ANALYSIS OF EARLY PERMIAN FAUNA OF THE UPLAND REGION OF BALLY MOUNTAIN FROM COLLECTED BLOCKS

by

Gemma Goss

Submitted in partial fulfillment of the

requirements for Departmental Honors in

the Department of Geology

Texas Christian University

Fort Worth, Texas

May 8, 2023

ANALYSIS OF EARLY PERMIAN FAUNA OF THE UPLAND REGION OF BALLY MOUNTAIN FROM COLLECTED BLOCKS

Project Approved:

Supervising Professor: Arthur Busbey III, Ph.D.

Department of Geology

John Holbrook, Ph.D.

Department of Geology

Mark Demarest, Ph.D.

Department of Biology

ABSTRACT

Bally Mountain and her sister site, Richards Spur, both located in Oklahoma, have long been sites for prominent fossil findings of Early Permian upland terrestrial fauna, owing to their unique methods of preservation. These methods, by which remains ended up clustered together in fissure fills, have allowed for fossils to survive the erosive and destructive processes that usually result in little fossil material from upland environments surviving to present day. Fauna from blocks collected at Bally Mountain were analyzed and sorted into taxa. The most common taxon remains were identified as *Captorhinikos valensis,* a moradisaurine present at wetter Bally Mountain but absent at more arid Richards Spur owing to the two sites' differing climates. Other fauna found in the blocks were those present at both sites: *Captorhinus aguti,* one of the most prominent members of Richards Spur, *Opisthodontosaurus carrolli, Cacops, Delorhynchus,* and *Doleserpeton.*

Table of Contents

I. Table of Contents 1
II. List of Figures 2
III. List of Tables 4
IV. Introduction 5
V. Background Geology 6
VI. Materials and Methods 16
VII. Results 23
VIII. Conclusions 45
IX. References 46

List of Figures

1. Richards Spur Dolese Brothers Limestone Quarry.. 6
2. Bally Mountain. 6
3. Geological Map of the region. 7
4. Photo and illustration of the karsting system of Richards Spur.. 8
5. Image of "white bone" from one of the gathered blocks from Bally Mountain 9
6. Restoration of *Captorhinus aguti* 10
7. Illustration of three preservation methods 13
8. *Doleserpeton*... 14
9. *Delorhynchus cifellii* skull... 15
10. Specimen 1. Captorhinid skull.. 23
11. *Captorhinus kierani* skull 23
12. *Captorhinus kierani* skull 23
13. Specimen 2. *Doleserpeton* jaw 25
14. SEM of the jaw of *Doleserpeton* 25
15. Three skull fragments of *Captorhinikos valenesis*... 27
16. Specimen 3.1 27
17. Specimen 3.2 28
18. Specimen 3.3 28
19. *Capcops* skull fragment 29
20. Skull reconstruction of *Cacops*. 29
21. *Cacops morrisi*.. 29
22. *Captorhinikos valensis* jaw 31
23. *Captorhinikos valensis* jaw reconstruction and images 31
24. Specimen 6. *Captorhinikos valensis* jaw. 33
25. Specimen 7. *Captorhinus aguti* jaw. 34
26. *Captorhinus aguti* jaw reconstruction... 35
27. Specimen 8. *Captorhinikos valensis* jaw. 36
28. Closer view of a portion of Specimen 8.. 37
29. *Opithodontosaurus carrolli* jaw.. 38

30. *Captorhinikos valensis*. 39
31. Specimen 9. *Captorhinikos valensis* jaw. 41
32. Specimen 10. *Captorhinikos valensis* or *Captorhinus aguti* jaw. 42
33. Specimen 11. *Delorhynchus* jaw 43
34. Specimen 11. 43
35. *Delorhynchus cifellii jaw* 44
36. *Delorhynchus cifellii* jaw 44

List of Tables

1. Fauna and Abundance Table Comparing Richards Spur and Bally Mountain….16
2. Table of findings on blocks from Bally Mountain………………………..……21
3. Specimens Identified from the Bally Mountain block………………………….22

Introduction

The main goal of this project is to categorize and sort bone and bone fragments within breccia fragments taken from the Leatherbury Quarry on Bally Mountain, in the Slick Hills of Oklahoma, a site near the well-known Richards Spur Dolese Brothers Quarry. Richards Spur and Bally Mountain share much of their fauna and provide a detailed window into upland early Permian fauna.

The fragments studied were collected in the late 1980s by Dr. Arthur Busbey and were in storage until the early 2020s, when this study began. The bones within the fragments were counted and sorted into rough categories of skull caps, long bones, vertebrae, and jaw fragments. After this, the bones were then identified to the lowest possible taxon.

Bally Mountain and Richards Spur both contain extensive karst systems, which create unique opportunities for highly abundant fossil preservation, particularly in the case of Richards Spur (Haridy et al., 2018). This unique preservation method consisted of remains being washed into the karst system and later infilled, preserving them in a commonly disarticulate fashion with a high level of abundance (MacDougal et al., 2017). This highly abundant fossil perseveration has allowed an extensive catalog of the most abundant species at Richards Spur to be developed, an unusual occurrence for an upland fauna that would not have been otherwise preserved.

The animals observed within the blocks from the Bally Mountain site are the reptiles *Captorhinikos valensis, Opisthodontosaurus carrolli, Captorhinus aguti, Cacops, Doleserpeton,* and *Delorhynchus*. Of these, *Captorhinikos valensis*, a moradisaurine, was the most abundant. This contrasts with Richards Spur, which contains no moradisaurines (LeBlanc et al. 2015).

Background Geology

The Bally Mountain and the Richards Spur locations (Figures 1 and 2) are early Permian fissure fill deposits (Figure 3) that, together, comprise some of the richest known collections of terrestrial Permian faunas in the world. Both deposits are located within the Slick Hills of Oklahoma, representing upland, early Permian deposits (MacDougal et al., 2017).

Figure 1: Richards Spur Dolese Brothers Limestone Quarry. Image from Google Maps

Figure 2: Bally Mountain location. Image (Google Maps)

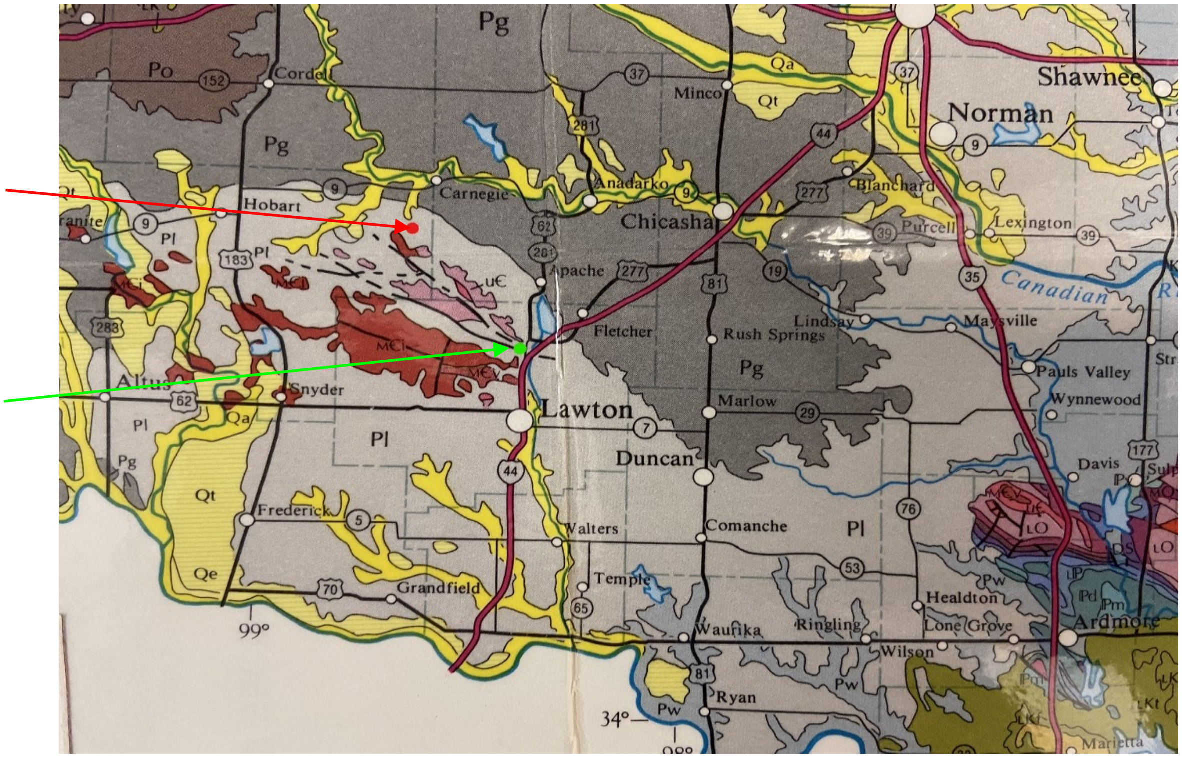

Figure 3: Geological Map of the region. Richards Spur Dolese Brothers Limestone Quarry is marked with a green dot and pointed to with a green arrow for ease of visibility. Bally Mountain is marked with a red dot and pointed to with a red arrow for ease of visibility. Map is modified from the AAPG Highway Map of the Midcontinent Region (1986)

The Dolese Brothers quarry, near Richards Spur, has been a major site of fossil discovery since the 1930s, with the first paper being published in 1935 (Price 1935). The operations revealed an extensive series of fissure fills within Ordovician limestone, interpreted as an extensive cave system. Quarrying operations have, however, made it impossible to establish a stratigraphic control for the site (MacDougal et al., 2017).

The fissure fills are interpreted as a cave system (Figure 4), with the karst fills making up the cave complex that were infilled with abundant vertebrate fossil material. This marks it as distinct from the surrounding lowland habitats. The extent of the cave system is unknown due to quarrying operations. It appears that the infills from the top 25 meters of the cave system contain fossils, while quarrying operations below have uncovered no additional fossiliferous material (MacDougal et al., 2017).

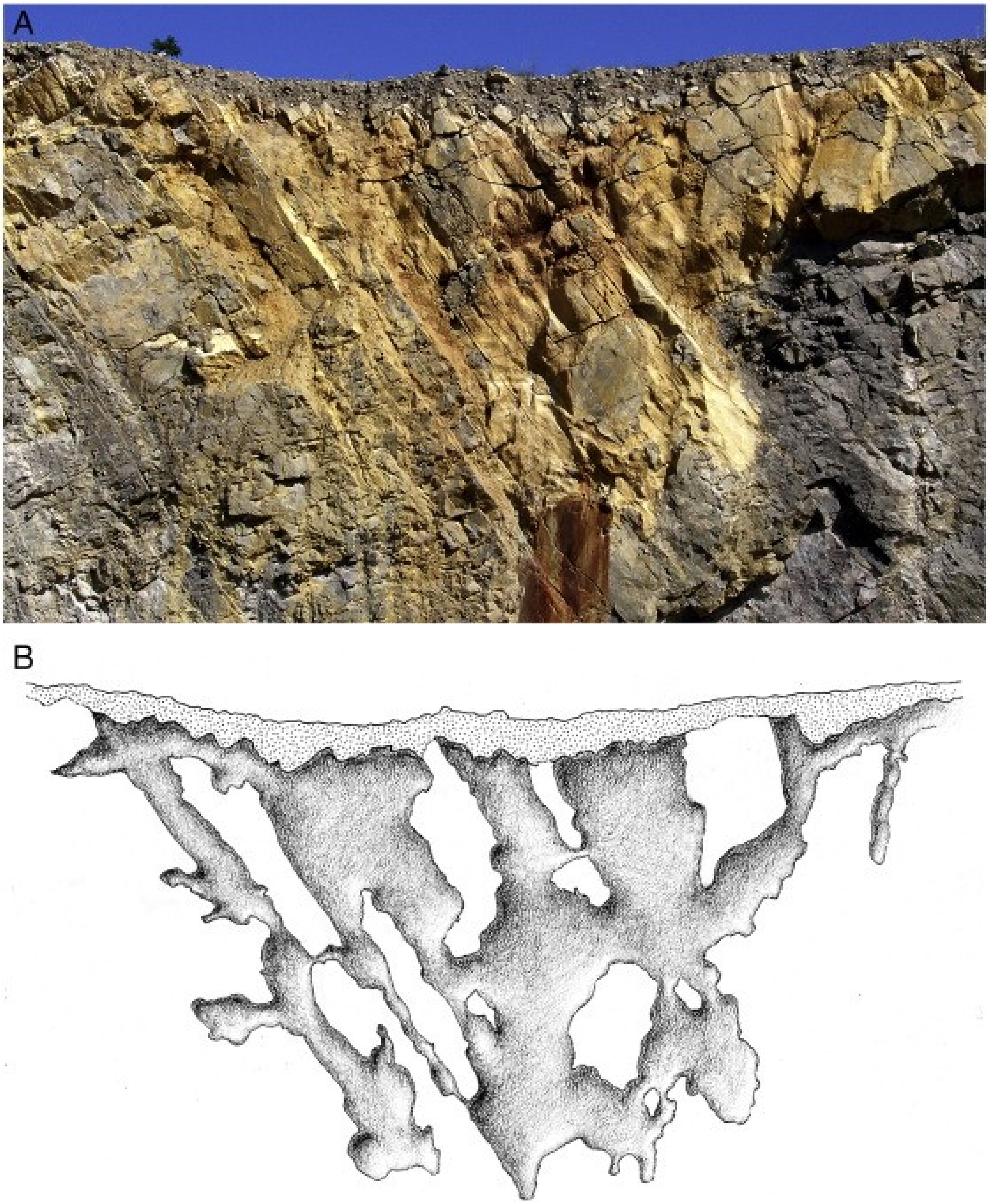

Figure 4: Photo and illustration of the karsting system of the Richards Spur location (MacDougal et al., 2017). A. quarry wall, B. Sketch of fissure and cave system

The Richards Spur cave system formed when Ordovician limestones of the Arbuckle Formation were uplifted during the Pennsylvanian and Permian Periods (MacDougal et al., 2017).

The limestones' orientation changed to be nearly vertical, allowing for water infiltration and dissolution, eventually forming a cave system. The presence of fossiliferous infills indicates that the cave systems were connected with the surface.

All of the material that has been unearthed from these infills, including a highly fossiliferous deposit unearthed in the late 1990s and a pocket unearthed in 2005 which has yielded a rich diversity of fossil fauna, supports a taxonomically diverse community (deBraga 2019; Reisz 2019).

The majority of the fossil found in the Richards Spur infills are permeated with hydrocarbons and are, as such, stained black in color. These remains are known as 'black bones' and are

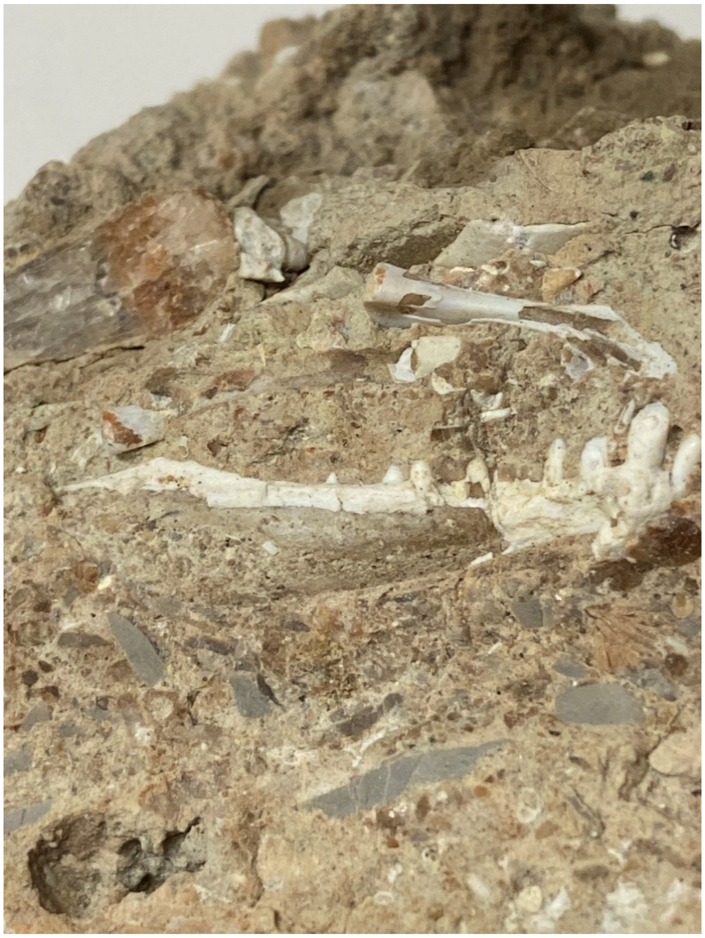

Figure 5: Image of "white bone" from one of the gathered fragments from Bally Mountain

more robust in nature, allowing for the dissolution of the surrounding clay-rich matrix without also removing smaller remains. This is of particular note with the small amphibamid *Doleserpeton*, one of the most common taxa found at the Richards Spur site (MacDougall et al., 2017; Reisz, 2019). The large deposit found in 1990s is unusual as it is a 'white bone' assemblage (Figure 5), without hydrocarbon impregnation. The fossils are thus a cream to white color and are less robust and less recognizable than those of 'black bone' assemblages. In the 'white bone' assemblages the small amphibamid *Doleserpeton* appears to be rare, although this may be due to the small size of the bones, the similar coloring of bone and matrix, and the poor separation between the bone and the surrounding matrix. Additionally, the separation method used for 'black bone' assemblages, i.e., dissolution of the matrix with acetic acid, does not work well for the 'white bone' assemblages. Also, the two commercial companies who collected the 'white bone' assemblages were focused on larger materials, ignoring or missing smaller bones (Reisz, 2019).

Most of the materials gathered from the infills are disarticulated, impregnated with hydrocarbons, and exhibit various states of wear ranging from unworn to highly worn. This wear is speculated to come from transportation into the caves and the flow of meteoric waters within the caves. (MacDougal, 2017). The material from the 'white bone' assemblage contained numerous disarticulated materials from the trematopid *Acheloma* and the large captorhinid *Captorhinus magnus,* and less material from the captorhinid *Captorhinus aguti*, (Figure 6) the most common captorhinid in Richards Spur (Reisz, 2019).

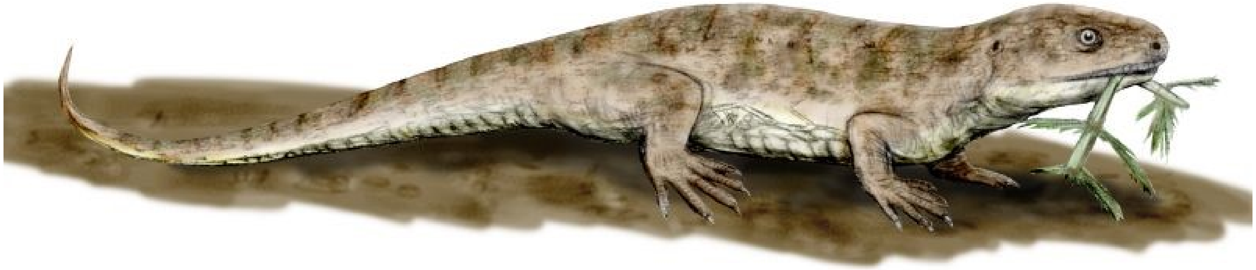

Figure 6: Restoration of *Captorhinus aguti* by Nora Tamura

Calcite speleothems have been gathered from the karst deposits and have been used to establish absolute dates of the speleothems and date ranges for the Richards Spur fissure fills. Speleothems have been dated to 286.7 + 2.9 Ma, 286.2 + 0.2 Ma, and 289.2 +0.68 Ma. From these absolute ages, the speleothems have been used to establish a date range of roughly 289-286 Ma for the formation of the Richards Spur fissure fills, with the total period of active cave formation ranging from a maximum of 6.1 Ma to a minimum of 2.1 Ma (MacDougal et al., 2017). A precise age for the fossiliferous pocket has not been established, but articulated and well-preserved remains found suggest that they were buried shortly after death (deBraga, 2019). Due to the lack of stratigraphic control, the relationship of the deposit unearthed in the 1990s and the 2005 fossiliferous pocket cannot be firmly established. These deposits may represent different times, leading to the differences in taxonomic abundance and composition (Reisz, 2019).

The date range establishes Richards Spur as Artinskian in age, a time in the Permian during which the surrounding lowlands experienced a semi-humid to humid climate (Modesto et al., 2018). Meanwhile, Richards Spur, itself, an upland environment, is indicated, based upon speleothem data, to have varied between periods of aridity and heavy rainfall as it experienced monsoon-like conditions (Modesto et al., 2018; deBraga, 2019). The Richards Spur fauna was more characteristic of the warmer and semi-arid fauna of the middle Kungurian Age than that of the cooler and wetter Artinskian and thus may have been “pre-adapted” to the warming climate conditions that would become overall more widespread 10 million years later (Modesto et al., 2018).

The presence of speleothems further indicates that the caves were hydrologically active, allowing for fossil specimens within them to be transported by water and in some cases, encased in calcite (MacDougal et al., 2017). The presence of and transportation by meteoric waters would not only disarticulate remains but also wear them. The remains that would suffer the most wear would be those that were already disarticulated, while remains that were articulated and remained stay articulated overall exhibited less wear (MacDougal et al., 2017).

Fossiliferous remains from Richards Spur show largely carnivorous dentition, with *C. aguti* being the most common captorhinid present, followed by *C. magnus* (Reisz, 2019). The diverse nature of the captorhinid reptiles and their dental anatomy, especially with the excavation of the 1990s deposit and the 2005 pocket, indicates that resource partitioning and the development of more specialized niches may have occurred at Richards Spur, with *C. aguti* potentially consuming some plant matter (Modesto et al., 2018; deBraga et al., 2019).

It is unlikely that animals would reside deep within the cave; instead, they likely resided in shallow portions of the cave or just outside the cave, using the caves for protection from predators. (MacDougal et al., 2017). Remains would enter the cave through numerous ways (Figure 7).

The first was that an animal would die outside the cave, be scavenged or would decompose in such a way that its remains would become disarticulated before washing into the cave. Once the remains were disarticulated, they could flow into the cave system during periods of rainfall.

The second method was animal would die and be washed into the cave before disarticulation could occur.

A third method was an animal would fall or be washed alive into the cave system and then would expire. These last two methods would increase the chance of the remains remaining articulated once decomposition had occurred (MacDougal et al., 2017).

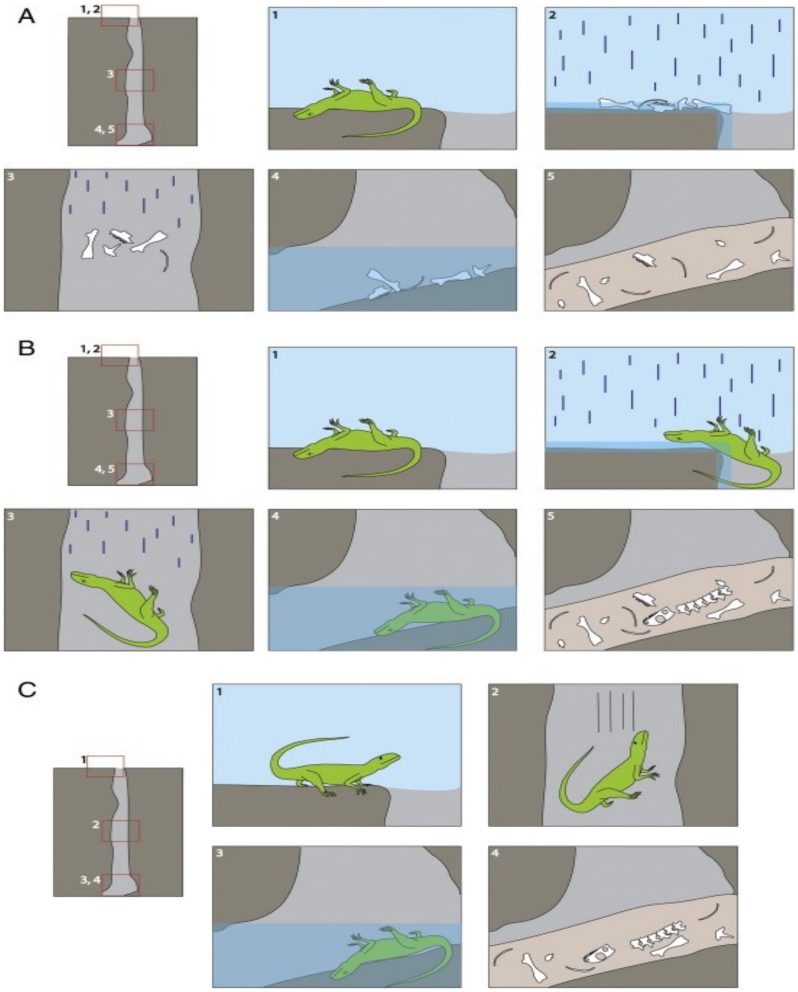

Figure 7: Illustration of the three above-mentioned methods from The unique preservational environment of the Early Permian (Cisuralian) fossiliferous cave deposits of the Richards Spur locality, Oklahoma (MacDougal et al., 2017). A) Representing scavenged remains being washed in. B) Representing whole, washed in remains and C) Representing a washed in specimen which died and decomposed within the cave itself.

All remains were extensively reworked and re-deposited elsewhere in the cave system, with disarticulated materials exhibiting the most reworking and becoming concentrated in pockets. Pyrite growth has been observed on the bones, likely a result of reducing fluids passing through the cave systems at a later time (MacDougal et al., 2017).

Both articulated and disarticulated materials exhibit wear, with variation of wear being due to a variety of factors such as: how the animals entered the cave, how long remains were on the surface, the size of the remains, and how much the remains moved around once inside the cave system. Three factors increased bone wear: the longer the bones were on the surface, the more disarticulated the bones were prior to entering the cave system, and the longer the bones moved around once inside the cave. Animals that fell or were washed in prior to disarticulation exhibited the least amount of wear (MacDougal et al., 2017).

The most common captorhinids at Richards Spur are *Captorhinus aguti, C. magnus,* and *Opisthodontosaurus carrolli*. These have been recovered in great abundance, the most common being *C. aguti*, and are taken to ubiquitous through the geologic lifetime of Richards Spur and its surrounding area (Modesto et al., 2018). The small amphibamid *Doleserpeton* is also extremely common (Figure 8) (Reisz 2019). Richards Spur is notable in that it contains no moradisaurines (LeBlanc et al. 2015).

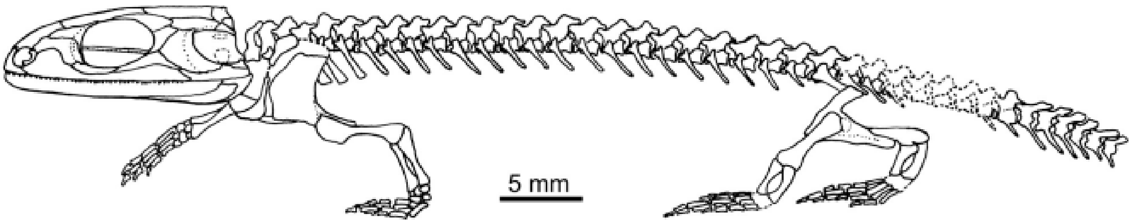

Figure 8: Reconstructed skeleton of *Doleserpeton* (Sigurdsen and Bolt, 2010)

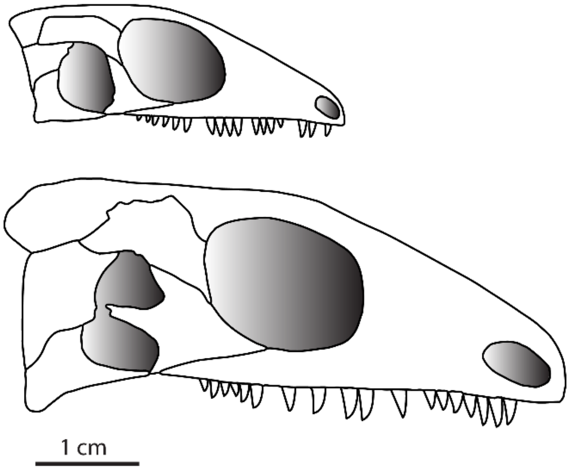

Figure 9: *Delorhynchus cifellii* skulls - young and adult (Haridy et al., 2016)

Bally Mountain, by contrast, contains moradisaurines, including an abundance of the herbivorous moradisaurine *Captorhinikos valensis*. The presence of a herbivorous animal indicates that Bally Mountain had a greater amount of vegetation than Richards Spur and was thus able to support herbivorous animals, such as *Captorhinikos valensis.* The Bally Mountain deposit has been taken to be temporally equivalent to that of Richards Spur, although there is no speleothem data to establish a date range for the Bally Mountain deposit. If the two were temporally equivalent, then the presence of *Captorhinikos valensis* and the greater amount of vegetation it needed to support itself suggests that Bally Mountain had a wetter climate than Richards Spur. Despite this, the overall faunal compositions between Richards Spur and Bally Mountain are fairly similar. (LeBlanc et al. 2015).

Fauna	Abundance	
	Richards Spur	Bally Mountain
Captorhinus aguti	Very Abundant	Rarer
Captorhinus magnus	Abundant	Rarer
Doleserpeton sp.?	Abundant	Present
Captorhinikos valensis	Absent	Abundant
Opisthodontosaurus carrolli	Present	Present
Delorhynchus	Present	Present

Table 1: Fauna and Abundance Table Comparing Richards Spur and Bally Mountain

Materials and Methods

The blocks studied during the project were collected by Dr. Arthur Busbey in May 1989 from a sinkhole on the southern face of the quarry at Bally Mountain. The blocks were located at the bottom of the sinkhole and were deposited before being covered by clay. The fill materials within the sinkhole were the below-lying breccia blocks and above-lying clay. The blocks and clay were stored at TCU and study of the breccia blocks began in the fall of 2021.

The materials used in the study of this project were a field notebook and pencil to note down initial observations when studying the blocks. Drawings of the blocks were also made during this time. Additionally, a light microscope was used to view the blocks and intercalated bones. Each block was assigned a letter: such as Unit A, Unit B, Unit C, etc. Each individual block's sides were then assigned a number to further differentiate them. For example: Side A1, A2, A3, etc. would all be on Unit A. Unit B would have Side B1, B2, B3, etc. The parts of the bones were also given their own abbreviations, which were as follows:

Vt: Vertebrae

Lb: Long bone
Sc: Skullcap

Photos of the blocks and the bones were taken with an iPhone. The photos were then uploaded to a Box account for storage, ease of access, and ability to download for later usage.

For the purposes of an overall count of materials, tables for Blocks A-N are presented below:

UNIT	SIDE	BODY PART	NOTES (if any)
A	A1	Lb	Looks partially calcified
A	A1	Lb	Part of a femur? Can see impression next to it
A	A1	Vt	n/a
A	A1	Jaw	Near the two lb On the edge
A	A2	Lb	Both ends
A	A2	Lb	Partial
A	A3	Sc	Possible
A	A3	Vt	Possible Somewhat on the A2 side
A	A4	Lb	Sliced “———" Can see impression of rest
A	A1	Sc	Impression of In between the 2 lb and the Vt
A	A3	Vt	Next to the possible Sc A3
Lots of long, thin and/or small bones on A2→A4 Toe bones			
B	B1	Lb	Looks partially calcified Can see impression or rest of bone next to it
B	B1	Vt	“lower” half of B1
B	B1	Lb	End of, westward of Vt B1
B	B2	Lb	Edge of/partial Can possibly see impression of rest

<table>
<tr><td>B</td><td>B3</td><td>Lb</td><td>Possible
If so only the end
Upper portion of B3 near B2</td></tr>
<tr><td colspan="4">Unknown bone midway though, possibly an LB
Some very small, possible toe bones in B4, otherwise only a new angle on other bones</td></tr>
<tr><td>B</td><td>B5</td><td>Lb</td><td>Largely filled on the right/eastern side of B5</td></tr>
<tr><td>C</td><td>C1</td><td>Sc</td><td>In the “lower half” of side C1</td></tr>
<tr><td>C</td><td>C1</td><td>Lb</td><td>Possible
Towards the broadside of C1</td></tr>
<tr><td>C</td><td>C1</td><td>Vt</td><td>Possible
Looks too big to be a Vt</td></tr>
<tr><td colspan="4">Some bones I can’t identify diagonally northward from Sc C1</td></tr>
<tr><td>C</td><td>C2</td><td>Vt</td><td>By the clast in the upper broad part</td></tr>
<tr><td>C</td><td>C2</td><td>Lb</td><td>Possibly 3 or more</td></tr>
<tr><td colspan="4">• One to the right of above Vt C2
• A 2nd just to the south of that
• A 3rd south of that (very tentative)</td></tr>
<tr><td>C</td><td>C2</td><td>Vt</td><td>Next to a sharp rock
Tentative</td></tr>
<tr><td>C</td><td>C3</td><td>Unknown</td><td>Visible on C3</td></tr>
<tr><td>C</td><td>C4</td><td>Lb</td><td>Appears to be</td></tr>
<tr><td>C</td><td>C4</td><td>Lb</td><td>On the border near C4 and C5</td></tr>
<tr><td>C</td><td>C5</td><td>Lb</td><td>Clear
On the big chunk</td></tr>
<tr><td>C</td><td>C5</td><td>Vt</td><td>Very tentative</td></tr>
<tr><td>C</td><td>C5</td><td>Jaw</td><td>Can see teeth
Left of Lb C5</td></tr>
<tr><td>C</td><td>C5</td><td>Sc</td><td>Leftward of Lb C5</td></tr>
<tr><td>D</td><td>D1</td><td>Vt</td><td>Sacral</td></tr>
<tr><td>D</td><td>D1</td><td>Vt</td><td>Possible
South of the above if unit “points” west</td></tr>
<tr><td colspan="4">Some more possible vt
Some possible Lb or small bones</td></tr>
</table>

D	D2	Sc	n/a
D	D3	Sc	Very small
Some small bones on D3 and D4			
A whole mess of bones on E1			
E	E1	Vt	Possible On the west ½ close to the pointy end
Some more possible vt, lb, and 3 short bones			
Several Sc E2, 3 clearly visible			
E	E2	Lb	2 of them
E	E3	Sc	n/a
E	E3	Lb	Just the end
Possibly some toe bones Lots of broken up bones			
F	F1	Lb	One the broader end of F1
F	F1	Lb	Toward the center In the mishmash of bones
F	F2	Sc	Above some Vt
F	F2	Vt	Multiple
• Possibly sacral, next to something that might be a vt or multi bones • Possible vt near it, looks a little big though			
G	G1	Lb	Partial Rest of impression more on G2 side
G	G1	Lb	Impression
G	G1	Lb	Towards the bony side of 1st Lb G1
G	G1	Lb	n/a
G	G1	Lb	n/a
G	G1	Vt	n/a
G	G1	Jaw	Not *Captorhinus*
G	G2	Lb	Impression
G	G2	Lb	Partial
H	H1	Sc	Very tentative
H	H1	Lb	n/a

H	H1	Lb	n/a
H	H2	Possible Rib	n/a
H	H3	Sc	Very tentative
I	I1	Sc	n/a
I	I1	Lb	In the little hole in I1
I	I1	Lb	Sort of also on side I4
I	I1	Vt	Tentative
I	I1	Lb	Next to the one in the hole
I	I2	Lb	n/a
I	I2	Lb	n/a
I	I2	Vt	n/a
I	I2	Lb	Tentative
I	I2	Lb	Partial
Some tentative (very) possibly Lbs			
Big unidentified bone, possible Sc			
I	I3	Lb	n/a
I	I3	Sc	Confirmed
I	I4	Lb	Partial
I	I4	Lb	Tentative Impression
I	I4	Lb	Partial
J	J1	Sc	Tentative
J	J1	Sc	n/a
J	J1	Lb	n/a
J	J1	Lb	n/a
J	J1	Lb	n/a
J	J1	Jaw	Very tentative
J	J1	Jaw	n/a
J	J1	Vt	Very tentative
J	J1	Vt	Very tentative
J	J1	Lb	n/a
J	J2	Lb	On the narrower end of J2 Toward J5

J	J3	Lb	Tentative
J	J4	Jaw	n/a
J	J4	Lb	many
J	J5	Lb	Straddles J4/J5
J	J6	Lb	n/a
J	J6	Lb	n/a
J	J6	Lb	n/a
K	K1	Lb	Cut Next to another small possible Lb
K	K1	Lb	The smaller one
K	K1	Lb	Longer
K	K1	Vt	Tentative
Some possible K2 bones			
L	L1	Vt	On the orange clast side
Some fairly worn bones			
L	L1	Vt	Possible Toward/on
L	L2	Lb	Fairly worn 3 of them
L	L3	Lb	Portions of 3 of them
L	L3	Vt	Below the abovementioned lb
L	L4	Toe bone	Tentative
L	L5	Vt	Near/on the L1 side
L	L5	Vt	Tentative
Some long, thin bones in L6			
N	Side on N remained unlabelled	Jaw	Long
N	Side on N remained unlabelled	Jaw	Short
N	Side on N remained unlabelled	Jaw	Medium

Table 2: Table of findings on blocks from Bally Mountain

Table 3 was produced after the study of bone fragments resulted in taxonomic assignment. **Taxon** represents the taxon assigned the material, **Label** represents either the label in the field notebook or how any photos were labelled. **Material** represents what body part was being analyzed. **Unit**, represents the block of which the material belonged to. **Applicable Specimen** corresponds to the **Label,** and a figure number was assigned to it when it was uploaded to the Box folder (this does not correspond to an overall figure count within the paper).

TAXON	**LABEL**	**MATERIAL**	**UNIT**	**APPLICABLE Specimen**
Captorhinid skull	C1 Skullcap	Skullcap	C1	Specimen 1
Doleserpeton	Tiny Jaw Unit C	Jaw	C1	Specimen 2
Captorhinikos valensis		Skullcap	Unit E	Specimen 3.1
Captorhinikos valensis		Skullcap	Unit E	Specimen 3.2
Captorhinikos valensis		Skullcap	Unit E	Specimen 3.3
Cacops		Skullcap	Unit E	Specimen 4
Captorhinikos valensis	*Captorhinikos* Jaw	Jaw	Unit N	Specimen 5
Captorhinikos valensis	Jaw short	Jaw	Unit N	Specimen 6
Captorhinus aguti	Jaw Medium	Jaw	Unit N	Specimen 7
Captorhinikos valensis	Unit J Big Jaw/Big tooth	Jaw	Unit J	Specimen 8
Captorhinikos valensis	Unit J Jaw Tip	Jaw	Unit J	Specimen 9
Captorhinus aguti* or *Captorhinikos valensis	Unit J Jaw Portion	Jaw	Unit J	Specimen 10
Delorhynchus	Unit G Long Jaw	Jaw	Unit G	Specimen 11

Table 3: Specimens Identified from the Bally Mountain blocks

Results

Captorhinid Skull, C1 Skullcap, Specimen 1

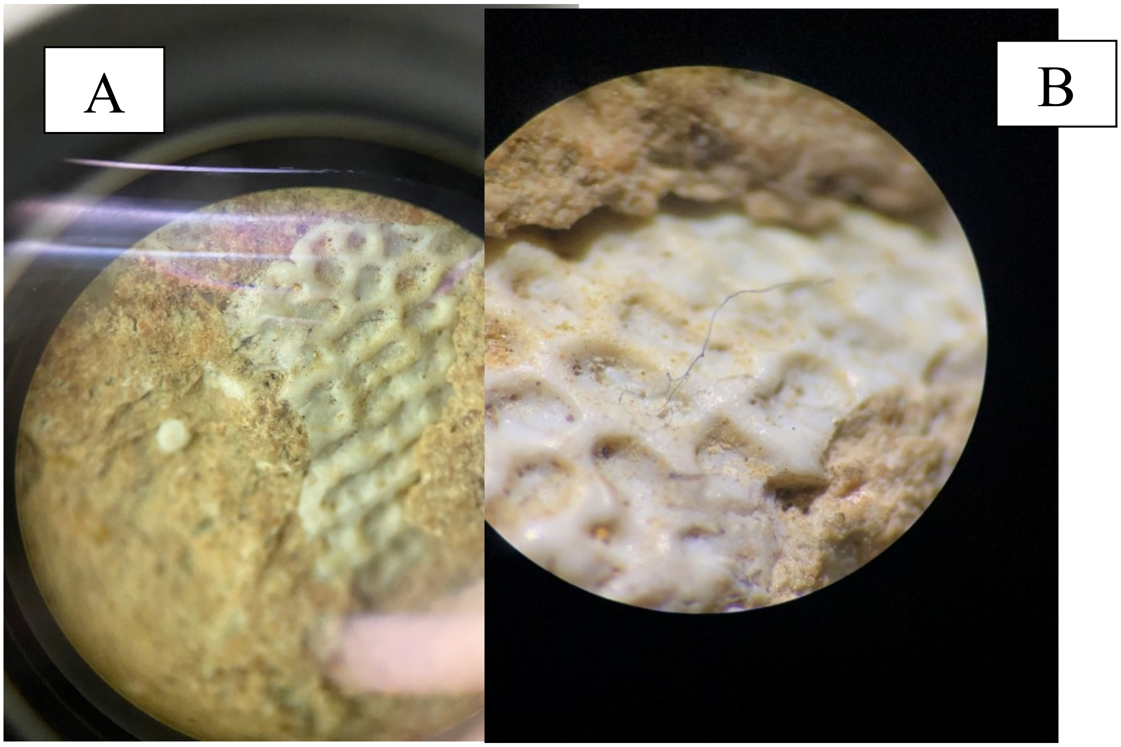

Figure 10: Specimen 1. Captorhinid Skull. **A)** and **B)** are both of the same specimen

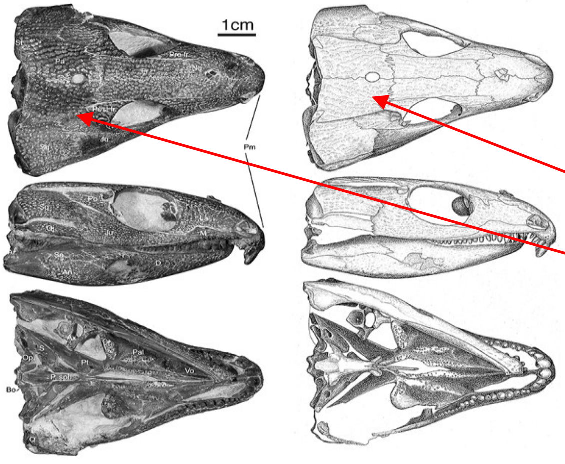

Figure 12: Image of *Captorhinus kierani* skull. (deBraga, Bevitt, & Reisz, 2019)

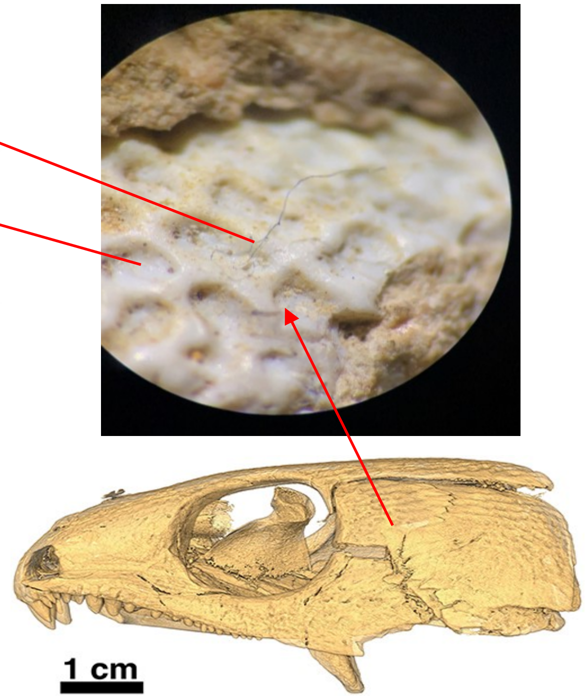

Figure 11: Image of *Captorhinus kierani* skull. (deBraga, Bevitt, & Reisz, 2019)

Figures 10, 11, and 12 refer to Specimen 1, a skull fragment located in Unit C. The small size of the skullcap and incompleteness made identification challenging. However, when compared to images and drawings of skull pieces of captorhinids, similarities in the shape of the pitting of the skull piece were enough to tentatively identify it as a captorhinid.

Points of particular comparison that led to the identification of the specimen as a captorhinid are marked with red arrows. The arrows are meant to show comparison and similarities between the drawing and the actual photographed unit, rather than point out where specifically on the skull it may be.

***Doleserpeton,* Small Jaw on Unit C**, Specimen 2

Figure 13: Specimen 2. *Doleserpeton* jaw

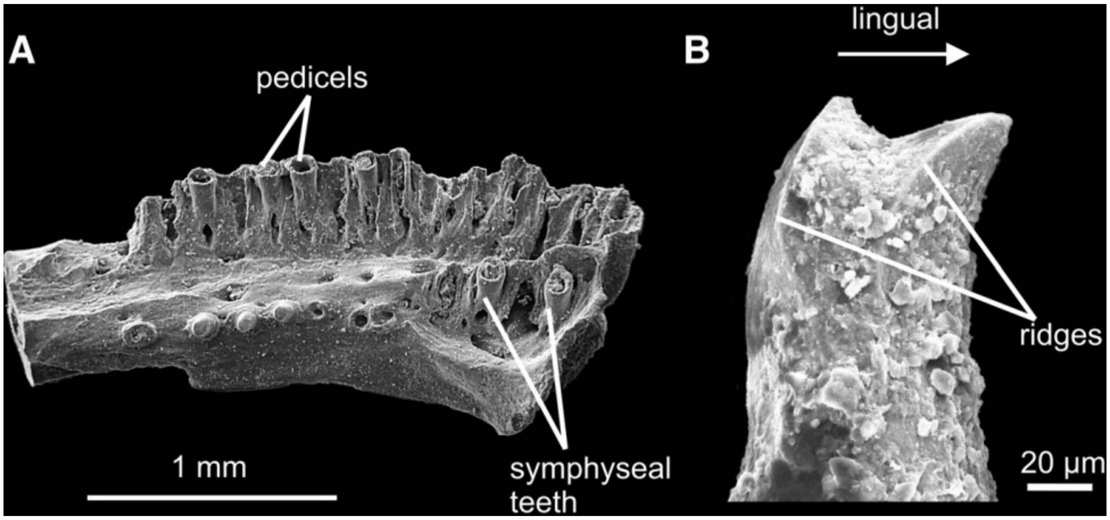

Figure 14: Image of SEM photograph of the jaw of *Dolesrpeton*. (Sigurdsen and Bolt, 2010).

Due to its small size (about 4 mm), Specimen 2, a jaw (see Figures 13 and 14) was extremely difficult to identify. Any attempts to do so would be in large part supposition and guesswork. Nonetheless, an attempt was made to do so. To the clearest interpretation of the observer, the jaw appeared to belong to *Doleserpeton*, due to the teeth and jaw shape being unlike those of *Opisthodontosaurus* and more similar to *Doleserpeton*. While it is possible that this is a sample of a young *Captorhinikos* or *Captorhinus,* both the size and shape of the jaw are closer to that *Doleserpeton*.

This is best seen when compared to the photograph of the *Doleserpeton* jaw from Sigurdsen and Bolt (2010) (Figure 14). While hard to see due to their small size, the teeth match up as closely. The jaw from Sigurdsen and Bolt (2010) and Specimen 2 both have bolt-like teeth.

***Captorhinikos valensis,* Skullcap, Unit E**, Specimen 3.1, 3.2, and 3.3

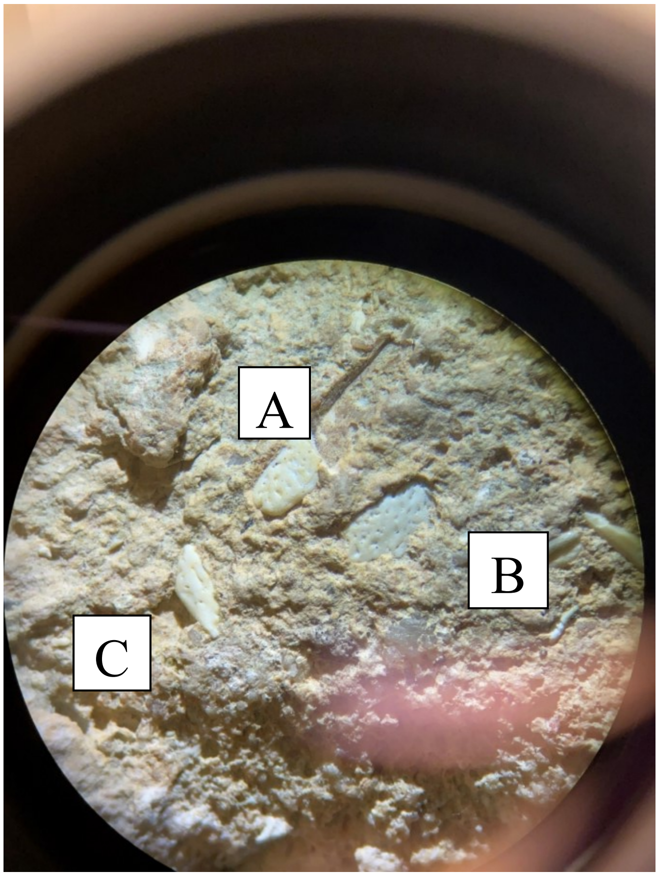

Figure 15: All three skull fragments of *Captorhinikos valenesis*. **A)** further defined as Specimen 3.1 B**)** further defined as Specimen 3.2 **C)** further defined as Specimen 3.3

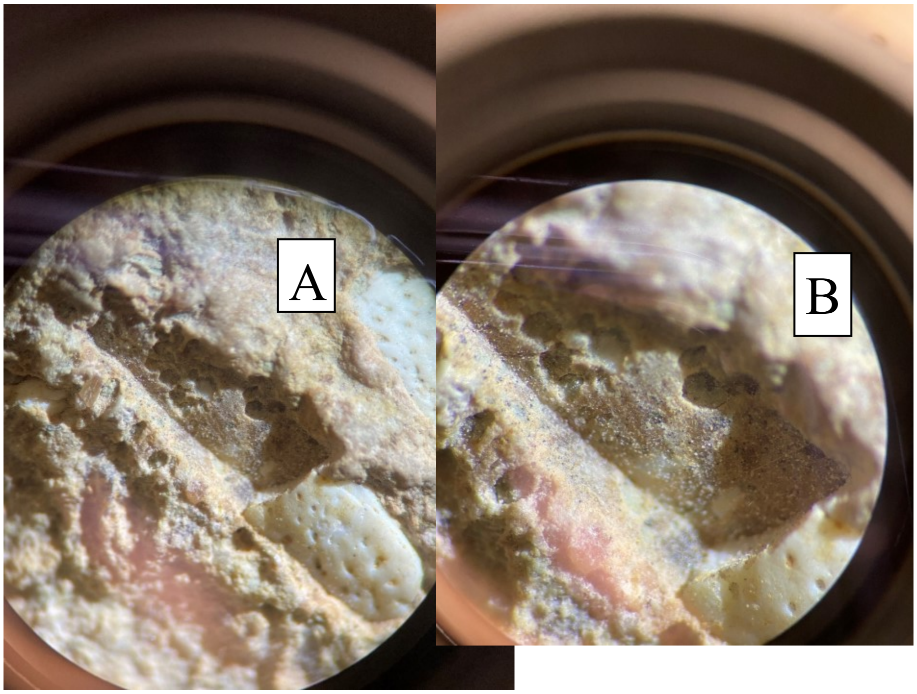

Figure 16: Specimen 3.1. **A)** Specimen 3.1 as a whole **B)** Closer view of the impression left by 3.1

Figure 17: Specimen 3.2

Figure 18: Specimen 3.3

Specimens 3.1, 3.2, and 3.3 (Figures 15,16, 17 and 18) were embedded so close one could reasonably assume they belonged to the same animal. Each was therefore labelled as though they all belonged to the same animal. The longest specimen was labelled 3.1, the medium rectangular specimen was labelled 3.2, and the smallest triangular piece was labelled 3.3.

Within the lower portion of the specimen, where the bone has been worn away or removed, small pits were seen within the matrix. When placed under light, these became more pronounced and easily visible. The presence and shape of these pits, depth of the rest of specimen had been removed, and its elongated shape led to an initial hypothesis that this was a portion of a jaw. The pits appear to be the left-over impressions of teeth, and the elongated shape and depth of the specimen are characteristic of the jaw itself.

However, the presence of these pits around Specimen 3.1 called this into question enough that it could not be definitively stated that these were tooth remnants. Rather, they could be due to erosion, weathering, or the physical removal or transport of the blocks themselves. Both 3.2

and 3.3 are, on their own, hard to place under any taxon due to their small size and lack of clear definition or shape. When combined with 3.1 a clearer candidate of *Captorhinikos valensis* arises.

***Cacops*, Skullcap, Unit E**, Specimen 4

Figure 19: *Capcops* skull fragment

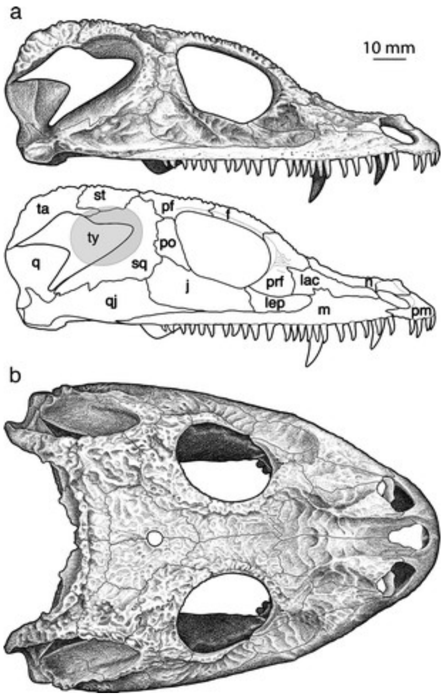

Figure 20: Skull reconstruction of *Cacops morrisi* (Reisz et al., 2009)

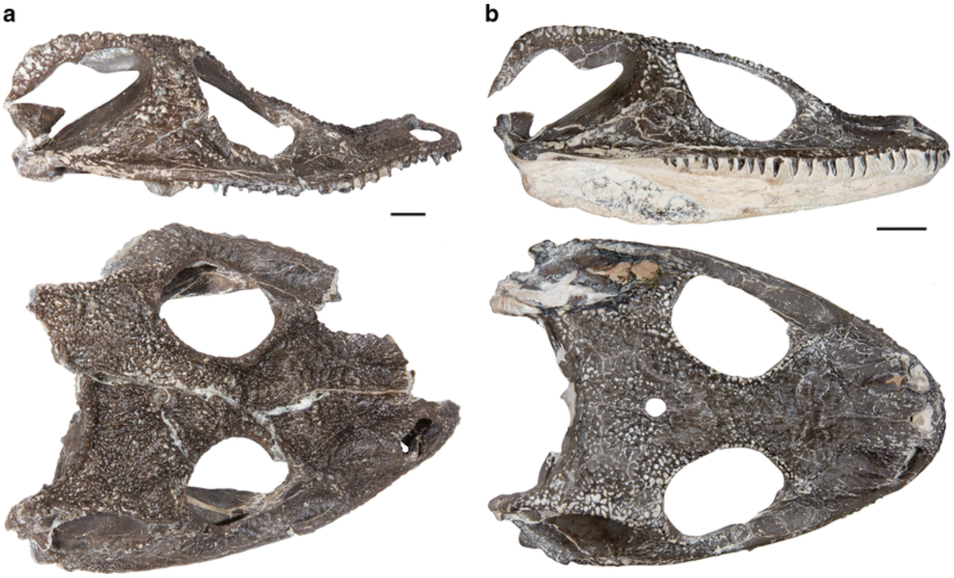

Figure 21: Photographs of *Cacops morrisi* skull (Reisz et al., 2009).

Specimen 4 (see Figures 19, 20, and 21) is small and fragmentary. The long and narrow pitting along the skullcap piece resembles pitting like that of *Cacops*. This is largely supported when compared to Figures 20 and 21, a reconstruction of skull, and an image of the *Capcops morrisi* skull from Reisz et al. (2009). As this is only a small skull piece, such a designation is by nature tentative and based upon some amount of speculation.

Captorhinikos valensis **Jaw, Large Jaw, Unit N (Formerly Unlabeled Unit)**, Specimen 5

Figure 22: *Captorhinikos valensis* jaw. **A)** the entire jaw **B)** the tip of the jaw

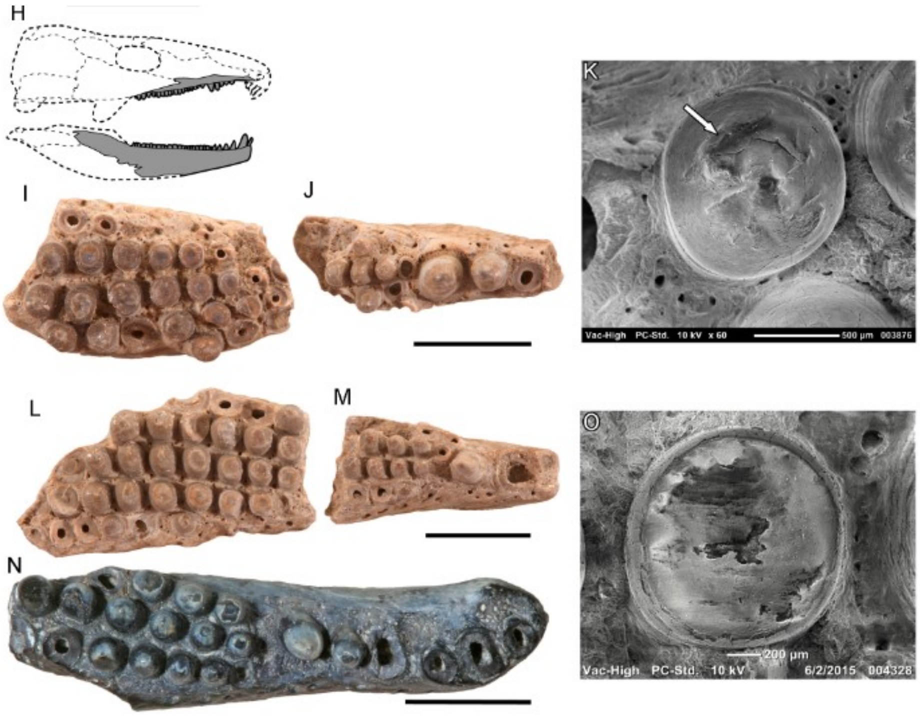

Figure 23: *Captorhinikos valensis* jaw, reconstruction and images (LeBlanc et al., 2015).

Specimen 5 (Figures 22 and 23) is relatively well preserved in the block where it sits. The general shape of the jaw itself, as well as the curvature of the teeth both match the moradenisaur *Captorhinikos valensis*, a prominent member of the Bally Mountain Formation fauna. Of particular note, the anterior portion of the dentary has a large outward protruding tooth followed by a smaller tooth that matches up nearly perfectly with the reconstruction and drawings shown in LeBlanc et al. (2015). This has led to the conclusion that the above specimen is indeed *Captorhinikos valensis.*

Captorhinikos valensis **Jaw short, Unit N**, Specimen 6

Figure 24: Specimen 6. *Captorhinikos valensis* jaw

Specimen 6 (Figure 24) appeared very similar to the larger *Captorhinikos valensis* jaw discussed above (Figure 22) in terms of both tooth shape and curvature and overall jaw shape. The similarities between the two, as well as this jaw appearing similar to the *Captorhinikos valensis* jaw depicted in the literature (LeBlanc et al., 2015), led to the conclusion that this jaw also belonged to a *Captorhinikos valensis*. Furthermore, there appears to be another row of teeth visible on the jaw, although they have been largely worn away and are only slightly visible in the remains. This further supports the hypothesis that this is *Captorhinikos valensis*.

***Captorhinus aguti* Jaw Medium, Unit N**, Specimen 7

Figure 25: Specimen 7. *Captorhinus aguti* jaw.

Specimen 7 (Figures 25 and 26) can be characterized by its elongated shape and multiple teeth. Additionally, there is a skull piece adjacent to the jaw, which, upon inspection, is not attached to the skull. The jaw has a slight curvature to it, most notable around the broken tooth,

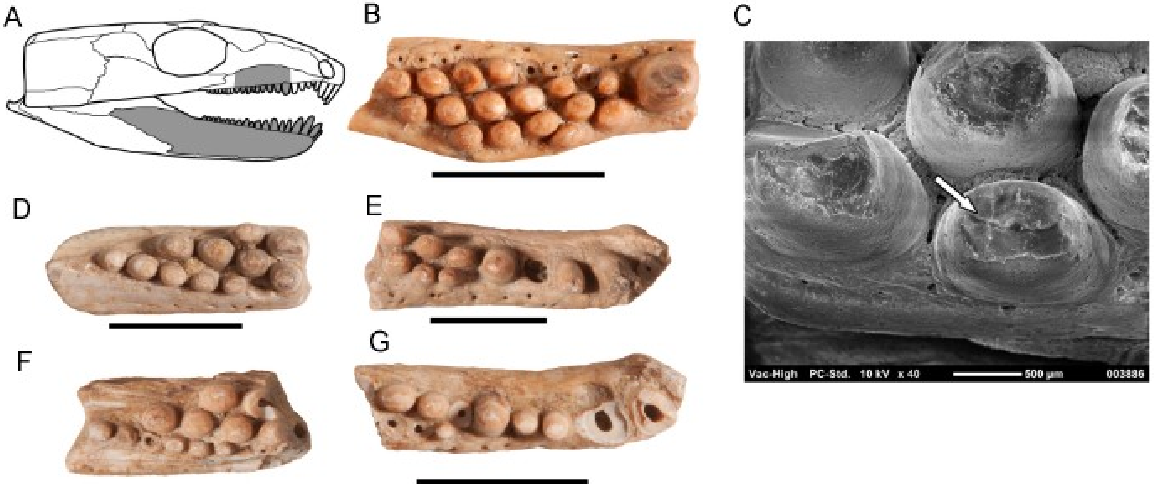

Figure 26: *Captorhinus aguti* jaw images and reconstruction,(LeBlanc et al., 2015)

and overall, the teeth are ovoid in shape, starting with rounder bases and decreasing in size upwards. Ossification around the base of the teeth can be seen, and additionally, the teeth are slightly offset from one another, with some being slightly more towards the viewer and others more backwards from the viewer (Figure 25).

Furthermore, there is a section on the jaw, the portion closest to the skull cap fragment, which appears to be the posterior portion of the jaw that would connect to the rest of the skull. Small grooves were visible within this section. Initially, these were believed to be fenestrae and attachment sites for muscles. However, the possibility that this was just damage cannot be ruled out with certainty.

This was further supported when compared to Figure 26, taken from LeBlanc, et al. (2015)., which depicts a reconstruction of a *C. aguti* jaw and several fragmentary specimens. The curvature of the teeth and the shape of the jaw match up particularly well with the representational drawing (A) from the above Figure 26.

Due to all of the above factors, in particular the posterior region discussed above and the curvature of the jaw matching up to this region, this specimen was identified as *Captorhinus aguti*.

***Captorhinikos valensis;* Unit J**, Specimen 8

Figure 27: Specimen 8. *Captorhinikos valensis* jaw.

Figure 28: Closer view of a portion of Specimen 8

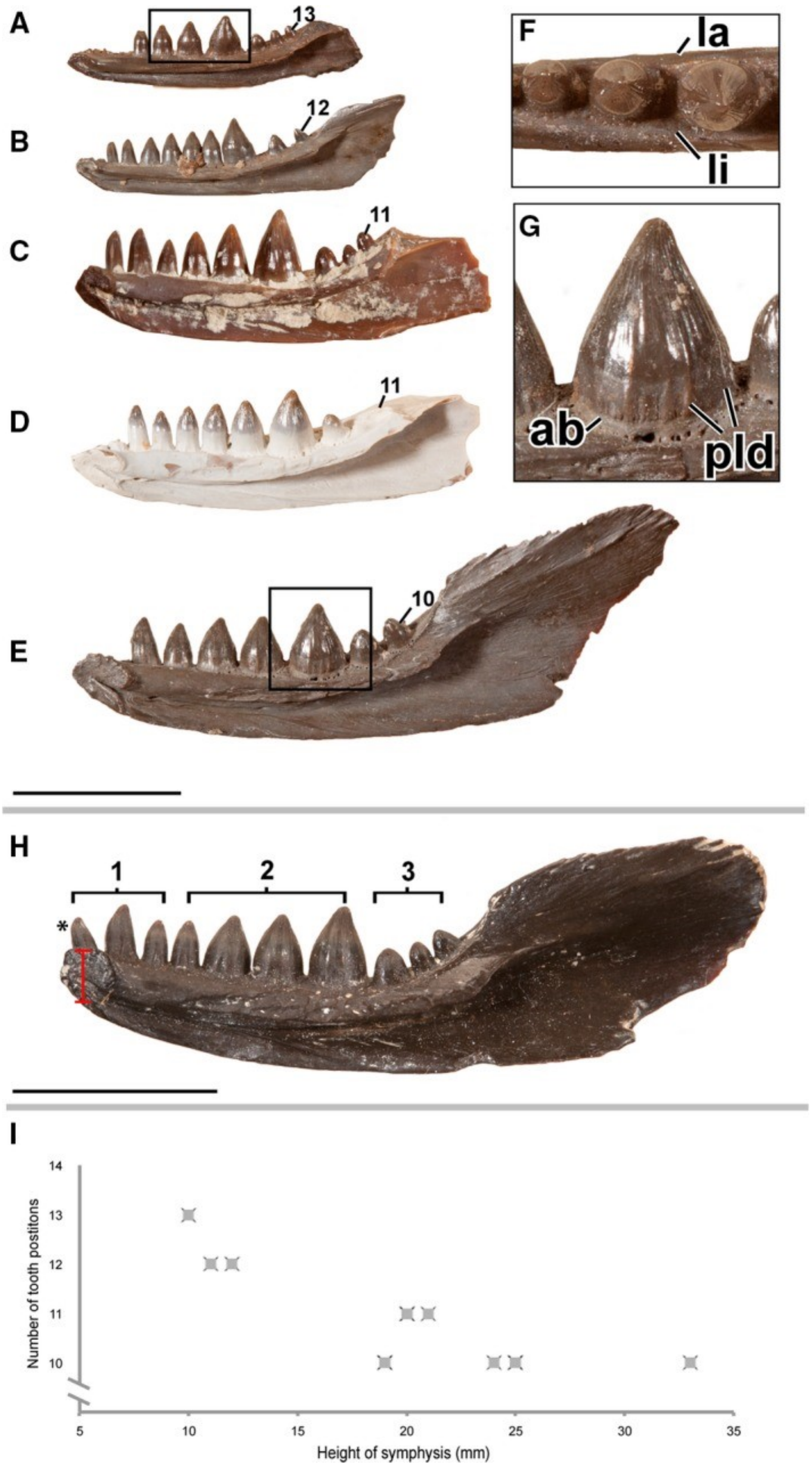

Figure 29: *Opithodontosaurus carrolli* jaw (Haridy et al., 2017).

Figure 30: *Captorhinikos valensis* jaw (Modesto et al., 2014).

This specimen is fragmentary and is easily noticeable by a large tooth surrounded by much smaller teeth on either side. The specimen also shows a curvature to the jaw. The presence of the larger tooth and the curvature of the jaw suggest identification as *Opisthodontosaurus*. However, this identification is called into question due to the shape of the teeth present in the specimen not matching those in *Opisthodontosaurus* figures. *Opisthodontosaurus* teeth have a wider base that rise to an angular point (Reisz et al., 2015; Haridy et al., 2018). Only the large tooth in this specimen could be characterized as exhibiting this feature. All other teeth are even in nature, presenting less of a visible tapering effect.

Additionally, the teeth to the right of the large tooth (when the unit is orientated such that the large tooth points upwards) are blunt and broken. Of particular note here is that at least one tooth is entirely missing, only the very base of its pit can be seen, and the internal structure and breakage of another tooth can be seen (Figure 28). The remaining teeth are blunt and fractured. The presence of the tooth pit alongside the blunt teeth, all of which are noticeably smaller than their much larger large left tooth counterpart, would indicate that the original specimen had a double row of teeth, as the tooth pit appears to be of a similar size to that of the other blunted teeth, rather than being an erupting replacement tooth. The blunt nature of the teeth also indicate that a different mechanism of food consumption was involved than in the more angular teeth of *Opisthodontosaurus.*

The combination of the above factors has led to the rejection of the initial conclusion that the specimen is *Opisthodontosaurus*. The multiple tooth rows and the blunt nature of teeth indicate *Captorhinikos*, more specifically, a portion of the mandible. The larger tooth would be anterior facing while the blunted teeth would be posterior facing. This was noted by Modesto and Reisz (2014). The curvature of the jaw and the shape of the teeth compare with Figure 30. These factors lead to the conclusion that the jaw fragments belong to *Captorhinikos valensis*.

***Captorhinikos valensis,* Unit J,** Specimen 9

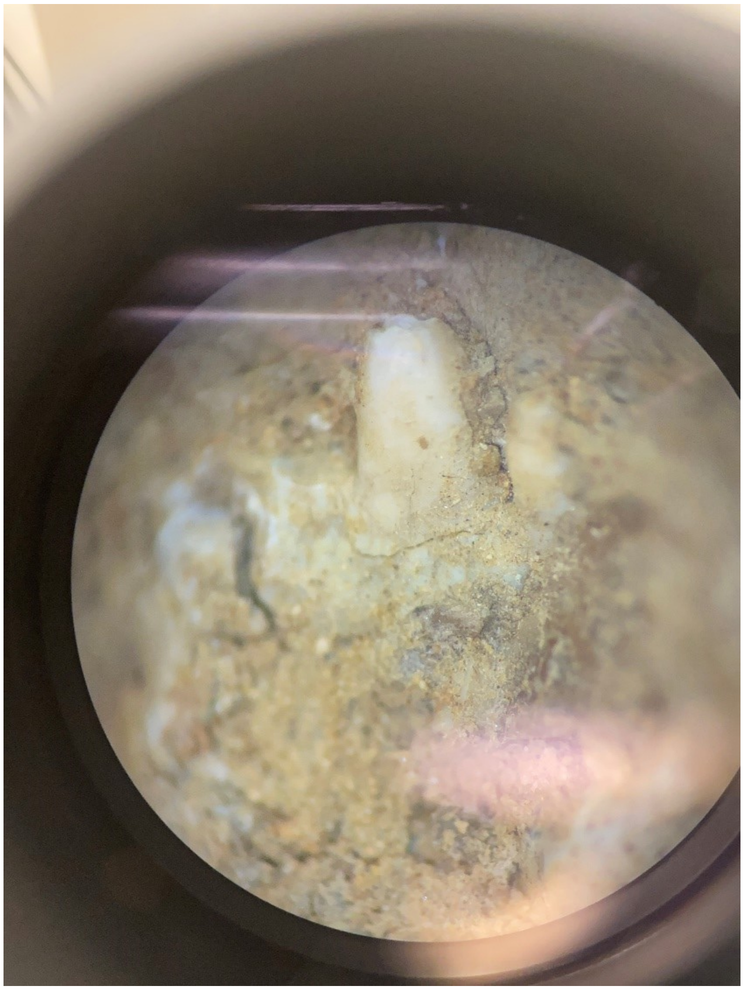

Figure 31: Specimen 9. *Captorhinikos valensis* jaw.

Specimen 9 (Figure 31) is small and fragmentary which makes identification, at least in part, tentative. Based upon the shape of the teeth, it was supposed that the material represented the anterior tip of the lower jaw of a *Captorhinikos valensis,* as the second tooth is larger than the other and the sample matched up well with the large *Captorhinikos* jaw in Figure 5 and the smaller one in Figure 7. Additionally, when compared to Figure 23 taken from LeBlanc et al. (2015), it matched as well as could be expected from such a small fragment.

Captorhinikos valensis or ***Captorhinus aguti*****, Unit J,** Specimen 10

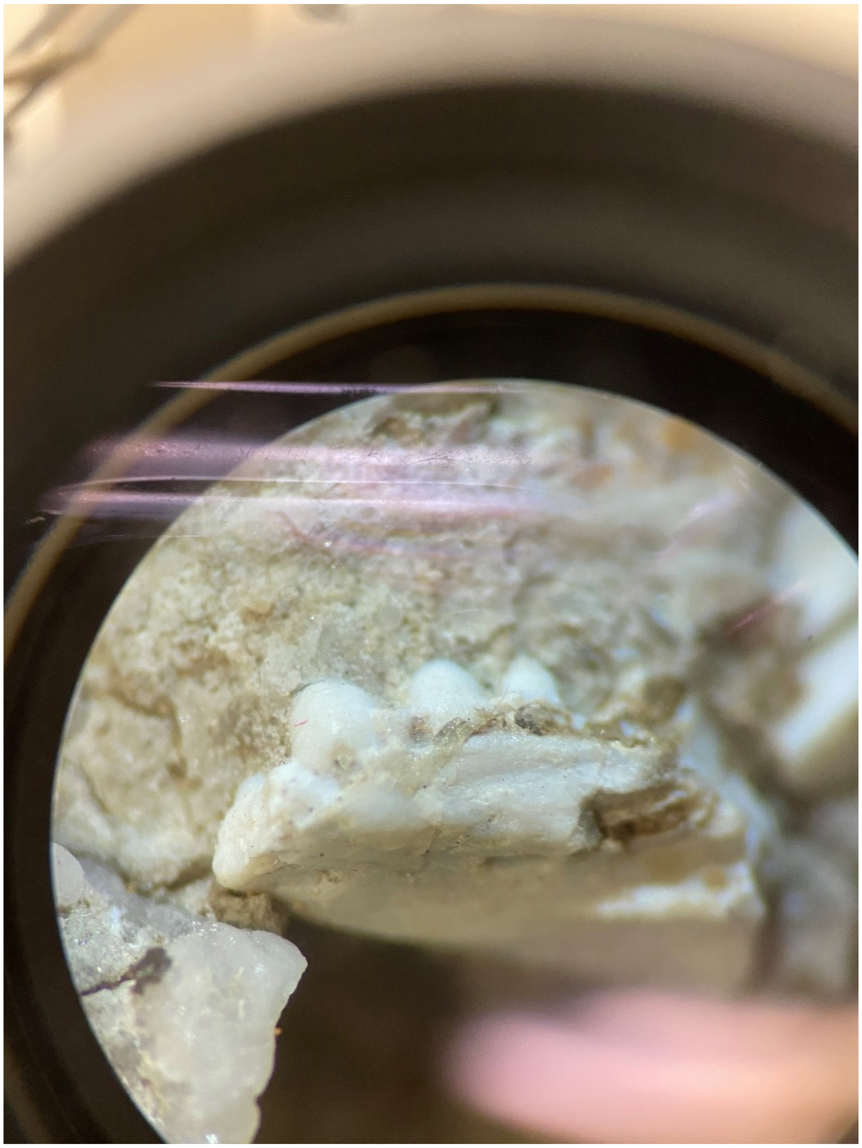

Figure 32: Specimen 10. *Captorhinikos valensis* or *Captorhinus aguti* jaw.

Specimen 10 (Figure 32) is another jaw fragment embedded into its block. The jaw itself is wider than some of the jaws previously reviewed. The teeth are blunt and stubby, ruling out that the jaw belonged to either *Opisthodontosaurus* or *Delorhynchus*. Both these factors, i.e., the blunt and stubby nature of the teeth, as well as the elimination of the two above genera, led to the consideration of *Captorhinus aguti* and *Captorhinikos valensis*. This supposition was further supported by a second row of teeth featuring a small tooth at the more pointed end of the jaw fragment. Further study is needed to determine, if possible, which of the above two genera, *Captorhinus aguti* or *Captorhinikos valensis*, the specimen belongs to.

Delorhynchus, **Unit G,** Specimen 11

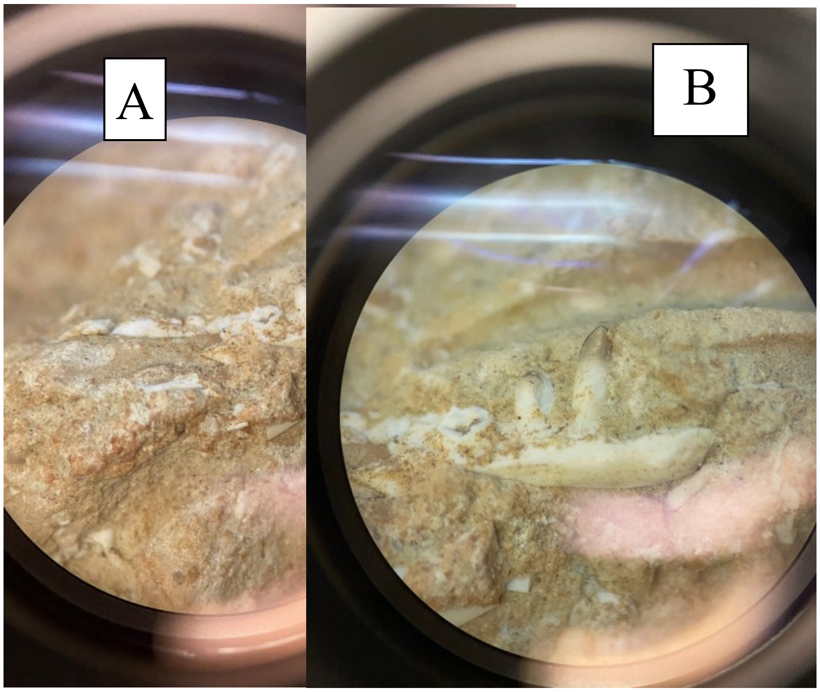

Figure 33: Specimen 11. *Delorhynchus* jaw. **A)** showing the whole jaw; **B)** showing a partial amount of the jaw

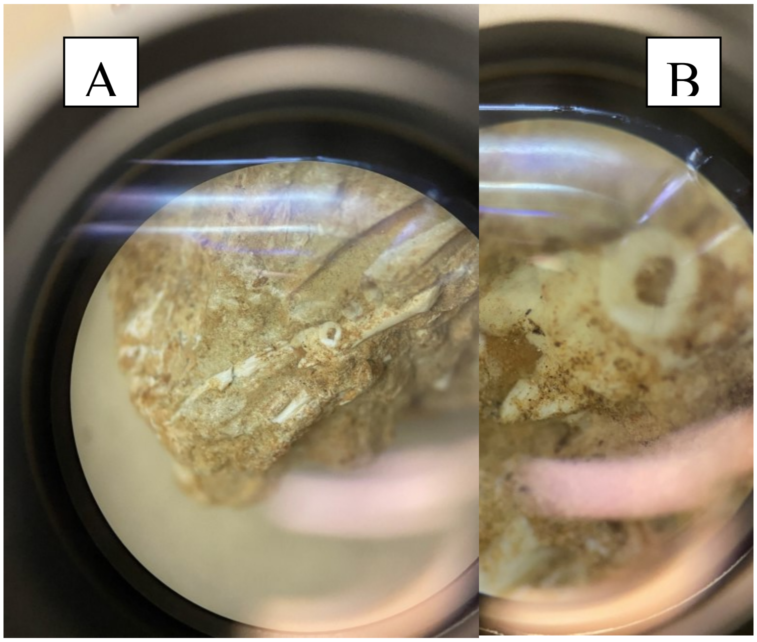

Figure 34: Specimen 11. **A)** a top-down view of the jaw; **B)** a closer view of the connecting section of the jaw

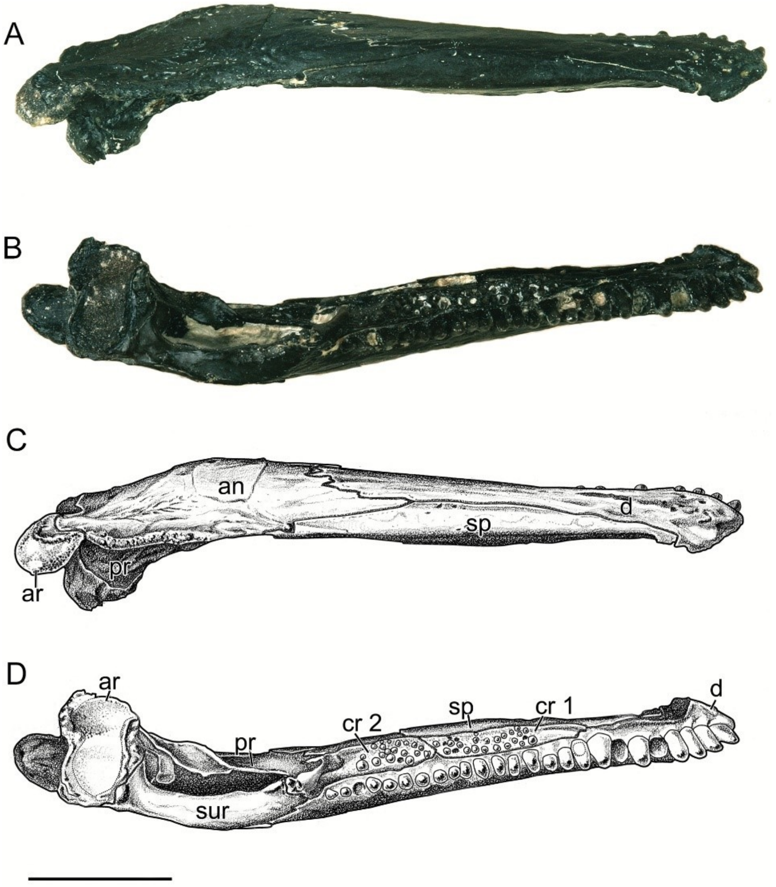

Figure 35: Image of *Delorhynchus cifellii* jaw (Haridy et al., 2016)

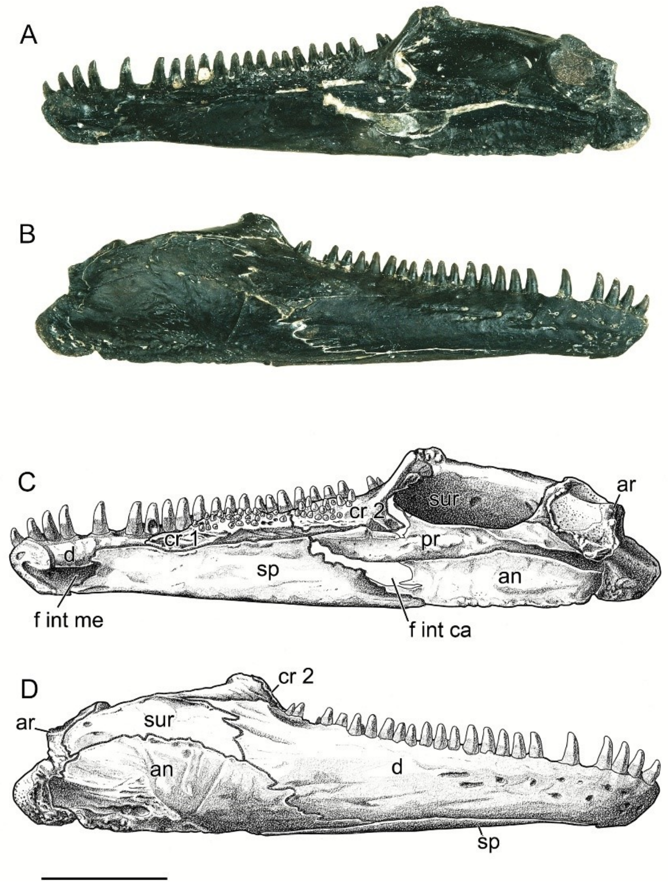

Figure 36: Image of *Delorhynchus cifellii* jaw (Haridy et al., 2016)

Specimen 11 (Figures 33 and 34) is a fairly long specimen, at first appearing to be a much smaller jawbone next to another bone of indeterminate type. However, upon closer inspection under a microscope and tilting of the block in which it was located, it was discovered that it was in fact, one long jaw. There are three readily visible teeth, two of which are whole or only slightly worn. A third tooth was broken off, with only the base remaining. The teeth were far too narrow to be *Opisthodontosaurus*, and the shape of the jaw as well as the teeth eliminated both *Captorhinus* and *Captorhinikos*. The shape of the teeth available for study, as well as the shape of the jaw, led to the hypothesis that the specimen was *Delorhynchus*. This was further evidenced by the appearance of tooth pits along the jaw.

Figures 35 and 36, from Haridy et al. (2018), are of a *Delorhynchus* jaw as well as representative drawings of the same jaw. When compared to Specimen 11 they appear to be similar in tooth and jaw shape. This is especially observable in Figure 34 compared to Figure 35.

Conclusions

Richards Spur and Bally Mountain both provide an abundance of anatomical, ecological, and evolutionary information on the characteristics and development of Early Permian terrestrial fauna, particularly those of upland environments. This is especially important as upland environments are quick to erode, making preservation rare. The depositional and preservation characteristics of these sites, wherein remains or entire organisms were washed into the cave system and subsequently quickly buried, have led to this massive abundance of fossils.

The materials studied within the blocks were all disarticulated in nature and many of them were broken and/or worn. Long bones were the most numerous in the blocks, followed by vertebrae, skull-pieces, and jaws. Jaws were, by comparison, relatively rare but far more valuable in terms of identifying what taxa are present in the blocks.

The most abundant identified remains were that of *Captorhinikos valensis*, a captorhinid not present at Richards Spur but present at Bally Mountain. This is not unexpected as *Captorhinikos valensis* was a prominent member of the Bally Mountain fauna. Also present were *Captorhinus aguti* followed by *Delorhynchus cifelli, Capcops,* and *Doleserpeton.*

The presence of all of these taxa provides a window into both the diversity of the Bally Mountain site and palaeobiological community, as well as that of upland Early Permian environments. The study and understanding of these upland terrestrial environments provides the ability to understand the evolution and development of Early Permian fauna and upland communities, the evolution of Permian parareptiles, and the development of multi-tooth dentaries— present in animals such as *Captorhinikos valensis* and *Captorhinus aguti*— and what the presence of these dentaries meant for the development of dietary habits within Permian parareptiles.

References

Bennison, AP. (1986). AAP Geological Highway Map of the Midcontinent Region.

deBraga, M., Bevitt, J.J., and Reisz, R.R. (2019). A New Captorhinid From the Permian Cave System Near Richards Spur, Oklahoma, and the Taxic Diversity of *Captorhinus* at This Locality. *Front. Earth Sci.* 7 (112). doi: 10.3389/feart.2019.00112

Google. (n.d.). [Google map of Dolese Brothers Quarry at Richards Spur]. Retrieved September 7th, 2022 from: https://goo.gl/maps/HnwtHoAaffbbaUKE7

Google. (n.d.). [Google map of Bally Mountain]. Retrieved September 7th, 2022 from: LINK: https://goo.gl/maps/uy6aAvWeKRmXNdiMA

Haridy, Y., LeBlanc, A.R.H., & Reisz, R.R. (2018). The Permian reptile *Opisthodontosaurus carrolli*: a model for acrodont tooth replacement and dental ontogeny. *Journal of Anatomy, 232* (3), 371-382. doi: 10.1111/joa.12754

Haridy, Y., Macdougall, M.J., & Reisz, R.R. (2018). The lower jaw of the Early Permian parareptile *Delorhynchus*, first evidence of multiple denticulate coronoids in a reptile, *Zoological Journal of the Linnean Society*, *184* (3), 791–803. https://doi.org/10.1093/zoolinnean/zlx085

Haridy, Y., Macdougall, M.J., Scott, D., & Reisz R.R. (2016). Ontogenetic Change in the Temporal Region of the Early Permian Parareptile *Delorhynchus cifellii* and the Implications for Closure of the Temporal Fenestra in Amniotes. *PLOS ONE, 11*(12). https://doi.org/10.1371/journal.pone.0166819

LeBlanc, A. R. H., Brar, A. K., May, W. J., & Reisz, R. R. (2015). Multiple tooth-rowed captorhinids from the Early Permian fissure fills of the Bally Mountain Locality of Oklahoma. *Vertebrate Anatomy Morphology Palaeontology*, *1*, 35–49. https://doi.org/10.18435/B5RP4N

MacDougall, M. J., Tabor, N. J., Woodhead, J., Daoust, A. R., & Reisz, R. R. (2017). The unique preservational environment of the early Permian (Cisuralian) fossiliferous cave deposits of the Richards Spur locality, Oklahoma. *Palaeogeography, Palaeoclimatology, Palaeoecology, 475*, 1-11. doi: https://doi.org/10.1016/j.palaeo.2017.02.019

Modesto, S.P., Lamb, A.J., & Reisz, R.R. (2014). The captorhinid reptile *Captorhinikos valensis* from the lower Permian Vale Formation of Texas, and the evolution of herbivory in eureptiles, *Journal of Paleontology*, *34*(2), 291-302. doi: 10.1080/02724634.2013.809358

Modesto, S.P., Scott, D. & Reisz, R.R. (2018). A new small captorhinid reptile from the lower Permian of Oklahoma and resource partitioning among small captorhinids in the Richards Spur fauna. *Papers in Paleoentology, 4*(2), 293-307. https://doi-org.ezproxy.tcu.edu/10.1002/spp2.1109

Price, Llewellyn. (1935). Notes on the braincase of *Captorhinus*. *Boston Society of Natural History*.

Tomora, Nora. (2008). *Captorhinus aguti* Restoration [Digital drawing]: https://commons.wikimedia.org/wiki/File:Captorhinus_BW.jpg

Reisz R. R. (2019). A small caseid synapsid, *Arisierpeton simplex* gen. et sp. nov., from the early Permian of Oklahoma, with a discussion of synapsid diversity at the classic Richards Spur locality. *PeerJ*, *7*. https://doi.org/10.7717/peerj.6615

Reisz R.R., LeBlanc, A.R.H., Sidor, C.A., Scott, D., & May W. (2015). A new captorhinid reptile from the Lower Permian of Oklahoma showing remarkable dental and mandibular convergence with microsaurian tetrapods. *Science Natural, 102*(50). doi: 10.1007/s00144-015-1299-y

Reisz, R.R., Schoch, R.R., & Anderson JS.(2009). The armoured dissorophid *Cacops* from the Early Permian of Oklahoma and the exploitation of the terrestrial realm by amphibians. *Naturwissenschaften*. *96*(7):789-96. doi: 10.1007/s00114-009-0533-x

Sigurdsen, T. & Bolt, J.R. (2010). The Lower Permian Amphibamid *Doleserpeton* (Temnospondyli: Dissorophoidea), The Interrelationships of Amphibamids, and the Origin of Modern Amphibians. *Journal of Vertebrate Paleontology*, *30*(5), 1360-1377. 10.1080/02724634.2010.501445