of 1923 (http://carnegiequarry.com). They focused on the eastern edge of the quarry, where a partially articulated *Diplodocus* skeleton had been left in place by the Carnegie Museum crew. The Smithsonian operation of the site was short lived, as soon as the *Diplodocus* skeleton was on its way to the Smithsonian they pulled out (Beidleman, 1956).

In 1923, the University of Utah was granted a one-year permit to excavate within the Monument. The UU team focused on the eastern edge of the quarry, near the USNM excavation (http://carnegiequarry.com). Earl Douglass, on a leave of absence from the Carnegie Museum, led the University of Utah's excavations until Golden York took his place in April (Beidelman, 1956). They uncovered another *Diplodocus*, as well as a *Stegosaurus*, and an *Allosaurus* (http://carnegiequarry.com). Satisfied that they had unearthed a skeleton fit for display, the University of Utah ceased excavations and the quarry lay dormant until the early 1930s (Neel, 2015).

In 1933, the Civilian Works Administration as a part of Franklin Delano Roosevelt's New Deal, removed significant amounts of overburden from the quarry face and rubble from the surrounding area so that the area would be more accessible (Boyle, 1938). However, after it was cleaned up, the quarry again lay dormant, until a new plan for the remaining (but still buried) bones resurfaced (http://carnegiequarry.com).

Early in the excavations, Douglass dreamed of a building over his beloved quarry to house the bones *in situ* (Douglass, 2009). Years later, in 1951, his dream was realized, and a temporary museum was constructed over a small part of the quarry at the east end, in the area of the present day "touch part" of the quarry. It was made of timbers and corrugated metal (Chure, personal commun., 2017). Theodore White with a team of National Park Service employees partially excavated the specimens *in situ*, creating a wall of bones in relief (http://carnegiequarry.com). This portion of the Carnegie Quarry is now known as "the wall of bones" (http://carnegiequarry.com). By the late 1950s, a more permanent structure, much of which still remains, was created to protect the quarry face, which measures 183 by 35 feet (Allaback, 2000). In 2006, the National Park Service closed the quarry visitor center due to an unstable foundation, primarily under the office and lab structures to the south of the quarry face. The offices and labs were demolished while the building covering the quarry face was rehabilitated and reopened in 2011 (Carpenter, 2013).

As of this writing, it has been 108 years since Earl Douglass' original find. During the interim, Dinosaur National Monument accumulated hundreds of records pertaining to the quarry and its bones. The National Park Service has been digitizing these records, but they are housed on-site and are not readily available to researchers or the public. Other repositories also have catalog numbers, descriptions and other information pertaining to quarry specimens in their collections. One of the goals of this thesis is to make information from these institutions more accessible.

Geology of Carnegie Quarry

Carnegie Quarry is within the Brushy Basin Member of the Morrison Formation and dates to the Late Jurassic (Turner and Peterson, 1999; Carpenter, 2013) about 151-152 Ma (Kowallis et al., 1991, 1998; Trujillo and Kowallis, 2015). The Brushy Basin ranges from 100 to 133 m thick (Carpenter, 2013). The east-central Utah portion of the Morrison Formation, was deposited in the back bulge of a foreland basin (Currie, 1997; DeCelles and Coogan, 2006). It consists of interspersed layers of marls, shales, sandstones and conglomerates representing fluvial-related environments with some minor lacustrine facies (Evanhoff and Carpenter, 1998; Engelmann et al., 2004). This system supported an abundant biota and proved favorable to the preservation of vertebrates. Thus, the Morrison Formation is renowned for its dinosaur remains, particularly the sauropods (Dodson et al., 1980).

The quarry horizon consists of broad lenses of sandstone within the Brushy Basin Member, about 30 feet thick (Carpenter, 2013). Turtles and bivalves corroborate the fluvial channel origin of the sandstone. Turner and Peterson (1992) suggested it was formed by a meandering river, but it is more commonly interpreted as a braided river deposit because of the coarse-grained, cross stratified sandstones (Lawton, 1977, Carpenter, 2013). Bone orientation indeicates the paleocurrent flowed to the southeast (Carpenter, 2013). Carpenter (2013) proposed that a drought hit the area causing many dinosaurs to die near the river and the bodies collected in the channel. For a more exhaustive discussion on evidence for the ancient river and the drought see Carpenter (2013).

In the Cretaceous and Paleogene periods, strata in this area were folded into a series of anticlines and synclines during the Laramide Orogeny (Gregson and Chure, 2000). The quarry is on the southern flank of the Split Mountain anticline (Lawton, 1977) where resistant strata, including the quarry sandstone, are exposed in bold relief as cuestas. The quarry sandstone dips 67º to the south (Allaback, 2000). While the steeply dipping sandstone provides a spectacular, mural-like, presentation of the bones exposed in bas relief on the quarry face, it greatly complicated excavation of the quarry.

METHODS

This project consists of two components; a database and a map. The database was designed and the tables populated with normalized data about the specimens and related records such as memos, literature and photographs pertaining to individual specimens and the quarry as a whole. The digital map is based on several of the most complete field maps. The culmination of these two steps is linking a portion of the database with the digital map to create a simple way to search the map for specific elements or taxa.

Database Design

Although quarry specimens are widely dispersed, the data about them has been inputted into a single database that includes interrelated tables with publications, taxonomic and element data, repositories, catalog and accession numbers, and other records (Appendix B). A relational database was necessary to consolidate and organize the extensive data. A relational database connects tables in multiple directions. Data are accessible through various tables and routes. This interrelatedness minimizes redundant data. Also, each table has a primary key or unique identifier which ensures that data are unique and represents the connected table when multiple tables are related to each other. This makes it easier for users to create queries and obtain information from the database without being intimately familiar with the complete design of the database (Hernandez, 2013). Windows Access 2016 was used to create the Digital Quarry Database (hereafter, simply the database).

Data Gathering.

Several institutions, described below, provided the data that are now included in the database. Many records of various types were provided by Daniel Chure, the paleontologist at Dinosaur National Monument. Much of the data about specimens still at Dinosaur National Monument were taken from the National Park Service museum cataloging system, ICMS (Interior Collection Management System), and imported into an Excel file. These data were augmented by *The Annotated Catalogue of the Dinosaurs (Reptilia, Archosauria) in the*

Collections of Carnegie Museum of Natural History by McIntosh (1981). Additional data were added from McIntosh's notebooks that are now owned by Daniel Chure and housed by Brigham Young University's Museum of Paleontology. Some specimen data, especially those at the Royal Ontario Museum and the Carnegie Museum, were also found at VertNet (http://vertnet.org), an online collaborative repository for biodiversity. Data about specimens currently at the University of Utah were obtained through personal email messages with Carrie Levitt-Bussian, Paleontology Collections Manager of the Natural History Museum of Utah (June 2, 6, 2017). A few specimens were added based on descriptions in the literature. For example, CM 11338 (IndID 242) and DINO 28, 32-37, 948-951, 953-971, 1104 (IndID 336) are described in Gilmore (1925) and White (1958) respectively.

Normalization

After gathering data from various sources, it was normalized. Normalization is the process of cleaning and organizing data into a set of normal forms to improve efficiency. This simply means that data are organized into discreet units with redundant data removed and unique identifiers added (https://support.office.com/en-us/article/Move-data-from-Excel-to-Access-90c35a40-bcc3-46d9-aa7f-4106f78850b4#bm1b). An example of normalization is that a field should contain only a first name, not a first and last name. If the last name needs to be included it should be placed in a separate field. Another part of the normalization process is to get rid of redundancy. This means each identity (such as a single bone) should only occur once in the database, although it can be linked to other queries or tables. Normalizing data is time consuming, but essential for a functional database. Once gathered, the data were imported into Excel files and normalized in preparation for importing into database tables.

Organization

The Digital Quarry Database design focuses on a table of individual specimens. Ideally each specimen is a single bone. Other data about taxonomy, repositories, records and photographs are recorded in separate tables and then linked to this central table (Figure 1). The resulting database is necessarily complex, consisting of 32 related tables and various queries (Appendix B).

To organize this complex database, a consistent naming system for the many tables and queries is used. Four types of tables are used in relational databases. Each table name begins with the first letter of the type of table it is, followed by "Tbl" and then a short, but descriptive title, for example, the central table contains data about individual specimens and is named “DTbl Specimens”. Queries are named in a similar manner with a few letters designating the use of the query followed by a “Q” and then a short descriptive name. “HRQ Specimens” is a query designed for human readability but contains the data found in “DTbl Specimens”. Thus, the names of the tables and queries reflect their role in the database and the type of data they contain.

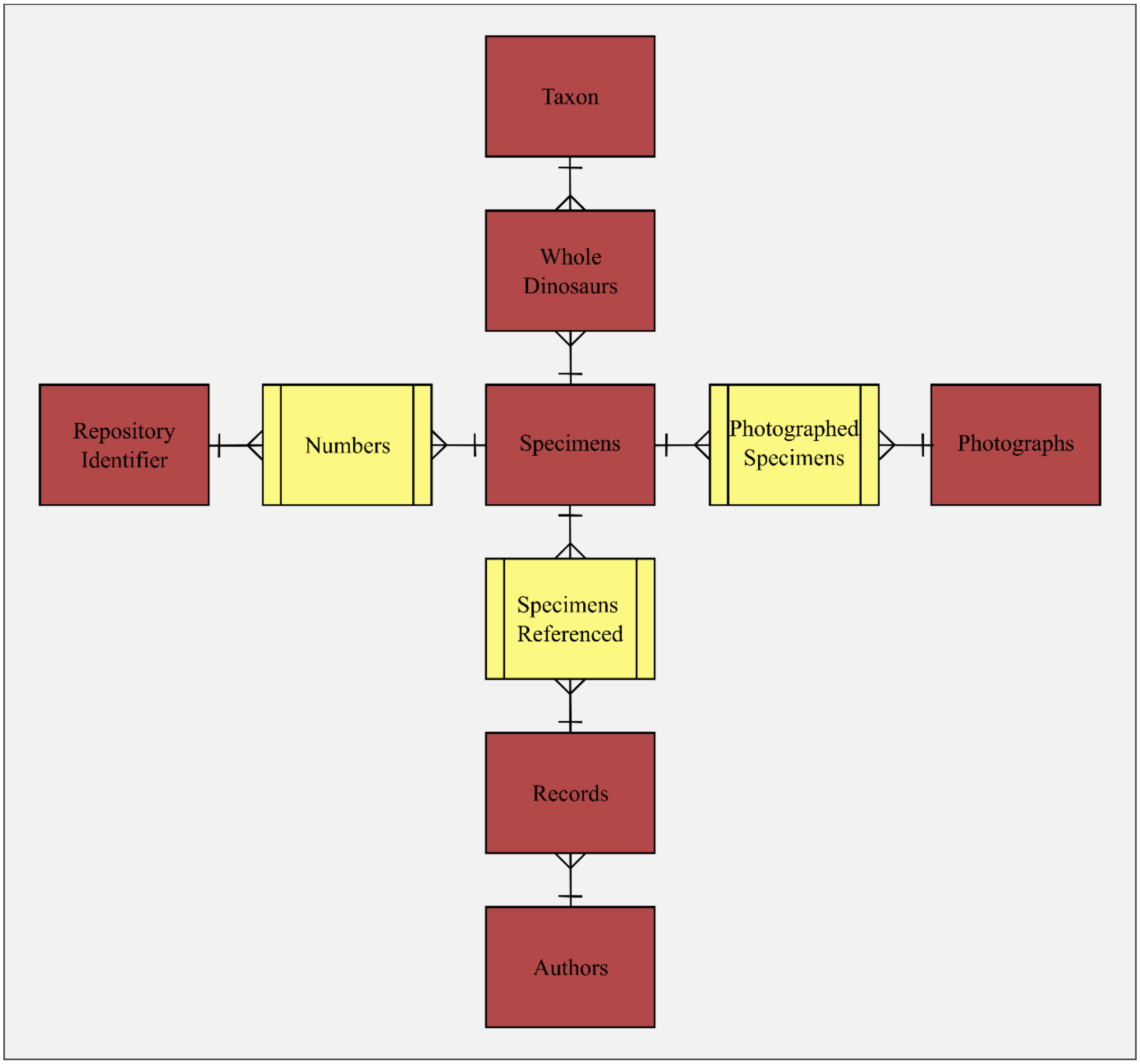


Figure 1: Simplified Digital Quarry Database schematic. The central table, “Specimens” includes individual specimens (usually bones), and the other data connect to this table. Red = data tables, yellow = linking tables.

Keys

Each database table uses a primary key to link with other tables. This is a value or combination of values unique to each record (row of a given table). Most primary keys are automatically generated numbers indicating the order in which the records were inputted. However, they are vital to the smooth running of the database because they provide a short number that can be used to link tables efficiently. Most primary keys are named in the database for the value they represent followed by the letters "ID". Each specimen (which is ideally one element, but is sometimes multiple bones) is assigned a "DigitalQuarryID". Likewise, every record, element, and potential individual also has an ID number. Tables are connected to each other using foreign or secondary keys. Thus a primary key from one table imported into another table becomes a foreign key (Figure 2). Keys are the basis for relationships between tables and ensure the data integrity.

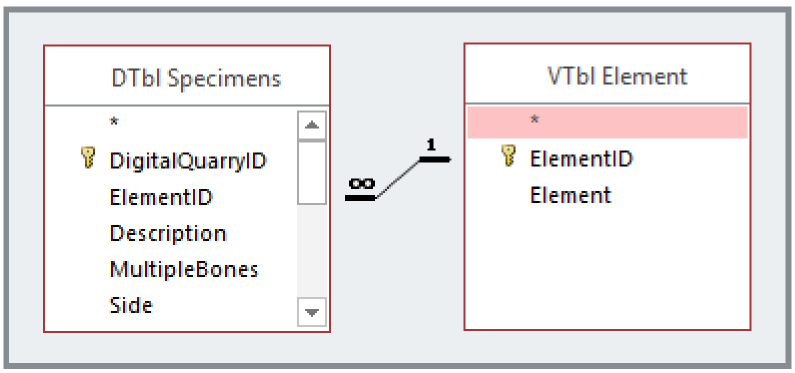


Figure 2: Primary and foreign keys. DigitalQuarrryID and ElementID are the primary keys in their respective tables (hence the key image next to them). ElementID is also a field in "DTbl Specimens", and links to "VTbl Element", thus, it is a foreign key within that table.

Tables

Four types of tables are used in relational databases; data, linking, subset, and validation (Hernandez, 2013). Data tables contain the bulk of the data and usually have many fields (columns) and records (rows). Linking tables connect two other tables in a many-to-many relationship. For example, many bones in "DTbl Specimens" have been referenced in scientific papers found within "DTbl Records". Thus, each bone could be mentioned in multiple articles, and each article could reference multiple bones. This is a many-to-many relationship. Microsoft Access does not allow direct many-to-many relationships between tables and thus a new table is needed. This table includes the primary keys from both data tables as foreign keys in the linking table. The combination of these foreign keys make up a composite primary key (Figure 3). “LTbl SpecimensReferencedinRecords” links specimens to the records that mention them. Instead of a many-to-many relationship this creates two one-to-many relationships. Linking tables are not common but they are important.

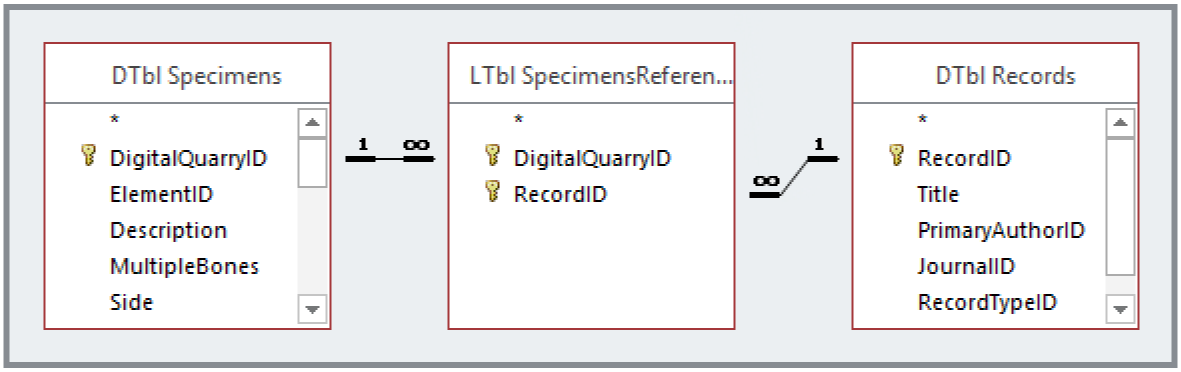


Figure 3: Linking tables. “DTbl Specimens” is connected to “DTbl Records” via “LTbl SpecimensReferencedinRecords”, which has a composite primary key made up of the primary keys of the other tables.

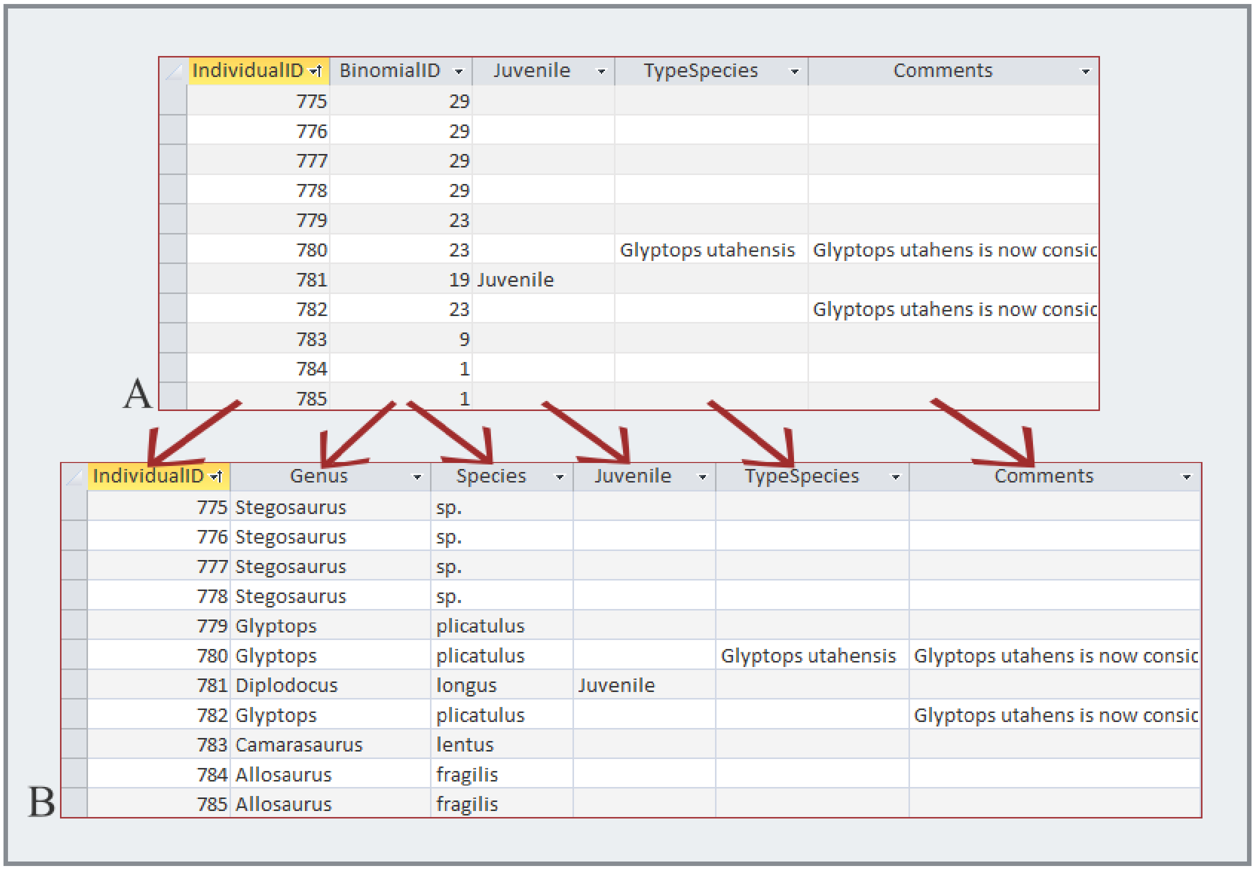
Subset tables are used when one table has many records and some of the records require more fields than the majority of records. Such tables have a one-to-one relationship with the parent table, but only include the fields that are required for part of the records. Validation tables are simple with few fields that link to data tables in a one-to-many relationship so that only values from the validation tables can be inputted into a particular field (Hernandez, 2013). “VTbl Elements” includes a list of skeletal elements such as ulna, tibia, and humerus. This table is connected to “DTbl Specimens” so that only the values found in the “VTbl Elements” can be used to describe a specimen. Well-designed tables make creating queries simple, and speeds up searches.

Queries

Views or queries (as they are called in Access) are "'virtual' tables" (Hernandez, 2013, p. 54). This means that they are made up of fields and records from related tables. They serve many purposes, but primarily make the database more user friendly. Although there are several types of queries, the final stage of this project primarily uses data queries. Append or update queries modify tables but data queries display connected tables in a single table. They are used to view large amounts of data or only specific fields or records. The data queries were named depending on the use of the query.

One of the main advantages of this database is that it is easy to look up specific specimens via museum catalog numbers. To make this easy there is series of queries that include much of the data from the main specimens table along with all the numbers of a specific type. For example, "NCQ DINOSpecimens" is a Number Check Query for all the DINO catalog numbers. This means that only specimens with DINO numbers appear in this query. Another query, called a crosstab query is also a great tool for manipulating the data. "NCCQ SpecimensWithNumbers" (Number Check Crosstab Query) is a query that lists the specimens by DigitalQuarryID and then their various field, catalog and accession numbers in a single row. This query makes it easy to look up a specimen with one type of number and relate it to other numbers, for example a researcher could use it to look at a CM catalog number and find the corresponding field and box numbers. This query, however, has limitations because if one bone has more than one of the same type of number (some bones were double catalogued by the Carnegie Museum or given multiple field numbers) then only one of these numbers is visible. Despite this shortcoming, queries such as these can simplify the work of researchers.

The queries also make the current tables easily understood. To reduce redundancy and inaccuracy, foreign keys are often just columns of numbers in the secondary table. This makes understanding the table difficult to read at a glance. Therefore, some queries are labeled "HRQ" for Human Readable Query, and are essentially a copy of a specific table but with words instead of numerical values. Figure 4 shows a portion of "Dtbl WholeDinosaurs" along with a query that shows essentially the same table but instead of using the BinomialID, (which is a foreign key from "Dtbl Taxon") it pulls the genus and species fields from "Dtbl Taxon". This makes the table understandable at a glance.



A

IndividualID	BinomialID	Juvenile	TypeSpecies	Comments
775	29			
776	29			
777	29			
778	29			
779	23			
780	23		Glyptops utahensis	Glyptops utahens is now consic
781	19	Juvenile		
782	23			Glyptops utahens is now consic
783	9			
784	1			
785	1			

B

IndividualID	Genus	Species	Juvenile	TypeSpecies	Comments
775	Stegosaurus	sp.			
776	Stegosaurus	sp.			
777	Stegosaurus	sp.			
778	Stegosaurus	sp.			
779	Glyptops	plicatulus			
780	Glyptops	plicatulus		Glyptops utahensis	Glyptops utahens is now consic
781	Diplodocus	longus	Juvenile		
782	Glyptops	plicatulus			Glyptops utahens is now consic
783	Camarasaurus	lentus			
784	Allosaurus	fragilis			
785	Allosaurus	fragilis			

Figure 4: Human Readable Query. A. Part of "Dtbl WholeDinosaurs". B. Portion of a query based off the same table with the genus and species visible instead of the BinomialID.

The final and most diverse group of queries is a series of "task queries" (TQ), each designed for a specific task. A simple task query is "TQ SkullPieces". This query uses fields from six related tables to display data related to specimens that are parts of skulls. "TQ NISP," is a query that is used in calculating the Number of Identified Specimens (NISP calculations are described in more depth under the results section). It displays only identified elements of a specific taxon (which can be changed manually). Automating these tasks make the calculation of NISP simpler, and working from this base the Minimum Number of Individuals (MNI) can also be calculated. Additional queries can be easily added by those with a knowledge of Access 2016 and an understanding of the database. The versatility of queries is what makes a database not just a reliable way to store data but a great research and reference tool.

Maps

As discussed earlier, four main institutions participated in the excavation of Carnegie Quarry. The first three, the teams from the Carnegie Museum, the Smithsonian, and the University of Utah, all created field maps based on their work. However, there was not one map that included the entire historic quarry. The wall has also been previously mapped by Rick Shugan for use at the monument (Shugan, 2008), and Carpenter (2013). Using various field maps, and photographs of the current quarry imported into Adobe Illustrator, I created one Master Map with various layers that include the data from the field maps and photographs, but also subset maps that are based on prepared specimens such as the iconic juvenile *Camarasaurus* (CM 11338 or IndID 242) on the right middle of the map, and the baby stegosaurus (DINO 2438-2439, 2441-2442, 2447-2448, 2450-2451, 2453-2456, 2463, 2465, 2469 – 2470 or IndID 358) found on the wall.

Map Names	Origin	Extent
Used in Master Map		
McIntosh blueprints	Possibly based off Douglass' original field maps	Historic quarry without the UU excavations
McIntosh annotated	Photocopied pieces of the Gilmore Map with additional bones drawn in and others deleted	Historic quarry
wall	Illustrator file based off photogrammetry	Wall
vellum	Gilmore map with additions from the UU and USNM field maps	UU and USNM excavations, East end of the quarry
Smithsonian	Photocopy of the USNM's field map	USNM excavations a small portion of the east end of the quarry
subsets	Some are hand-drawn block maps from the UU, others are McIntosh's additional drawings based off prepared individuals	small areas including juvenile Camarasaurus, UU *Allosaurus*, Baby *Stegosaurus*, *Camptosaurus aphanoecetes* holotype
Not Used Directly in Master Map		
Gilmore map	Published by Charles Gilmore in 1936	Historic quarry without the UU excavations
Rick Shugan's map	A map drawn and labeled for use by DNM	Wall

Table 1: Carnegie Quarry maps.

Historic Quarry Maps

Field maps created by the various excavation teams and other partial maps were combined in various ways to create a wide variety of maps that cover larger parts of the whole quarry. Several of these maps are combined to create the historically excavated portions of the Master Map (Figure 5).

The map called the “Smithsonian map” in this paper, is owned by Dinosaur National Monument. It is a photocopy of a field map that includes the *Diplodocus* excavated by the Smithsonian as well as a partial skeleton excavated by UU. This map was used as the basis for the *Diplodocus* skeleton in the Master Map.

Arguably the most complete map of the historic quarry is one that will hereafter be called the University of Utah map. This map was based on the Gilmore map (Gilmore, 1936) with the addition of the compiled University of Utah field maps. A portion of this map, focusing on the University of Utah and U.S. National Museum excavations, printed on vellum is on file at Dinosaur National Monument. This vellum map was used as the basis for the University of Utah excavations in the Master Map.

In sum, the historic quarry face portion of the Master Map is based on three maps, the blueprint version, the Smithsonian and the vellum maps (Appendix C). Augmenting these maps, is a series of photocopied maps (presumably of the original Carnegie map) with handwritten notes and additional bones drawn in by John S. McIntosh. This series also includes several detailed maps that show areas that were further prepared after the initial maps were drawn. These maps were included in the Master Map because they show more detail and accuracy then was preserved elsewhere. However, they are only sublayers that can be turned on and off. This was done so that the main map stays uncluttered and true to the historic integrity of the map, while preserving the highest level of accuracy available.

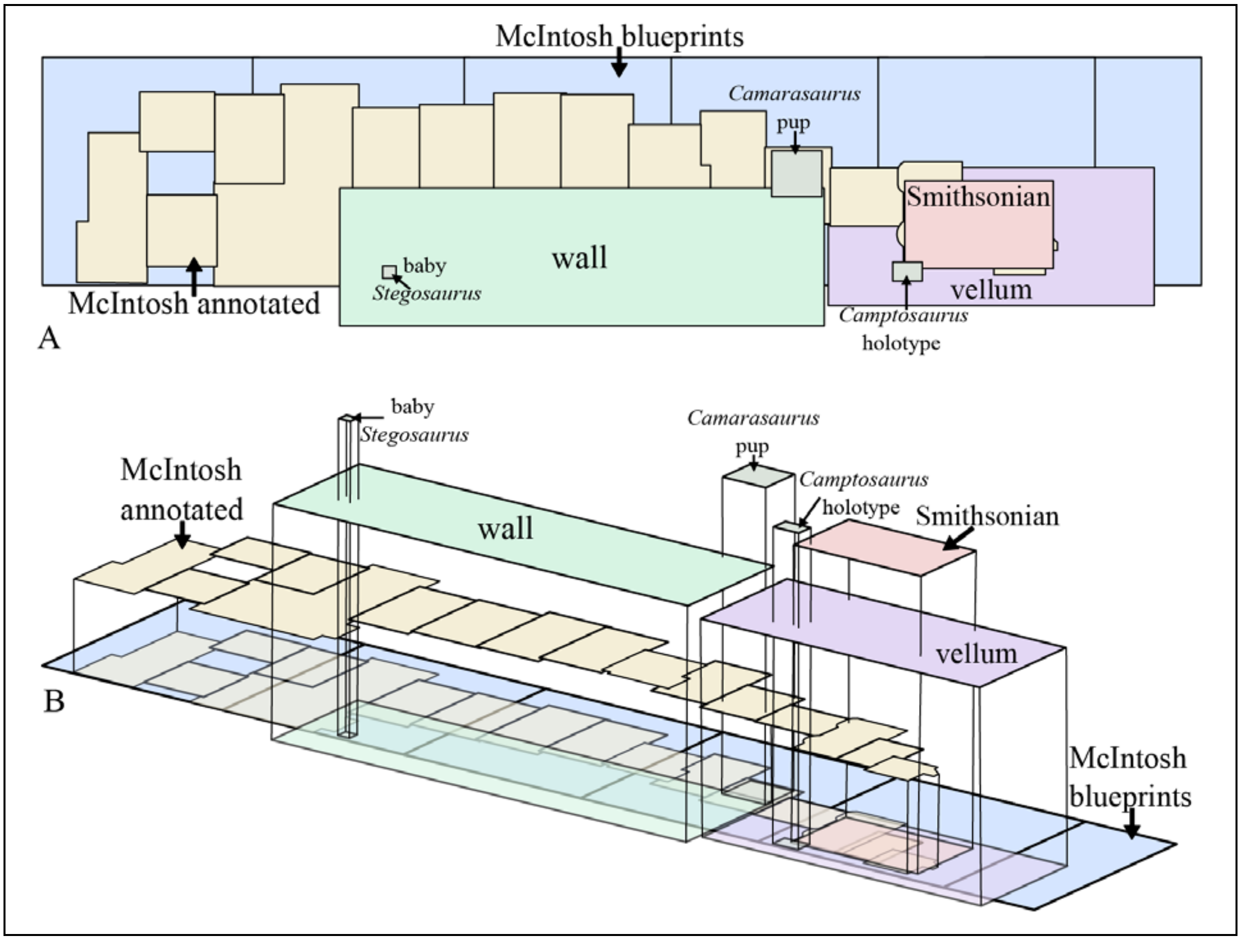


Figure 5: Relationship of maps used to develop the Master Map. A. Maps in plan view. B. Maps in oblique view to show overlap between maps. Detailed information for the maps is given in Table 1.

Present Day Quarry Maps

There have been several attempts to map the present-day quarry face. Due to the steep angle of the quarry face as well as its size, it is difficult to create an accurate map, even based on photographs due to perspective and relief issues. In 2014, the quarry face was photographed, and the photographs digitally stitched together. The same year, Ben Otoo and Nicole Ridgwell traced the vast majority of the bones in the composite image of the current quarry face. However, the perspective of the stitched photographs is inconsistent and ridges of rock and bone obscure other bones causing some bones to not be included in the map. Ben and Nichole melded their map with the Gilmore map using Adobe Illustrator. These vectors only needed to be slightly adjusted in shape and location to fit the blueprint map and photographs of the present-day quarry face. This map, adapted during the summer of 2016 by Sara Oser, a Dinosaur National Monument intern, is the map used in the Master Map for the present-day quarry face.

Once the combined historic field maps and the present-day quarry face map were created the next step was to combine them. This was difficult because although starting in 1910 or 1911, Douglass and his crew painted a grid system directly on the rock (Carpenter, 2013), it had faded to non-existence by the time Theodore White began excavating the current quarry face in the 1950s. Thus, the precise location of the present-day quarry face in relation to the historic quarry is unknown. Based on personal communications from (now deceased) John S. McIntosh to D.J. Chure one string of 24 *Apatosaurus* caudals (Block Number 60/E, G-H, DINO 4475-4488) is likely to continue from the current quarry to the historic quarry (Appendix C). Like pieces of a puzzle, the outline of the current quarry face “fits” into a gap in the historical quarry map.

Database and Map Integration

The keystone of this project is the integration of the database and the Master Map, creating a geographic information system. Once the bones were drawn the lines or paths were named based on their map labels: the field or block numbers on the Blueprint Maps and the DINO numbers for the current wall. A query including information about each specimen was then exported from Microsoft Access into a file compatible with Avenza MAPublisher within Illustrator CC. MAPublisher is a GIS add-on for illustrator. In this way the named paths or vectors are linked to the corresponding record from the database. Of the 5016 records in “DTbl

Specimens", 2753 are connected in this way. This allows the bones to be searched by attribute (such as taxon, element, or repository) and visually grouped.

Using the grid system recorded on the McIntosh blueprint maps the dimensions of the quarry, past and present, were calculated. The quarry is approximately 23 m tall and 106 m wide at the largest extents.

Challenges

There are several challenges in this project that relate to how data should be documented. Many logical solutions are possible, but to stay consistent, only one was chosen. Thus, several problems are listed and the favored solutions provided.

Juveniles

The Carnegie Quarry is known for a significant amount of uncommonly small individuals, most notably the *Camarasaurus* pup (CM 11338 or IndID 242) (Gilmore, 1925), the baby *Stegosaurus* (DINO 2438-2439, 2441-2442, 2447-2448, 2450-2451, 2453-2456, 2463, 2465, 2469 – 2470 or IndID 358) (Galton, 1982), and the minute *Dryosaurus* (CM 11340 or IndID 243). However, there are some individuals that may just be small adults. In the database the term juvenile is used loosely to refer to specimens that are significantly smaller than normal for their taxon. It is not necessarily based on histology. If any sources recorded a specimen as being juvenile this is noted in the "Juvenile" field in "DTbl WholeDinosaurs". Although, not backed by a consistent definition of juvenile this solution provides a basis for interested professionals to find small individuals.

Skulls and Shells

Eight percent of the specimens from the quarry are articulated or associated with at least one other element. The Carnegie Museum excavators often assigned a single field number to what they judged to be a single individual. Inevitably, many of these field judgements proved to be incorrect. For example, field number 60 was assigned to *Apatosaurus, Camarasaurus, Diplodocus, Dryosaurus,* and *Stegosaurus* elements. To accurately track individual elements and avoid errors such as the one mentioned before, each individual bone was assigned a unique and arbitrary Digital Quarry ID number whenever possible. Some specimens lacked precise descriptions that were inadequate to pinpoint specific bones, and these are recorded in the "MultipleBones" field. Occasionally this solution, when working with whole dinosaur skulls or testudines' plastrons and carapaces, seems overly complex. However, to be consistent and embrace the normalization process necessary for databases, both skulls and shells were divided into individual bones (even when articulated) when possible. Thus, instead of one or two records, CM 3380, the carapace and plastron of a *Glyptops plicatulus* is now 53 records (IndividualID 782). Although this at first appears to bloat the system, it in fact creates less ambiguity. DQ 1648 is recorded as a "nearly complete shell" of another *Glyptops plicatulus*. Unfortunately, this record is less helpful because it is unclear whether it refers to the carapace alone, or a partially broken carapace and plastron. This makes it less precise when using it in calculations such as those discussed later. On the other hand, dividing articulated series of bones into separate records allows researchers to search for individual bones such as a pleural or a dentary as well as the structure of a carapace or skull. Ultimately these divisions provide increased searchability.

Nielsen Gulch

Nielsen Gulch is an area immediately east of the Carnegie Quarry. It contains a physical continuation of the quarry sandstone but also significant exposures of the Brushy Basin mudstones both above and below the sandstone. The Carnegie Museum collected specimens from Nielsen Gulch, although their stratigraphic location was sometimes uncertain (see McIntosh, 1981 for specifics). The proximity and simultaneous excavation of Nielsen Gulch has caused specimens found there to sometimes be improperly included with Carnegie Quarry specimens (http://vertnet.org). This causes inaccurate taxon counts because some genera are found in Nielsen Gulch, but are absent in the quarry, such as *Marshosaurus bicentesimus* (Carpenter, 2013) and *Hoplosuchus kayi* (Foster, 2003). However, because Nielsen Gulch specimens could have come from stratigraphic levels other than the quarry, they are not included in the database.

RESULTS

Previous quantitative analyses of the Carnegie Quarry were few and limited. Foster (2003, p83) compiled data for various Morrison Formation quarries including the Carnegie Quarry. Using personal observations of the wall, museum records and references in the literature Foster calculated the Minimum Number of Individuals (MNI) for vertebrates at the Carnegie Quarry to be 124. Carpenter (2013, p216) noted that this sort of analysis is not an overview of quarry specimens but that it “basically represent[ed] percentages of prepared material of a few museums”.

Many specimens from the quarry are still not prepared, so the database may be no more complete than Foster’s work in this regard. However, there are records for quarry specimens currently at 20 repositories. In the past, specimens passed through at least 23 different repositories, including the current 20 (Appendix A). Eighty-eight percent of the specimens, are currently in three repositories: Dinosaur National Monument (2451), the Carnegie Museum (1723) and the Royal Ontario Museum (267). The other repositories have less than 100 specimens apiece, with most having fewer than 10. McIntosh's notebooks indicate at least 128 specimens were destroyed or discarded, usually after the original crates were opened and the specimens were deemed too damaged to preserve.

Despite these limitations, the integrated map and database allows for the most complete quantitative-based exploration of the specimens of Carnegie Quarry to-date. The NSP, NISP, and MNI provide additional insights into the taphonomic history of the quarry as well as make it possible to compare the quarry to other dinosaur quarries in the future.

NSP and NISP

The Number of Specimens (NSP), is the total number of specimens found at the quarry. This includes all specimens, defined as individual bones or bone fragments, including those that are degraded, or for some other reason unrecognizable as to specific taxon and/or skeletal element (Lyman, 2012). The NSP is 5016, which is substantially higher than Carpenter's (2013, p179) estimate of 3300 bones, but only marginally higher than the 5000-bone estimate given at carnegiequarry.com. Related to the NSP is the Number of Identified Specimens (NISP), which only includes specimens that are identifiable to skeletal element and, as defined here, to the family level taxonomically. The NISP is 4146 (for a break down between taxa see Appendix D). These numbers are calculated using individual bones, unless the data were unclear as to what elements and how many were included in a specific group. This happened when specimens were described with terms like “pes”, “articulated vertebral column” or “skull”. These records are marked as having multiple bones and there are 193 of these in the database. Thus, the overall NISP and NSP tend to be lower than the actual specimen number. Although calculating these numbers is not perfect it is the first time it has been calculated instead of estimated.

MNI

Perhaps the most important new information relates to taxonomic abundances. Gregson and Chure (2000) estimated 400 vertebrate individuals are preserved in the quarry (an admittedly “seat of the pants’ estimate based on conversations with the late John S. McIntosh. D.J. Chure, personal commun., 2016) while Foster (2003) gave a more modest estimate of 124 individuals representing 16 genera. Neither study noted their methodology or supporting data. Foster may have been able to use relative sizes in his MNI calculations. I measured taxonomic abundance in various ways (Figure 6). First, specimens belonging to each taxon were counted. Then the Minimum Number of Individuals (MNI) was taken for each taxon by counting the most commonly occurring element and its sidedness following Voorhies (1969) and Lyman (2012). To avoid double counting, specimens that could be identified to species were calculated first, then those that are identifiable to genus and, finally, specimens that are only identified to a family level.

These different measurements (NISP and MNI) show a similar trend in abundances (Figure 6). One of the most pronounced difference is that *Glyptops plicatulus* and *Unio utahensis* become more prominent when the MNIs are compared to NISP. This is because MNI for turtle species was calculated using carapaces and plastrons for turtle species. Most of the carapaces and plastrons in the database are not separated into specific bones and in this study are excluded from NISP counts. Thus, NISP is low compared to MNI for turtles. The difference between MNI and NISP among *Unio utahensis* is because their skeleton is made up of only two valves and thus, their specimen number can be significantly lower than in species with complete skeletons with hundreds of bones. The total MNI for the quarry (when each genus is tallied separately including non-vertebrates) is 105. If data about relative size was available and records that are currently marked as multiple bones were separated this number would likely be higher. These numbers look at taxonomic abundances but taphonomic insights can also be gained from quantitative analysis.

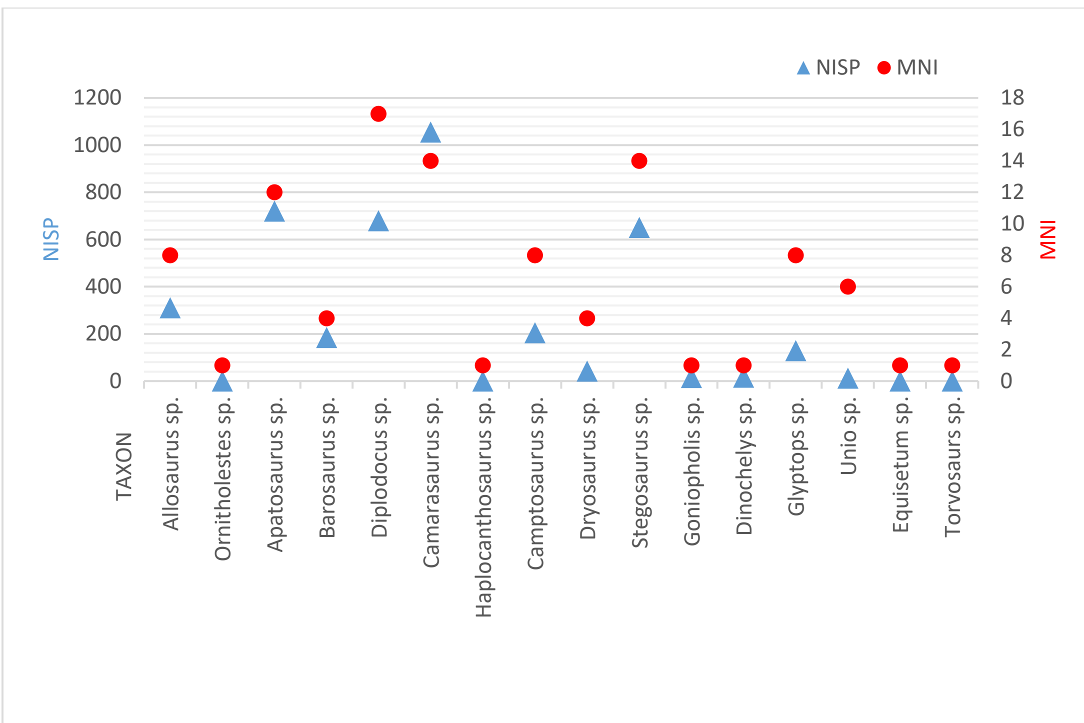


Figure 6: Taxonomic abundances at Carnegie Quarry. NISP compared to MNI for various taxa. NISP and MNI were calculated for separate species (Appendix D) but then added together when they belong to the same genus.

The amount of skeleton disarticulation can reflect taphonomic processes (Badgley, 1986). Thirty-four percent of the 5000+ quarry specimens are isolated bones. Only 8% of the specimens are associated with at least one other bone, while eight individuals consist of more than 100 bones. More bones were probably found articulated or at least associated, but were not documented as such, so these percentages are low relative to reality, and could be modified by studying the map. Gregson and Chure (2000) noted that 20 skeletons were complete enough to be mounted. Carpenter (2013) noted that at least eight partial skeletons include portions of articulated vertebral columns and limb bones but "only a single skeleton is essentially complete" (p.180). Adopting Carpenter's definition of a partial skeleton, articulated vertebrae and limb bones (and thus excluding invertebrates) there are 23 partial skeletons (Appendix E). However, this is not a perfect definition because it leaves out some well-known partial skeletons, such as the baby *Stegosaurus* (Galton, 1982, DINO 2438-2439, 2441-2442, 2447-2448, 2450-2451, 2453-2456, 2463, 2465, 2469 – 2470 or IndID 358). Despite this, it is another way to review taxonomic abundances, and the partial skeletons correlate to MNI (Figure 7), which shows that they are a reasonable approximation of reality.

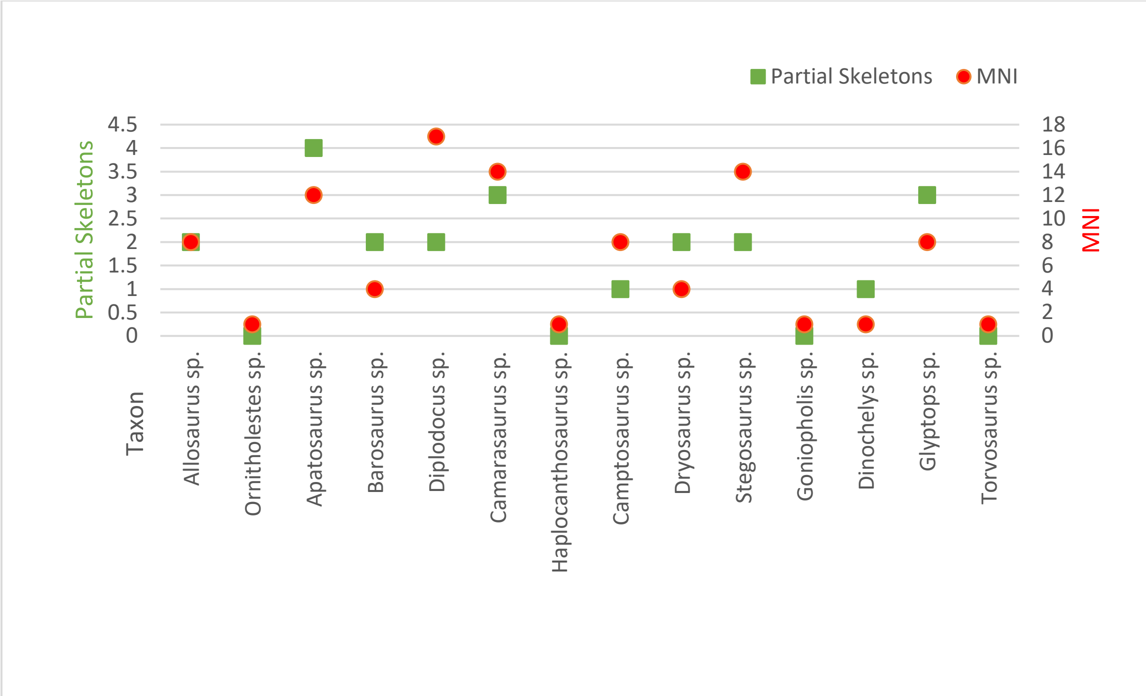


Figure 7: The relationships between MNI and partial skeletons. Partial vertebrate skeleton information is given in Appendix D.

SIGNIFICANCE

This project solves several problems that vexed caretakers of Dinosaur National Monument while making data from the quarry available to scientists around the world. Although specimens are dispersed they are accounted for in the database and as many as possible are included in the map. Also, large quantities of data are distilled down so that the important parts are included in, or linked to, the database putting all the available information in one place. Notably, a Master Map of the quarry, with labeled bones, was created for the first time. Previously, many of the studies on Carnegie Quarry use only the data and specimens that are presently at the quarry (Carpenter, 2013).

Specimens scattered across multiple institutions, large quantities of data, and incomplete maps are traits many quarries have in common. Just like other repositories followed the example of the Monument to create *in situ* exhibits, this project could be used as a template for researchers working with other quarries to collect, organize and consolidate their data. Ultimately, the database and Master Map could also be made available online, making national and international collaboration possible.

FUTURE WORK

Now that there is a map of the bones it would be beneficial to add more geological information. A map of the channels on the current quarry face could be added to the Master Map. In addition some channel data could be added based on Douglass' writings and historic photographs. Cross-sections of these channels would also be useful.

Our data sources were mostly connected with Dinosaur National Monument, the Carnegie Museum, the Royal Ontario Museum, and the Natural History Museum of Utah where most of the specimens are curated. As such, most of the specimens in the database are currently at these institutions. Additional specimens would likely be added if records from other repositories were included. Tracking down these missing bones, or more details about some of the specimens we already have is beyond the scope of this project.

Other fields in the database could also be filled out in greater detail. For example, 299 specimens have insect traces, but only 1695 specimens of the total 5055 (NSP) have been examined for insect marks. Although, 126 specimens are destroyed so they can no longer be examined and many of the historically collected specimens reside in outside institutions (as well as the UU collections now housed at DINO) are covered in thick, dark brown shellac which may hide subtle insect traces on the surface of the bone (Chure, personal commun., 2017). More detailed taphonomic data, as well as data about ontogeny, measurements and the original excavators would be useful additions to the database. In addition, more field numbers (or locational data) would mean that a higher percentage of the records in the database could be connected with specific vectors on the Master Map.

In addition to adding data to partially populated tables, two tables that are almost entirely empty could be filled out. The first table, "DTbl Photographs", has a handful of captions, descriptions and hyperlinks to historic photographs found at carnegiequarry.com. The other unpopulated table, "LTbl PhotographedSpecimens", connects photographs to specimens. The large number of photographs of individual bones in multiple views puts this task beyond the scope of this thesis.

Similar to "LTbl PhotographedSpecimens" is "LTbl SpecimensReferencedinRecords", a table that links literature to specific specimens. There are some connections made here but a thorough review of the literature, matching up specific bones would make this table more useful and complete. The database is dynamic and future workers can expand it as existing and new data is added. It is already a useful tool even though it is not complete, and may never be.

REFERENCES

Allaback, S. 2000. Mission 66 Visitor Centers: The History of a Building type. Available at https://www.nps.gov/parkhistory/online_books/allaback/vc1d.htm (accessed May 2017).

Badgley, C. 1986. Counting individuals in mammalian fossil assemblages from fluvial environments. *Palaios*, 1:328-338.

Beidleman, R. G. 1956. Administrative History: Dinosaur National Monument. http://carnegiequarry.com (accessed October 2017)

Boyle, A. C., Jr. 1938. Report Relating to Status of Project: Dinosaur National Monument. Carnegie Quarry: http://carnegiequarry.com (accessed May 2017).

Carnegie Quarry. http://carnegiequarry.com (accessed May 2017).

Carpenter, K. 2013. History, sedimentology, and taphonomy of the Carnegie Quarry, Dinosaur National Monument, Utah. *Annals of Carnegie Museum*, 81(3): 153-232.

Currie, B. S. 1997. Sequence stratigraphy of nonmarine Jurassic-Cretaceous rocks, central Cordilleran foreland-basin system. *Geological Society of American Bulletin*, 109:1206-1222.

DeCelles, P. G., and Coogan, J. C. 2006., Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah. *Geological Society of American Bulletin*, 118:841-864.

Dodson, P., Behrensmeyer, A.K., Bakker, R.T., and McIntosh, J.S. 1980. Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation. *Paleobiology*, 6:208-232.

Douglass, E. 1909. Earl Douglass diary no. 24, August 6, 12, 17. Douglass Papers, quoted in S. R. Neel, 2015, Love among the fossils: Earl and Pearl Douglass at Dinosaur National Monument. *Utah Historical Quarterly*, 83:290-307.

Douglass, G. E. 2009. *Speak to the earth and it will teach you: The Life and Times of Earl Douglass*, *1862-1931*. BookSurge Publishing, Charleston, South Carolina.

Engelmann, G.F., Chure, D.J., and Fiorillo, A.R. 2004. The implications of dry climate for the paleoecology of the fauna of the Upper Jurassic Morrison Formation. *Sedimentary Geology*, 167:297-308.

Evanhoff, E., and Carpenter, K. 1998. History, sedimentology, and taphonomy of the Felch Quarry 1 and associated sandbodies in the Morrison Formation near Garden Park, Colorado. *Modern Geology*, 22:145-169.

Foster, J. R. 2003. Paleoecological Analysis of the Vertebrate Fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain Region, U.S.A. *New Mexico Museum of Natural History and Science Bulletin*, 23:1-95.

Galton, P. M. 1982. Juveniles of the Stegosaurian Dinosaur Stegosaurus from the Upper Jurassic of North America. *Journal of Vertebrate Paleontology*, 2:47-62.

Gilmore, C. W. 1925. A Nearly Complete Articulated Skeleton of Camarasaurus, A Saurischian Dinosaur from the Dinosaur National Monument, Utah. *Memoirs of the Carnegie Museum*, 10(3): 347-384.

Gilmore, C. W. 1936. Osteology of Apatosaurus, with Special Reference to Specimens in the Carnegie Museum. *Memoirs of the Carnegie Museum*, 11(4): 175-298.

Gregson, J. D., and Chure, D. J. 2000. Geology and Paleontology of Dinosaur National Monument, Utah-Colorado. *Geology of Utah's Parks and Monuments* 28.

Hernandez, M. J. 2013. *Database Design for Mere Mortals A Hands-On Guide to Relational Database Design*. Addison-Wesley Professional, Boston, Massachusetts.

Holland, W. J. 1911. William Holland to Earl Douglass, December 9, 1911, February 12, and March 12, 1912. Douglass Papers, quoted in S. R. Neel, 2015, Love among the fossils: Earl and Pearl Douglass at Dinosaur National Monument. *Utah Historical Quarterly*, 83: 290-307.

Johnson, D. 2017. 2016 Visitation at Dinosaur National Monument Increases 4%. https://www.nps.gov/dino/learn/news/2016visitation.htm (accessed October 2017).

Kowallis, B.J., Christiansen, E.H., and Deino, A. 1991. Age of the Brushy Basin Member of the Morrison Formation, Colorado Plateau, western USA. *Cretaceous Research*, 12:483-493.

Kowallis, B.J., Christiansen, E.H., Deino, A.L., Peterson, F., Turner, C.E., Kunk, M.J., and Obradovich, J.D. 1998. The Age of the Morrison Formation. *Modern Geology*, 22:235-260.

Lawton, R. 1977. Taphonomy of the dinosaur quarry, Dinosaur National Monument. *Contributions to Geology*, 15(2):119-126.

Lyman, R. L. 2012. A Historical Sketch on the Concepts of Archaeological Association, Context, and Provenience. *Journal of Archaeological Method and Theory*, 19(2):207-240.

McIntosh, J. S. 1981. Annotated Catalogue of the Dinosaurs (Reptilia, Archosauria) in the Collections of Carnegie Museum of Natural History. *Bulletin of Carnegie Museum of Natural History,* 18:1-67.

Move data from Excel to Access Support Office. https://support.office.com/en-us/article/Move-data-from-Excel-to-Access-90c35a40-bcc3-46d9-aa7f-4106f78850b4#bm1b (accessed May 2017).

Neel, S. R. 2015. Love among the fossils Earl and Pearl Douglass at Dinosaur National Monument. *Utah Historical Quarterly*, 83:290-307.

Shugan, R. 2008. Douglass Quarry Excavation Operations, 1950-1990. *Douglass Quarry Maps*. Acc -00402, Cat: 17719.

Trujillo, K.C., and Kowallis, B.J. 2015. Recalibrated legacy 40Ar/39Ar ages for the Upper Jurassic Morrison Formation, Western Interior, U.S.A. *Utah Geological Association's Geology of the Intermountain West,* 2:1-8.

Turner, C.E., and Peterson, F. 1992. Study of the Jurassic Morrison Formation at Dinosaur National Monument. *Society of Economic Paleontologists and Mineralogists, Colorado and Utah, Abstracts*, 64.

Turner, C.E., and Peterson, F. 1999. Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A. In Gillette, D. D. (ed.), *Vertebrate Paleontology in Utah*. Miscellaneous Publications-Utah Geological Survey, 99-1:77-114.

VertNet. http://vertnet.org (accessed May 2017).

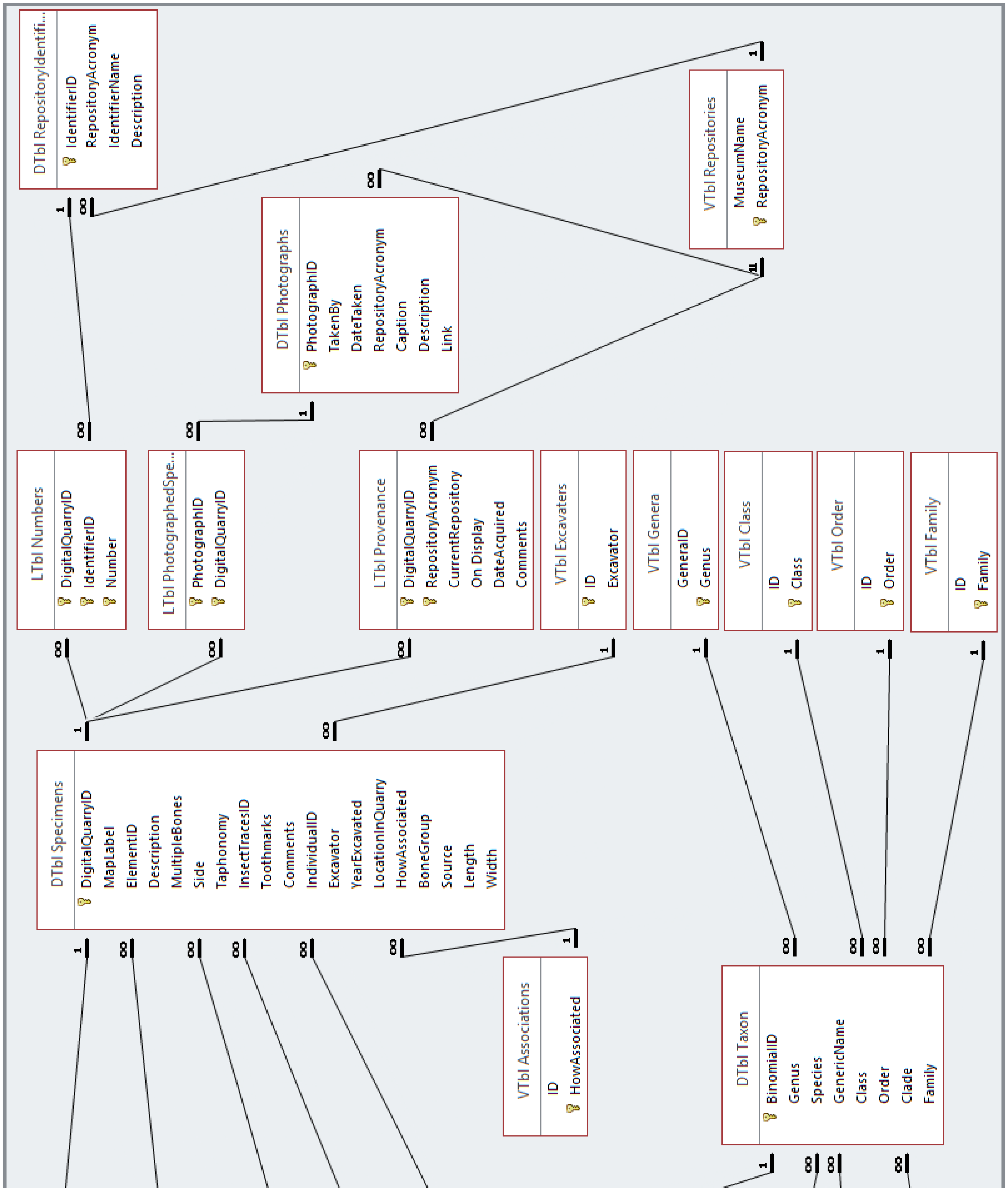
Voorhies, M. R. 1969. Taphonomy and Population Dynamics of an Early Pliocene Vertebrate Fauna, Knox County, Nebraska. Contributions to Geology. PhD Dissertation, Department of Philosophy, University of Wyoming, Laramie, Wyoming, USA.

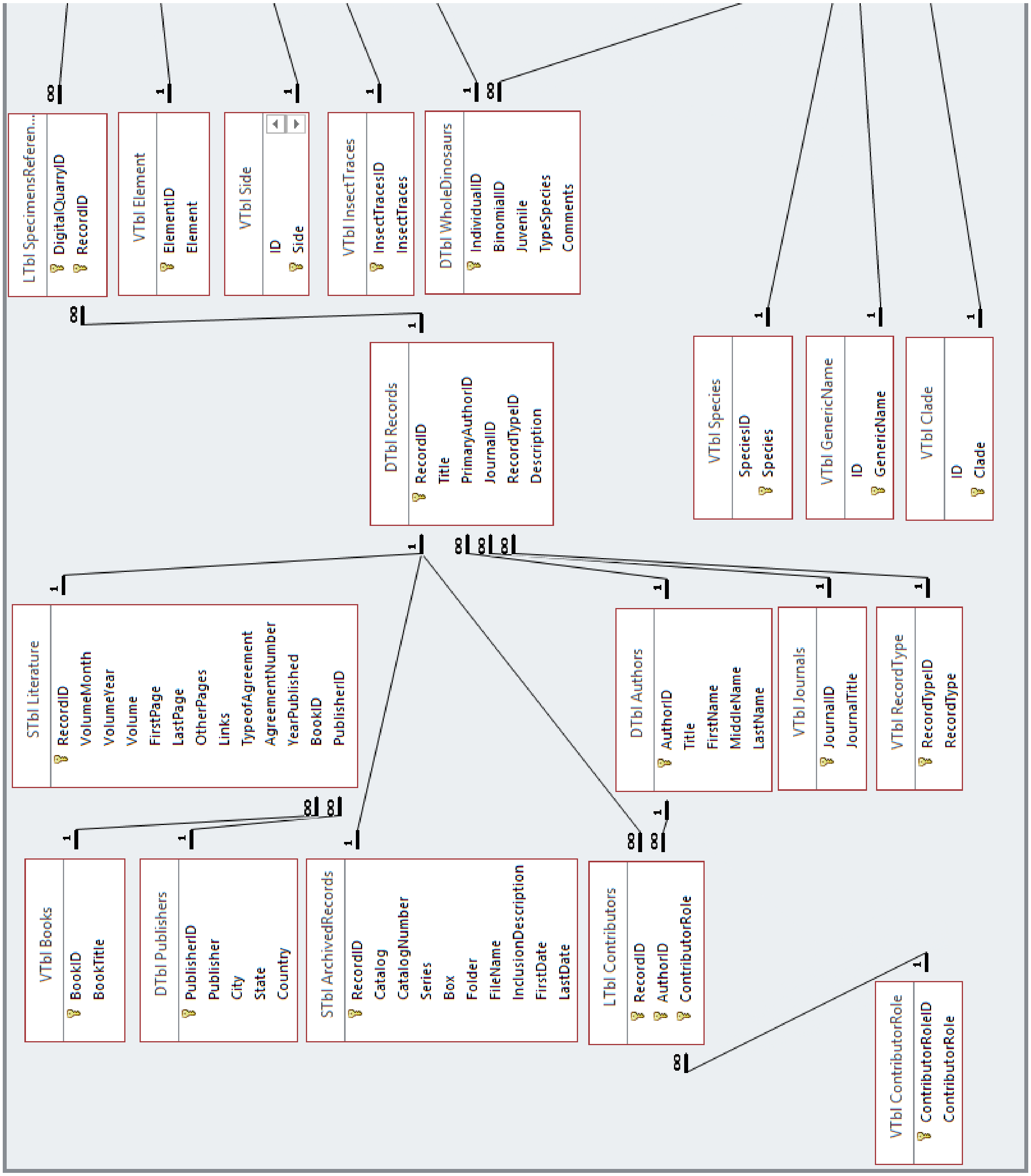
White, T. E. 1958. The Braincase of *Camarasaurus lentus. Journal of Paleontology*, 32(3): 477-494.

Appendix A: Specimen count for quarry specimens by repositories. If specimens are currently at or passed through a repository they are counted in the Previous # of Specimens column.

Museum Name	**Repository Acronym**	**Previous # of Specimens**	**Current # of Specimens**	**Current % of Total Specimens**
American Museum of Natural History	AMNH	82	82	1.63
Brigham Young University	BYU	3	3	0.06
California Academy of Sciences	Cal Acad	7	7	0.14
Carnegie Museum of Natural History	CM	1951	1723	34.34
Cologne, Germany	Germany	1	1	0.02
Denver Museum of Natural History	DMNH	69	17	0.34
Dinosaur National Monument	DINO	2563	2451	48.85
Fort Worth Museum	FW	19	0	0
Junior Randall Museum	Randall	2	0	0
Museum of Life and Science	NCM	2	2	0.04
Natural History Museum of Los Angeles County	LACM	31	31	0.61
Nebraska State Museum	NE	6	6	0.12
Newark Museum	Newark	1	0	0
North Carolina Museum of Natural Sciences	NCSM	5	3	0.06
Royal Ontario Museum	ROM	270	267	5.32
Smithsonian Institution National Museum of Natural History	USNM	125	67	1.34
South Africa Museum	South Africa	1	1	0.02
Spain	Spain	1	1	0.02
Texas Memorial Museum; University of Texas	TMM	4	0	0
University of California Museum of Paleontology	UCMP	31	31	0.62
University of Cincinnati	UC	5	5	0.1
University of Michigan Museum of Paleontology	UMMP	11	8	0.16
Utah Museum of Natural History	UMNH	92	29	0.58
	Unknown	194	194	3.87
	Discarded	50	34	0.68
	Destroyed	94	94	1.87
	Top Three Repositories (DINO, CM, ROM)		4441	88.52
	Destroyed and Discarded		128	2.55

Appendix B: Database design. Relationships between the thirty-two tables in the database.





LTbl SpecimensReferen...
DigitalQuarryID
RecordID
VTbl Element
ElementID
Element
VTbl Side
ID
Side
VTbl InsectTraces
InsectTracesID
InsectTraces
DTbl WholeDinosaurs
IndividualID
BinomialID
Juvenile
TypeSpecies
Comments
DTbl Records
RecordID
Title
PrimaryAuthorID
JournalID
RecordTypeID
Description
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Folder
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FirstDate
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LTbl Contributors
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AuthorID
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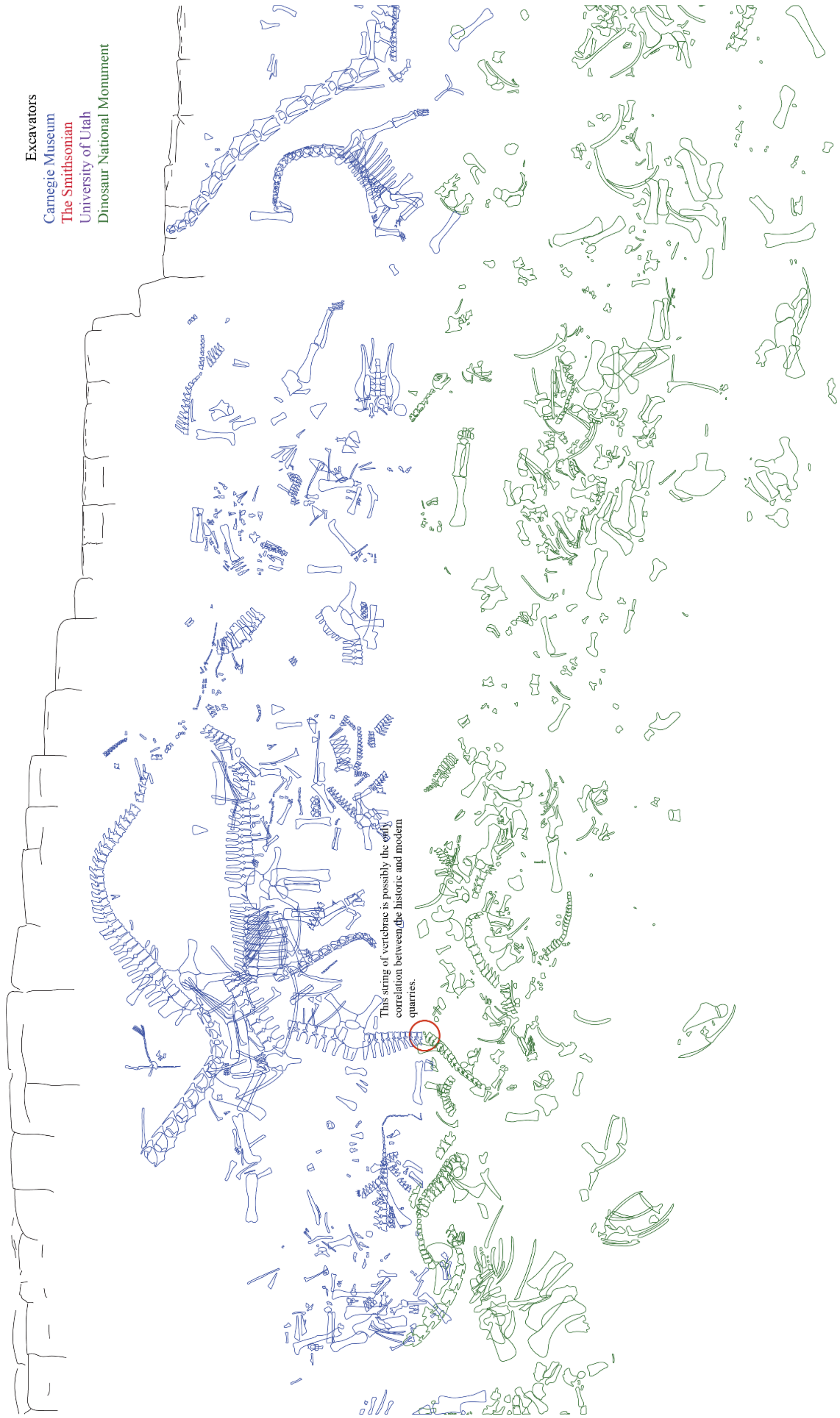
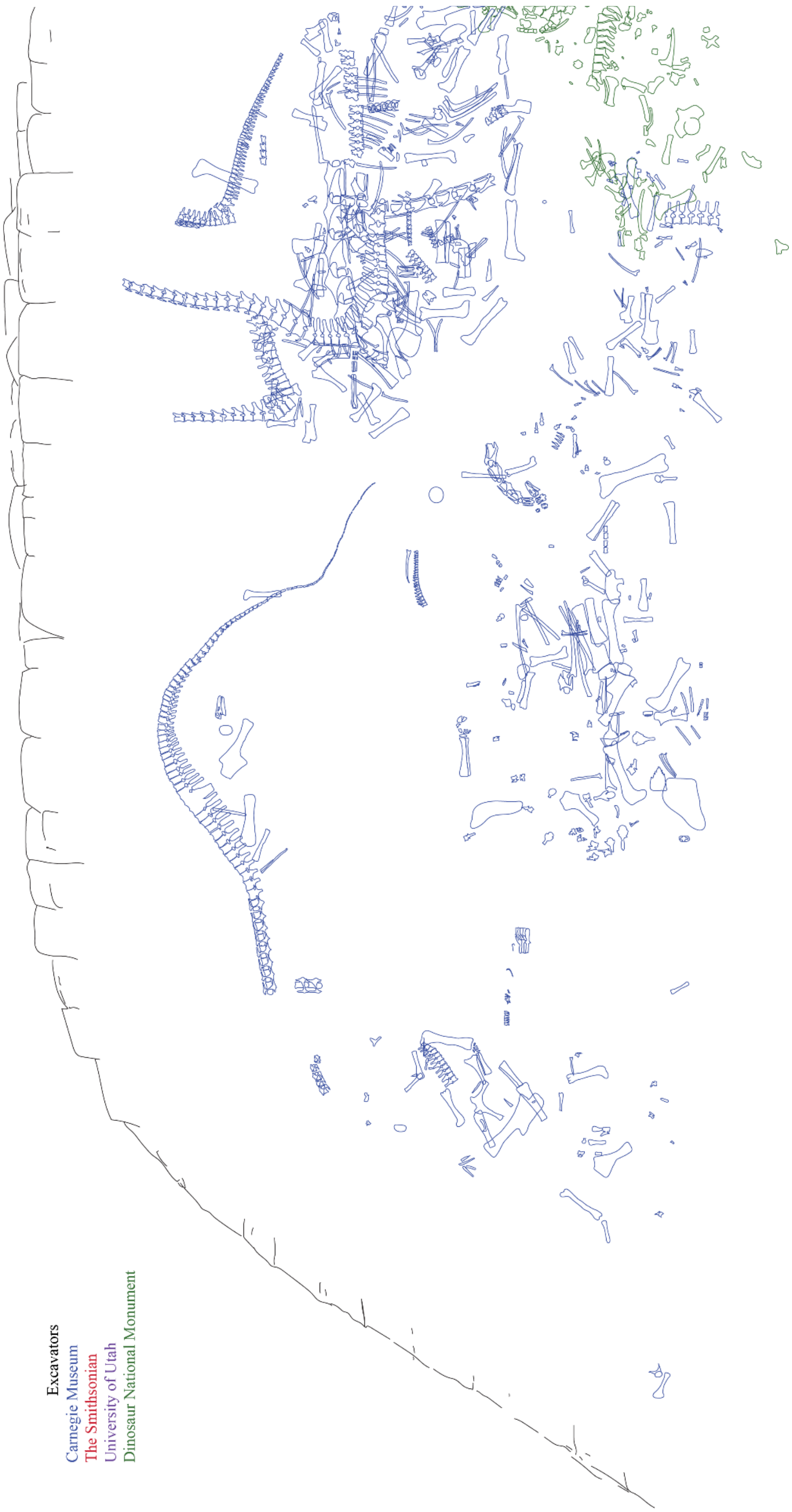
VTbl ContributorRole
ContributorRoleID
ContributorRole

Appendix C: Master Map of Carnegie Quarry with different excavation institutions in different colors.


Excavators
Carnegie Museum
The Smithsonian
University of Utah
Dinosaur National Monument
This string of vertebrae is possibly the only correlation between the historic and modern quarries.


Excavators
Carnegie Museum
The Smithsonian
University of Utah
Dinosaur National Monument

Appendix D: Table of taxonomic abundances for Carnegie Quarry. Only a few specimens of *Unio utahensis* have been collected although there are many thousands in the present day quarry face that have not been catalogued (Chure, personal commun., 2017).

Clade	Family	Genus	Species	NISP	Taxon NISP /Total NISP %	MNI	Element used for MNI
Theropod				74	1.78	0	
	Allosauridae			3	0.07	1	Dorsal Vertebra
		Allosaurus		30	0.72	1	Skull
			fragilis	287	6.92	6	Left Femur
	Ceratosauridae			0			
		Ceratosaurus		0			
			nasicornis	3	0.07	1	Dentary
	Coeluridae			0			
		Ornitholestes†		1	0.02	1	Tooth
	Megalosauridae			0			
		Torvosaurus		0			
			tanneri	1	0.02	1	Dorsal Vertebra
Sauropod				500	12.06	0	
	Diplodocidae			65	1.57	2	Left Fibula
		Apatosaurus		457	11.02	9	Right Femur
			louisae	263	6.34	3	Right Tibia
		Barosaurus		63	1.52	1	Right Humerus
			lentus	123	2.97	3	Right Humerus
		Diplodocus		504	12.16	10	Left Femur
			longus	177	4.27	7	Left Femur
	Camarasauridae			0			
		Camarasaurus		346	8.35	6	Left Scapula
			lentus	702	16.93	7	Right Humerus
			supremus†	7	0.17	1	Left Scapula
	Haplocanthosauridae			0			
		Haplocanthosaurus		1	0.02	1	Left Scapula
Ornithopod				18	0.43	0	
	Camptosauridae			0			
		Camptosaurus		6	0.14	1	Left Scapula
			apanoecetes	196	4.73	5	Right Femur
			dispar	2	0.05	1	Left Dorsal Rib
			nanus†	1	0.02	1	Right Humerus
	Dryosauridae			0			
		Dryosaurus		5	0.12	1	Left Ulna
			altus	37	0.89	3	Skull

Clade	Family	Genus	Species	NISP	Taxon NISP /Total NISP %	MNI	Element used for MNI
Thyreophora				0			
	Stegosauridae			0			
		Stegosaurus		641	15.46	10	Right Scapula
			ungulatus	46	1.11	2	Tibia
			stenops†	4	0.10	1	Left Radius
			sulcatus†	2	0.05	1	Left Radius
Crocodile				0			
	Crocodylidae			1	0.02	1	Caudal Vertebra
	Goniopholididae			0			
		Goniopholis		15	0.36	1	Left Ischium
Turtle				3	0.07	0	
	Pleurosternidae			0			
		Dinochelys		0			
			whitei	16	0.39	1	Right Femur
		Glyptops		1	0.02	1	Carapace
			plicatulus	128	3.09	7	Carapace
Clam				0			
	Unionidae			0			
		Unio		0			
			utahensis	12	0.29	6	Valve
Plant				0			
	Equistaceae			0			
		Equisetum		1	0.02	1	Plant Cast
	Araucariaceae			1*			
Mammal				1*			
Salientia				1*			

*Specimens that have not been identified to family and thus cannot be included in a true NISP calculation but are included here to show the variety at the quarry.
†Species that might be misidentified. There are only small numbers of them recorded and many of another species of the same genus.

Appendix E: Partial skeletons found in the Carnegie Quarry.

IndID#	Taxon	Catalog Numbers	Field Numbers	Skeletal Parts	Number of DQ Records	Current Repository	Other Notes
123	*Diplodocus sp.*	DINO 4926-4931, 4999		cervical vertebrae and left hindlimb and pes	11	DINO	
169	*Camarasaurus sp.*	DINO 4390-4473, 4511-4518, 4520, 4826-4839		skull, cervical, dorsal and caudal vertebrae, both shoulder girdles, ribs, left forelimb and manus, pelvis, both hindlimbs	108	DINO	
222	*Apatosaurus louisae*	CM 3018, 11162	1, 25	skull, cervical, dorsal and caudal vertebrae, chevrons, both shoulder girdles, ribs, both forelimbs and manus, pelvis and sacrum, right hindlimb and parts of both pes	144	CM	Holotype for Apatosaurus louisae
223	*Apatosaurus sp.*	CM 3378	160	cervical, dorsal, and caudal vertebrae, part of right scapula, rib, partial left forelimb, partial pelvis and sacrum, foot	105	CM	
230	*Dryosaurus altus*	CM 3392, 3390	26	skull, skeleton	3	CM	
242	*Camarasaurus lentus*	CM 11338, DINO 3809, 4026-4029, 4073, UCMP 138251	333	skull, cervical, dorsal and caudal vertebrae, chevrons, both coracoids, ribs, parts of all limbs and feet, pelvis and sacrum	252	CM	This is the Camarasaurus pup on the eastern half of the quarry.
243	*Dryosaurus altus*	CM 11340	360	skull, cervical, dorsal, and caudal vertebrae, shoulder girdle, ribs, partial limbs, pelvis	13	CM	Minute dinosaur is a post-hatchling, and is the smallest in the quarry.
244	*Stegosaurus ungulatus*	CM 11341	350	dorsal and caudal vertebrae, ribs, forelimb, partial manus, pelvis and sacrum, left hindlimb, plate, ans tail spikes	30	CM	
246	*Camarasaurus lentus*	CM 3018, 11393, 12020, 37003, UMMP V 16995	1, 25, 232, 240, 270	skull, cervical, dorsal, and caudal vertebrae, chevrons, both shoulder girdles, ribs, right forelimb and both manus, pelvis, parts of both hindlimbs and left pes	110	CM with a couple of cervicals at UMMP	

IndID#	Taxon	Catalog Numbers	Field Numbers	Skeletal Parts	Number of DQ Records	Current Repository	Other Notes
247	*Allosaurus fragilis*	CM 11844, 11868	20, 171, 202-205	skull, cervical, dorsal, and caudal vertebrae, chevrons, shoulder girdle, ribs, parts of all limbs, left manus, pelvis and sacrum	39	CM	
250	*Barosaurus lentus*	CM 11984	310	skull, cervical and dorsal vertebrae, ribs, forelimb and manus	20	CM	Sometimes recorded as a Brachiosaurus or an Apatosaurus.
251	*Apatosaurus louisae*	CM 11969, 11990, LACM 52844	40	cervical, dorsal, and caudal vertebrae, ribs, partial forelimb, pelvis and sacrum, both hindlimbs, left pes	31	LACM	
273	*Diplodocus longus*	CM 21745	145	cervical, dorsal, and caudal vertebrae, partial pelvis and sacrum, and right femur	18	CM	
288	*Apatosaurus sp.*	CM 2905, 10000, 30766	175	caudal vertebrae, chevrons, right forelimb and manus, and left femur	21	CM	
338	*Glyptops plicatulus*	DINO 495		carapace, plastron	3	DINO	
344	*Dinochelys whitei*	DINO 986		shell and skeleton	2	DINO	
363	*Allosaurus fragilis*	DINO 2560, UUVP 6000	310, 400, 410	shoulder girdle, pelvis, hindlimb, hindfoot, skull, ribs, verts,	102	UMNH or unknown, but with the skull at DINO	
434	*Camptosaurus aphanoecetes*	CM 11337	353, 370	cervical, dorsal, and caudal vertebrae, both shoulder girdles, ribs, pelvis, both hindlimbs and pes	121	CM	Holotype for Camptosaurus aphanoecetes
780	*Glyptops plicatulus*	CM 3412	175	carapace, plastron	53	CM	Holotype for the now junior synonom Glyptops utahensis.
782	*Glyptops plicatulus*	CM 3380		carapace, plastron	53	CM	

IndID#	Taxon	Catalog Numbers	Field Numbers	Skeletal Parts	Number of DQ Records	Current Repository	Other Notes
944	*Barosaurus lentus*	AMNH 6341	340	cervical, dorsal, and caudal vertebrae, chevrons, both shoulder girdles, ribs, partial right forelimb, pelvis and sacrum, right hindlimb and both pes	82	AMNH	
1918	*Stegosaurus sp.*	ROM 60335	39, 60, 65, 78, 83, 84, 87	vertebrae, shoulder girdle, ribs, forelimb, partial pelvis	17	ROM	
2087	Unknown	ROM 12735	270, 340	caudal vertebrae, ribs, left humerus, pelvis, left femur, foot	28	Unknown although the ROM has a femur	

Appendix F: Database instructions.

After designing and populating the database, information can primarily be accessed through user-friendly queries. Existing queries are listed on the right side panel of Access, below the tables.

Left clicking on the arrow on the right edge of a field (column) header brings up a menu that allows the column to be searched or organized. Numerical or alphabetical organizations are the simplest ways to organize but searching for specific numbers, or records that contains or excludes certain values is also possible. Below are explanations of how to use several queries.

"HRQ Literature" lists the scientific literature including titles, authors and journal names, that references quarry specimens.

"HRQ Specimens" lists the specimens, skeletal elements, individual id number, location in the quarry, excavator, sources, and repository, taphonomic and taxonomic information, and other information.

"NCQ DINOSpecimens" lists the specimens by DINO number and includes much of the other data from HRQ Specimens as well. The other number check queries (NCQ) provide the same function but for other catalog or field numbers.

"TQ NISP" is a query used to calculate MNI. It includes many of the fields of "DTbl Specimens" and excludes specimens that are not identified to the family level and skeletal element. By selecting unique values in the family or genus fields and then counting skeletal elements by side this can be used to calculate MNI by taxon.

Additional queries could be created for other purposes by individuals familiar with Access or databases.

CarnegieQuarry.mxd is the ArcMap file of the Master Map. Open the file in ArcMap. The arbitrary origin is in the bottom left corner. The measurements in feet shown at the bottom right-hand corner are measured from the origin. Right click on any bone and select "identify". This brings up information about a specific bone. To access information about all the bones right click on the "IntegratedDBBones" layer and select "open attribute table". All of the bones that have map labels that link to the database are on this layer. To search for specimens with specific attributes click the "Select by Attributes" icon ( ). Using this pop out window you can create queries such as "Repository" = 'CM' or "Family" = 'Diplodocidae' OR "Family" = 'Camarasauridae'. These queries can be typed in to the text box at the bottom of the window or the fields can be selected from the list, the symbols can be selected in the calculator-like pad and then by clicking on "Get Unique Values" a list of the values for the selected field will appear and can be chosen from.

CarnegieQuarryMasterMap.ai is the Adobe Illustrator file of the Master Map. Its many layers are described in the table below. If you have access to MAPublisher, under the window tab select MAPublisher this brings up a new ribbon. Under properties click on the second icon ( ) which brings up the attribute table for the integrated bones. These can then be organized alphabetically or queried similarly to the ArcMap select by attribute.

Layer Name	Sublayer Name	Contents	Organization	Source
Background		white background		
BlocksBluePrint		blocks from the Carnegie excavated quarry	numerically by block	McIntosh blueprint maps
BlocksUofU		blocks on the eastern edge of the quarry	numerically by block	vellum map
BonesBluePrint		bones from the Carnegie excavated quarry		McIntosh blueprint maps
	Not in Excel	bones from the blueprint maps that are not linked to a bone in the database	numerically by field number	
	In Excel	bones from the blueprint maps that are linked to a bone in the database	numerically by field number	
BonesMAnnotated		bones from the Carnegie excavated quarry that were not included (or excluded) from the blueprint maps	numerically by field number	McIntosh annotated maps
BonesQuarryFaceNew		bones from the current quarry face		wall map
	Not in Excel	bones from the current quarry face that are not linked to a bone in the database	Alphabetically by grid section and then by DINO number	
	In Excel	bones from the current quarry face that are linked to a bone in the database	Alphabetically by grid section and then by DINO number	
BonesUofU		bones on the eastern edge of the quarry		vellum map
	Not in Excel	bones from the UU excavations that are not linked to a bone in the database	numerically by field number	
	In Excel	bones from the UU excavations that are linked to a bone in the database	numerically by field number	

Layer Name	Sublayer Name	Contents	Organization	Source
Grids		grid systems		
	GridGilmore	grid based on the grid painted on to the historic quarry		Gilmore map
	GridQuarryFaceNew	grid over current quarry face		Rick Shugan map
	Full Grid	grid over entire quarry		extended from Gilmore map
Hill Outline		hill outline		McIntosh blueprint maps
IntegratedDBBones		bone from all other layers that are connected to the database		other layers
Subset Maps		small maps from various places		
	Log	log in the current quarry face		Carpenter (2013) p179
	BabyStegosaurus	baby *Stegosaurus* (DINO 2438 and others) in the current quarry face	numerically by DINO number	Galton (1982) p48
	Unknown2	partial *Diplodocus* (CM 416911) in the historic quarry	numerically by number on McIntosh annotated map	McIntosh annotated maps
	Unknown3	Blk 39/60 AA in the historic quarry	numerically by number on McIntosh annotated map	McIntosh annotated maps
	II1'"A+2'"A	partial *Diplodocus* (AMNH 6341) excavated by UU	numerically by number on McIntosh annotated map	McIntosh annotated maps
	13C CamptosaurusTypeSpec	Holotype of *Camptosaurus aphanoecetes* (CM 11337)	numerically by number on McIntosh annotated map	McIntosh annotated maps
	12A CamarasaurusPup	*Camarasaurus lentus* pup (CM 11338)	numerically by number on McIntosh annotated map	McIntosh annotated maps