BULLION CREEK AND SENTIAL BUTTE FORMATIONS:

A STUDY OF RELATIVE DATING AND SPECIMEN DESCRIPTIONS FROM NEAR CARTWRIGHT NORTH DAKOTA

by

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of

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in

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DEDICATION

This paper is dedicated to a few very important people in my life. First, to my children, who are my reason for life itself. They educate me each day and share a love of science that no instrument could measure. To Keegan, for sharing my love of Paleontology and being my sidekick on this grand adventure. To Gracie, for always being my rock, even at a young age and who spent countless hours cataloging specimens with me. You never cease to amaze me with your never give up attitude and constant loyalty. To my mom, for raising me alone for a long time and showing me that being strong and independent can be your finest attributes. To Jennifer Bearden, for being my biggest fan. Without you, this degree path quite possibly may never have started. Finally, to my father, Alan Sandy. To the man who chose to be my dad when he didn't have to. You have given me gifts I can never repay. You have pushed me all my life to be the best I possibly can be and when I lose my way you are always there to help put me back on my feet. Without each of you this paper would not be possible. I love you all.

ACKNOWLEDGEMENTS

There are so many who have helped this project become reality. So, to all of you I say thank you! In no particular order, below are the individuals who have helped me beyond measure to ensure my success.

Dr. Dan Lawver thank you for keeping me along the straight and narrow path and constantly reviewing my paper for edits and errors I couldn't possibly notice on my own. Thank you for pushing me to complete this project, though I thought of giving up frequently, your guidance and support along the way is immeasurable.

Dr. Graves, thank you for believing in this project even though it is slightly unique, given our program and its focus. Thank you for having faith in me to complete it and providing me with many opportunities and options along the way. This has been a longer process for me due to unforeseen circumstances and your guidance and patience have given me strength and determination to push to the finish line.

To Donald Croy, Doug Hettich, and Doug Gullickson, thank you for allowing myself and my team to tromp all over your properties in search of specimens during fieldwork. Thank you for telling us family stories, dating back through the ages, and providing us with important history along the way. These clues have helped us tremendously.

Again, to Alan Sandy, a huge thank you. Thank you for allowing my team access to your land as well as offering me the idea to use it for my research initially. Without your contributions the ground floor, the fieldwork, of this paperwork would never have happened.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

Figure Page

ABSTRACT

Makenzie County in North Dakota, especially near Cartwright has not been explored by paleontologists for some time and never in great detail, yet the area is full evidence of the past. This paper focuses on the period of time between 50 and 65 million years ago when the area was believed to be a swampy sub-tropical forest skirting an inner continental seaway. It is the purpose of this paper to determine, through rock description and fossil leaf identification, the formation or formations present in this area of focus. These formations will in-turn pinpoint the time period in which the exposures were deposited. Identification of leaf impressions and molds are based on 9 key identifiers; lamina width and length, type of margin, lobation, apex and base type, apex and base angle, and vein pattern. Fossil leaf specimens can be identified to the class Magnoliopsida and other family levels, such as Taxodiaceae, Ulmaceae, Alismaceae, Betulaceae, and Sabiaceae. Additionally, some leaf specimens can be identified to the genus and species levels, including *Metasequoia occidentalis*, *Ulmites microphylla, Alismaphyllites grandifolius*, *Meliosma vandaelium*, and *Corylus insignis*. Fossils were collected on private land just outside Cartwright North Dakota where they were prepped for transport. In the lab setting they were cleaned, cataloged, and identified for the purpose of relative dating. These results demonstrate that both Sentinel Butte and Bullion Creek formations are present in the study area.

BACKGROUND AND INTRODUCTION

When I was a kid growing up in Montana, camping and fishing were a common occurrence. One of the places we frequented was my father's family farm near Cartwright, North Dakota. This area is a mixture of flat farmland and the sandy Yellowstone River's banks. We spent a vast majority of our time catching large toads and avoiding harsh sunburns. In this region, the river is deep and cuts into the soft sedimentary banks with ease. The surrounding hills and higher lying areas are composed of more resilient rock layers (Figure 1).

Figure 1. Research Site Landscape. View of landscape within the area of focus. Photo taken by Veronica Graham

Within these strata, a plethora of treasures can be discovered. As a child fascinated with dinosaurs and a master rock collector, I found myself quite at home searching those hills with my father for small shells and imprints of tiny fish and plants.

A Brief Family History

This land has been in my father's family for generations and even includes the old broken-down farmhouse my father calls the old homestead. His grandfather's family settled here back in the early 1900s from Norway and his mother and father, who adopted him, were raised here. It has since been passed down to him and a few cousins. My father's portion of the property is roughly 240 acres in total with some of that being leased to outside entities for mineral and oil reserve rights. Don Croy, his cousin, still lives on a section of this homestead, which was also entrusted to his family.

Family friends and local farmers, who have been in this valley for generations, round out this area in terms of acreage and residency. Doug Hettich owns a parcel of land just south of my father's property and to the east of the river. He maintains his land for hiking and hunting purposes. It contains taller exposures of rock scattered with grasses and thick vegetation. The Gullickson family owns several parcels to the north of the old homestead. These fields and low-lying areas are mainly utilized for farming. All of this land was offered to me for prospecting and research purposes (Appendix A).

Property's Use of North Dakota Natural Resources

North Dakota is known for its rich mineral and oil reserves and the area of focus is a large contributor. In the higher dry lands, oil derricks and gravel pits are scattered across the landscape. "In 2020, North Dakota ranked second in the nation, after Texas, in both crude oil production and proved crude oil reserves" (U.S. Energy Information Administration; North Dakota State Energy Profile, 2021). North Dakota produces roughly 3% of the nation's ethanol and natural gas resources as well as 4% of its coal production. The Bakken Formation oil production saw one of its highest peaks between 2019 and 2020, producing roughly 1500 thousand barrels of oil per day (Figure 2).

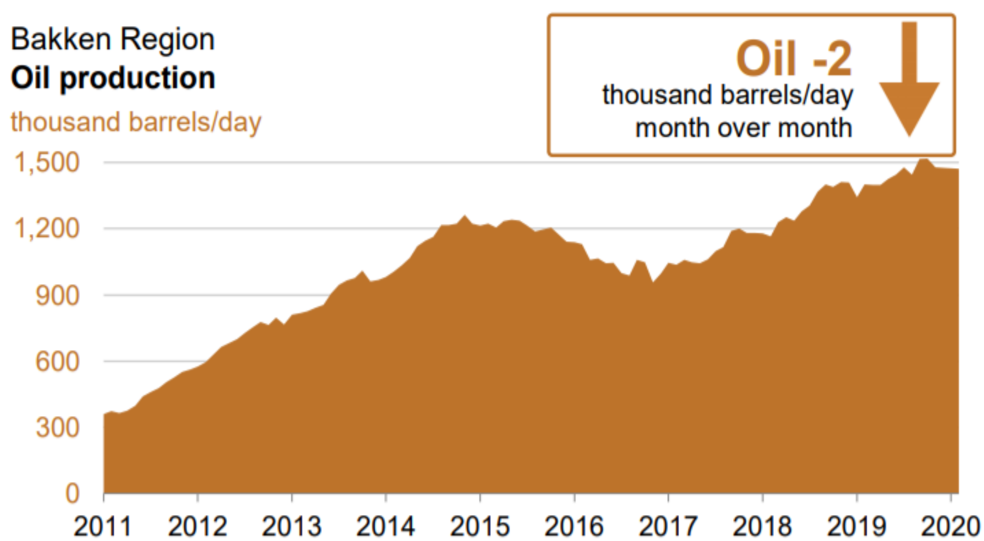


Figure 2. Bakken Region Oil Production. Picture via U.S. Energy Information Administration/Drilling Productivity Report (2022).

North Dakota is also rich in other mineral resources such as clay, salt, volcanic ash, and uranium. (North Dakota Geological Survey; Mineral Resources, n.d.). The states clay deposits are exported to make brick, tile, soap, and cat litter among other products. (North Dakota Geological Survey; Mineral Resources of North Dakota: Clay, n.d.). One of the lesser-known resources in this state, uranium, has a measurable presence. “It has been estimated that North Dakota contains a mineable reserve of 480,000 pounds of U_3O_8 at an $8.00 per pound market price.” (North Dakota Geological Survey: Mineral Resources of North Dakota: Uranium, n.d.).

Farms take up almost 90% of North Dakota’s land area and span over 39 million acres. (North Dakota Department of Agriculture, 2022). The low-lying land in this valley contributes to these statistics. It is reserved for grains such as barley, used for making beer, and cash crops such as sugar beets and oats. The state’s top grain product, wheat, is also produced in this area as crops are rotated through seasons. It is common to see legumes during crop rotation and dry bean production as well. However, several areas of the property still grow wild with native trees, grasses, and other plants while the river runs the westward side adjacent the property line.

Focus Statement and Sub-Questioning

Many factors came to play when I considered investigating this property. Not only is it private land, but it is also mostly uncharted territory for the scientific community. It has not been explored in detail for fossils or analyzed to assess which geologic formations lie within its borders. The main focus for this study was to determine which geologic formations could be positively identified through stratigraphic and fossil specimen identification. My goal was to analyze the stratigraphy and collect specimens on site, then identify and classify these specimens in a laboratory setting. Based on these findings, I planned to compare them with previously documented fossils from North Dakota and surrounding regions.

The focus question for this study was; Does fossil analysis confirm exposures of Sentinel Butte, Bullion Creek, or both formations at the area of focus?

Sub-questions included the following:

1. What, if any, other formations might be present in the focus area?
2. What are the geographic and temporal ranges of the fossils present in the study area?

CONCEPTUAL FRAMEWORK

McKenzie County Paleontological History

For the purpose of this study, I have focused on the rock formations and stratigraphy of the land near Cartwright, North Dakota (Figure 3).

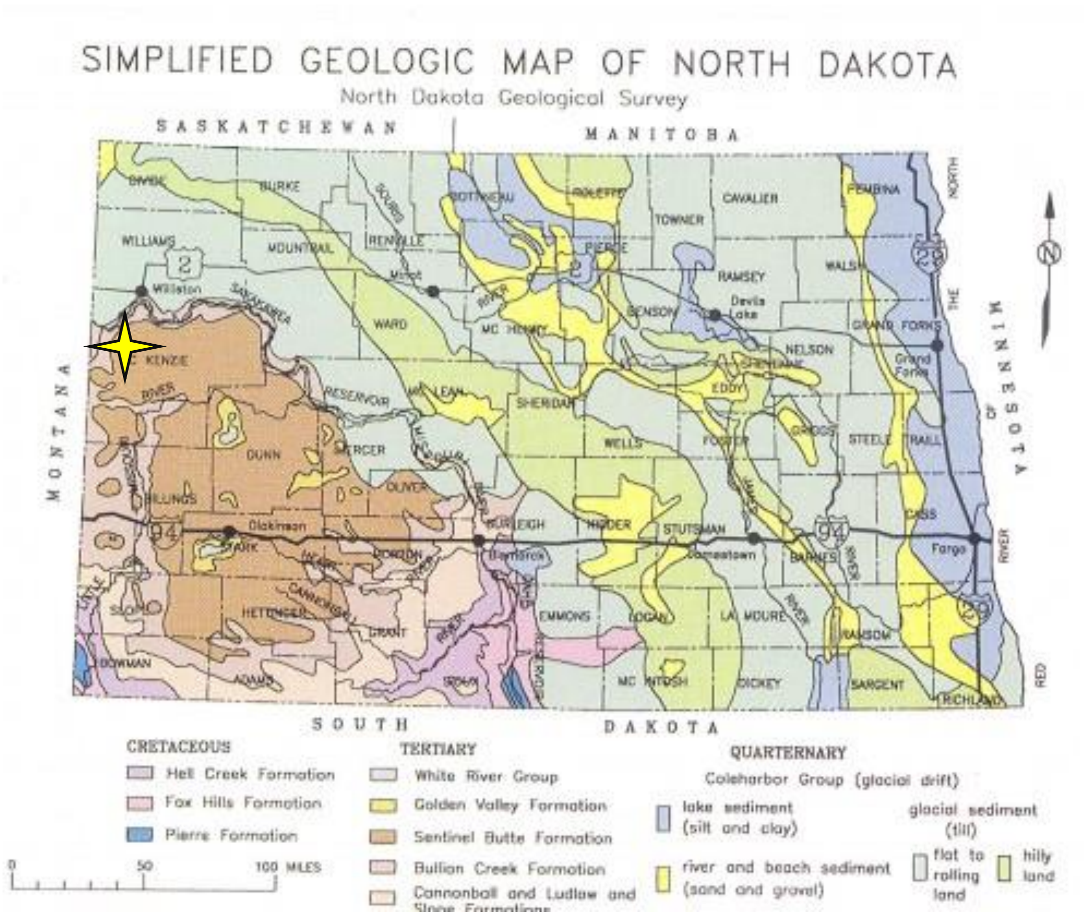


Figure 3. Geologic map of North Dakota. Area of field research denoted with yellow star. ndstudies.gov, Changing Landscapes Section 3, The Environment.

Previous studies suggest a vast majority of these formations make up the Fort Union Group (Figure 4), which is Paleocene in age (65 – 56 mya).

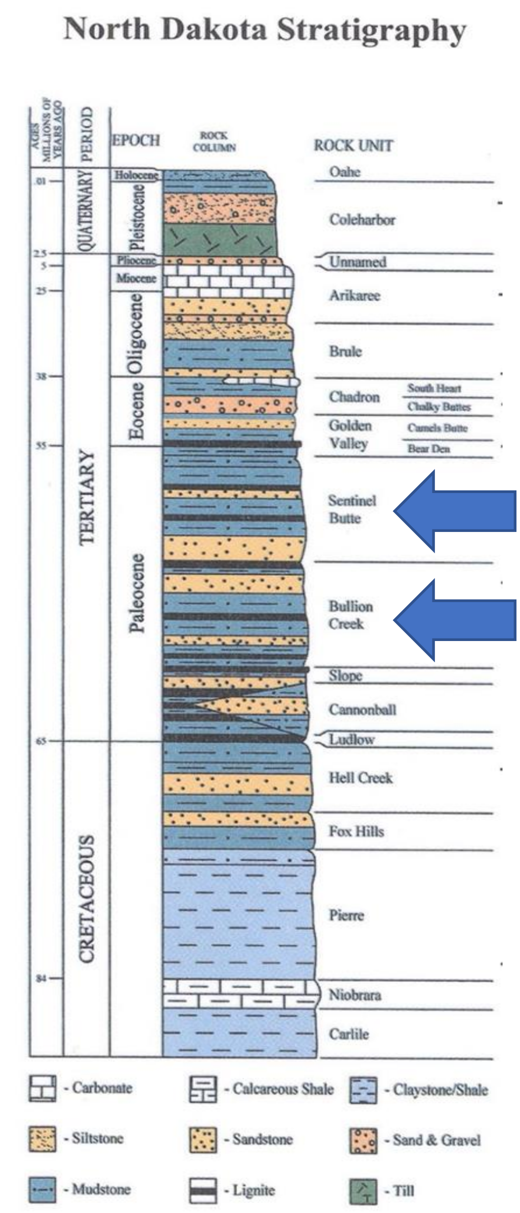


Figure 4. Stratigraphic column of the Fort Union Group. Arrows notate formations of interest. ndstudies.gov, Changing Landscapes Section 1, Formations: Easy As Cake!

The Fort Union Group consists of the Ludlow, Cannonball, Slope, Sentinel Butte, and Bullion Creek members. Its substratum is found in outcroppings and protrusions caused by tectonic upthrust and glacial erosion. This grouping, in North Dakota, has been the center of attention for some time, but not explored extensively at this locality. Research has been done since the late seventies in and around Theodore Roosevelt National Park.

> Over the years, many attempts have been made to correlate the complex sequence of continental deposits that make up the Fort Union Group over areas in which surface exposures are scarce and testhole data were lacking. (Carlson et al., 1977, p. 1)

For years the funding to study public land has been available but much of the private sector remains elusive to the scientific community. Deposits such as Ludlow, Slope and Cannonball represent lower members of the Fort Union Group, which have been the main focus of researchers for several decades, mainly due to accessibility (Carlson, 1985). However, in 1984, Wallick focused on two formations within McKenzie County. The purpose of that study was to “interpret the depositional environments, depositional history, and provenance of the strata in...McKenzie County, North Dakota” (xiv). It is through his research on sediment composition and stratigraphic deposition that supporting identification of the formations for my research is founded.

Several hypotheses suggest the patterning within the Fort Union Group and those formations therein vary considerably. Inconsistent outcropping across vast distances affects the classification and validity of naming strata within this grouping. An excellent example of the depositional layering argument is the identification and classification of the Bullion Creek Formation. It is suggested that this name is irrelevant and redundant due to a potential connection made between the Tongue River Formation in Wyoming and similar strata noted in North

Dakota (Carlson, 1985). For the purposes of this paper, the name Bullion Creek Formation will be used interchangeably with the Tongue River Formation. Therefore, determination of the strata present at the research site, will utilize information categorized as both Bullion Creek and Tongue River formations.

The Bullion Creek Formation was introduced in the late 70's and identified as the horizons found between the "White Marker Zone", and HT Butte Lignite bed of the Sentinel Butte Formation (Clayton, 1977, p. 9). Clayton further described the "White Marker Zone" as "The top of the Slope Formation [is] a widespread, white bleached zone, which is commonly associated with a siliceous bed" (p. 7) (Figure 5).

Figure 5. White Marker Zone. The "White Marker Zone" marking the top of the Slope Formation (SW corner sec 15, T136N, R83W. Carlson, p. 21)

Several coal and “clinker” layers are present, many of which separate the individual formations with extensively burned lignite (Carlson, 1985, p. 21), suggesting that multiple major climatic events likely occurred during this time. One of these beds, the HT Butte Lignite (Figure 6), separates the Sentinel Butte and Bullion Creek formations.

Figure 6. Bullion Creek & Sentinel Butte Contact Point. Photo identifying the Bullion Creek and Sentinel Butte contact point. (View looking northeast at Sentinel Butte-Tongue River contact on north side of Bennett Creek in SW sec 29, T147N, R100W. Carlson, p. 17).

However, in many locations this bed is absent, in which case, the HT Butte Clinker layer separates the Bullion Creek and Sentinel Butte formations. This layer is a horizon that consists of lignite materials that have been burned into a pink to deep red color. This layer, which can measure upwards of 25 feet, also serves as a marker for fossil identification and relative dating. This is extremely important when determining the age of specimens and then placing them chronologically (Hoganson & Campbell, 2002).

The climate during the Paleocene Epoch in North Dakota was considered sub-tropical and many of the recovered fossils are aquatic in nature. The strata of focus, the Billion Creek and Sentinel Butte formations, consist mainly of mudstone and sandstone with alternating deposits of silt and clay (Peppe, 2014, p. 227). This suggests that the dispositional environment during the Paleocene in this region represents a fluvial system, that includes overbank and point bar deposits (Clayton, 1977, p. 9). The environmental conditions were in constant flux due to the seasonal flooding and alternating dry periods. These movements created the settling of sediment and the defined differences in grain size. Finer particles such as silt and clay suggest flooding events where rivers overflowed their banks, while the larger grain sizes suggest high energy environments such as river channels (Wallick, 1984, p.104).

Additionally, dispositional strata and fossil evidence found within this grouping suggests a marine and brackish water intrusion which was previously perceived to only be present in counties south of Cartwright, ND. Belt et al. (2005) conclude that these marine and brackish water deposits were the result of a transgression of the Cannonball Sea.

A large variety of organisms were present during the Paleocene of North Dakota, many of which have been collected from both Sentinel Butte and Bullion Creek formations. This list includes vertebrates such as fish and reptiles including crocodiles, and *Champsosaurus*. This region also contained several invertebrates such as snails, insects, and clams (Belt et al., 2005, p. 4; Carlson, 1985, p. 17; Hoganson & Campbell, 2002). An abundance of freshwater snail and clam shell fossils have been identified in deposits within the Bullion Creek Formation (Carlson, 1985, p. 17), whereas, ironstone nodules and petrified wood are characteristic of the Sentinel Butte Formation (Carlson, 1985, p. 22).

Preserved plant matter is common throughout both formations, with the abundance of fossil leaves and leaf impressions typically recovered from finer-grained sediments. A variety of plant species have been documented in North Dakota that date back to the Paleocene. Trees such as the *Metasequoia occidentalis* or *Glyptostrobus europaeus* have been found in both the Sentinel Butte and Bullion Creek Formations (Peppe & Hickey, 2014, p. 184). Additionally, “Lush forests containing ferns, cycads, figs, bald cypress, Ginkgo, katsura, Magnolia, sycamore, giant dawn redwoods and other subtropical plants flourished [here]” (Hoganson & Campbell, 2002; Paleontology of Theodore Roosevelt National Park, n.d.).

METHODOLOGY

Processes and Procedures

The process of collecting a fossil specimen begins with prospecting. This activity is not for the faint of heart. Most terrains where fossils are found are rough and difficult to maneuver. The conditions are usually hot and dusty because most fieldwork is completed in summer months around our region due to snow pack and access to high elevations. The property under study is located in North Dakota which sees winter conditions six to eight months out of the year. This leaves a very narrow window of time for fieldwork during summer months when the heat of the sun is at its highest. To begin prospecting one must know how to identify fossil from surrounding stone and understand that even when finding them, not all will be collected. Many are unidentifiable and therefore useless for study. The most important element of prospecting is patience. It is a slow process of walking grids and once something is found extracting it from the surrounding rock at snail’s pace to preserve critical data.

After locating a specimen worthy of excavation, the digging process begins. The fossil is carefully uncovered using large tools such as rock hammers and shovels to remove the overlying rock. Once close to the specimen, brushes and awes become the tool of the trade to perform more detailed and delicate removal of debris. After being completely exposed, the specimen is protected with a layer of Vinac (composed of plastic that has been dissolved in acetone) to prevent degradation of the surface structures. The fossil may also (though not needed in our case) be jacketed with a burlap or cloth material and plaster to protect it while in transport. For our purposes, tinfoil and padding such as paper towel or toilet paper were sufficient.

Field Methodology

We arrived at the location in late afternoon on June 11th 2020, set up camp, and met with Don Croy. Don served as our guide to specific sites that were known to produce fossils. He also was our liaison with the other landowners to ensure that the history and territorial lines were clearly conveyed. Our first objective was to determine possible rock outcroppings that would serve as prospect sites. Don led our group through his own land, Alan Sandy's property, and three other properties that had possible rock outcrops available for study. After quickly surveying these areas, our team opted to focus on two pieces of property (Don Croy's and Doug Hettich's) with the best rock exposures that were easily accessible while on tight time constraints. Some field study was also performed on Doug Gullickson and his father's property but provided less fruitful results (Figure 7).

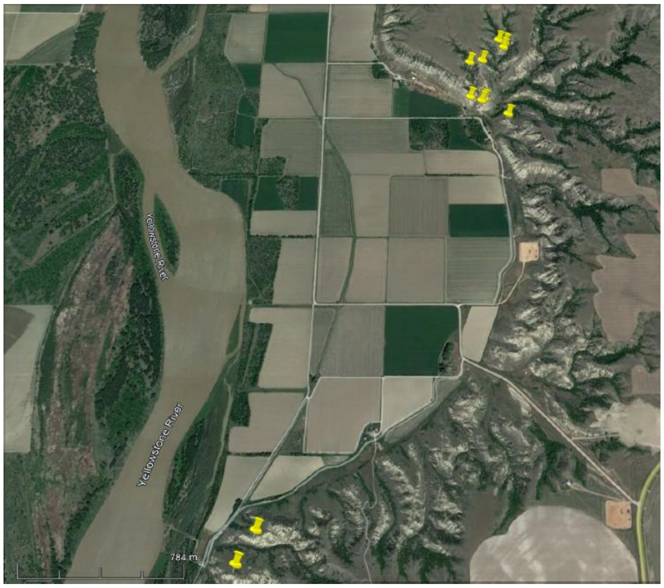


Figure 7. Specimen Collection Sites. Map with GPS pin locations of specimen collection sites.

Fieldwork commenced during June 2020 on private land near Cartwright, North Dakota. These parcels included family land owned by Alan Sandy and adjoining parcels owned by the

Gullickson family, Don Croy, and Doug Hettich. My team consisted of Dr. Dan Lawver and a colleague in the MSSE Program, Ben DiGiovanni (Figure 8). We also had a few young helpers Keegan and Grace Graham (my children), and their father Nick Graham. They helped by collecting small shells and other specimen for study on Day 1 of the trip and helped pack and organize fossils for transport.

Figure 8. Fieldwork Crew. Dr. Dan Lawver and Ben DiGiovanni, fieldwork on Don Croy's property, June 2020, Photo credit Veronica Graham.

On Day 2 of the trip, we spent most of our time at the first location, my children named, "Butte Hill". This area is where most of the specimens were collected. At this site a layer of mudstone preserved leaf impressions and several layers of gastropod shells. It was at a slightly higher elevation than our base camp and contained several outcroppings of rock along with few trees and shrubs, allowing for multiple members to dig simultaneously.

Day 3 was spent at a second location farther to the West of "Butte Hill". This locality was comprised mainly of sandstone. Here leaf impressions were also present but detail was much harder to identify due to sediment grain size and impression quality. This area also provided the team with gastropod shells of various sizes and representing several different taxa. At a third final location; samples of an evaporite mineral, coal, and a highly fragmentary bivalve shell (possibly oyster shell) were collected for later analysis.

Fieldwork for this project utilized GPS coordinate mapping, standard digging tools such as rock hammer, brushes and awes, and Cannon EOS Rebel T4i camera for most photography. All specimens were carefully packaged and marked with GPS coordinates (Figure 9) and general description of fossil, then loaded into a large chest for transport. Roughly 150 leaf impressions and casts, both partial and whole leaflet, were collected and studied. A total of 113 gastropod shells, fragmentary bivalve shells from three different locations, multiple specimens of petrified wood, and other potential trace fossils were collected for future study. These could prove beneficial for possible linkage to unique formation characteristics at a later date.

GPS Coordinates and Associated Land		
Land By Owner	**GPS Location**	**Notes**
"Goose Peak" –Croy Land	LAT 47.916477 LONG -103.932751	Only bivalve shell fragments & gastropods noted
"Goose Peak" –Croy Land	LAT 47.920873 LONG -103.932868	Soil Sample taken
Croy Land	LAT 47.917519 LONG -103.934628	Leaf impressions in mud or siltstone– mostly small/smooth and small to medium serrated leaves
Croy Land	LAT 47.921244 LONG -103.933259	Rolled tumbled rocks & smooth petrified wood
"Butte Hill" – Croy Land	LAT 47.917447 LONG -103.934823	Most Leaf Impressions in mudstone/siltstone includes: Davidia Antiqua, Metasequioa Officiallis, G
Heddick Land	LAT 47.893821 LONG -103.951427	Unknown plant specimen, gastropod shell fragments
Heddick Land	LAT 47.89519 LONG -103.950354	Red layer or clinker layer noted/coal layer sample taken
Gullickson Land	LAT 47.917723 LONG -103.935725	Some modern bone, unknown mineral deposits
Gullickson Land	LAT 47.921125 LONG -103.932746	Leaf impressions in sandstone – Mostly smooth medium size leaves with revolute leaf margin
Gullickson Land	LAT 47.917723 LONG -103.935725	Concretions
Gullickson Land	LAT 47.919801 LONG -103.934714	Gastropod shells

Figure 9. Collection Data by Site. Table of GPS Coordinates of specimen collection sites.

Lab Methodology

Once the specimens returned to the Bozeman area, they we carefully unpackaged and cataloged individually. In order to document intricate detail, all the fossils were carefully cleaned with a pick set and brushes. Celestron MicroCapture Pro program and digital microscope were utilized to capture fine detail. Some of the more delicate impressions were coated with Vinac. Measurements were taken both of the entire fossil and then individual leaf sets (in the case of the leaf impressions) and the fossilized gastropod shells.

After data was logged, each specimen was again packaged for transport. Once I have completed my research the specimens will be donated to the North Dakota Heritage Center and State Museum in Bismarck North Dakota, to either be placed on public display or utilized for further research.

Taxonomic identifications were made by comparing their morphological characteristics to those of fossil specimens also found in the state of North Dakota in previous studies. After identifying each specimen, to at least the class or family level, I reviewed the literature containing fossils found in the same formations, and compared my findings to those that have already been documented regionally. Any identifications to the species level, is based on physical characteristics. The characteristics assessed were based on general leaf structure (Appendix B). All measurements were collected using a metric ruler for smaller specimen and a metric tape measure for large fossils. All plant specific structures were determined using botany anatomical guides. (Ellis et al., 2009).

DATA ANALYSIS

Geological Samples

Sediment Type #1

Description: Rocks found during fieldwork can be separated into three subunits based on grain size, color, relative stratigraphic position. The stratigraphically lowest rocks are characterized by small grain size ranging from siltstone to mudstone and are highly cemented. Coloration varies from olive drab to light or dark gray with rust-colored blotches. Notable dark brown discoloration is visible when close to organic material. These rocks become lighter in color when weathered and are more resilient than surrounding rocks (Figure 10). This stone splits along bedding planes and frequently shatters into smaller (5mm thick) sharp fragments.

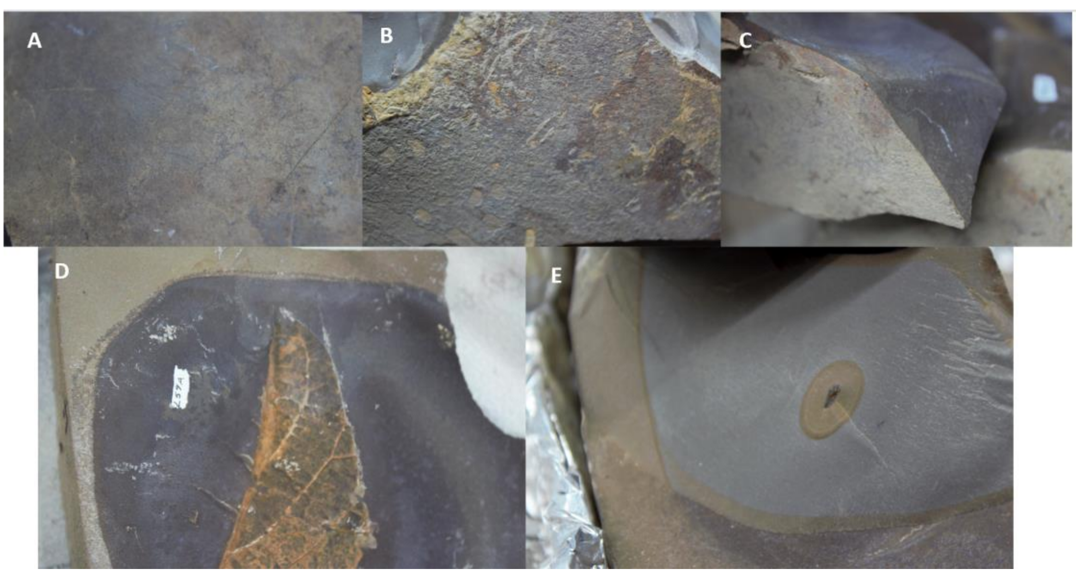


Figure 10 A-E. Rock specimens Sediment Type#1, A: Generalized coloration of sediment type #1. B: Rust color and mineral deposits on exposed surfaces. C: Color difference between exposed and not exposed surfaces, D: dark halo coloring found around organic material, E: Unique color differences noted.

Sediment Type #2 - Red Sediment Layer

A thick layer of red to pink colored sediment was identified within the research area. It is situated over top a layer of dark gray colored rock unit (described above) and overlain by light tan deposits. In several areas where this red layer was identified, it was relatively thick and heavily eroded (Figure 11). I would describe this rock composition as a clinker. It breaks into small pieces that look like melted clumps of rock. It appears to have sustained high heat that turned the color of the sediment into a vibrant pink color.

Figure 11. The Red Sediment Clinker Layer. This layer is present at several sites and absent at others of relative same elevation and stratigraphic layering. Grace Graham is junior fieldwork volunteer for scale.

Sediment Type #3

Description: The third rock subunit present is stratigraphically higher than the mudstone and clinker layers. This sandstone is light tan and varies little in color between specimens. Numerous iron concretions (Figure 12) are found within this rock unit. These concretions form when iron in the groundwater nucleates round organic particles in the sediment. This rock bubbles when acetic acid is applied to the surface which indicates that the cement consists of calcium carbonate. This sandstone sediment is highly cemented but erodes away easily when exposed to the elements. Due to the large grain sediment, much of the fine scale details of leaf impressions are not preserved. Larger pieces may still split at bedding planes, similar to sediment type #1, but most breakdown of this material occurs as the cementing material holding particles together is removed by environmental elements.

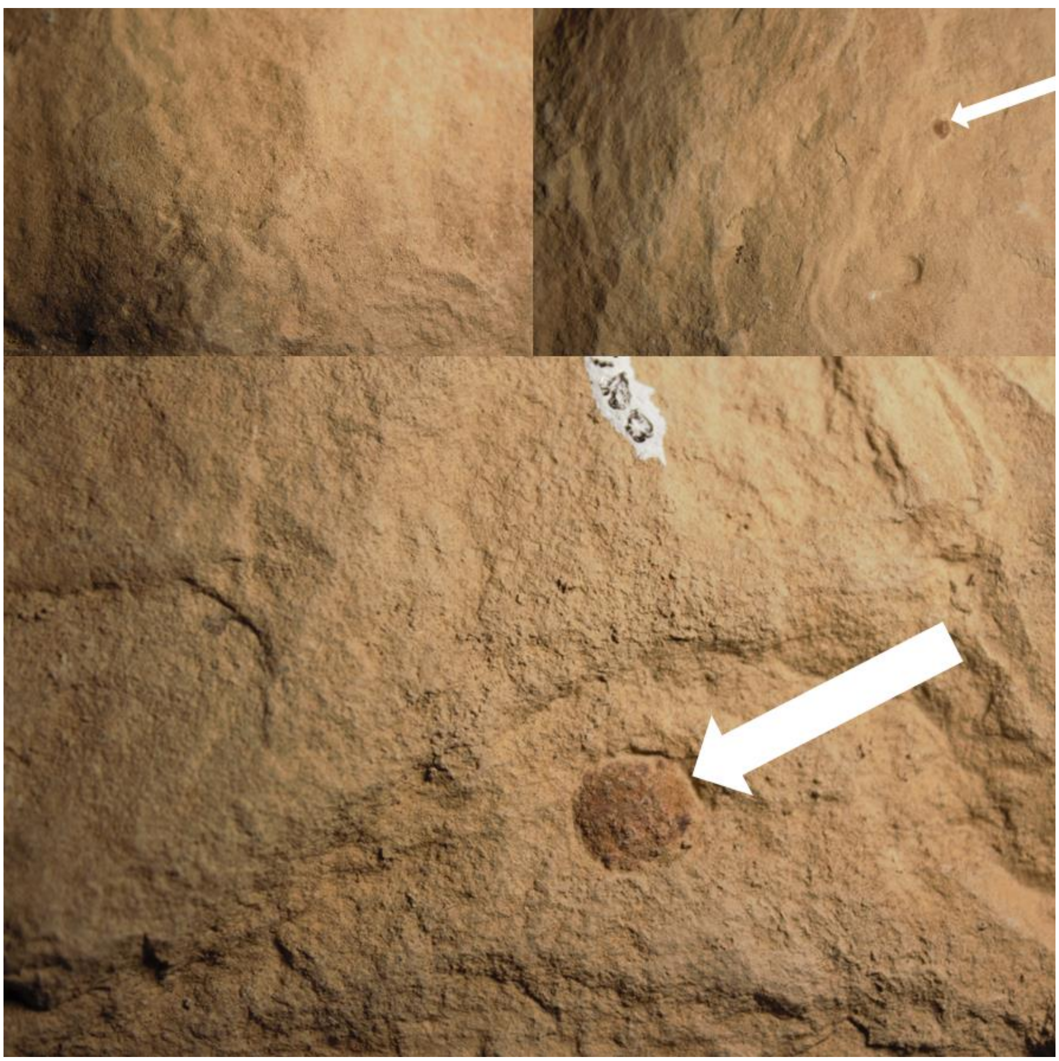


Figure 12. Sediment Type#3. White arrows indicate concretions.

Fossil Specimens

Specimen Grouping #1

Taxodiaceae Family

Description: Conifer type leaf structure with awl shaped lamina, taxodioid type needles with sessile attachment and acute apex. Alternating branch arrangement, lamina roughly 2-3mm long by 1mm wide.

Specimens J01A & J01B exhibit 50mm medial branch length, overall specimen width ratio from midline branch is 20/20mm, acute base and tip, scale type foliage (Figure 13A&B).

Specimens J02A & J02B have 40mm medial branch length, overall specimen width ratio from midline branch is 14/16mm, acute base and tip, scale type foliage (Figure 13C&D).

Specimen J03 displays medial branch length varies between 25mm – 31mm, multiple stems present, overall specimen width ratio from midline branch is not present due to no central branching, acute base and tip, scale type foliage, pile of leaf litter with no uniformity (Figure 13E).

Specimen J06 displays medial branch lengths that varies between 20mm – 49mm, multiple stems are present, secondary branching extends on of the stems present and measures 10mm in length, no branching on opposite side of midline. It exhibits an acute base and tip, scale type foliage, and preserved as a pile of leaf litter with no uniformity (Figure 14A).

Specimen J07 has all the same characteristics as specimens noted above and includes, a 38mm medial branch length, acute base and tip, and scale type foliage (Figure 14B).

Specimens J72A & J72B have roughly 18mm medial branch length and no branching present. They also share the characteristics noted above, however, the base angle is unidentifiable from these specimens (Figure 14A&B).

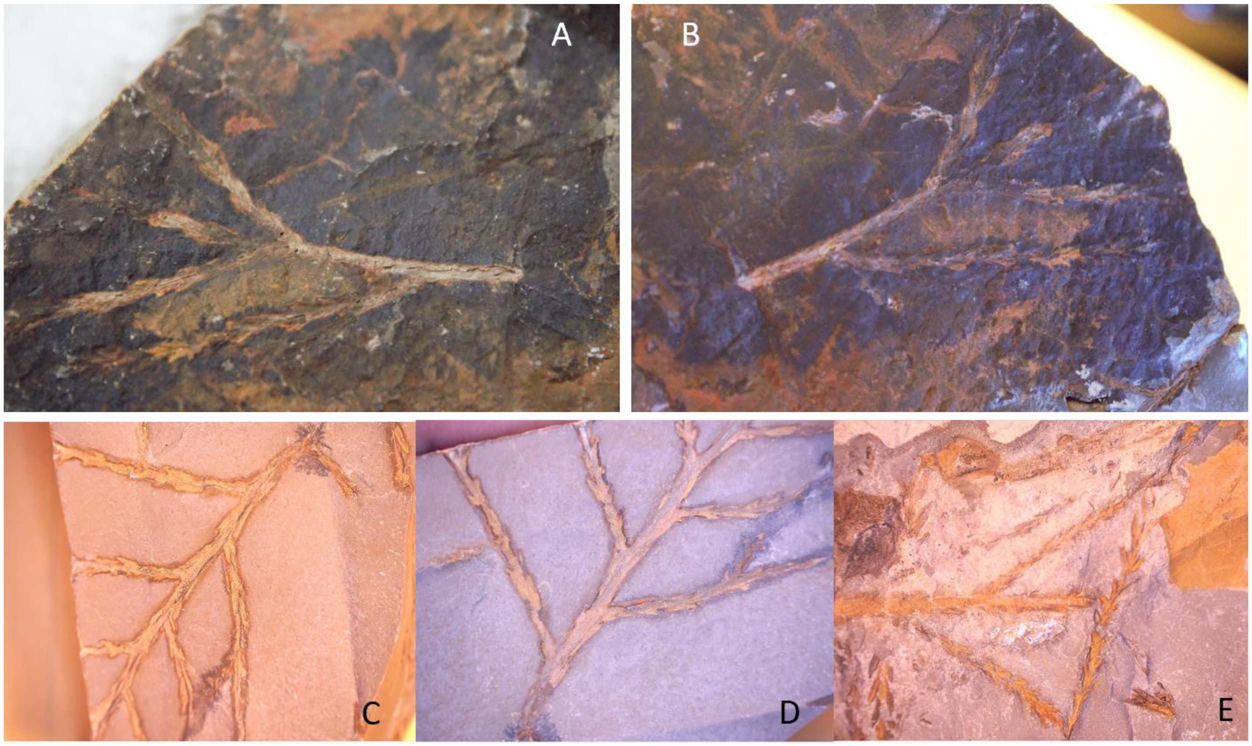


Figure 13 A-E. Taxodiaceae Specimens. A: Specimen J01A, B: Specimen J01B counterpart to J01A, C: Specimen J02A, D: Specimen J02B counterpart to J02A, E: Specimen J03.

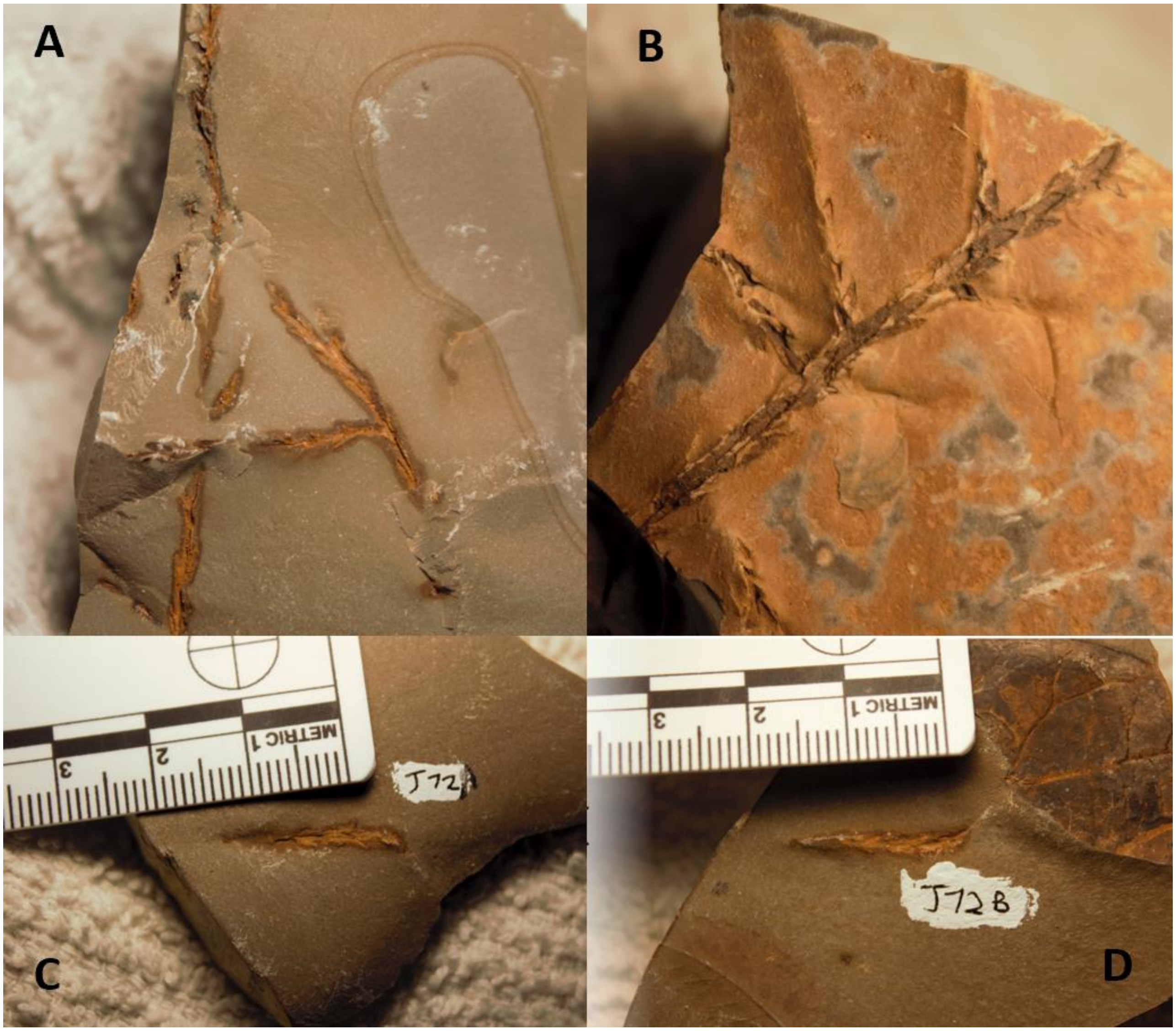


Figure 14 A&B. Taxodiaceae Specimens. A: Specimen J06, B: Specimen J07, C: Specimen J72A, D: Specimen J72B counterpart to J72A.

Metasequoia occidentalis

Description: Specimen L09 is 29mm long with a width ratio from centerline of approximately 3mm/4mm, relatively. Each leaf is roughly 3-4mm in length with only primary vein visible. There are 12 pairs of leaves arranged in alternating sequence. Each leaf has an entire or smooth margin, round base and tip, and an oblong lamina shape. The leaves are symmetrical along the x-axis. A few leaves exhibit a notable twist at the base attachment. (Figure 15).

Figure 15. *Metasequoia occidentalis*. Specimen L09. White arrow pointing to seed pod.

Specimen Grouping #2

Ulmaceae Family – Elm

Ulmites microphylla

Description: This set of specimens is grouped by its serrated edges and general size similarities. All are simple leaves with central primary vein, secondary veins present, and some tertiary veins visible. It is noted that in almost all of these specimens there is at least one y-spilt in the secondary veins prior to termination at margin.

Planera microphylla

Specimens L08A and L08B are part and counterpart semi-complete leaf impressions that are roughly 20mm long with a width ratio of 4/5mm. Leaf is symmetrical with double convex acuminate serrated margin and strong primary and secondary veins present. Tertiary veins are reticulate in nature. Midvein runs the entire lamina length and the leaf is craspedodromous meaning the secondary veins terminate at the leaf margin. The leaf appears ovate in shape with an acute apex angle but no definition to determine apex shape. Base angle is obtuse and appears rounded in shape but base is not completely exposed to confirm this (Figure 16B&C).

Specimen L42 is a partial impression with apex incomplete and cordate base. Overall lamina shape is oblong to ovate. Specimen L42 is 23mm long and roughly 14mm wide. This specimen displays 8 pairs of secondary veins, many of which form ‘Y’ shaped splits prior to termination at the margin. Margin is double straight to concave serrated (Figure 16A).

Specimen L25 is a complete leaf impression that are roughly 20mm long with a width ratio of 4/5mm. Leaf is symmetrical with double convex acuminate serrated margin and strong primary and secondary veins present. Tertiary veins are reticulate in nature. Midvein runs the entire lamina length and leaf is craspedodromous. Leaf appears ovate in shape with an acute angle but the apex shape is slightly distorted (Figure 16F).

Specimen L31 measures a total of 36mm long and symmetrical on the x-axis with width equally spread on each side of midvein for a total of 18mm. Specimen is incomplete due to the tip of the apex missing but all other characteristics are well preserved. Base is cordate, 8 pairs of secondary veins terminate at the margin, and tertiary veins are visible but only moderately defined. Overall shape of lamina is oblong to ovate and margin is straight to concave double serrated (Figure 16D).

Specimen L37 is a partial leaf impression that lacks base preservation. The apex is attenuate and the overall shape of the lamina appears to be ovate. It measures 40mm long and approximately 16mm wide (exposure limits this measurement). A few ‘Y’ splits in secondary veins are visible and specimen presents with craspedodromous venation. Margin is straight to convex single serrated at regular spacing (Figure 16E).

Specimen L47 shares the characteristics noted above with the other impressions grouped here. It possesses a cordate base, overall ovate shape, and double straight to convex serrated margin. It also exhibits some ‘Y’ splits among the 7 pairs of secondary craspedodromous veins. This specimen is 28mm long by 15mm wide (Figure 16G).

Specimens L57A and L57B are part and counterpart partial impressions. Exposure and preservation limits accuracy of measurements and overall shape, however venation and some margin serrations are exceptionally well preserved. Both specimens have visible petiole and minor curve in midvein. Secondary veins are craspedodromous and many form ‘Y’ splits prior to termination. Margin appears to be single convex serrated (Figure 16H&I).

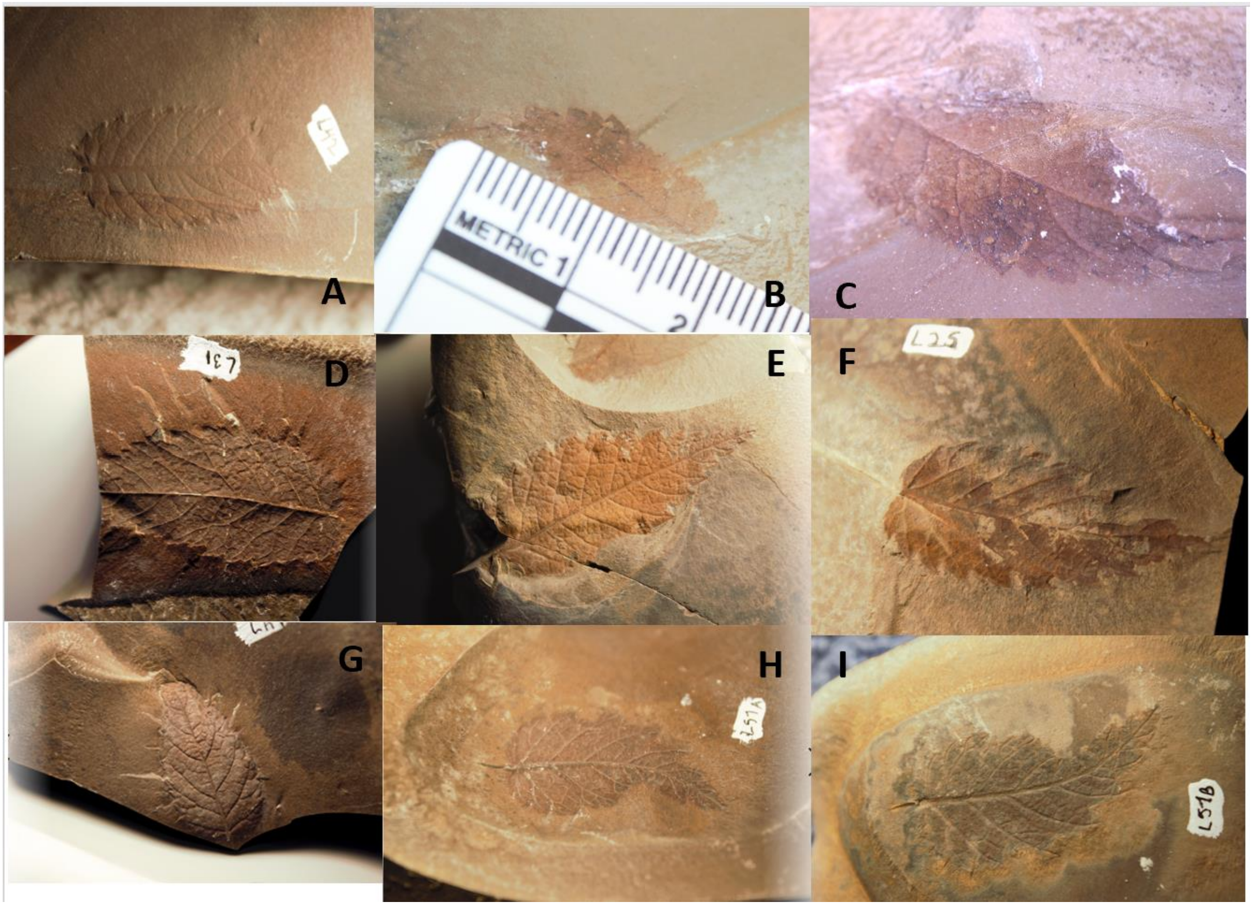


Figure 16 A-I. Ulmaceae Specimens. A: Specimen L42, B: Specimen L08A, C: Specimen L08B and is counterpart to L08A, D: Specimen L31, E: Specimen L37, F: Specimen L25, G: Specimen L47, H: Specimen L57A, I: Specimen L57B and is counterpart to L57A.

Zelkova planeroides

Specimens L26A and L26B are part and counterpart. L26A is 20mm long and has a total width of 4mm. There is a line of symmetry running along the x-axis giving both parts of lamina on either side of the midvein equal distance (2mm). Lamina shape is oblong with obtuse angle base and acute apex. Specimen L26B shares all of these characteristics except the base is more exposed, its shape is considered round. Both specimens have serrated margins with regular spacing. Tertiary veins arear to be reticulate and secondary veins terminate at margin (Figure 17D&E).

<u>*Ulmus rhamnifolia*</u>

Specimen L28B and L28A are part and counterpart. They share the same size and overall characteristics. This is a complete leaf impression showing detail on both upper and lower planes. These specimens are roughly 44mm long and have a width ratio of 9/9mm. Midvein is well defined and approximately 13 to 14 pairs of secondary veins are aligned in an alternating pattern. Secondary veins terminate at the margin. Margin has a straight to concaved serrated edge. Tertiary veins are mildly present but not preserved enough for notation. Base is not fully exposed but appears to have an angle of greater than 90°. Apex angle is acute and shape is attenuate. Entire leaf curves to the leaf when moving from base to apex (Figure 17A&B).

Specimen L29 is the largest leaf noted in this grouping. From base to apex it is 70mm long and 28mm wide. There is a clear line of symmetry running along the midvein. Thirteen pairs of secondary veins are present. Reticulate tertiary vein pattern is noted along with secondaries that terminate at the margin. Apex is acute and base is cordate with an obvious obtuse angle. Margin has either concave or acuminate serration and overall shape of the lamina appears to be oblong (Figure 17C).

Specimens L40A & L40B are part and counterpart. Exposure on both is equal and measurements for this pair are the same. They are 52mm long by roughly 14mm wide. The both exhibit extensive detail to include preservation of tertiary veining. Overall shape of the lamina appears to be ovate, apex shape is attenuate, and base shape is cordate. There are eight distinctive pairs of secondary veins that terminate at the margin. Margin is a single convex shaped serration at regular spacing (Figure 17G&H).

<u>*Unknown genus*</u>

Specimen L07 is a partial leaf impression roughly 21mm long with a width ratio of 15/18mm, difference being due to the partial leaf exposure. Leaf is symmetrical with double convex acuminate serrated margin and strong primary and secondary veins present. Tertiary veins are reticulate in nature. Midvein runs the entire lamina length and leaf is craspedodromous. From what is present, leaf appears ovate in shape but no apex or base is present for conformation (Figure 17F).

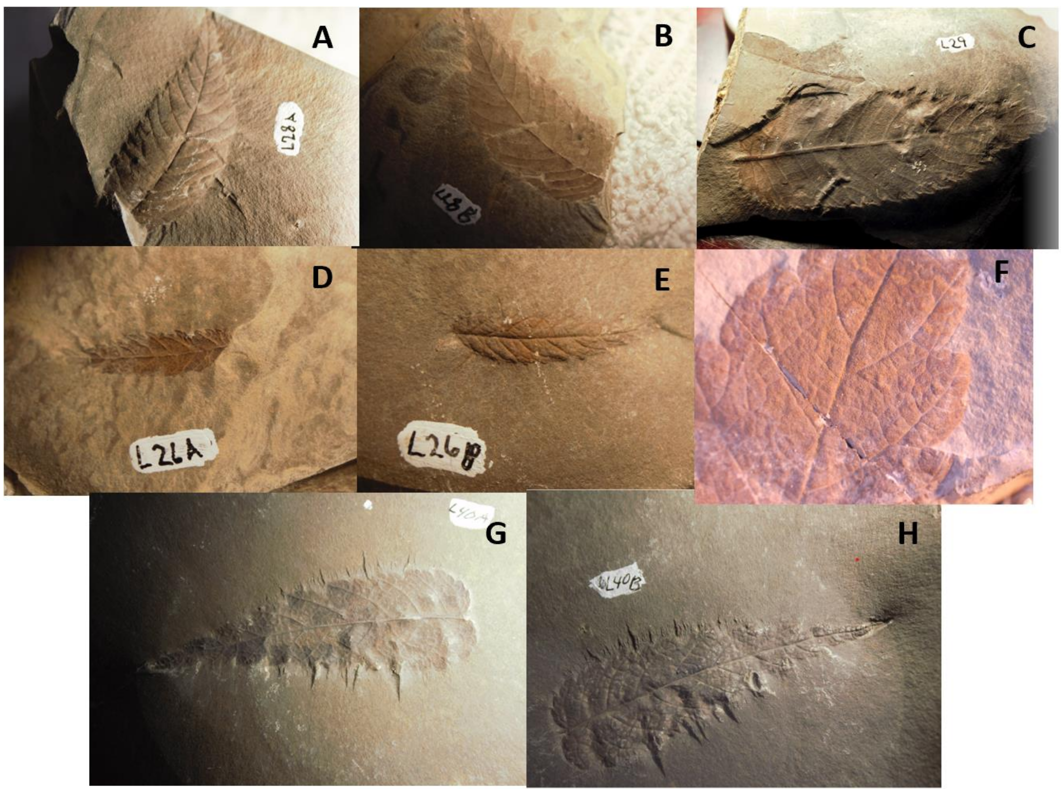


Figure 17 A-H. Ulmaceae Specimens. A: Specimen L28A, B: Specimen L28B and counterpart to L28A, C: Specimen L29, D: Specimen L26A, E: Specimen L26B and counterpart to L26A, F: Specimen L07, G: Specimen L40A, H: Specimen L40B and counterpart to L40A.

<u>Monocot Grouping</u>

<u>Haemanthophyllum/Alismaphyllites grandifolius</u>

Description: This group is a collection on partial leaf impressions. One entire rock sample was taken and split along many sediment planes, each containing partials of what appears to be the same monocot plant species (Figure 18F). Ten total partials were collected with notation that many more existed underneath each but for fear of destroying the intact specimen overlay these specimens were left untouched. Each partial specimen ranged between 62mm and 54mm in length, but none preserve a complete lamina length. It can be assumed that the total length of one of these leaves would be much greater. Specimen width ranges from 31mm to 25mm and it appears that this too is not an accurate range due to the incomplete nature of all specimens. All of these specimens display multiple primary veins that run parallel to one another and secondary veins that run perpendicular to the primary (Figure 18E). No tertiary veins are preserved. The margin is entire or smooth and has multiple primary veins that are closer together than those found near the middle (Figure 18D). Small perpendicular secondary veins are noted here as well but they are much shorter and occur at wider intervals than the rest (Figure 18A-C).

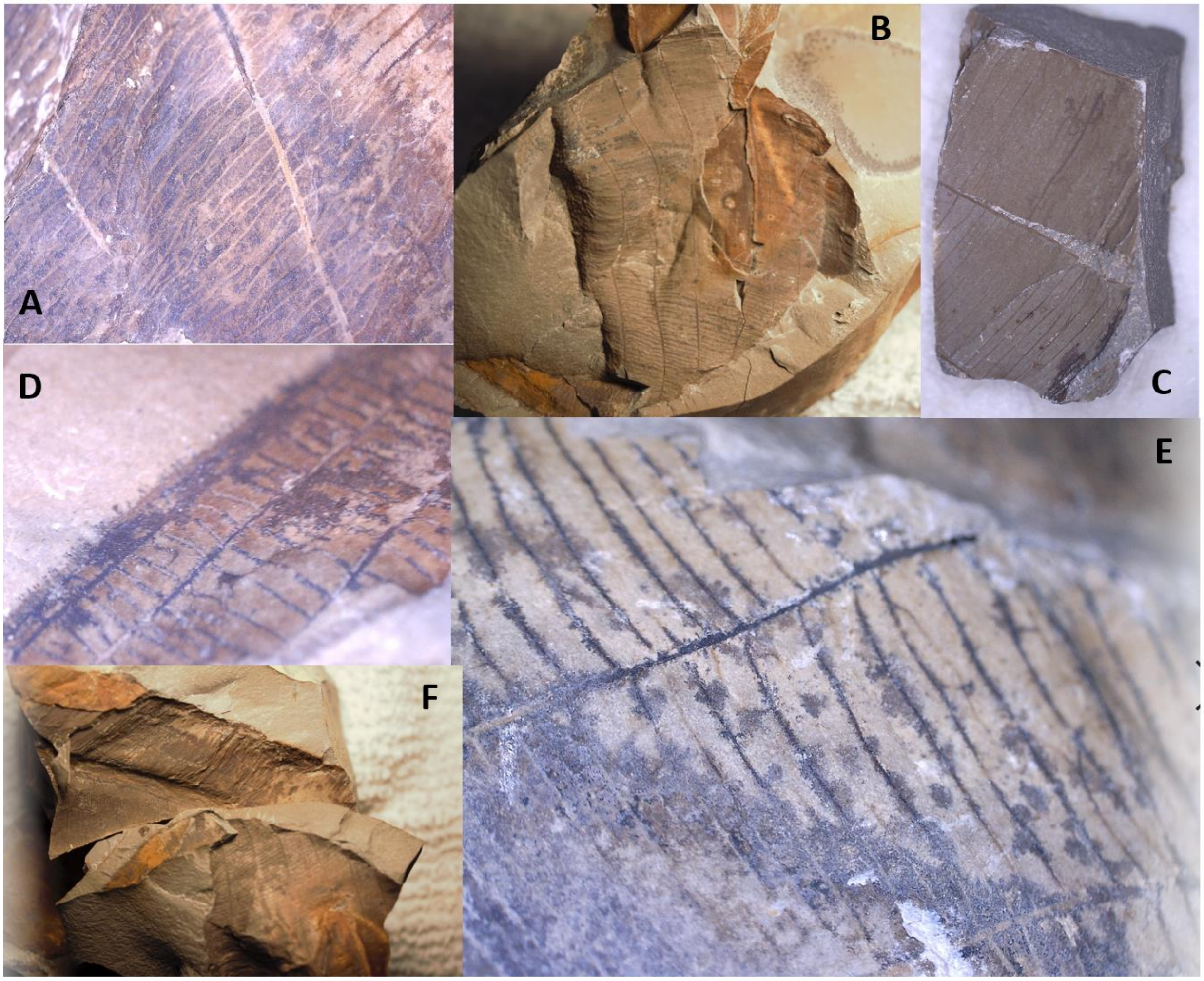


Figure 18 A-F. *Alismaphyllites grandifolius*. A: Specimen M01 Veining, B: Specimen M02, C: Specimen M03, D: Specimen M01 Margin, E: Specimen M01 Magnified Vein Pattern, F: Specimens M04 &M06A.

Specimen Grouping #3

Betulaceae Family - Birch

Corylus insignis

Specimen L06 and L061 both display the same characteristics. They are both larger sized leaves, 81mm long by approximately 60mm wide and 93mm long by approximately 73mm wide respectively. L061 has a relatively long petiole of approximately 17mm long. Both specimens have 6 pair of secondary veins that develop directly off the primary vein. They also have 4 veins that run perpendicular to the secondaries at the base of each leaf on both sides of the primary vein. These veins form 90° angles with the secondary vein they branch from. Margin appears to be semi-serrated and each has well defined tertiary veins (Figure 19A-C).

Specimen 0011 shares many of the same characteristics as specimens L06 and L061. It has well preserved primary and 6 pairs of secondary veins. Specimen 0011 is 90mm long by 55mm wide and symmetrical. As in specimens L06 and L061 this specimen exhibits unique venation from the basal secondary veins. Specimen 0011 has a well-preserved insertion point and basal extension, where petiole meets veins. (Figure 19D&E).

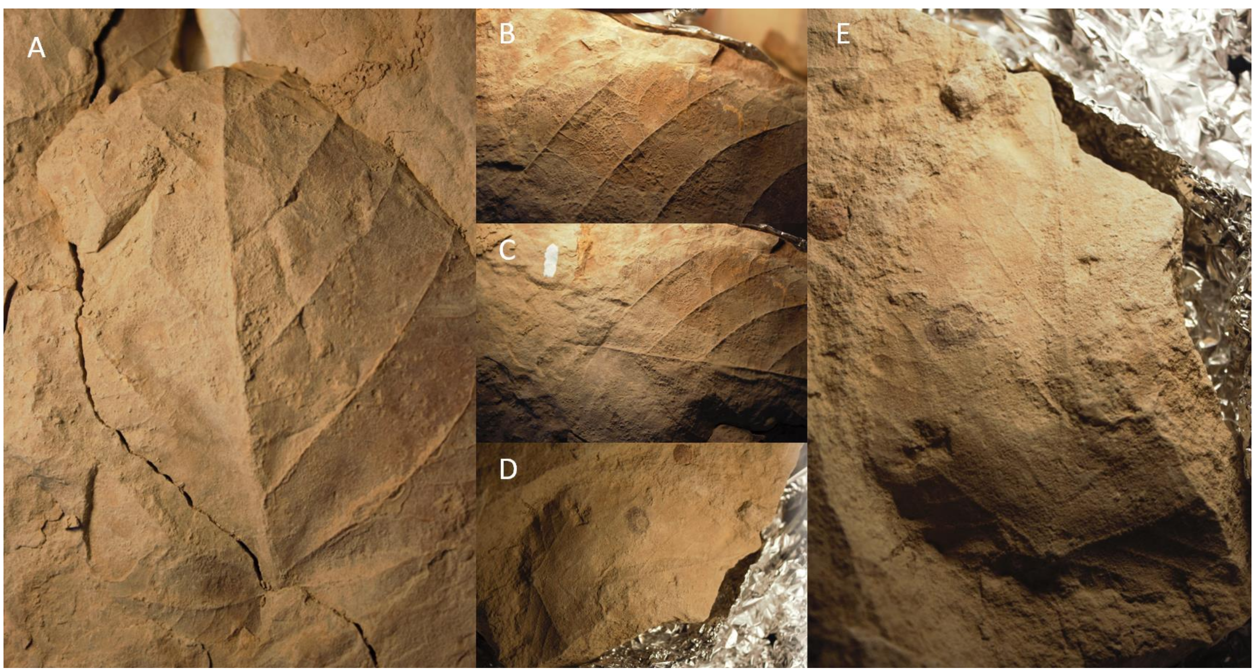


Figure 19 A-E. Betulaceae Specimens. A: Specimen L06, B: Specimen L06 Veining and margin, C: Specimen L061, D&E: Specimen 0011.

Specimen Grouping #4

Sabiaceae Family

Meliosma vandaelium

Specimen 0012 is a medium sized leaf impression that is ovate in shape with an acute apex. Margin appears to be entire or smooth and the only visible veins aside from the primary are 3 pairs of secondaries (Figure 20A). Specimen 0014 shares all of the same characteristics of specimen 0012 but more of the leaf is exposed and with it more secondaries are also visible (Figure 20D).

Specimen L32 is a partial leaf impression but extremely well preserved. Leaf appears to be leathery and sediments in direct association with the leaf specimen are stained a darker brown color. Leaf appears to be oblong in shape and contains 6 pairs of secondary veins. The edge of this leaf exhibits a pronounced revolute curl. Judging by the angle of the secondary veins the apex is the end more exposed and it appears to taper in moving out from center. This would suggest that the apex has an acute angle (Figure 20B).

Specimen 006 shares many of the same characteristics as specimen L32 does, one difference being a lack of curvature of the edge toward the underside of the leaf. This specimen is 63mm long and approx. 23mm wide. It displays roughly 7 pairs of secondary veins and has the same taper that specimen L32 does. The base is more exposed on this specimen but not enough to confidently identify the shape. This specimen also has the same leathery look as specimen L32 (Figure 20C).

Figure 20 A-D. Sabiaceae Specimens. A: Specimen 0012, B: Specimen L32, C: Specimen 006, D: Specimen 0014.

Specimen Grouping #5

Magnoliopsida Class

Specimen L11A is the largest specimen found during fieldwork. It spans 178mm long and has a width ratio of 105mm/125mm respectively. The lamina on this specimen is dentate to crenate with rounded tooth apex and slight irregular spacing. The primary vein spans the length of the lamina and branches into cacraspedodromous secondary veins. Tertiary veins are visible and appear to be percurrent in nature. The base and apex are both obtuse in angle and rounded in shape. The base of the midvein displays a tighter grouping of secondary veins than the rest of the lamina and the distance between these veins seems to expand when moving toward the apex. A notable 'Y' shaped split at the terminal end of those secondaries is present in multiple locations across the lamina (Figure 21).

Figure 21. Magnoliopsida Specimens. Specimen L11A, whole specimen showing dimensions, magnification for tertiary vein, margin detail, and primary vein cluster.

DISCUSSION

Based on the rock units described above both the Bullion Creek and Sentinel Butte formations are present in the research locality. Previous studies suggest that a distinction in color variation is a basic visual separation between these two formations. The Bullion Creek formation has been described as olive drab in color and consists of mudstone (Peppe, 2014, p. 227). Sediment group #1 displays these characteristics. It was also identified as the lower of the two rock units I explored, which is consistent with the sequence stratigraphy described in the literature (Clayton et al., 1977). Sediment group #3 is courser grained sandstone that is light in color similar to that of the Sentinel Butte formation described by previous researchers (Peppe, 2014, p. 227). It is also much higher on the stratigraphic column, matching that of previous research. There is a distinct layer of red to pink colored rock noted at the research locality that separates sediment group #1 and sediment group #3, which corresponds the HT Butte Clinker Layer.

Specimen grouping #1 has the characteristic scale like leaf structure of the Taxodiaceae plant family. This family has three major genera that are documented from the Paleocene of North America; Metasequoia, Sequoia, and Taxodium, all of which have very similar characteristics (Arnold, 1955). Specimen L09 is the only fossil that can be identified to the species level based on physical features. It has a fossil seed preserved with the leaf impression that resembles *Metasequoia occidentalis*. This leaf impression has opposite leaf arrangement, which is characteristic for this particular species. Therefore, I identify these specimens as *M. occidentalis*. The other specimens in this grouping have characteristics of more than one genus within this family and due to preservation limits of key features the appropriate classification cannot be made farther than the family level.

The specimens categorized as Specimen Grouping #3 area all members of the Ulmaceae or Elm family. All specimens in this family share some variation of margin serration, round to cordate base shape, craspedodromous secondary veins, and percurrent tertiary veins. A notable characteristic of this group is a 'Y' shaped fork in secondary veins prior to termination at the margin. This grouping has also been broken down into several genus/species identifications. The classification of this family has changed multiple times over the decades. Initially specimens collected from this family were cataloged into three main genera; *Planera microphylla, Zelkova planeroides,* and *Ulmus rhamnifolia* (Brown, 1962, p. 59-60). A cordate shaped base and the 'Y' shaped forks in secondary veining characterize *Planera microphylla,* however, in 1977 Leo Hickey renamed this taxon as a new combination *Chaetoptelea microphylla.* On the other hand, *Zelkova planeroides* displays a rounded base shape rather than cordate and *Ulmus rhamnifolia* was separated by its large size. Specimens of each of these genera have been identified at my research locality; however, Manchester suggests that all three of these genera represent a single taxon and synonymized them into *Ulmites microphylla* (2014, p. 173-174), due to the minute differences between genera.

The group containing the M-series specimens from our locality exhibits characteristics consistent with monocot members of the family Alismaceae. This plant family is more commonly known for being aquatic flowering plants. These leaves have entire margins and parallel veins that are intersected at perpendicular angles by secondary veins. The specimens collected in the research area are fragmented but display these attributes. Based on literature review and notation of key characteristics, I identify these specimens as *Alismaphyllites grandifolius* or, by updated name, (Manchester, 2014, p. 159) as *Haemanthophyllum*.

Specimen Grouping #3 consists of leaf impressions from the Betulaceae or Birch family. The leaves in this family and the specimens from this research locality share attributes such as smooth to very mildly toothed margin and a pronounced set of tertiary veins extending from the leaf's basal secondary veins. This unique venation is a notable attribute of *Corylus insignis* and thus I assign these specimens to this taxon.

Specimen Grouping #4 shares characteristics that are common with members of the Sabiaceae family. The leaves from this plant family are oblong to elliptic in shape and possess thin secondary venation (Peppe & Hickey, 2014, p. 174) and can be identified as *Meliosma vandaelium.* This species has a characteristic roll to the marginal edge that is also a noted characteristic found in Specimen Grouping #4 (Specimen L32, Figure 20B). This taxon is often mistaken for *Quercus sullyi,* however it lacks brochidodromous secondary venation which is present in *Quercus sullyi* (Peppe & Hickey, 2014, p. 174).

Specimen Grouping #5 has at this point been identified to the Magnoliopsida class level due to the specimen's partial preservation. The genus cannot be distinguished between *Davidia antiquia* and multiple members of the genus *Viburnum* for this specimen due to the petiole not being preserved. This feature is used to identify *Davidia antiquia* which exhibits a lengthy petiole, whereas Viburnum is characterized by a short, stocky petiole (Manchester, p. 376, 2002). Characteristics such as large blunt teeth, cordate base, basal secondary veins, and straight percurrent tertiary veins and craspedodromous venation are also identified in *Davidia antiquia*.

A combination of geologic and palaeobotanical evidence suggests that both Bullion Creek and Sentinel Butte formations are present at the study location. Literature review suggests that all of these fossil plant taxa described here have long temporal ranges that span from the Late Cretaceous to the Paleocene. Therefore, these fossil plant specimens alone are insufficient to determine the geologic formations present at the study because they are likely present in both Bullion Creek and Sentinel Butte formations. Despite this, we did not discover overlapping taxa during our fieldwork. This is likely due to the limited amount of time available to us and future fieldwork may uncover additional specimens to support this hypothesis.

Limitations and Future Direction of the Research

A limitation of the current study is the lack of microscopic analysis of the leaf impressions. This analysis is used to study the margin and tertiary venation up close, which is important for taxonomic identification. Additionally, due to the pandemic I was unable to visit museum collections to look at comparative specimens. This would have allowed me a better opportunity to assess characteristics of my specimens and links more common features to those taxa already identified. A third limitation is that I was unable to describe the invertebrate specimens, which would have likely contributed to my conclusions. In the future, would like to return to the fieldwork sites to gather more data, develop a detailed stratigraphic column, and hopefully discover other fossils such as mammals, reptiles, or fish.

Conclusions

Based on the geology of the research locality and the fossils recovered, both the Bullion Creek and Sentinel Butte formations are present. The Bullion Creek is characterized by fine-grained gray to olive-colored mudstones, whereas the Sentinel Butte is dominated by courser grained, tan sandstones. Additionally, the red clinker layer that is consistent with the HT Butte Clinker separates these units. Fossil leaf specimens can be identified to the class Magnoliopsida and other family levels, such as Taxodiaceae, Ulmaceae, Alismaceae, Betulaceae, and Sabiaceae. Additionally, some leaf specimens can be identified to the genus and species levels, including *Metasequoia occidentalis, Ulmites microphylla, Alismaphyllites grandifolius, Meliosma vandaelium,* and *Corylus insignis*.

Impact on the Educator

This project has impacted me in several ways but I believe the most profound impact was its ability to change my perspective on my career and long-term job goals. Before I began this program, I aspired to be a librarian and somehow teach science. My passions included plants and investigation of the environmental world around me, but I hadn't contemplated a career in paleontology or even thought about fossils, let alone fossilized plant material and a path that might lead that direction. Through this program and this project, I developed a love of fieldwork and a true passion to show others the past through fossil identification. From this capstone, I have found that the history of plants dates back millions of years. On a career level many doors have opened and my network of science professionals and educators has grown immensely. My name has been considered for jobs that without this experience or degree I would not have qualified for. I have developed relationships with people from all across the world and have gathered a wealth of knowledge from each and every encounter.

This project has also developed my independence as a non-traditional educator. I have taught science outside of a classroom through many different avenues but, his whole experience has helped me recognize that it is my true passion to teach in this manner. I enjoy educating youth and sharing my findings with the public. It has given me the confidence I need to pursue a life in the paleontology world. This experience has shown me that I would much rather take a group of students to an outcropping of rock in search of specimens than sit in a classroom and teach from a textbook.

REFERENCES CITED

Arnold, C. (1955). *Tertiary conifers from the Princeton Coal Field of British Columbia*, XII, 12, 245-258. Contributions from the Museum of Paleontology University of Michigan. 08/17/2006,09:10:35,"University of Michigan University Library",|PT07_002_ID137_00000020.TIF| (umich.edu)

Belt, E., Tibert, N., Curran, A., Diemer, J., Hartman, J., Kroeger, T., & Harwood, D., (2005). Evidence for marine influence on a low-gradient coastal plain: Ichnology and invertebrate paleontology of the lower Tongue River Member (Fort Union Formation, middle Paleocene), western Williston Basin, U.S.A., Rocky Mountain Geology, 40, 1, 1-24. University of Nebraska-Lincoln. Evidence for marine influence on a low-gradient coastal plain: Ichnology and invertebrate paleontology of the lower Tongue River Member (Fort Union Formation, middle Paleocene), western Williston Basin, U.S.A. (unl.edu)

Brown, B. (1962). *Paleocene flora of the rocky mountains and great plains.* United States Government Printing Office.

Carlson, C. (1985). Geology of McKenzie County North Dakota. *County Groundwater Studies 37-part 1 North Dakota Geological Survey*, Bulletin 80, 1-48. Fine Print Inc. McKenzie_Part_I.pdf (nd.gov)

Clayton, L., Carlson, C.G., Moore, W. L., Groenewold, G., Holland, F. D., & Moran, S. (1977). The slope (Paleocene) and Bullion Creek (Paleocene) formations of North Dakota. *North Dakota Geological Survey,* (59), 1-14. Kaye's Inc. RI-59.pdf (nd.gov)

Ellis, B., Daly, D., Hickey, L., Johnson, K., Mitchell, J., Wilf, P., & Wing, S. (2009). *Manual of leaf architecture*. Cornell University. (PDF) Manual of Leaf Architecture (researchgate.net)

Hickey, L. (1977). *Stratigraphy and paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota*. The Geological Society of America, Inc.

Hoganson, J.W. & Campbell, J. (n.d). Paleontology of Theodore Roosevelt National Park. *North Dakota Geological Survey*. North Dakota Geologic Survey (nd.gov)

LaPage, B. (2011). *A classification system to separate leaves of the Cephalotaxaceae, Taxaceae, and Taxodiaceae,* 19, 1-2, 109-116. Japanese Association of Historical Botany. (PDF) A classification system to separate leaves of the Cephalotaxaceae, Taxaceae, and Taxodiaceae (researchgate.net)

Manchester, S. (2002). Leaves and Fruits of Davidia (Cornales) from the paleocene of North America. *Systematic Botany*, 27, 2, 368-382. The American Society of Plant Taxonomists. https://doi.org/10.1043/0363-6445-27.2.368

Manchester, S. (2014). Revisions to Roland Brown's North American Paleocene Flora. *Acta Musei Nationalis Pragae*, 70, 3-4, 153-210. Praha. http://dx.doi.org/10.14446/AMNP.2014.153

Meidani, M. (n.d.) *Fracture toughness of leaves: overview and observations.* Theses and Dissertations at University of Massachusetts Amherst. (PDF) Fracture toughness of leaves: Overview and observations (researchgate.net)

North Dakota Geological Survey. (n.d.). *Mineral resources of North Dakota*. North Dakota Geologic Survey (nd.gov)

North Dakota Department of Agriculture. (2022). *North Dakota agriculture 2022.* Journal Communications Inc. North Dakota Agriculture - Farm Flavor

Peppe, Daniel J. & Hickey, L. (2014). Fort Union Formation fossil leaves, Paleocene, Williston Basin, North Dakota, USA, Indicate Evolutionary relationships between paleocene and eocene plant species. *Bulletin of the Peabody Museum of Natural History*, 55, 2, 171-189. Peabody Museum of Natural History, Yale University. https://doi.org/10.3374/014.055.0209

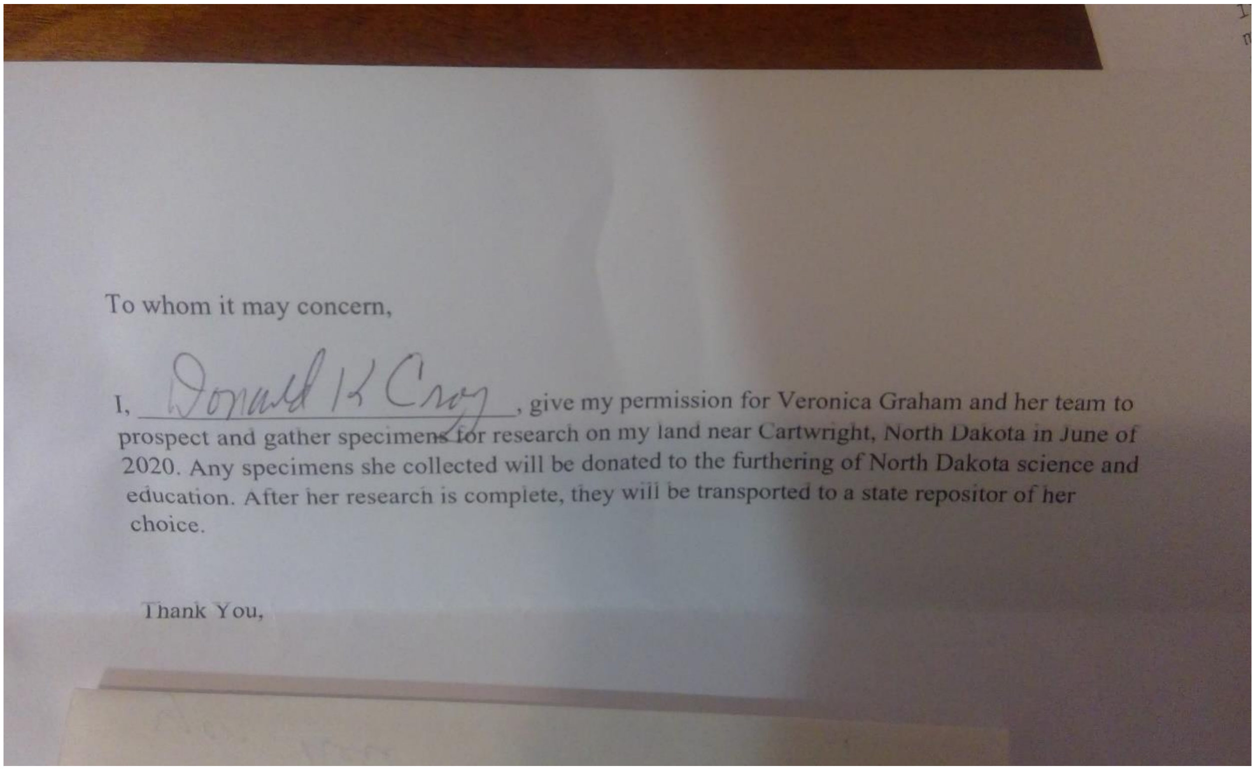
Wallick, Brian P. (1984). *Sedimentology of the Bullion Creek and Sentinel Butte formations (Paleocene) in a part of southern McKenzie County, North Dakota.* [Master's thesis, University of North Dakota]. Theses and Dissertations at University of North Dakota (UND). https://commons.und.edu/theses/311

U.S Energy Information Administration. (2021). *North Dakota Energy Profile*. North Dakota Profile (eia.gov)

APPENDICES

APPENDIX A

APPROVAL LETTER – DON CROY



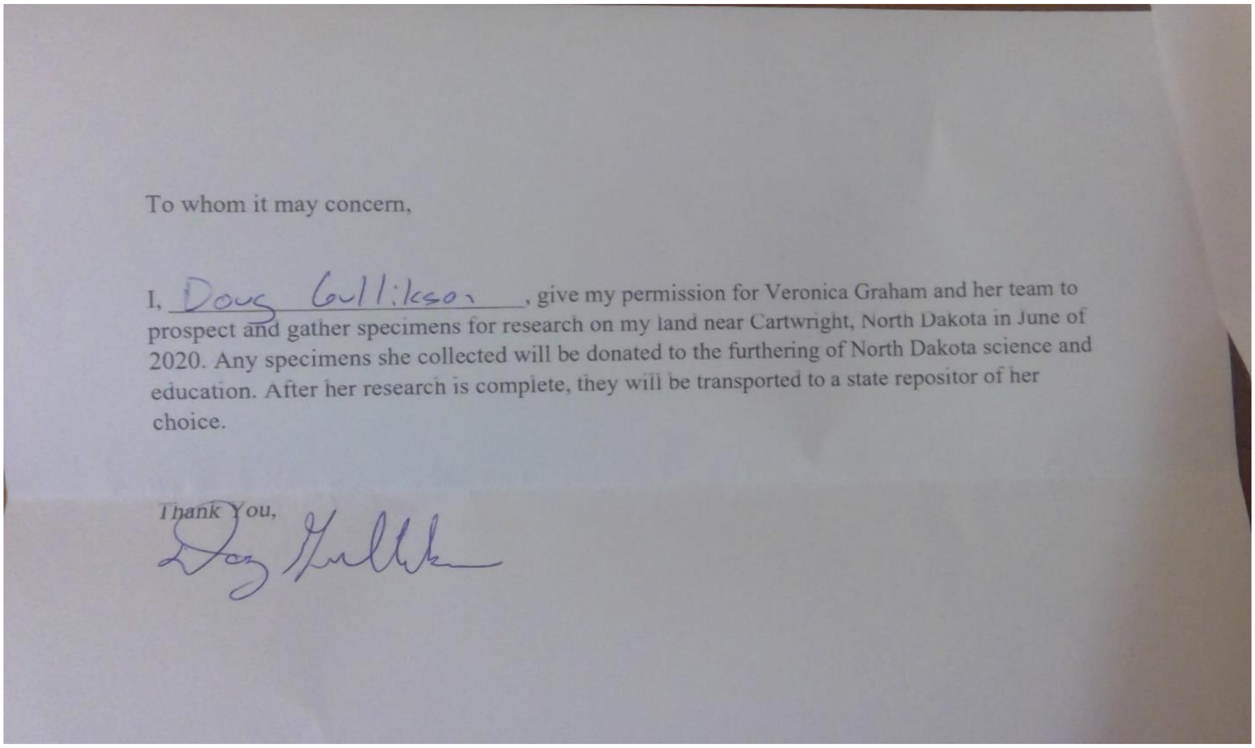
To whom it may concern,

I, Donald K Croy, give my permission for Veronica Graham and her team to prospect and gather specimens for research on my land near Cartwright, North Dakota in June of 2020. Any specimens she collected will be donated to the furthering of North Dakota science and education. After her research is complete, they will be transported to a state repositor of her choice.

Thank You,

APPENDIX B

APPROVAL LETTER – DOUG GULLIKSON



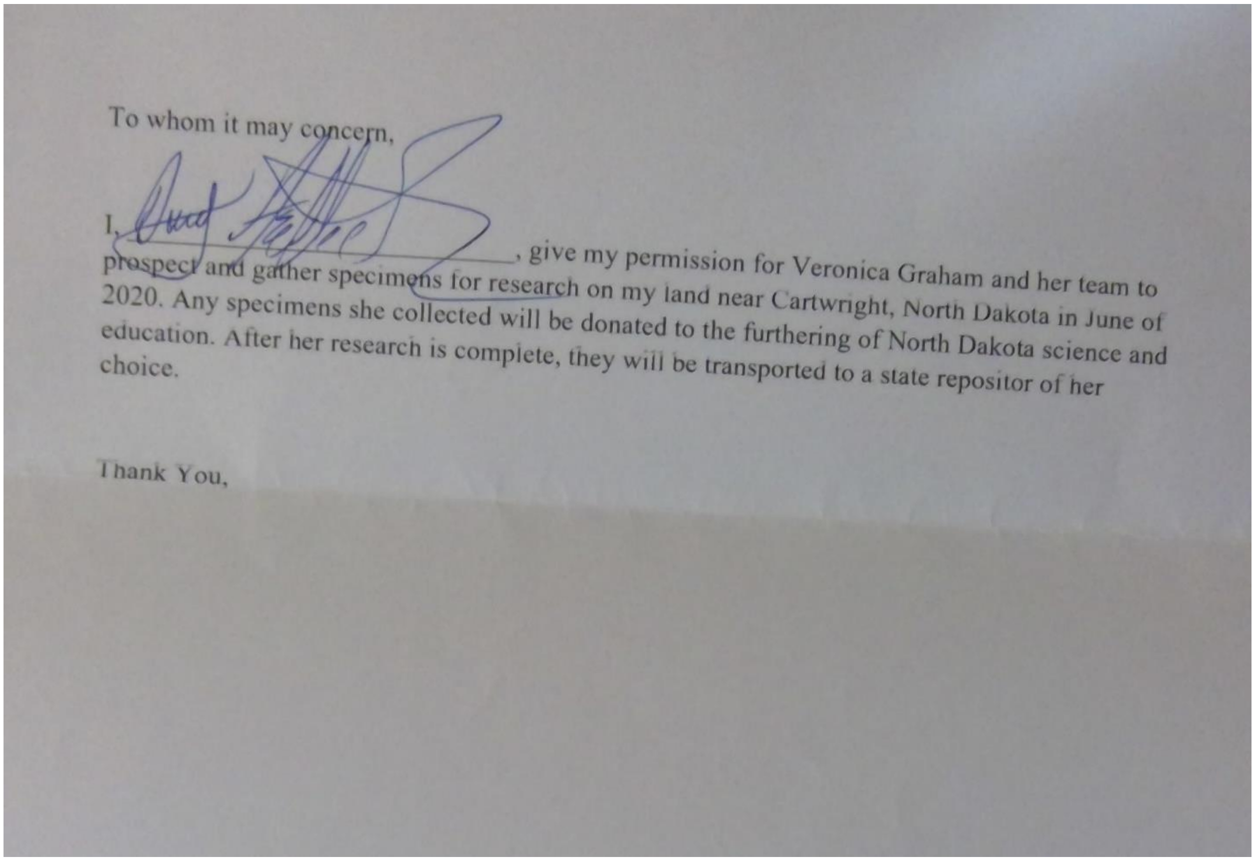
To whom it may concern,

I, Doug Gullikson, give my permission for Veronica Graham and her team to prospect and gather specimens for research on my land near Cartwright, North Dakota in June of 2020. Any specimens she collected will be donated to the furthering of North Dakota science and education. After her research is complete, they will be transported to a state repositor of her choice.

Thank You,

APPENDIX C

APPROVAL LETTER –DOUG HETTICH



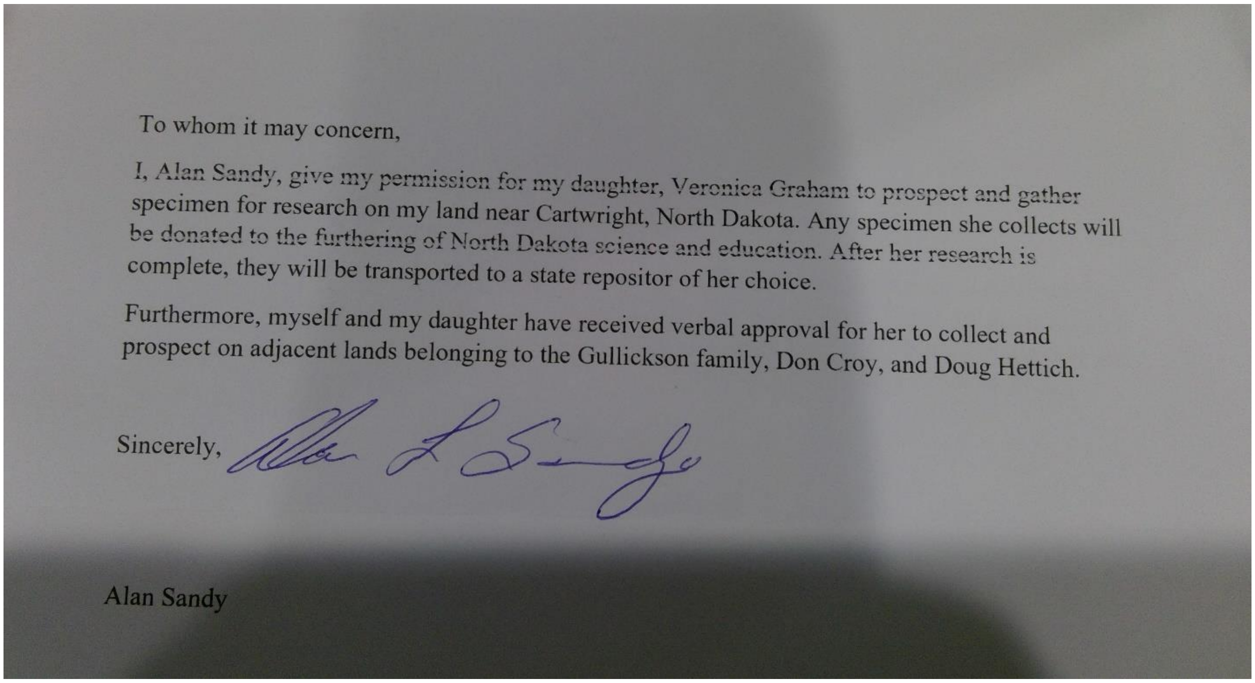
To whom it may concern,

I, ____________________, give my permission for Veronica Graham and her team to prospect and gather specimens for research on my land near Cartwright, North Dakota in June of 2020. Any specimens she collected will be donated to the furthering of North Dakota science and education. After her research is complete, they will be transported to a state repositor of her choice.

Thank You,

APPENDIX D

APPROVAL LETTER – ALAN SANDY



To whom it may concern,

I, Alan Sandy, give my permission for my daughter, Veronica Graham to prospect and gather specimen for research on my land near Cartwright, North Dakota. Any specimen she collects will be donated to the furthering of North Dakota science and education. After her research is complete, they will be transported to a state repositor of her choice.

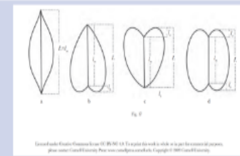
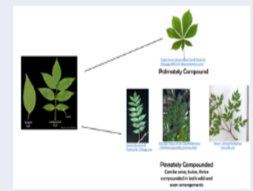
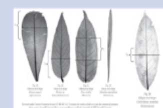
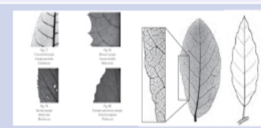
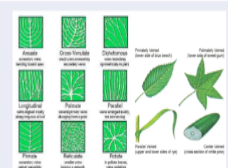
Furthermore, myself and my daughter have received verbal approval for her to collect and prospect on adjacent lands belonging to the Gullickson family, Don Croy, and Doug Hettich.

Sincerely,

Alan Sandy

APPENDIX E

IDENTIFYING CHARACTERISTICS OF LEAF SPECIMENS

Characteristic	Description/Category	Image/Examples
Specimen measurements	Includes lamina length, midvein length, width ratio, and if present base and/or apex dimensions	
Leaf Organization	Simple or Compound (multiple types of compound exist)	
Lamina Shape	Obovate, Ovate, Oblong, Linear, and Elliptic	
Lobation	Unlobed, Palmate, Palmatisect, Pinnate, Pinnatisect, Bilobed, combination	
Margin Type	Untoothed, serrated, dentate, crenate w/wo serrate, erose, sinuous	
Vein Pattern	Arcuate, Cross-Venulate, Dichotomous, Longitudinal, Palmate, Parallel, Pinnate, Reticulate, Rotate	
Unique Characteristics	base symmetry, apex shape or angle, base shape or angle, appearance of abaxial-adaxial plane