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Unique Preservation of Fossil Ghost Fish in the Green River Formation

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School of Medicine
in conjunction with the
Faculty of Graduate Studies

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Unique Preservation of Fossil Ghost Fish in the Green River Formation

by

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A thesis submitted in partial satisfaction of the requirements
for the degree Master of Science in Geology

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABBREVIATIONS

GF	Ghost Fish
UGF	Upper Ghost Fish
LGF	Lower Ghost Fish
XRD	X-Ray Diffractometry
XRF	X-Ray Fluoresence
TOC	Total Organic Carbon
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive X-Ray Spectroscopy
P/E	Precipitation/Evaporation

ABSTRACT OF THE THESIS

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Loma Linda University, March 2017

Dr. Kevin Nick, Chairperson

Two beds with unique fossil fish preservation occur within the predominantly evaporite-rich, fossil poor Angelo Member in the Green River Formation in Fossil Basin, Wyoming. These two beds, termed “Ghost Fish” beds, contain fossil fish that are two-dimensional carbonaceous compressions with no bone and detailed soft part preservation. These beds were measured and samples were collected from 8 quarries and 19 additional locations. Stratigraphic sections and fossil content were recorded at each quarry location. Analysis included XRD, stable isotope, XRF, TOC, and SEM analysis. Results were inputted into tables, graphs, and spatial maps to show trends, interpret the paleoenvironment, and examine the unique preservation.

Interpretation of the results suggests freshwater entering the lake from the SW region of the study area during the UGF bed deposition. This research suggests that the unique style of preservation found in the Ghost Fish beds is the result of high alkalinity, salinity, and microbial mat activity.

CHAPTER 1

INTRODUCTION

Fossil Lake was the smallest of three Eocene lakes that made up the Green River lake system, into which the Green River Formation was deposited (Figure 1). Fossil Basin, which includes sediments from Fossil Lake, has been the focus of many studies, predominantly paleontological (McGrew and Casilliano, 1975, and Grande, 1984). Geologic mapping within Fossil Basin has been completed by Oriel and Tracey (1970), McGrew and Casilliano (1975), Buchheim and Eugster (1984), and Buchheim et al. (2015). These studies primarily focused on the fossiliferous Fossil Butte Member, especially the 18'' layer, a mid-lake deposit rich in kerogen and well-preserved fossils (Buchheim & Eugster, 1984). Little research has been done on the fossil-bearing layers of the Angelo Member, which overlies the Fossil Butte Member (Figure 2).

The goal of this research is to examine and interpret the geochemistry and paleoenvironments of Fossil Lake during deposition of the Ghost Fish beds (two beds within the Angelo Member that are being described for the first time. These beds are unique not only because they are fossiliferous within a predominantly evaporative section of the Green River Formation, but because of the manner of preservation. Bones of fossil fish in these beds are, for the most part, absent yet detailed soft parts (skin, eyes, etc.) are preserved. Mineral content, oxygen and carbon isotopic ratios, and fossil content have been previously used to interpret paleoenvironments of Fossil Lake (Loewen, 1999; Amato, 2008) and these research techniques were also applied in this study.

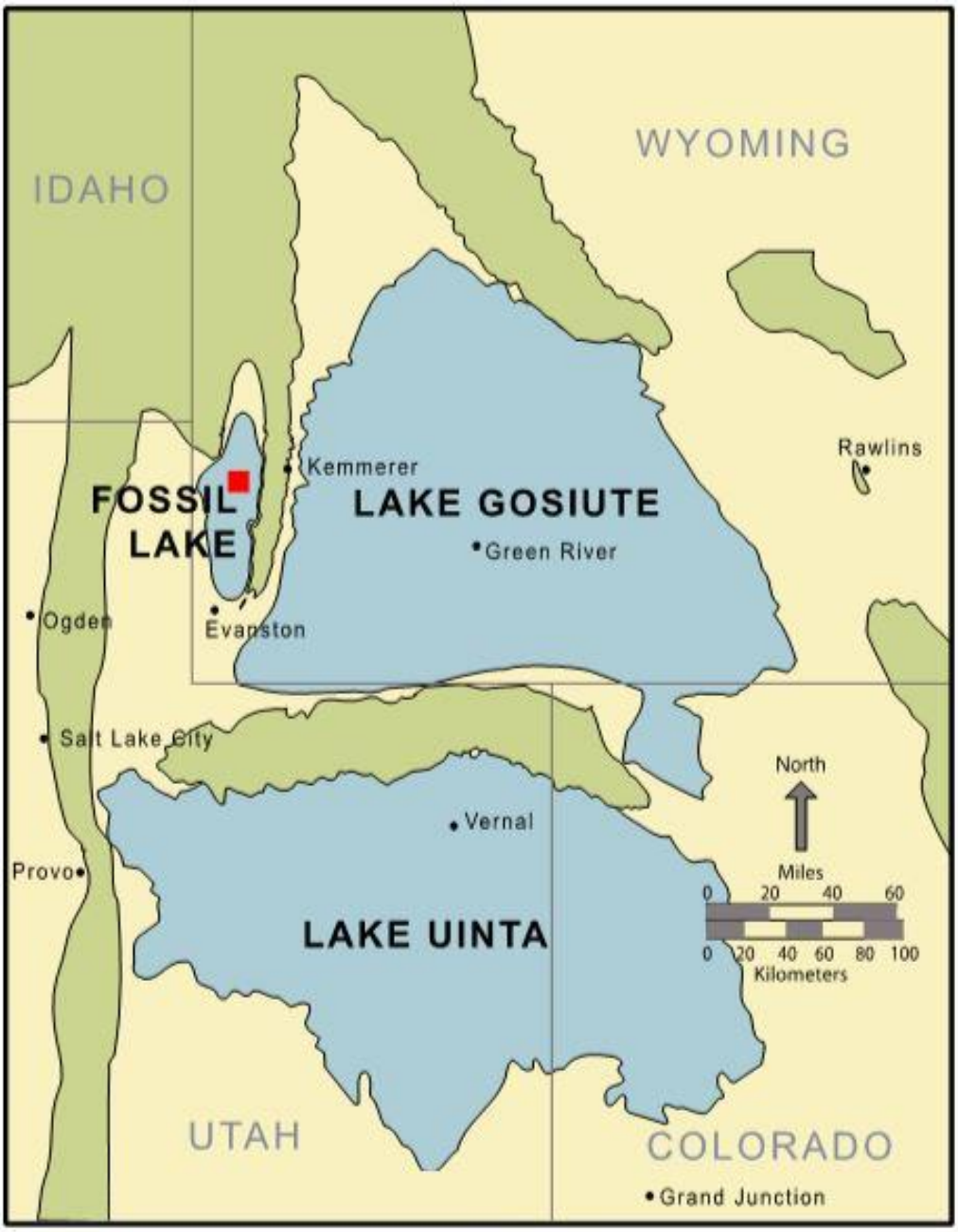

Figure 1: Eocene Green River Formation Lake System. Approximate study area is marked with a red square. Green sections indicate elevated areas during the Eocene. City and state names along with state boundaries are included for reference points. Lake boundaries were determined using outcrop data. Figure modified from MacGinitie (1969) and Bradley (1964).

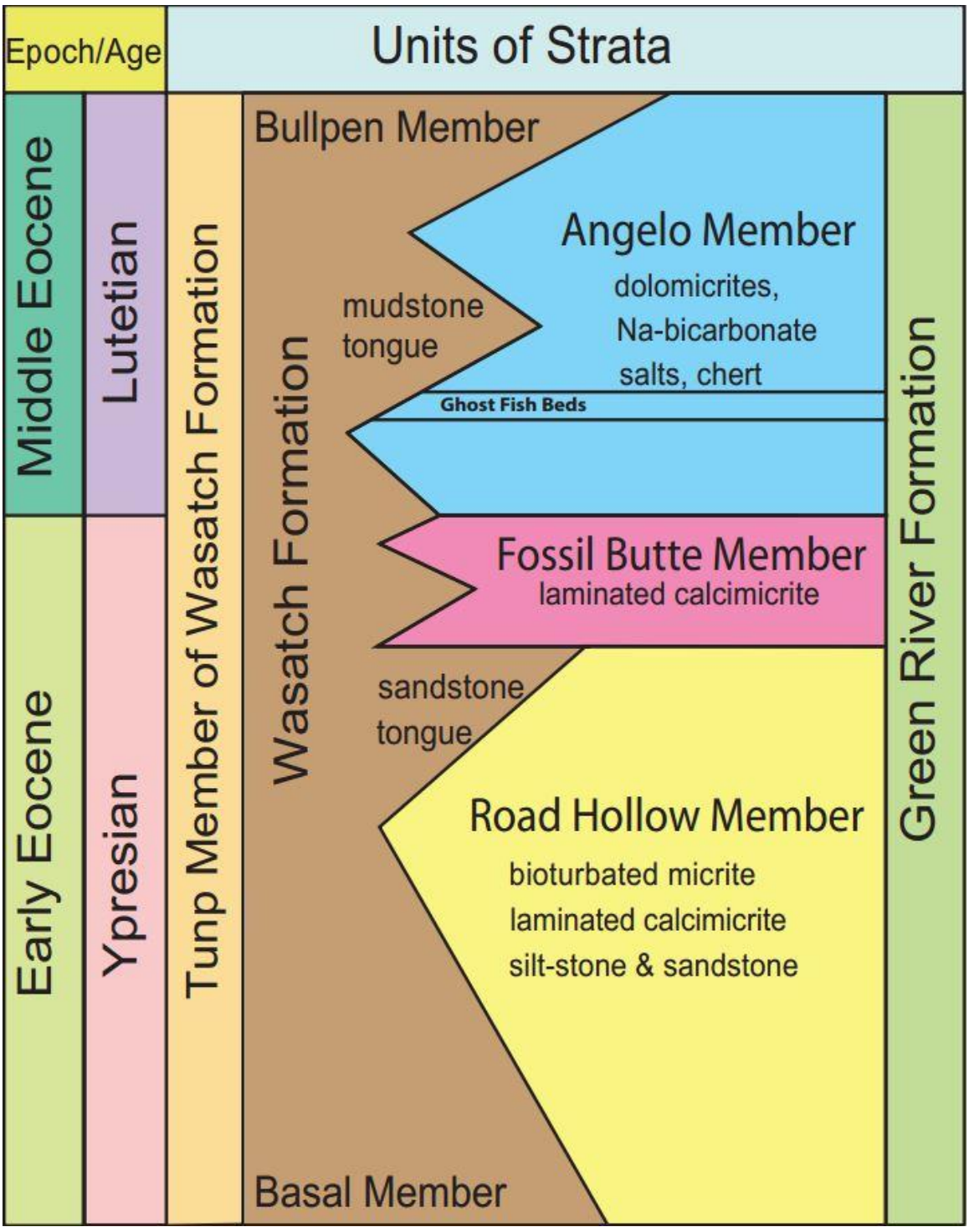

Figure 2: Stratigraphy of the Green River Formation of Fossil Basin. The Ghost Fish beds occur in the base of the Angelo Member. Figure modified from Buchheim, 1984.

Geologic Setting

Fossil Basin is an elongated basin that is part of the Wyoming thrust belt. During the Laramide and Sevier Orogenies, many parts of the surrounding region were being uplifted while Fossil Basin subsided during the late Cretaceous and early Tertiary (Oriel and Tracey, 1970). During the Eocene, precipitation began collecting in this depression, forming Fossil Lake. Sedimentary rocks from Fossil Lake were first described and divided into members by Oriel and Tracey: the Fossil Butte and Angelo Members. (Oriel and Tracey, 1970). Later, Buchheim divided the Green River Formation further into the Road Hollow Member, the Fossil Butte Member, and the Angelo Member using lithologic characteristics (Buchheim, 2002).

Fossil Lake was a low-gradient, playa lake with a maximum depth of 15 meters (Buchheim, 1994a). Loewen and Buchheim (1997) and Amato (2008) show that lateral changes in the lake's chemistry were caused primarily by changes in evaporation, precipitation, and inflow of fresh water. The Ghost Fish beds are located in the middle part of the Angelo Member during the final stages of the lake's existence (Figure 2). This was a period of predominantly hypersaline conditions in which evaporation exceeded precipitation (Loewen, 1999). The lake was much smaller during this period, deepest in the area that is now Fossil Butte National Monument (Figure 3).

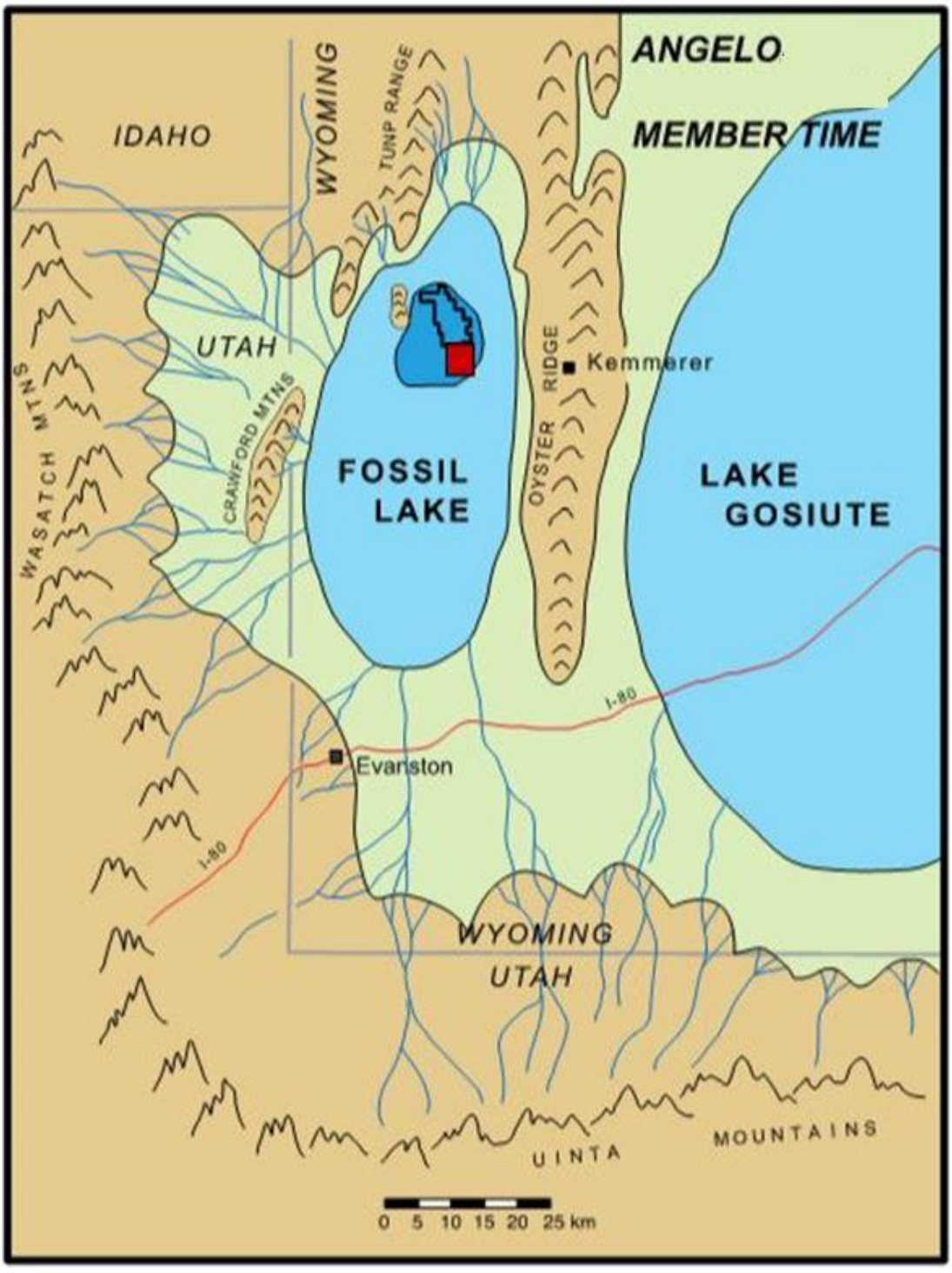

Figure 3: Map of Fossil Lake during Angelo Member time. An outline of Fossil Butte National Monument and city locations are marked for reference. The red rectangle marks the study area. The darker blue region marks the lake center. The lighter blue regions mark the lake margins. Figure modified from Buchheim et al. 2011.

Previous Work

Loewen (1999), Amato (2008), and Buchheim (2011) studied the geochemistry of the Angelo Member and determined deposition occurred during a late-stage period in Fossil Lake's existence in which the lake transitioned from a moderately fresh-water, open hydrographic basin to a dominantly hypersaline, closed hydrographic basin. This change established lateral and vertical salinity gradients within the lake. Research on salinity gradients has been conducted by Buchheim (1996), Loewen and Buchheim (1997), Trivino (1998), Loewen and Buchheim (1998), and Loewen (1999). Calcite and dolomite facies along with stable isotope patterns indicate a lateral salinity gradient. Freshwater indicators occur along the lake margins and hypersaline indicators occur at the lake center.

There has been some debate over the apparent contradiction of sedimentologic indicators of saline water and biological indicators of fresh water (Grande and Buchheim, 1994). The presence of dolomite and evaporite pseudomorphs suggest a hypersaline environment while the presence of freshwater fish and other freshwater organisms suggest a freshwater environment. The current explanation for this contradiction is that freshwater streams flowed into the saline lake, creating freshwater regions near the lake's margin where freshwater organisms lived (Grande and Buchheim, 1994).

Fossil Lake is a classic closed lake basin that demonstrates fluctuations in lake chemistry as described by Talbot (1990) and Ki and Ku (1997). Catalysts for lake chemistry fluctuation include changes in temperature, salinity, inflow, precipitation, and

evaporation (Talbot, 1990; Ki and Ku, 1997). Talbot (1990), and Ki and Ku (1997) emphasize the importance of oxygen and carbon isotopes in studying lake histories. The amount of ^{18}O vs. ^{16}O in carbonate minerals relates to the precipitation-evaporation ratio. Because ^{16}O is a lighter isotope, it preferentially evaporates, leaving a higher concentration of ^{18}O in the lake. Positive $\delta^{18}O$ values in carbonates suggest a period of higher evaporation than precipitation (Talbot, 1990). The amount of ^{13}C vs. ^{12}C is an indicator of lake productivity. Photosynthesis removes ^{12}C from the lake water, leaving a larger ^{13}C percentage. A high $\delta^{13}C$ value in carbonates is indicative of high lake productivity (Mason and Surdam, 1992).

The environmental models explaining well-preserved, fully articulated fossils from the Green River Formation have shifted over time. Early authors believe that this method of fossil preservation required rapid sedimentation and/or anoxic conditions (Buchheim and Surdam, 1977, Grande, 1984). Buchheim (1994b) questioned rapid sedimentation and anoxic conditions, arguing for an oxic lake bottom due to burrows in the sediment and fish fossils. A microbial mat preservation model has become an interesting way to preserve fish that decreases the need for rapid sedimentation and anoxic conditions for preservation (Whitmore, 2003, Hellawell and Orr, 2012, Iniesto, 2015). According to this model, once an organism reaches the lake bottom, microbial mats cover it within hours or days, slowing decay, and acting as a barrier from destructive forces (Hellawell and Orr, 2012). Iniesto (2015) conducted lab experiments using microbial mats and found that fish covered with microbial mats were more likely to remain articulated.

The presence of dolomite in modern hypersaline lakes has been studied by Warthmann, R., Vasconcelos, C., Sass, H., & McKenzie, J. A. (2005) and Vasconcelos, C., McKenzie, J. A., Warthmann, R., & Bernasconi, S. M. (2005). Their work suggests that bacteria present in microbial mats biologically induce the production of dolomite in hypersaline lakes. The microbial mats create a microenvironment that helps to overcome the kinetic barrier usually restricting the production of dolomite in low-temperature environments.

Microenvironments created by microbial mats have also been studied by Iniesto (2015), Dupraz (2009), and Wilby (1996). Iniesto monitored the dissolved oxygen and pH inside and outside of fish both isolated on sediment and covered with microbial mats. His research showed substantial differences in dissolved oxygen and pH levels between fish with and without microbial mats covering them. Photosynthesis and sulfate reduction were two main agents affecting the microbial mats and their microenvironments, especially during the first 90 days (Iniesto, 2015). Dupraz (2009) studied the nature of microbial mats represented in the rock record in multiple environments over earth's history. He emphasized the alkalinity engine, including the community composition and metabolic rate, as the factor determining the resulting microenvironment and structure of the microbial mat along with the resulting mineral formation. He also refers to microbial mats as "geochemical bioreactors", altering geochemistry to create unique microenvironments. Wilby (1996) also supports the existence of microenvironments created by microbial mats. He emphasizes the ability of microbial mats to extract phosphorus from organic remains and/or trap elements from

the surrounding water column. Major factors preserving fossils in his research area were attributed to low sedimentation rates, allowing microbial mats to develop, anoxic conditions, and a decreased pH. Whitmore (2003) also supports the capability of microbial mats to extract nutrients from organisms, thereby emaciating the organism to a flatter shape and allowing precipitation of nutrients elsewhere.

Fossil preservation, similar in some aspects to Fossil Lake "Ghost Fish," was studied by McNamara (2009), Parsons-Hubbard, (2008), and Wilby (1996). McNamara studied frogs from Libros displaying 2-dimensional, detailed preservation of soft-body parts including neural tissue and eye spots along with authigenic minerals. These minerals, while different from those found in ghost fish, provide evidence of the ability of authigenic mineral precipitation within microenvironments. Daniel (2010) supports this mineral precipitation theory with his studies of the ability of bacteria to precipitate a variety of minerals including the recrystallization of bone from its original material to a more stable crystal form with less pore space. Parsons-Hubbard et al. (2008) studied soft tissue preservation in brine pools, concluding that the hypersaline water and high alkalinity were responsible for soft tissue preservation. Wilby (1996) studied fossils that had undergone phosphogenesis, the process of phosphorus preserving soft tissues. Microbial mats acted as a seal, containing phosphorus to this microenvironment. The source of the phosphorus is speculated to have come from the water column although other dying microbial mats and/or bones are alternate sources. A detailed explanation of this microbial mat process has not yet been discovered. Wilby (1996) also suggests that highly alkaline water, with the presence of dissolved carbonate, can remove bone

material from fossils. This observation is supported by Bell, Mika, and Kruger (1978) who concluded that the solubility of hydroxyapatite increases with an increase in pH and the presence of dissolved carbonate.

CHAPTER 2

METHODS

Samples were taken from multiple localities throughout the basin (Figure 4). Quarries were excavated to collect fossils and lithologic samples. Additional rock samples were collected between quarry locations. Selective rock samples were analyzed through a variety of methods: 1) XRD analysis was performed to determine the mineral composition and abundance, 2) Stable isotope analysis was performed for both oxygen and carbon to interpret lake salinity and lake productivity, 3) Elemental analysis was performed to find total organic carbon and interpret geochemistry, 4) X-Ray Fluorescence was performed to compare element percentages, 5) Thin sections were made to compare carbonate and organic laminae thicknesses, and 6) Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy analyses were used to examine mineral composition of both rock samples and fossils.

Field Methods

Eight locations were excavated. The upper Ghost Fish Bed was sampled at all locations but the lower Ghost Fish bed was sampled at 5 locations (the LGF could not be found at 3 locations). Each quarry was 0.5-1 m square and 30-50 cm deep, depending on the thickness of the bed. Tuff beds were commonly used as marker beds at the base of both the upper and lower Ghost Fish beds (Figure 5). In some locations, the UGF tuff was mixed with mudstone or replaced by a mudstone layer. Quarry locations were

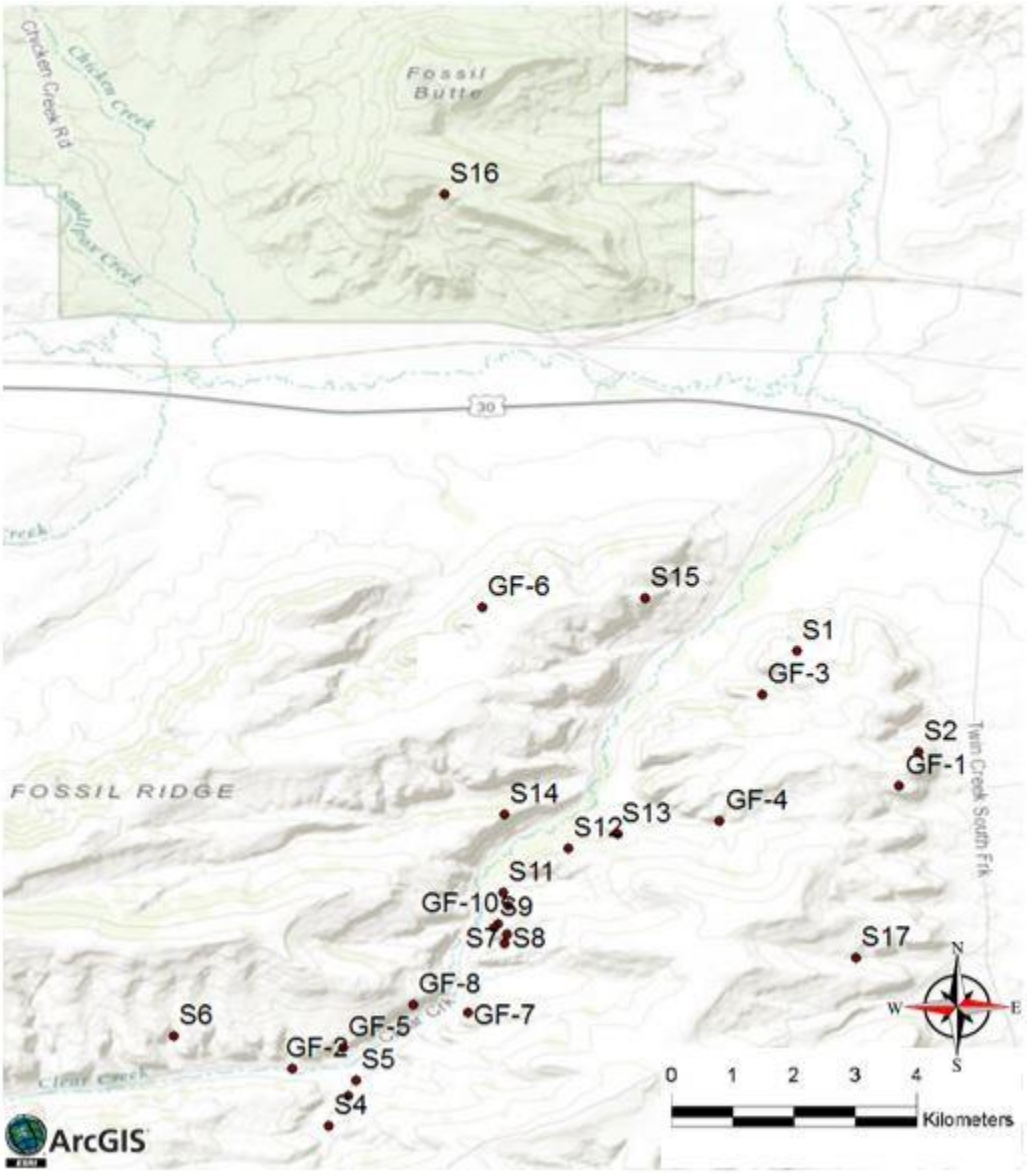

Figure 4: Map of Ghost Fish Bed quarry and sample locations. “GF” represent Ghost Fish quarries and “S” represent sample locations. Most samples are directly south of Fossil Butte National Monument.

Figure 5: Photograph of UGF basal tuff. This tuff is typically found at the base of the Ghost Fish beds and was used as a marker bed. Thickness is 5 cm on average. The color of the tuff bed varies depending on location but can include white, yellow, orange, and pink.

selected to create transects in both N/S and E/W directions but were ultimately selected based on accessibility, proximity to other quarries, and quality of rock.

At each location, overburden was removed from the beds and laminated layers were split along bedding planes as finely as possible using rock hammers and putty knives. Collecting increments were measured from the tuff or mudstone at the base of the bed through the laminated layer and marked using putty knives (Figure 6). A lithologic sample was collected from each increment. The fossil content of the layers was recorded and good specimens were collected.

Data recorded at each excavation included GPS coordinates, 2 m stratigraphic sections below and above the Ghost Fish beds, thicknesses of the Ghost Fish beds, and samples collected vertically through the Ghost Fish beds. Fossil data included layer (distance above the base of the bed), type of fossil (fish, plant, seed, insect, etc.), size, articulation, and bone preservation percentage.

Rock samples were also collected from 19 non-quarry locations. In an attempt to be consistent, samples from non-quarry locations were collected 20 cm above the base of the bed. The base of the bed was defined as the boundary between tuff and/or mudstone and laminated dolomicrite. This horizon (20 cm above the base) was selected to correspond with abundant fossil fish.

Laboratory Methods

Selected samples were processed in the lab and analyzed by X-ray diffraction (XRD), stable isotope mass spectrometry, total organic carbon (TOC), X-ray Fluorescence

Figure 6: Typical Ghost Fish bed quarry site. Photo taken at LGF-8. Chisels and putty knives were used as layer markers. A tuff layer marks the base of the bed.

(XRF), laminae counts, scanning electron microscopy (SEM), energy dispersive x-ray spectroscopy (EDS), and spatial mapping. Lithologic samples were rinsed and air-dried before powdering to avoid contamination. Analyzed samples were collected from 20 cm above the base of the bed except at GF-7 and S16. All samples from GF-7 were analyzed to create a vertical profile. From S16, two samples were analyzed due to a substantial difference in appearance between the top and bottom half of the bed.

X-Ray Diffraction (XRD)

Powdered carbonate samples were mounted on 27x27 mm petrographic slides using a solution of acetone and Duco® Cement and analyzed using a Bruker D8 X-ray diffractometer and MDI Jade 2010 software. This software uses peak intensities to determine mineral percentages. Lateral values derived from analysis were plotted on a map in ArcGIS to show spatial trends. Vertical values were graphed to show trends through time. Some values may not reflect original conditions of the lake due to abundant diagenetic calcite growth within the upper Ghost Fish Bed, especially in the top 10 cm.

Stable Isotope Mass Spectrometry

Powdered carbonate samples were analyzed at UC Berkeley for stable isotope composition. $\delta^{13}C$ and $\delta^{18}O$ values were determined using a MultiCarb system with a GV IsoPrime mass spectrometer. Two standards, $CaCO_3$ I & II were also analyzed with the batch along with the international standard NBS19. Samples were powdered before

sending them to the lab. Results were to show spatial trends. Results from GF-7 were graphed to show vertical trends through time.

Total Organic Carbon (TOC)

TOC was determined using an Elementar Vario Micro Cube Elemental Analyzer at Pomona College, CA. Powdered samples were treated with hydrochloric acid to remove carbonates, and dried in an oven to removed moisture. Samples (9 mg) were loaded into aluminum boats, sealed, and placed in the Elemental Analyzer. Non-treated carbonate samples were also analyzed by the same method. A ratio of organic carbon to total carbon was then calculated to determine total organic carbon in the samples. Results were mapped to show spatial trends.

X-ray Fluorescence (XRF)

XRF was performed using a Rigaku Ultima IV XRF instrument at Pomona College. XRF samples were prepared by first powdering the rock and then combining 3.1 g sample, 0.4 g ultra high purity quartz, and 7.0 g of Li-tetraborate flux. These proportions were mixed and then emptied into graphite crucibles. The crucibles were heated in a furnace at 1000°C for 10 minutes. After cooling, the beads were powdered again and heated in the furnace again for 10 minutes. After cooling a second time, sample names were engraved on the base of each bead, the flat surface was ground slightly, and the samples were cleaned with alcohol. Samples were then loaded into the XRF

spectrometer for analysis. “Undilution” of quartz was calculated by Robert Gaines at Pomona College using a spreadsheet compiled by Washington State University.

Laminae Analysis

Rock samples from two quarries were epoxied, slabbed, and cut to size. Cut samples were sent to Spectrum Petrographics for thin section preparation. Slides were analyzed under a petrographic microscope to compare variance in laminae thicknesses.

Scanning Electron Microscopy (SEM) / Energy Dispersive X-Ray Spectroscopy (EDS)

A TESCAN VEGA LSH scanning electron microscope with a Thermo Noran System Six energy dispersive x-ray spectrophotometer was used to examine samples in detail. Three samples were selected that best demonstrated the distribution of preservation: no bone, some bone, and some bone with high amounts of carbon. Samples were coated with gold/palladium to reduce the electrostatic charge. Each sample was viewed at various magnifications, examining element and mineral content in both fossil and rock.

Data Distribution Maps

Maps were constructed that display the spatial distribution of mineral content, oxygen and carbon isotope ratios, TOC, and type of fossil preservation. GPS locations where the samples were collected along with various data results were entered into spreadsheets on Microsoft Excel and then imported into ArcGIS (10.3.1). This file was

then opened in ArcMap to display spatial distribution and a world topographic map was added as an additional layer to provide reference points.

CHAPTER 3

RESULTS

The Ghost Fish beds were excavated at 8 quarry locations and 19 additional sample locations within Fossil Basin (Figure 4). The base of the lower Ghost Fish bed is approximately 7.5 meters above the K-Spar tuff at GF-1 (Figure 7) and is at a similar stratigraphic position at all other sites. The total thicknesses of both Ghost Fish beds are about 1 meter (Figures 8, 9).

Confidence of Field Sampling Method

Five-cm thick tuff beds generally occur at the base of both Ghost Fish beds (Figure 5) and were used to determine stratigraphic position. These tuff beds are sometimes mixed with or replaced by mudstone. Ultimately, the presence of Ghost Fish fossils was the final determination of correct bed location. All samples used for lab analysis examining horizontal trends were collected 20 cm above the tuff or mudstone base. It can reasonably be concluded that sampling was consistent both in location and method because of many factors including: 1) the stratigraphic sections at each location are similar in rock type and thicknesses, 2) the tuffs were often used as marker beds, 3) samples were taken from the same distance above the tuff or mudstone at each location, and 4) every section sampled contained “Ghost Fish.”

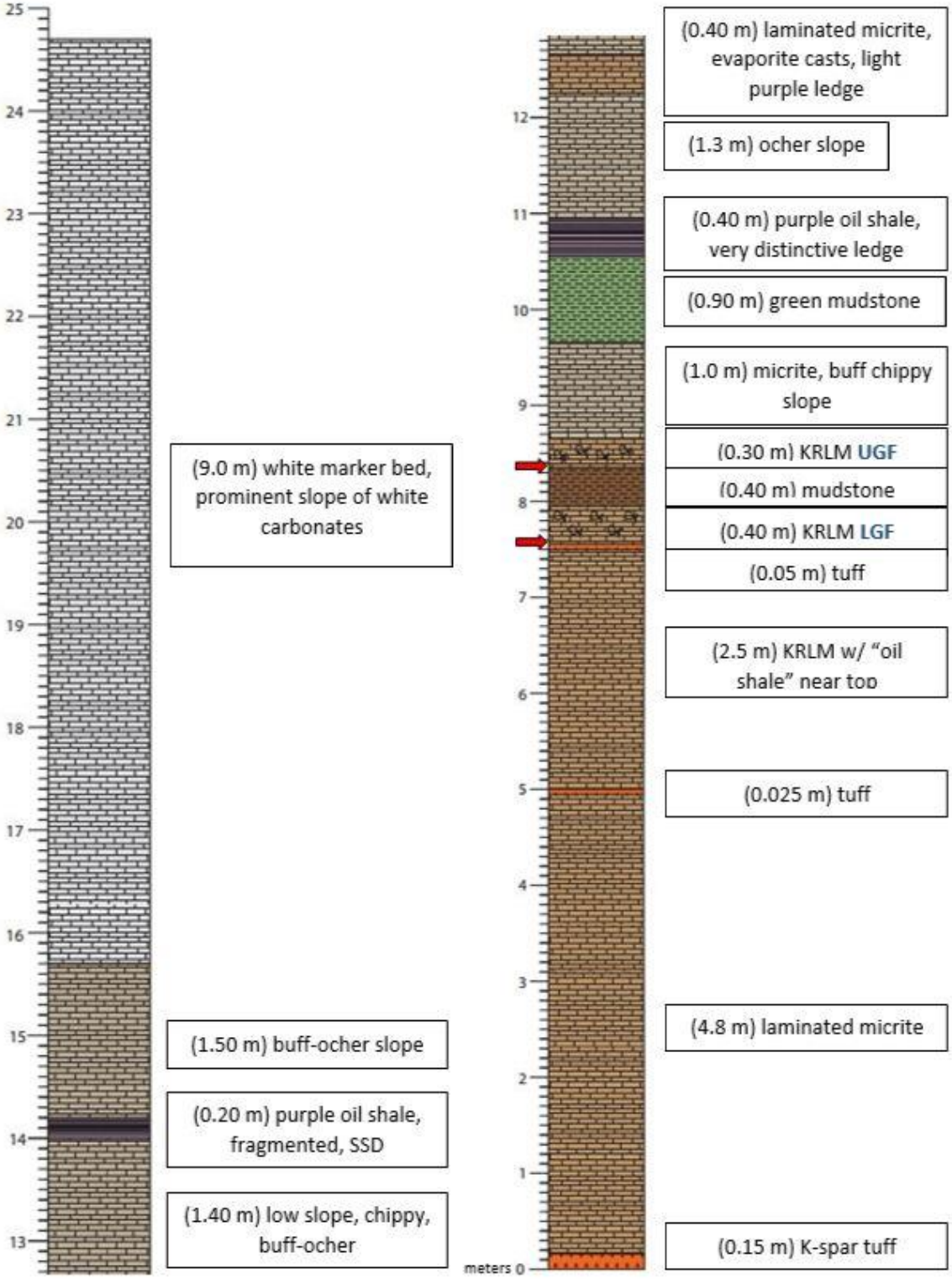

Figure 7: Full stratigraphic section at GF-1. Red arrows mark the base of the Ghost Fish beds. For legend, see Appendix B.

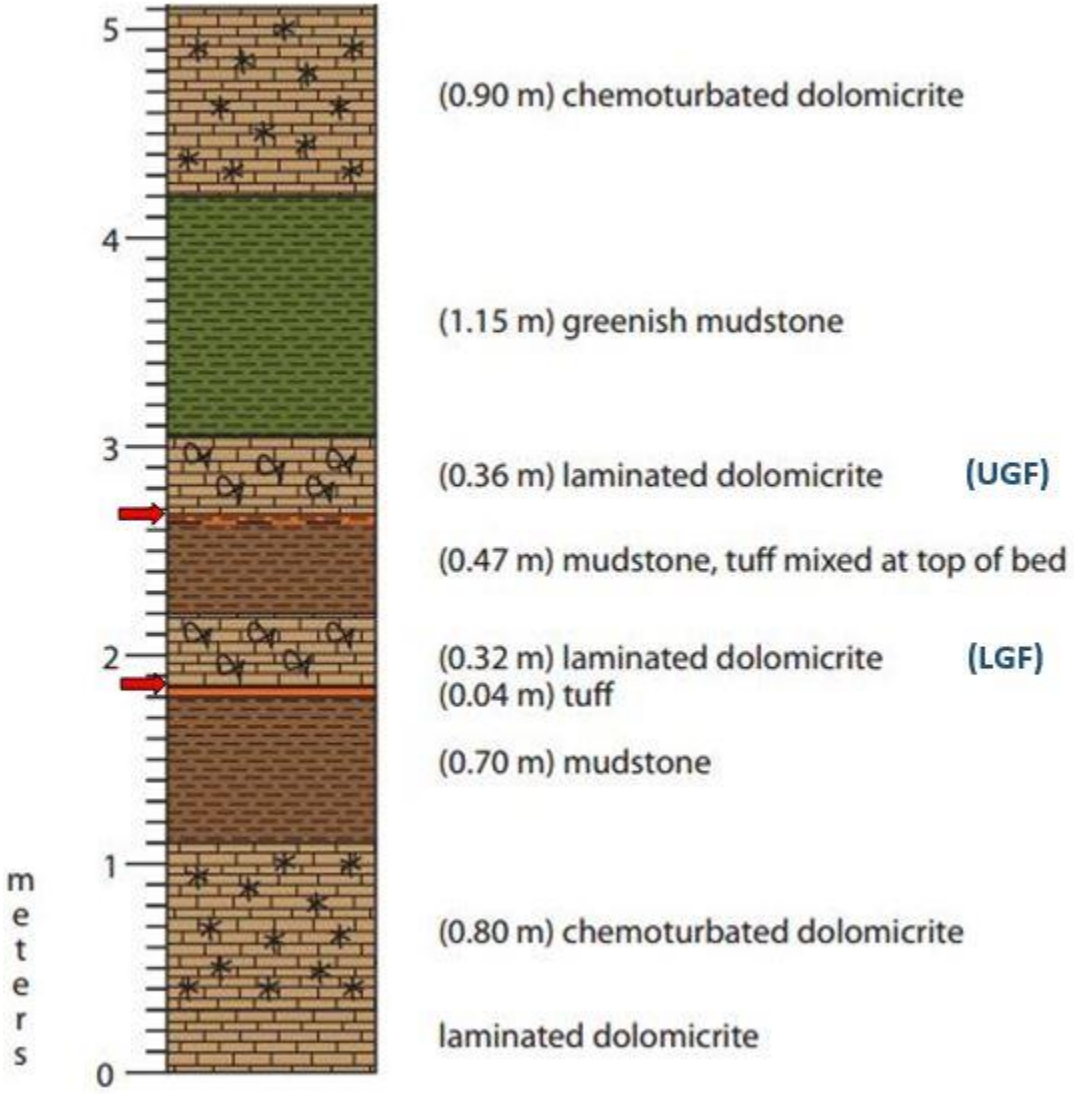

Figure 8: Stratigraphic Section at GF-8. This section best represents most quarry locations. Both fossiliferous sections in the Ghost Fish Bed are underlain with orange tuff. Red arrows mark the base of the Ghost Fish beds. For legend, see Appendix B.

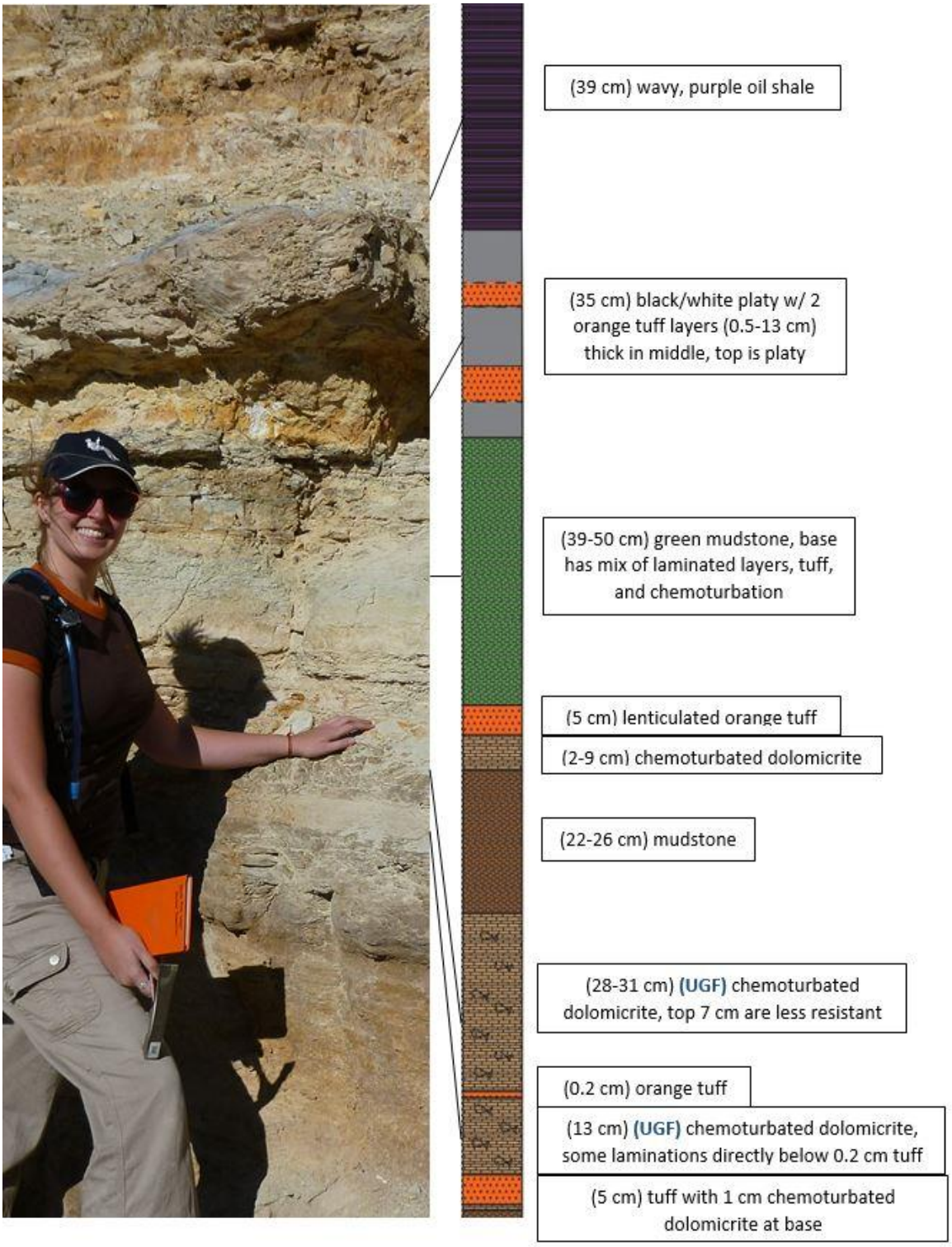

Figure 9: Stratigraphic section at GF-6 with photograph comparison. Correlations are shown with connecting lines. For legend, see Appendix B.

Stratigraphy

The UGF bed was present at all locations in the study area. However, the LGF bed was absent in quarry locations GF-2, GF-3, and GF-9 (Appendix B). The difference between UGF and LGF in these situations was determined using stratigraphy. In the study area, UGF laminated layers range from 23-54 cm thick while LGF laminated layers range from 30-40 cm thick (Appendix A, Appendix B).

Mineral Content/XRD

The Ghost Fish beds are primarily composed of calcite, dolomite, K-feldspar, and quartz. Calcite is the dominant mineral at most locations, typically ranging from 60-85% with the largest percentages in the SW half of the UGF sampling area (Figure 10) and in the center of the LGF sampling area (Figure 11). Dolomite percentages are overall greater in the LGF bed than the UGF bed, reaching as high as 64%. Quartz and K-feldspar are more abundant toward the margins of the study area with relatively low percentages near the center of the study area (Appendix B). Vertically, in the UGF bed, calcite values are higher in the top 14 cm (Figure 12). In the LGF bed, calcite percentages are consistent throughout the bed (Figure 13). Mineral values in the Upper Ghost Fish Bed may not reflect original lake conditions accurately due to chemoturbation, especially in the top of the section. These diagenetic calcite crystals formed in voids previously filled with evaporite minerals.

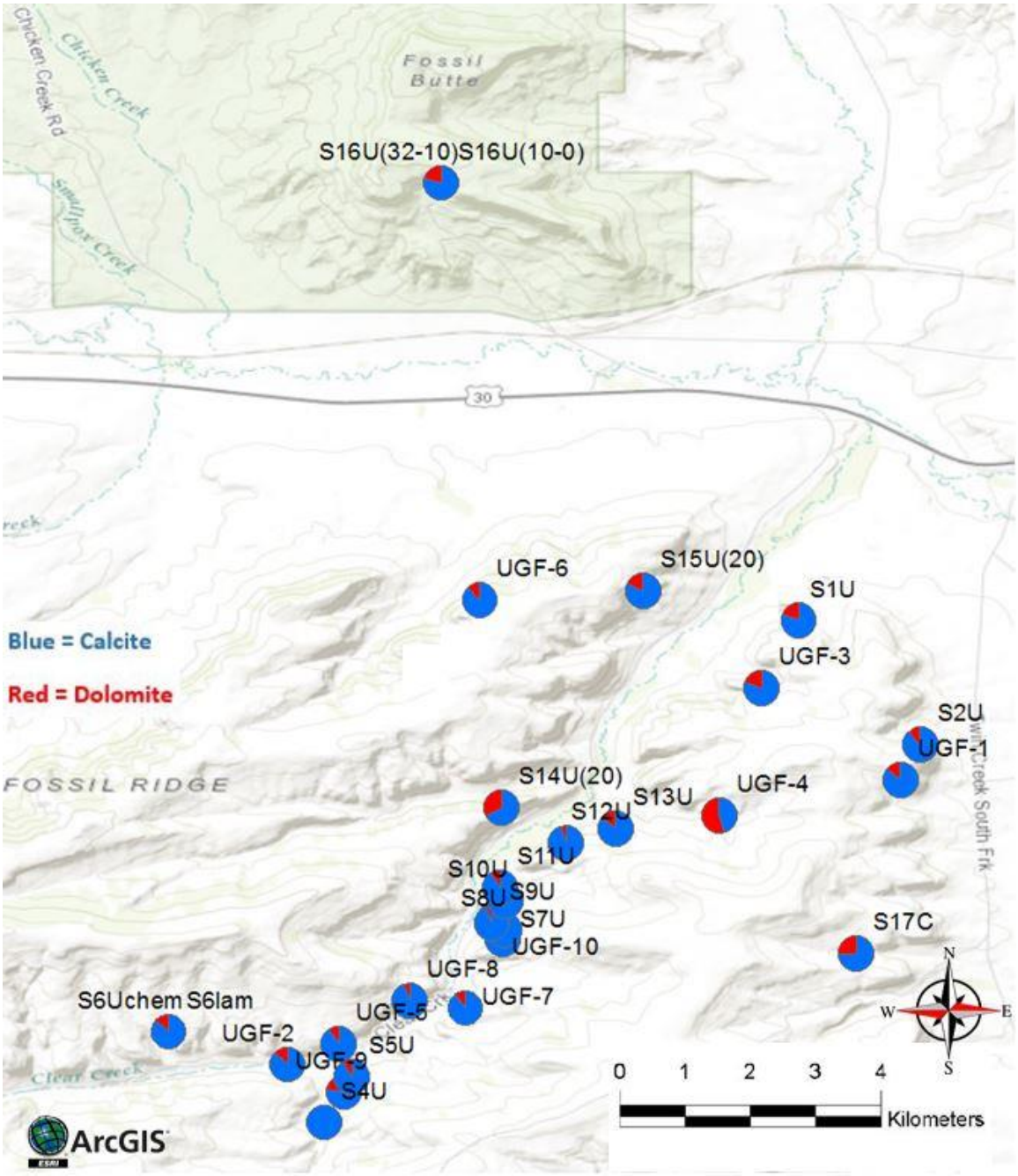

Figure 10: Upper Ghost Fish calcite/dolomite ratio map. Samples were taken from 20 cm above the base of the UGF bed. Calcite is more abundant in the SW half whereas dolomite increases in the NE half of the study area.

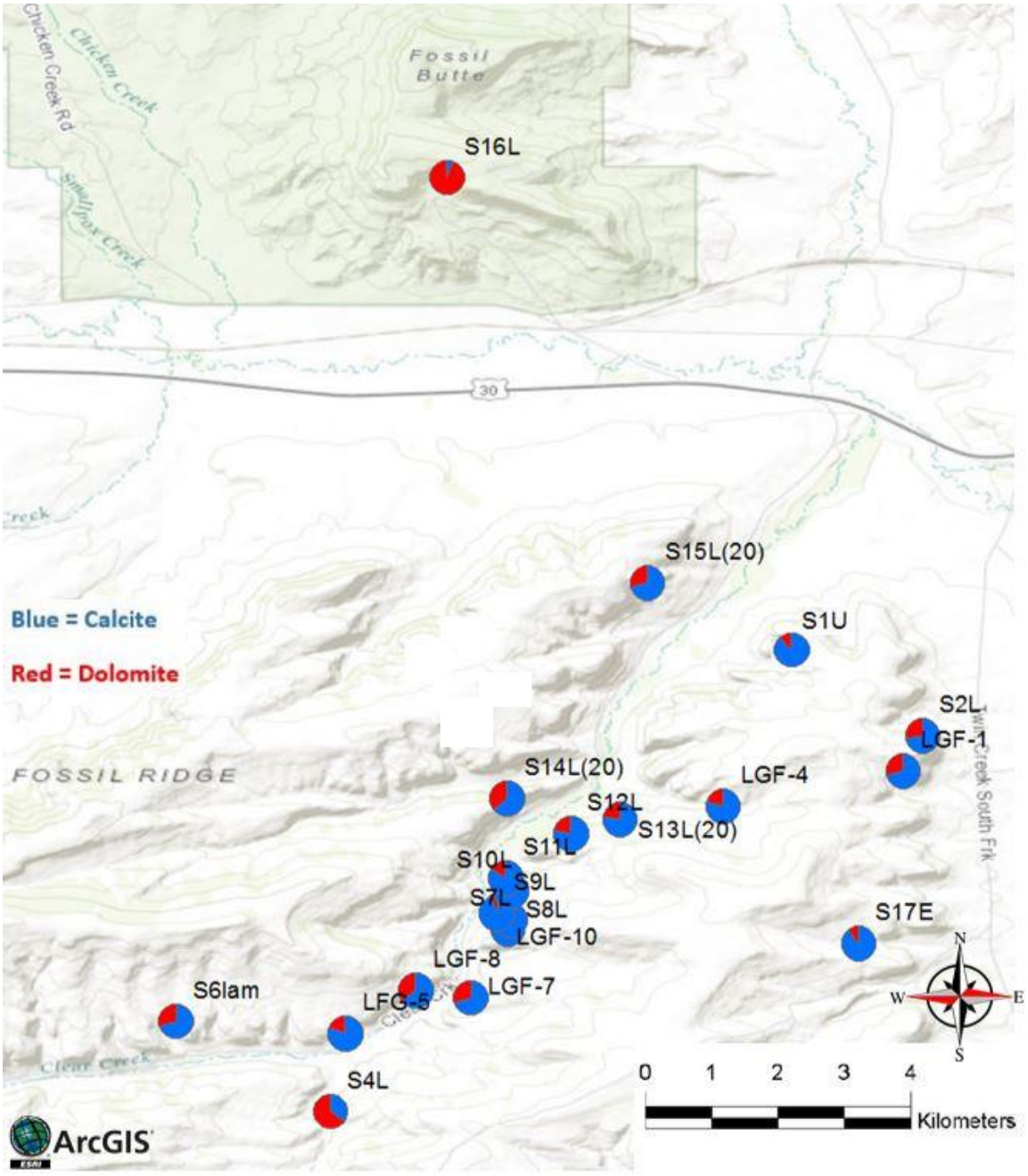

Figure 11: Lower Ghost Fish calcite/dolomite ratio map. Samples taken from 20 cm above the base of the LGF bed. Calcite is more abundant near center locations whereas dolomite is higher near the margins of the study area.

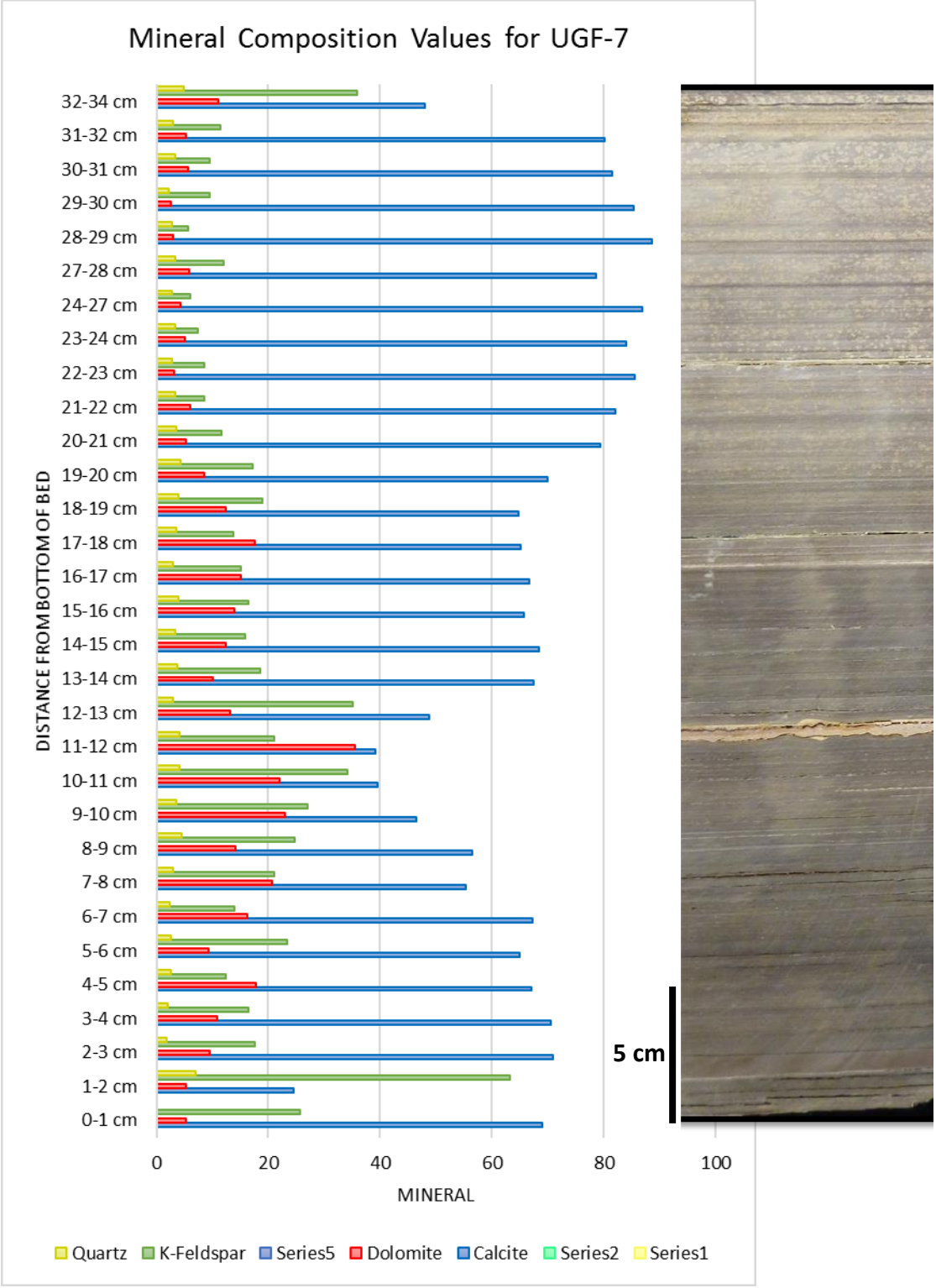

Figure 12: UGF-7 stratigraphic distribution of mineral composition. Weight percentages of minerals are shown relative to a slab through the section.

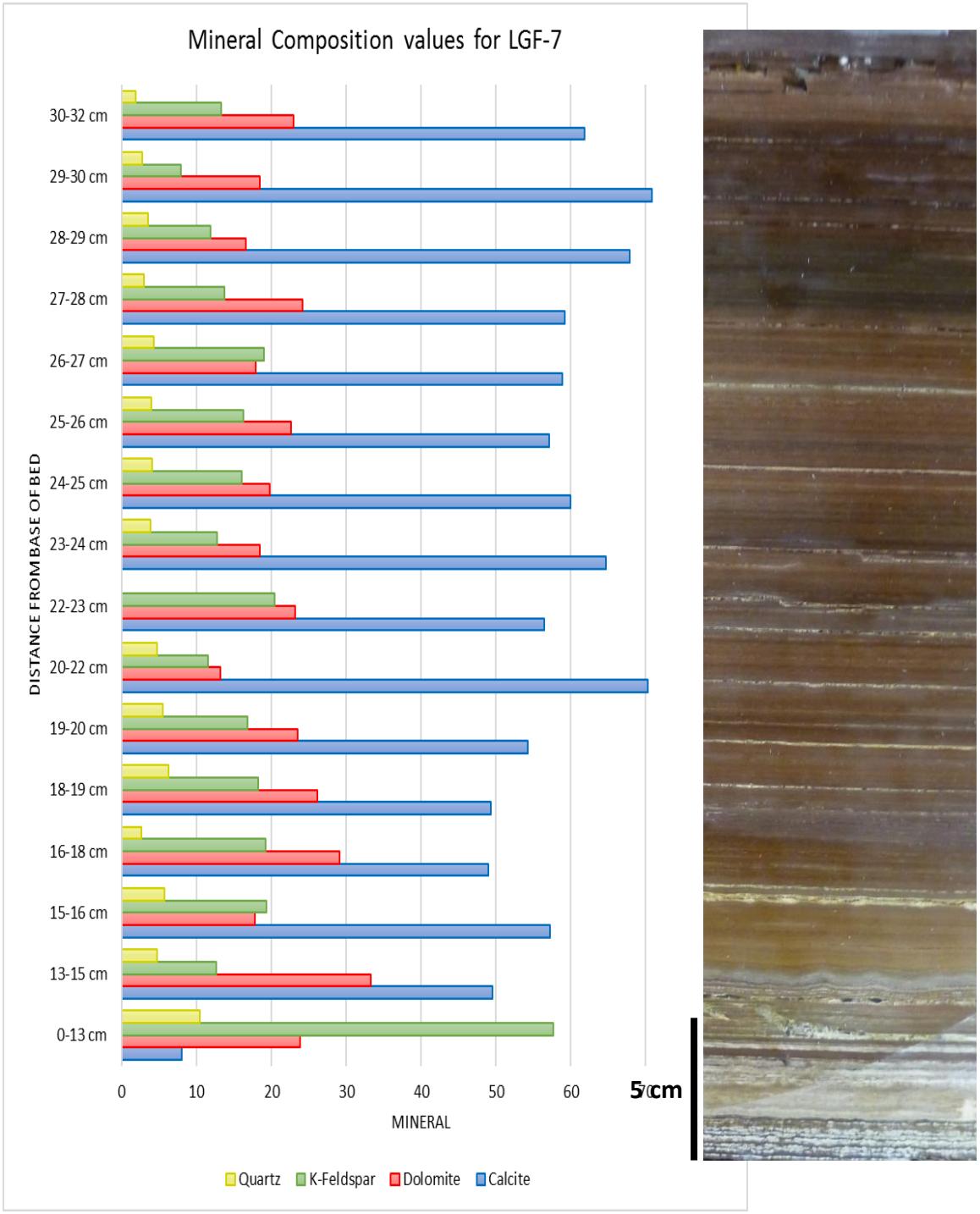

Figure 13: LGF-7 stratigraphic distribution of mineral composition. Weight percentages of minerals are shown relative to a slab through the section.

Stable Isotopes

Lab analysis was completed for both oxygen and carbon stable isotopes from carbonates. $\delta^{18}O$ values are all negative, ranging from -20.76 to -1.00 ‰ VPDB. Laterally, oxygen stable isotope values in the UGF and LGF beds are the most negative in the center of the study area (Figures 14, 15). Stratigraphically, oxygen stable isotope values in the Lower Ghost Fish bed are similar throughout the bed (Figure 16). In the Upper Ghost Fish Bed, values vary little, except for more negative values at the top of the bed that are considered unreliable due to probable diagenesis (replacement of saline minerals with calcite psuedomorphs after saline minerals) (Figure 16). $\delta^{13}C$ values range from -0.63 to 2.79 ‰ VPDB. Laterally, there is no obvious trend (Figures 17, 18). Vertically, values are also consistent (Figure 19). Isotopic covariance trend diagrams for vertical values in the UGF and LGF beds have R values of ~0.7 (Figure 20).

Total Organic Carbon

Total Organic Carbon values range from 0 to 25.75 ppm. There is no obvious spatial trend (Figures 21, 22).

X-ray Fluorescence

Elemental values derived from XRF analysis show differences in the amount of many elements found in the Ghost Fish beds as compared to the 18-inch layer (Appendix E). The Ghost Fish beds contain much larger amounts of Si, Ti, Al, Fe, Mg, K, Ni, Cr, Ba, Zr, Ga, Cu, and Zn. They also contain a smaller amount of P.

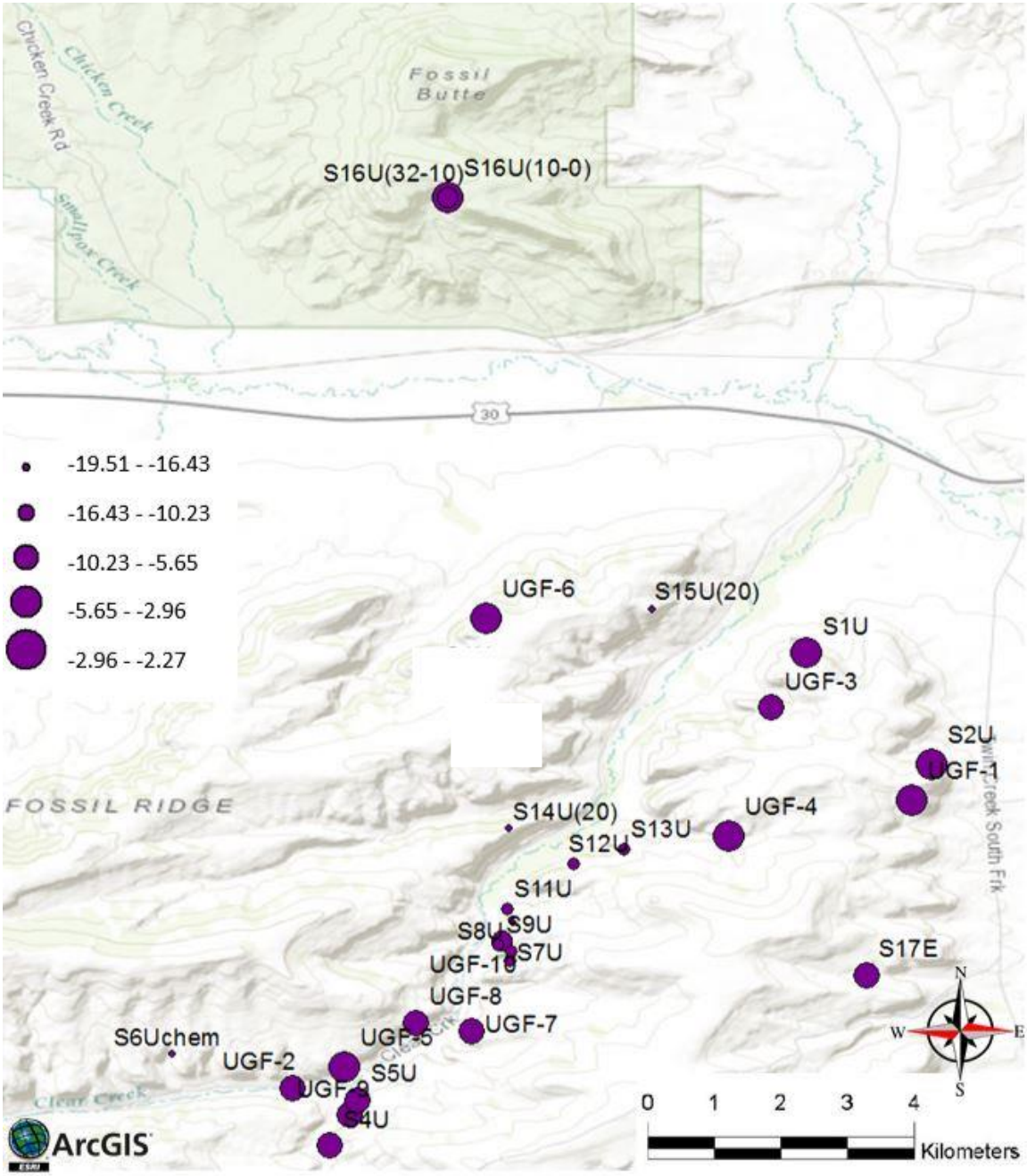

Figure 14: Upper Ghost Fish bed $\delta^{18}O$ (‰ VPDB) stable oxygen isotope map. Samples taken from 20 cm above the base of the bed. Values are more negative in the center of the study area.

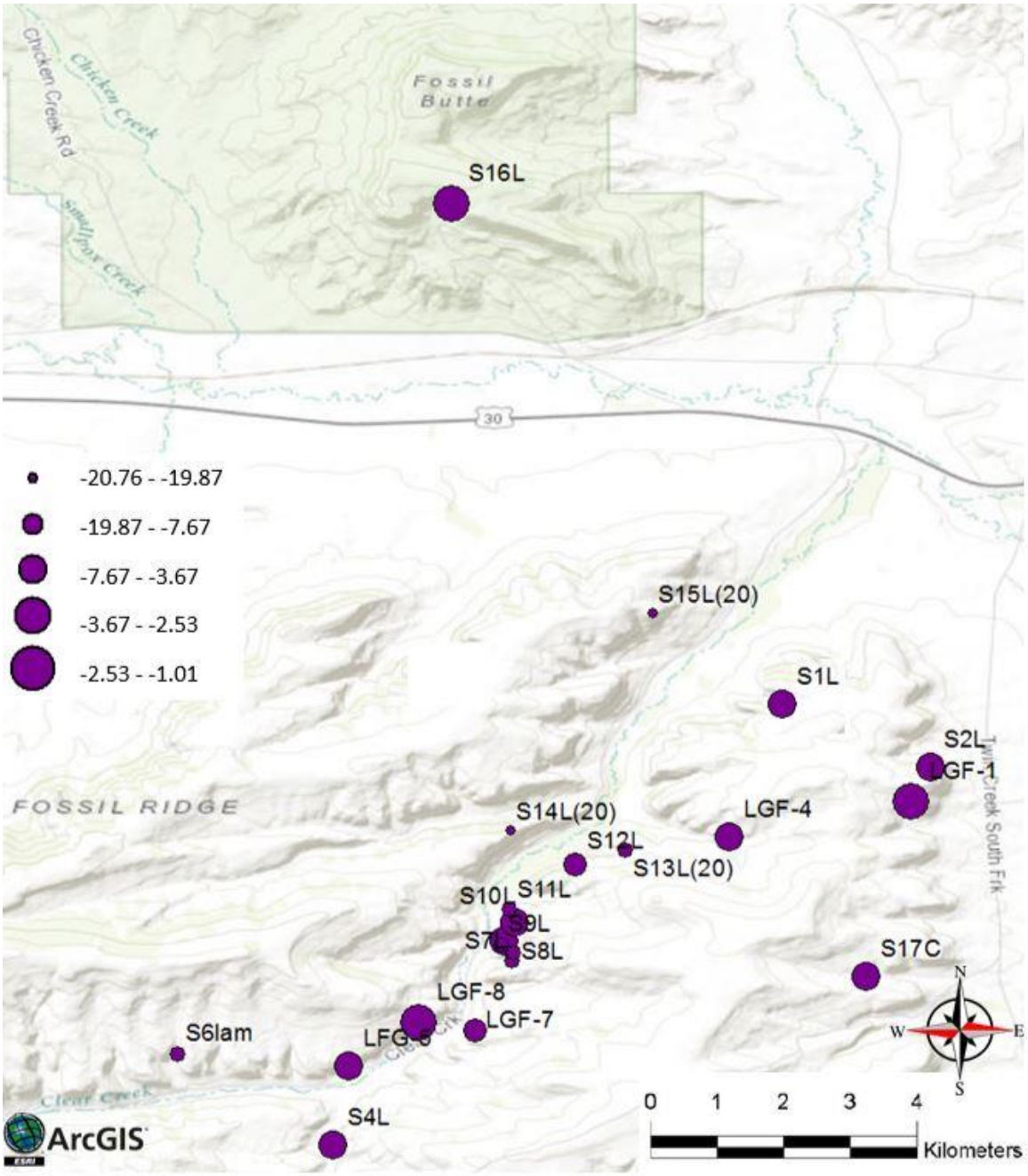

Figure 15: Lower Ghost Fish bed $\delta^{18}O$ (‰ VPDB) stable oxygen isotope map. Samples taken from 20 cm above the base of the bed. Values are more negative near the center of the study area.

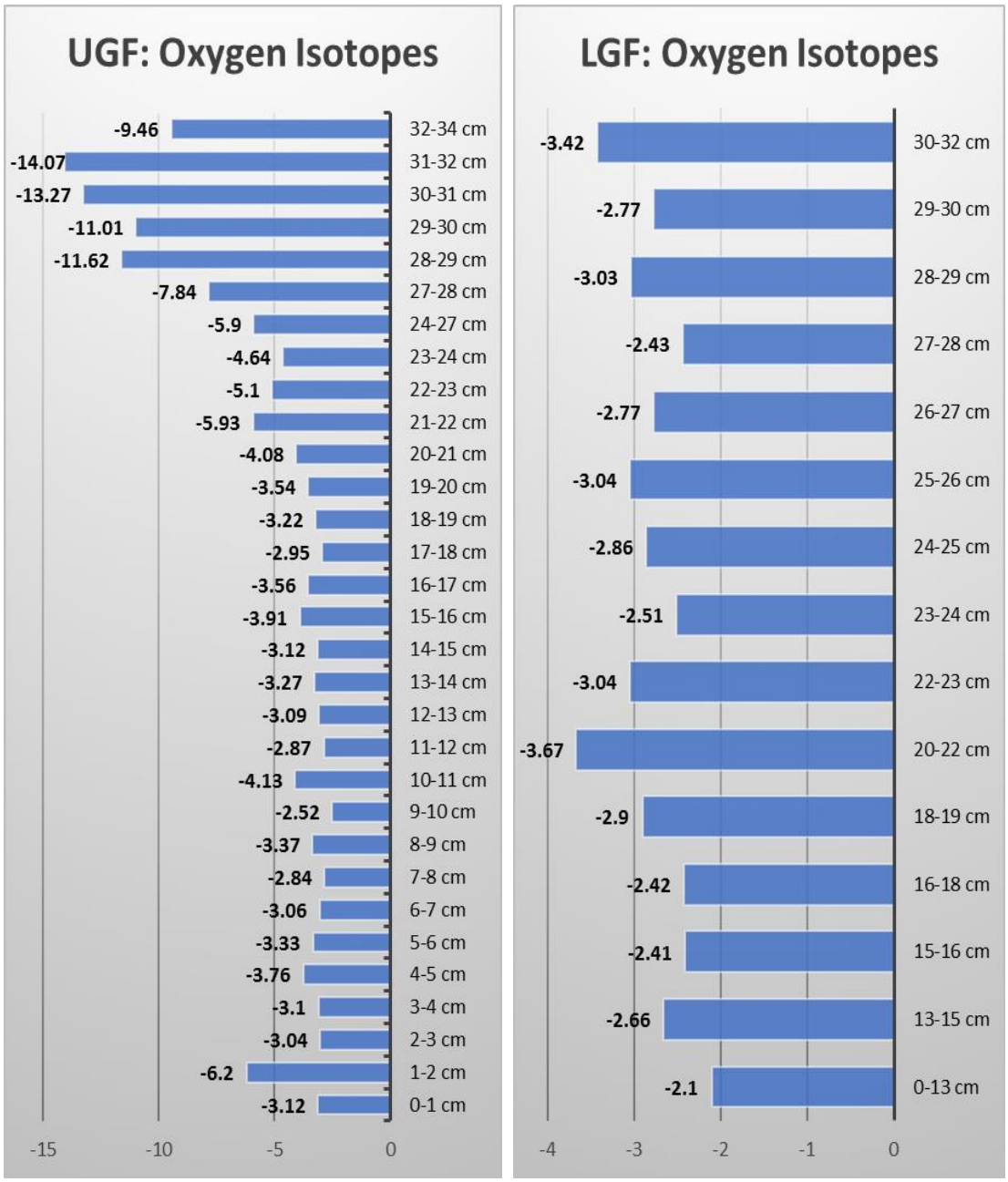

Figure 16: Upper and Lower Ghost Fish beds stratigraphic $\delta^{18}O$ (‰ VPDB) stable oxygen isotope graphs.

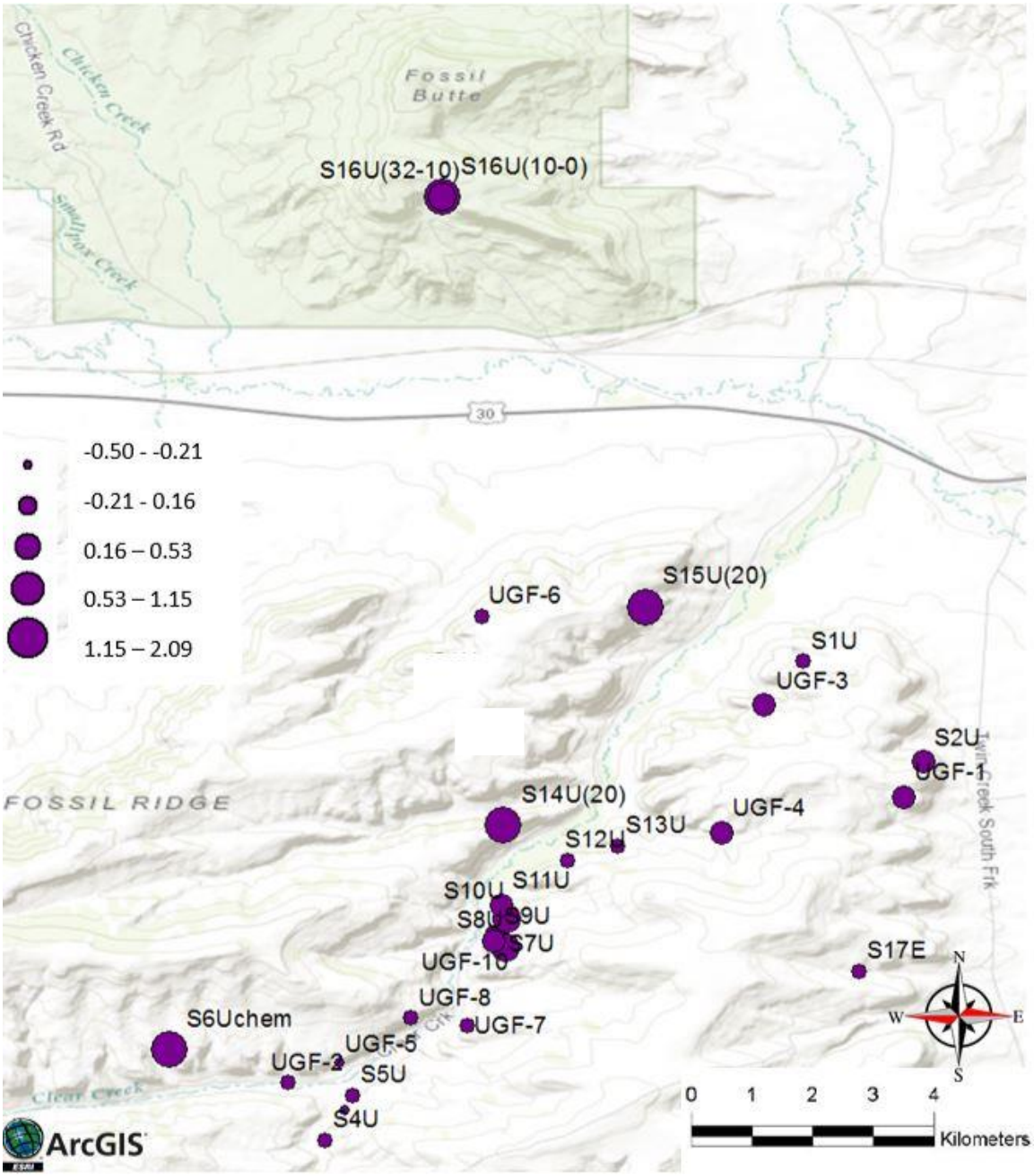

Figure 17: Upper Ghost Fish bed $\delta^{13}C$ (‰ VPDB) stable carbon isotope map. Samples taken from 20 cm above the base of the bed.

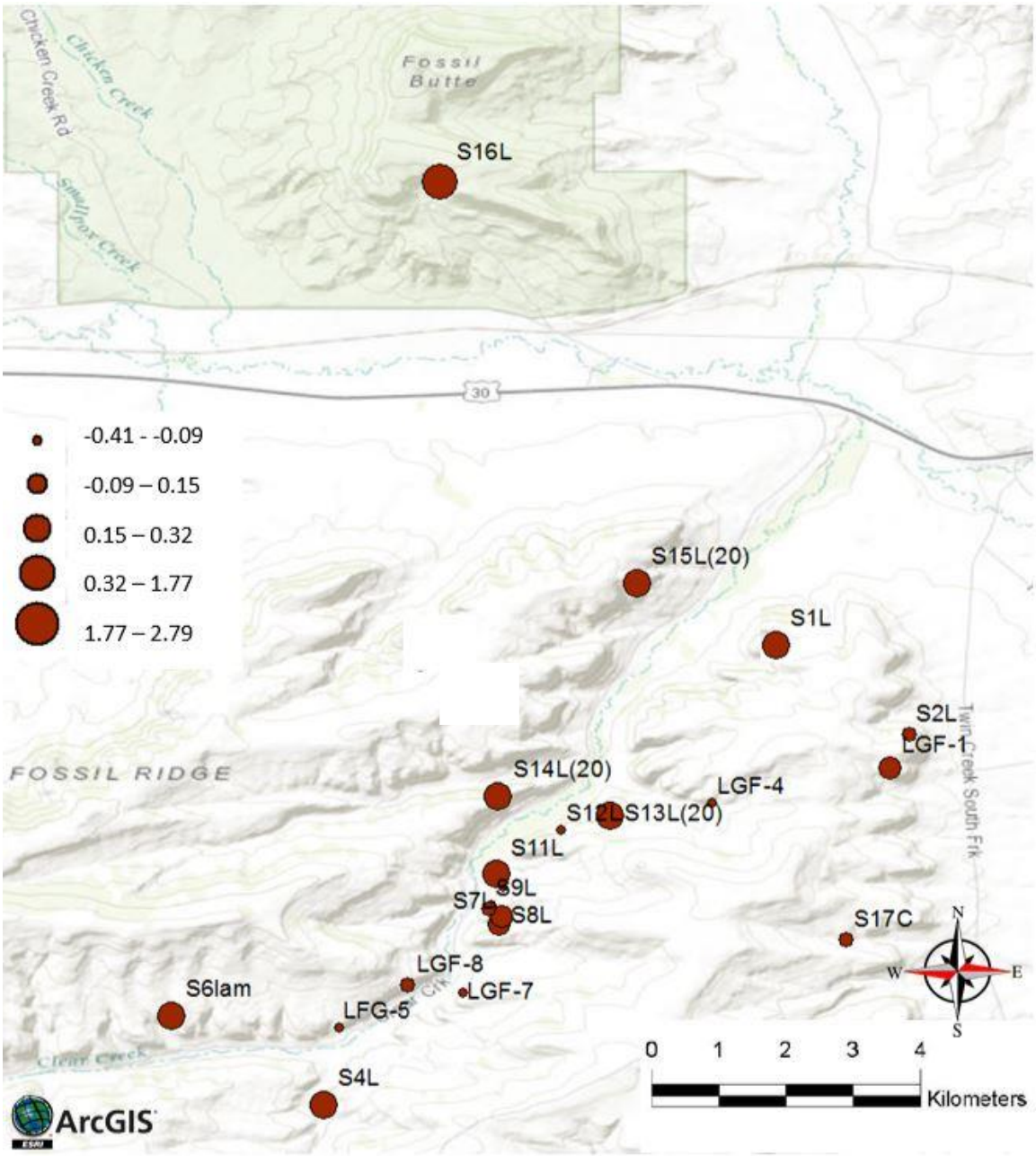

Figure 18: Lower Ghost Fish bed $\delta^{13}C$ (‰ VPDB) stable carbon isotope map. Samples taken from 20 cm above the base of the bed.

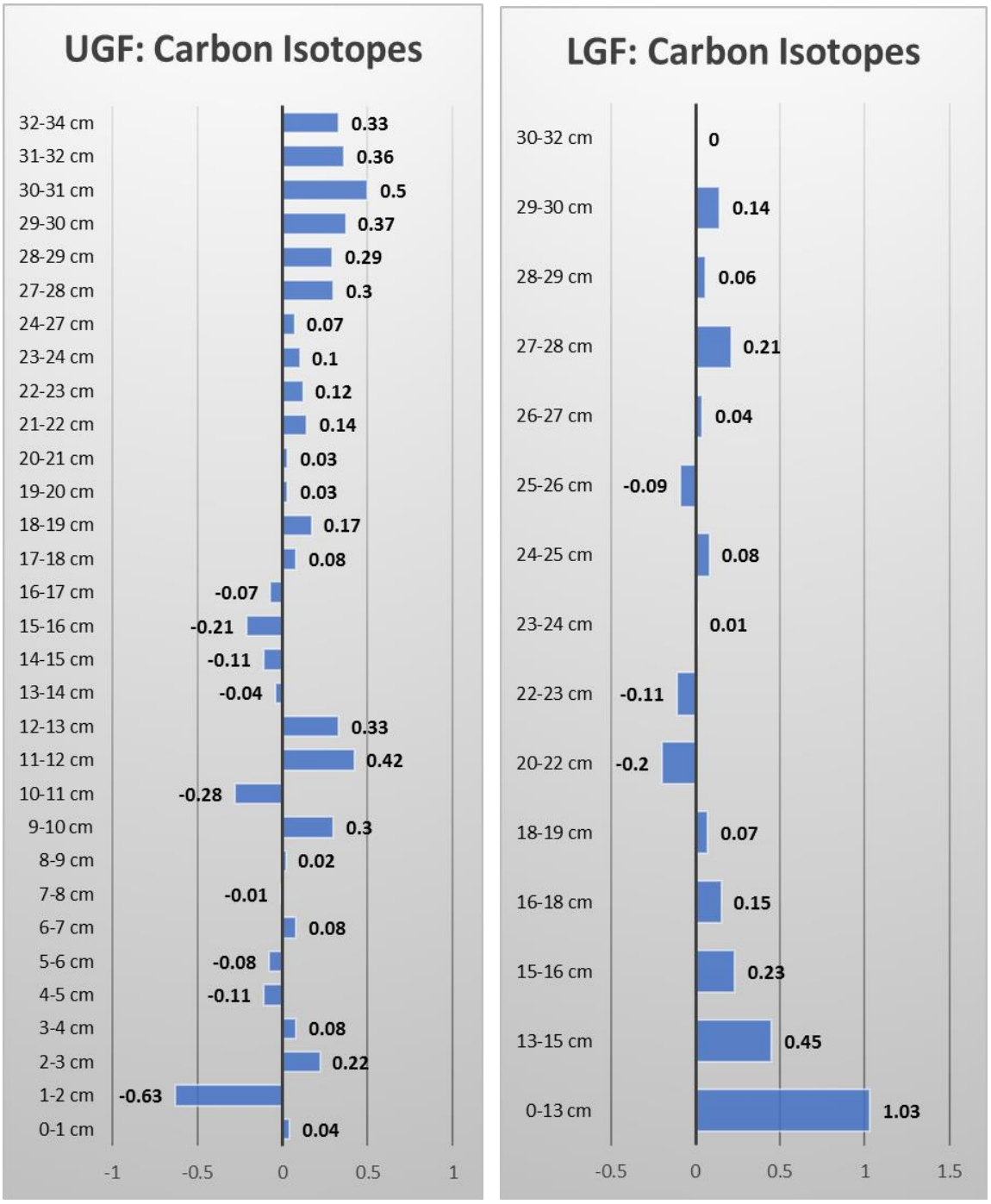

Figure 19: Upper and Lower Ghost Fish Beds vertical $\delta^{13}C$ (‰ VPDB) stable carbon isotope graphs.

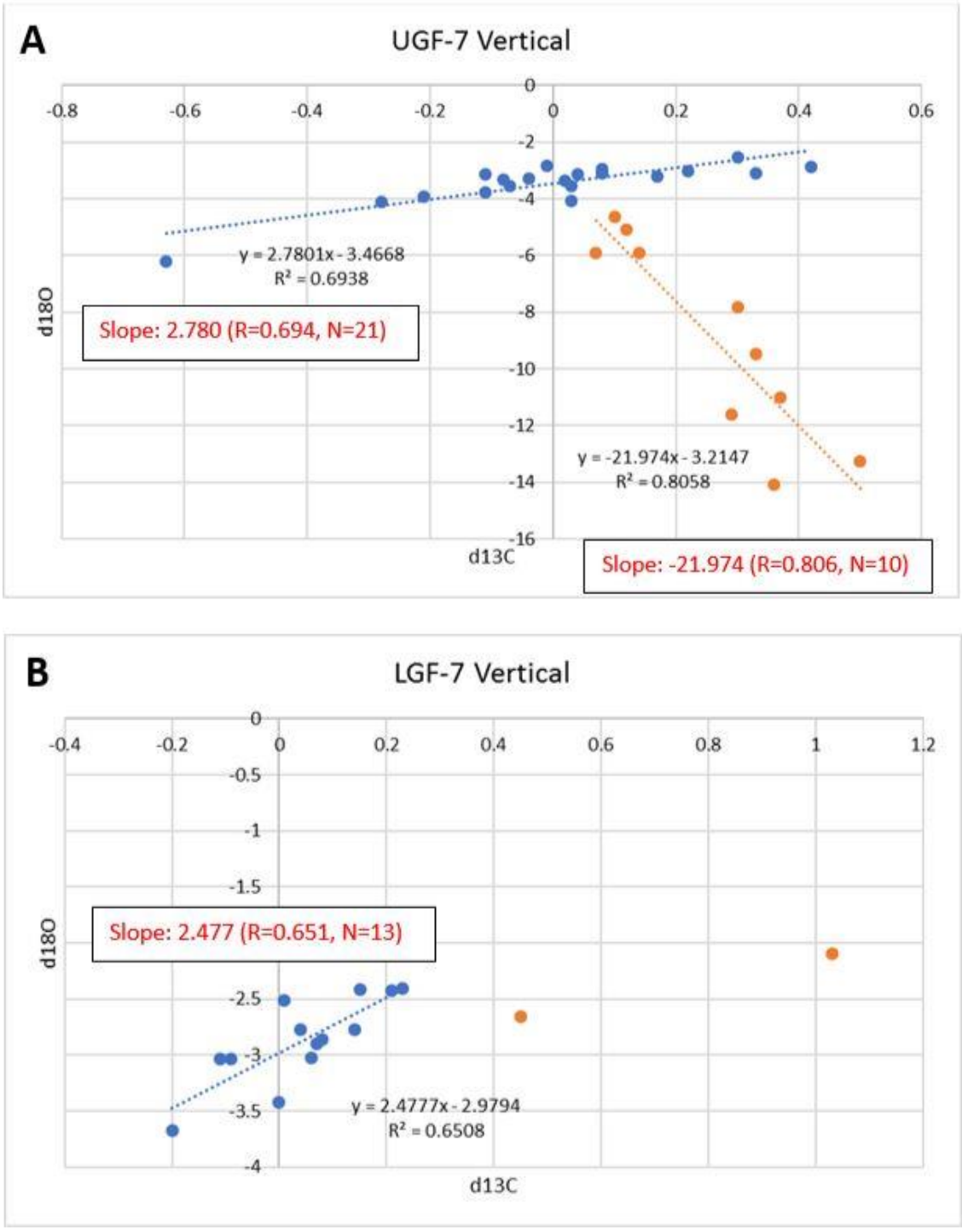

Figure 20: Isotopic covariance trend diagrams (‰ VPDB). (A) Ten samples from the top of the Upper Ghost Fish Bed (34-21cm) were plotted separately due because of diagenesis. (B) Two samples from the base of the Lower Ghost Fish Bed (0-15cm) were also plotted separately due to minimal carbonate content. These data sets have R-values of ~0.7, suggesting that Fossil Lake was a closed basin during the time the Ghost Fish beds were deposited.

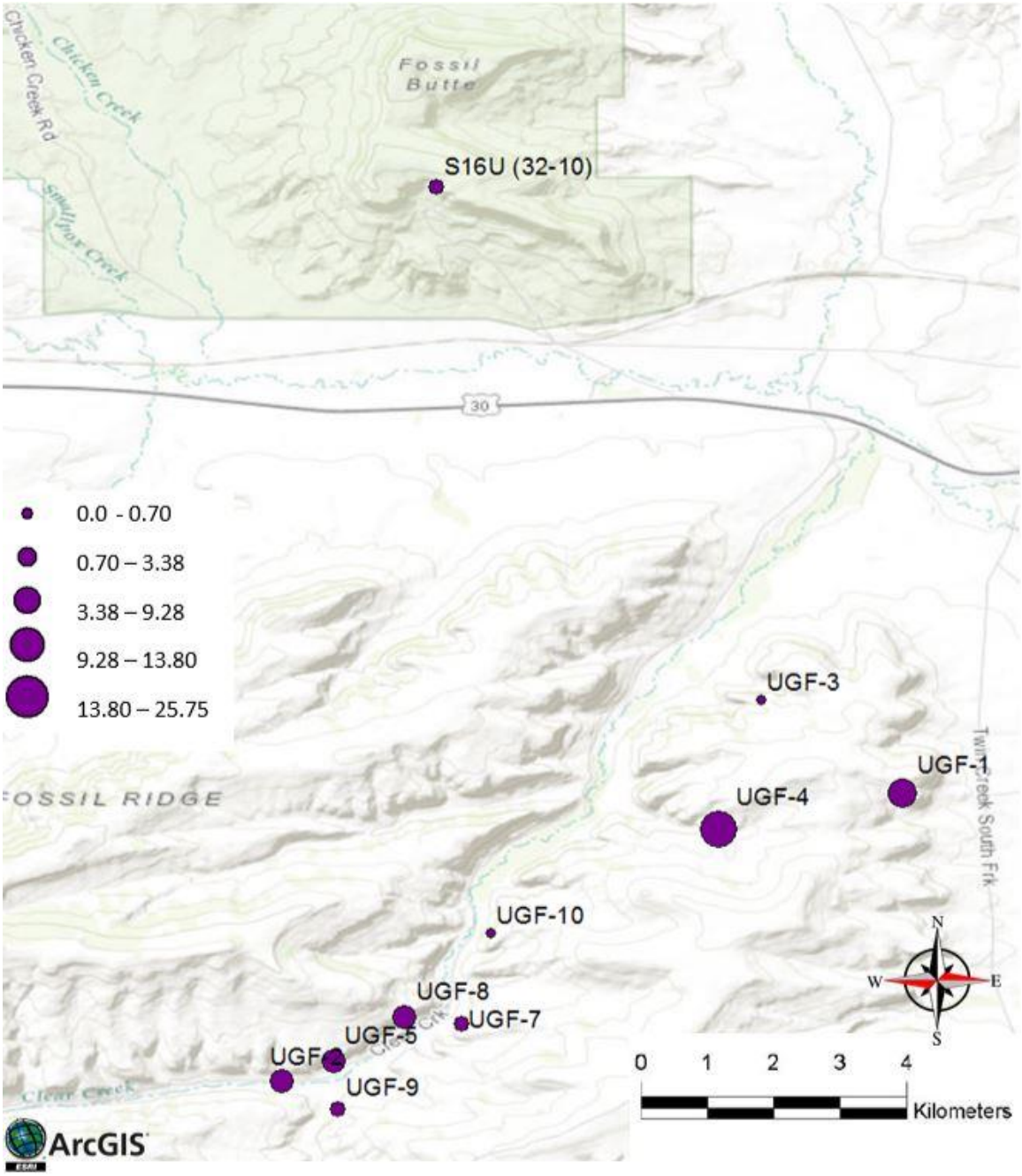

Figure 21: Upper Ghost Fish Bed TOC values map. Samples taken from 20 cm above the base of the bed.

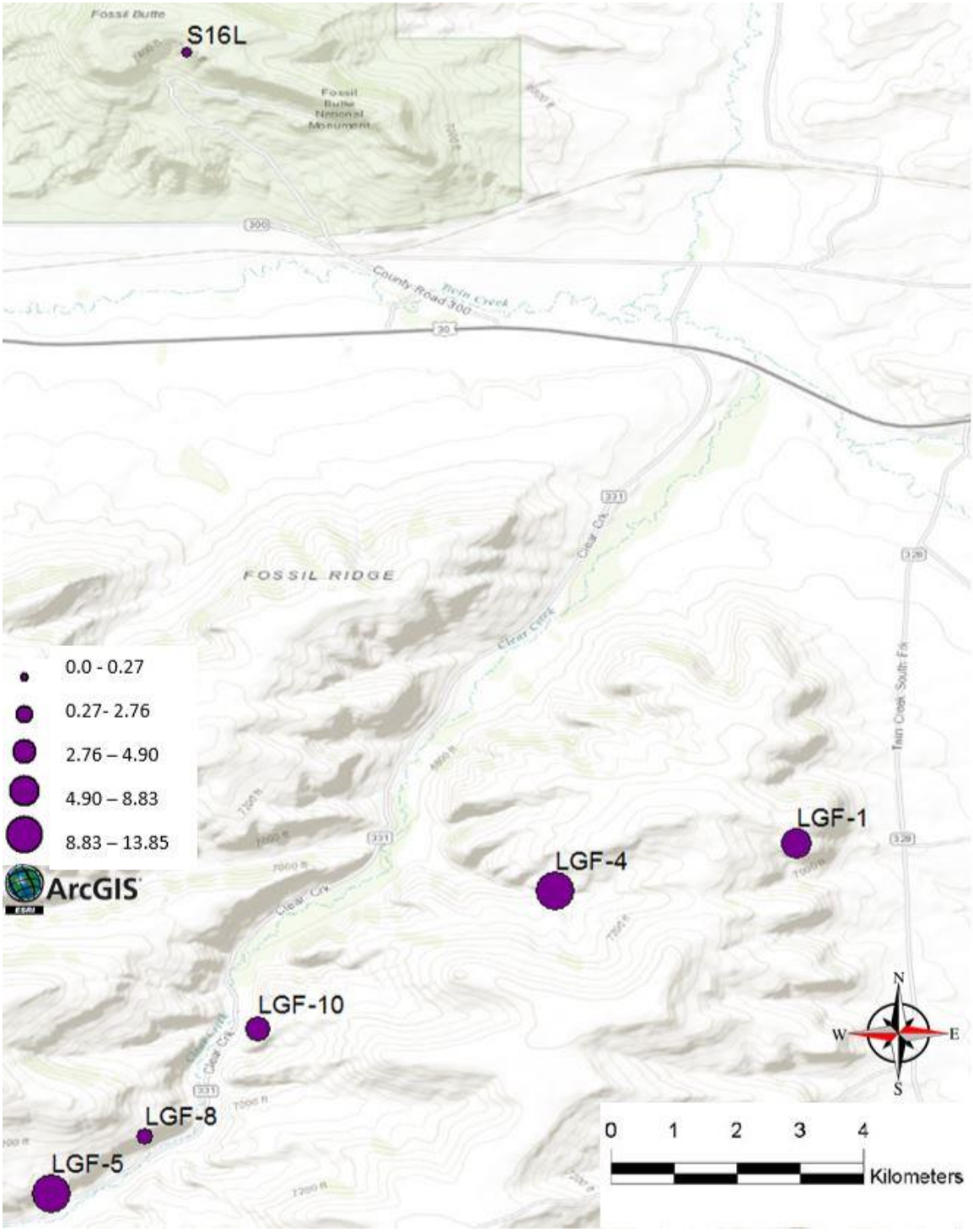

Figure 22: Lower Ghost Fish Bed TOC values map. Samples taken from 20 cm above the base of the bed.

Laminations / Thin Sections/ Chemoturbation

The Upper Ghost Fish bed has been heavily chemoturbated in many areas (Figure 23), making the comparison of laminae within and among locations very difficult (Figures 24, 25). Chemoturbation is the disruption of sediment due to chemical processes (Loewen, 1999). Most laminae are too distorted by secondary evaporite growth replaced with calcite to count or compare laminae between or within sections. The Lower Ghost Fish bed also has indistinctive laminae that could not be accurately counted (Figure 26).

Chemoturbation forms a distinctive boundary within the study area with chemoturbation in the NW half of the study area and normal laminations in the SE half of the study area (Figure 23). Chemoturbation is, for the most part, limited to the top half of the Upper Ghost Fish bed. Evaporite casts in the chemoturbated sections have been replaced by calcite. This can be seen in the thin sections at the top of each unit (Figures 24, 25).

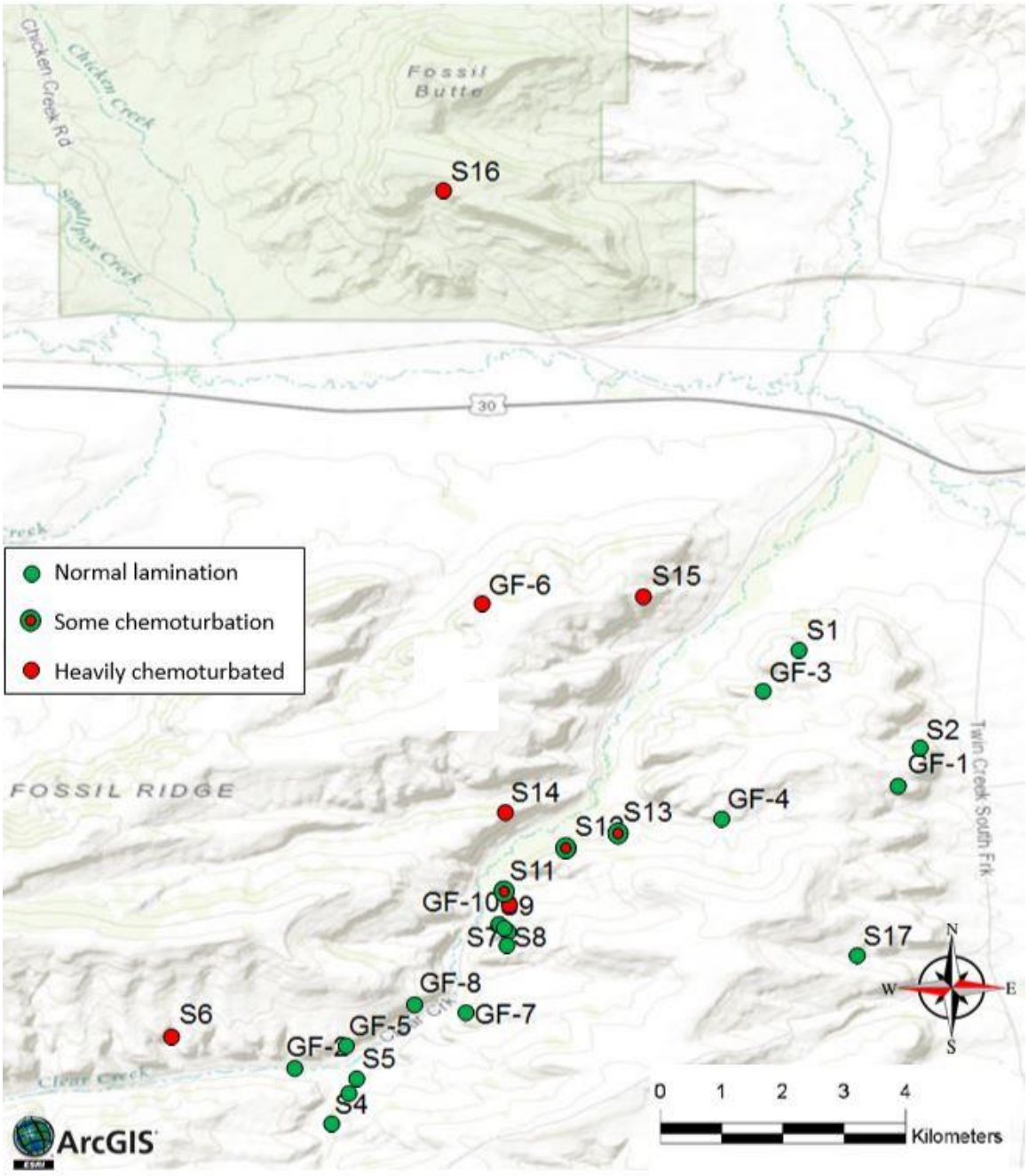

Figure 23: Map displaying variation in chemoturbation in the UGF bed. The NW half of study area is chemoturbated whereas the SE half of the study area contains undisturbed laminations. Amount of chemoturbation was determined in the field and was most likely an underestimate of number of locations affected by chemoturbation.

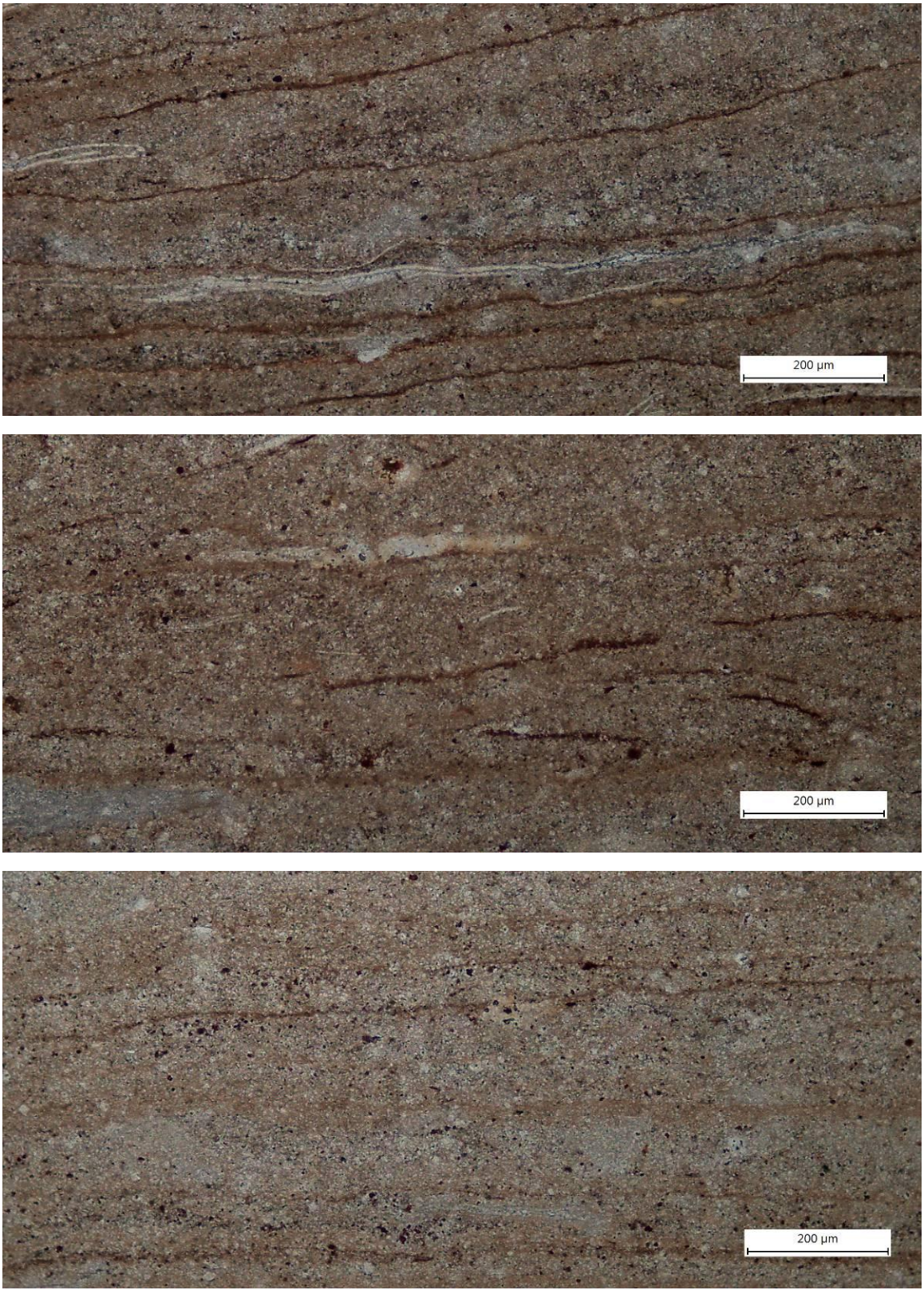

Figure 24: Thin sections from UGF-9. Samples are from the top, middle, and base of UGF-9. Organic laminae are clearer at the top of the bed.

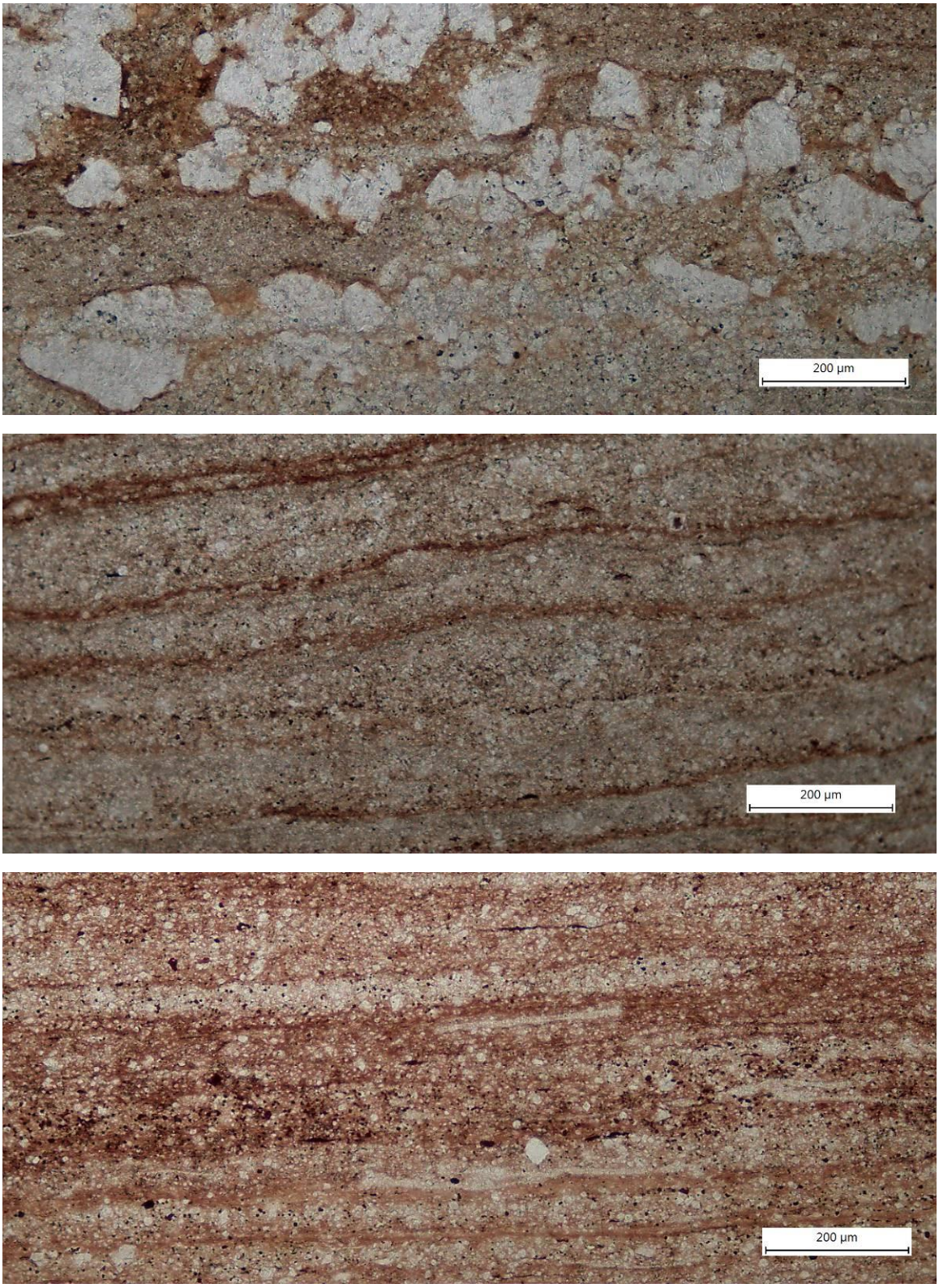

Figure 25: Thin sections from UGF-7. Samples are from the top, middle, and base of UGF-7. Sample from the top of UGF-7 contains evaporite casts filled with calcite.

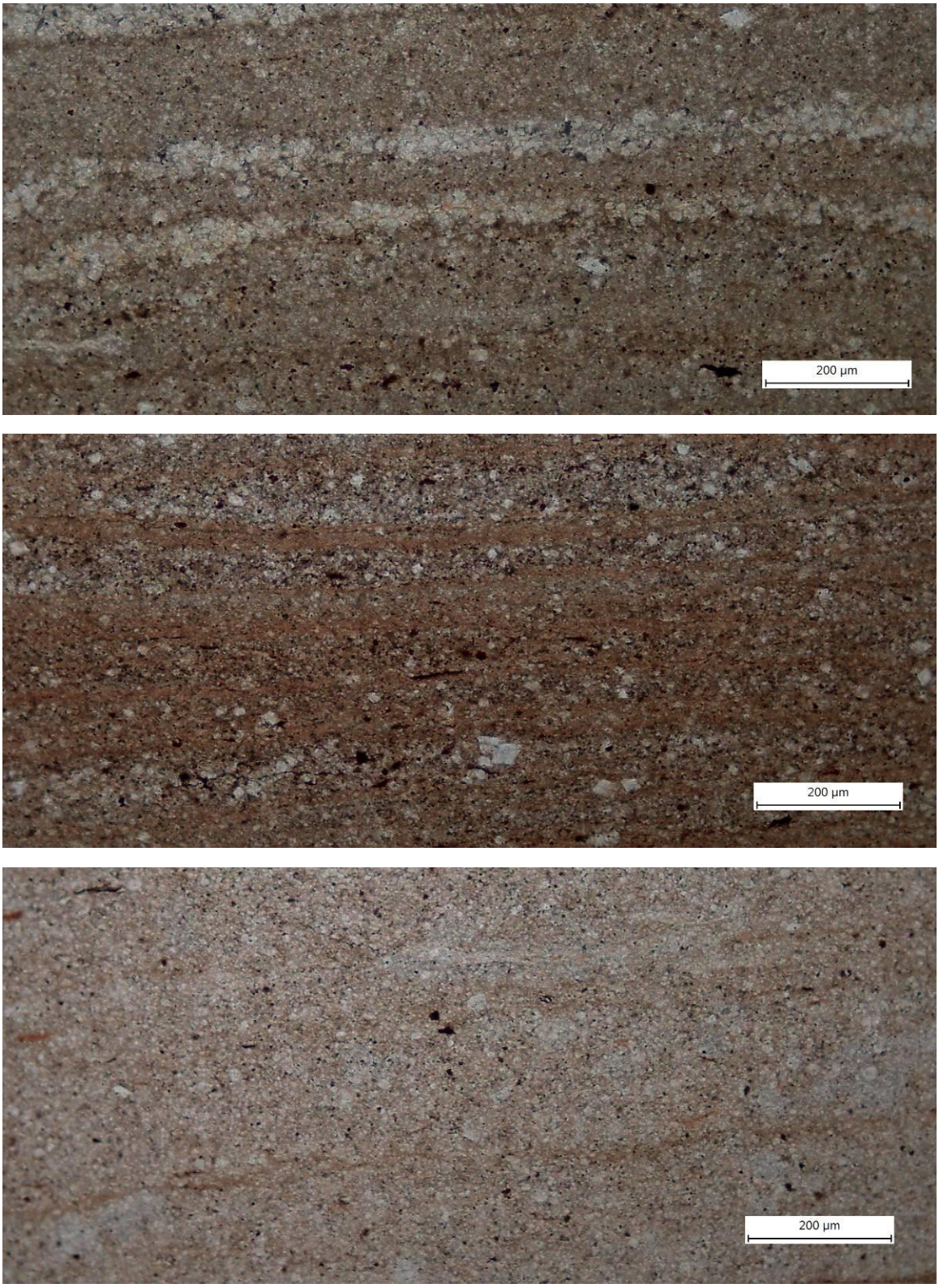

Figure 26: Thin sections from LGF-7. Samples are from the top, middle, and base of LGF-7. Organic laminae are clearer at the top of the bed.

Fossil Content

The Ghost Fish beds contain a variety of fossils including fish, plants, insects, and coprolites (Figures 27, 28, 29). The highest concentration of fish was typically found ~20 cm above the basal tuff in both the UGF and LGF (Appendix 7). Fish abundance in the UGF is highest in the SW region of the study area (Figure 30). The abundance of fish in the LGF is highest in the margins of the study area (Figure 31). Values were calculated using the number of fish recorded in each quarry per volume of rock and then extrapolated to 1 m^3. A variety of terrestrial plants including stems, leaves, and seeds were discovered at multiple locations (Figure 28). The only insects found are March flies from multiple locations (Figure 29).

Fossil Preservation

SEM analysis was the predominant method used to describe preservation of fossil Ghost Fish. Three types of preservation were discovered: Type 1) Some bone in vertebrae and rib regions with high amounts of carbon (Figure 32), Type 2) Bone replaced with feldspar (Figure 33), and Type 3) No 3-dimensionality, only a carbonaceous compression (Figure 34). 2-dimensional carbonaceous compressions are the only type in the Lower Ghost Fish Bed. The Upper Ghost Fish Bed contains all three types of preservation. Only three localities in the Upper Ghost Fish Bed appear to contain fossils with feldspar or bone (Figure 35). Almost all fossil fish were fully articulated.

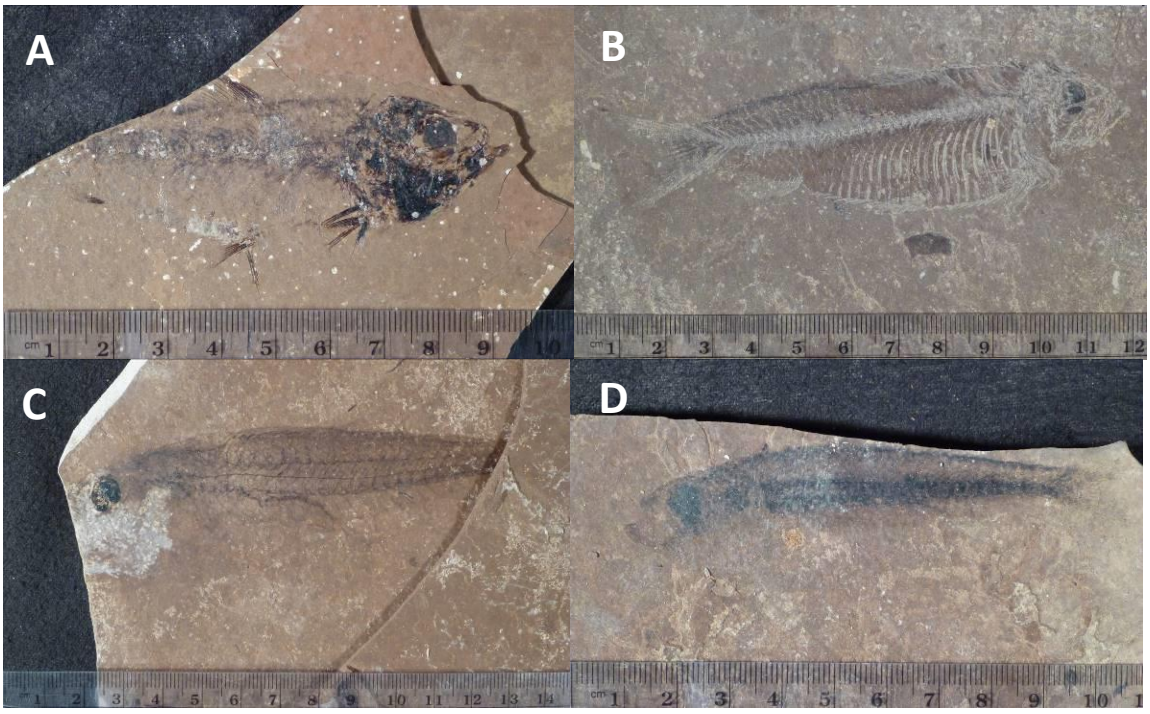

Figure 27: Photographs of fossil fish from multiple locations. Top two samples are from the UGF. Bottom two samples are from the LGF. Sample A is Type 1 preservation (bone with carbon). Sample B is Type 2 preservation (bone replaced by feldspar). Samples C and D are Type 3 preservation (2-dimensional carbon).

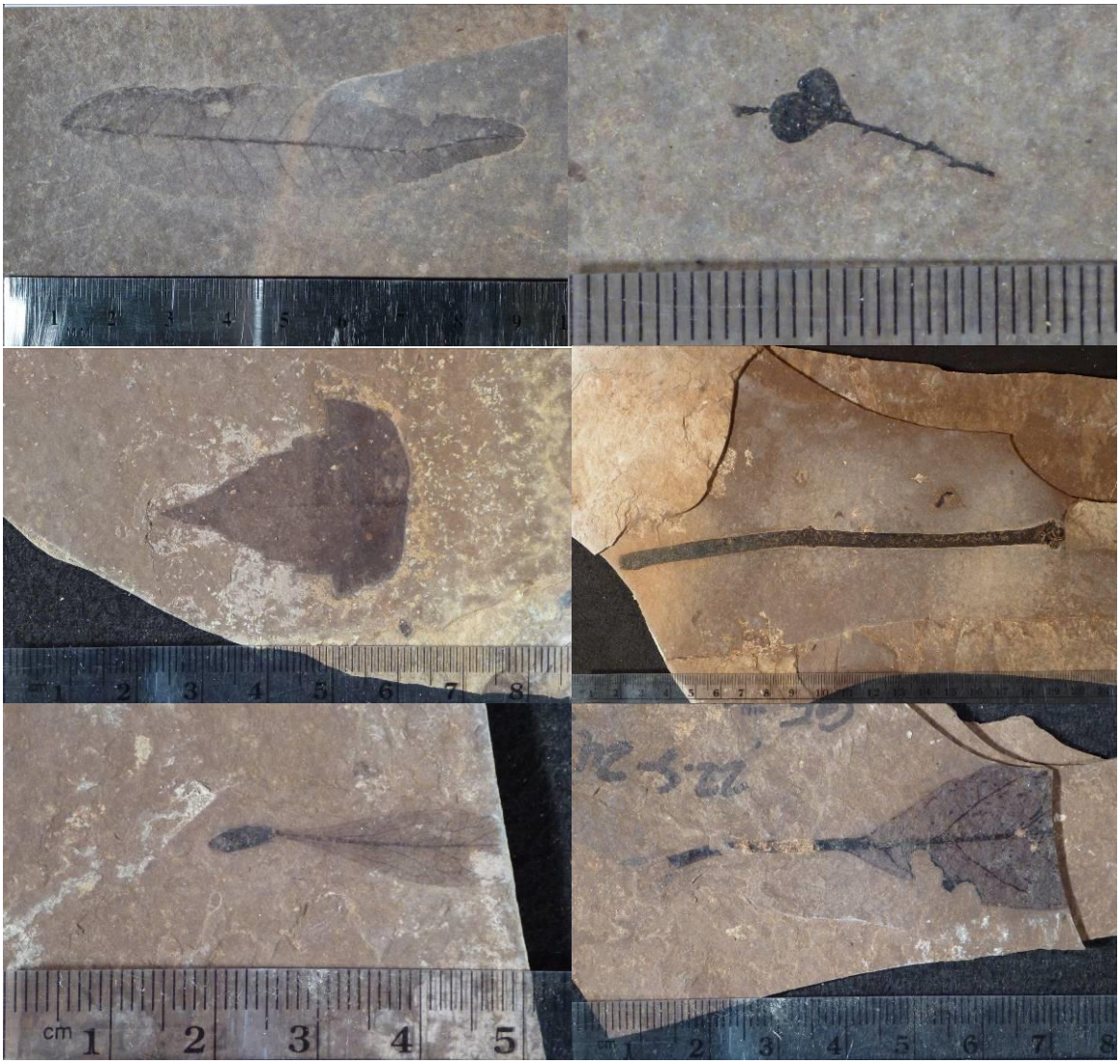

Figure 28: Photographs of fossil plants from multiple locations. These include stems, leaves, and seeds preserved as carbonaceous compressions.

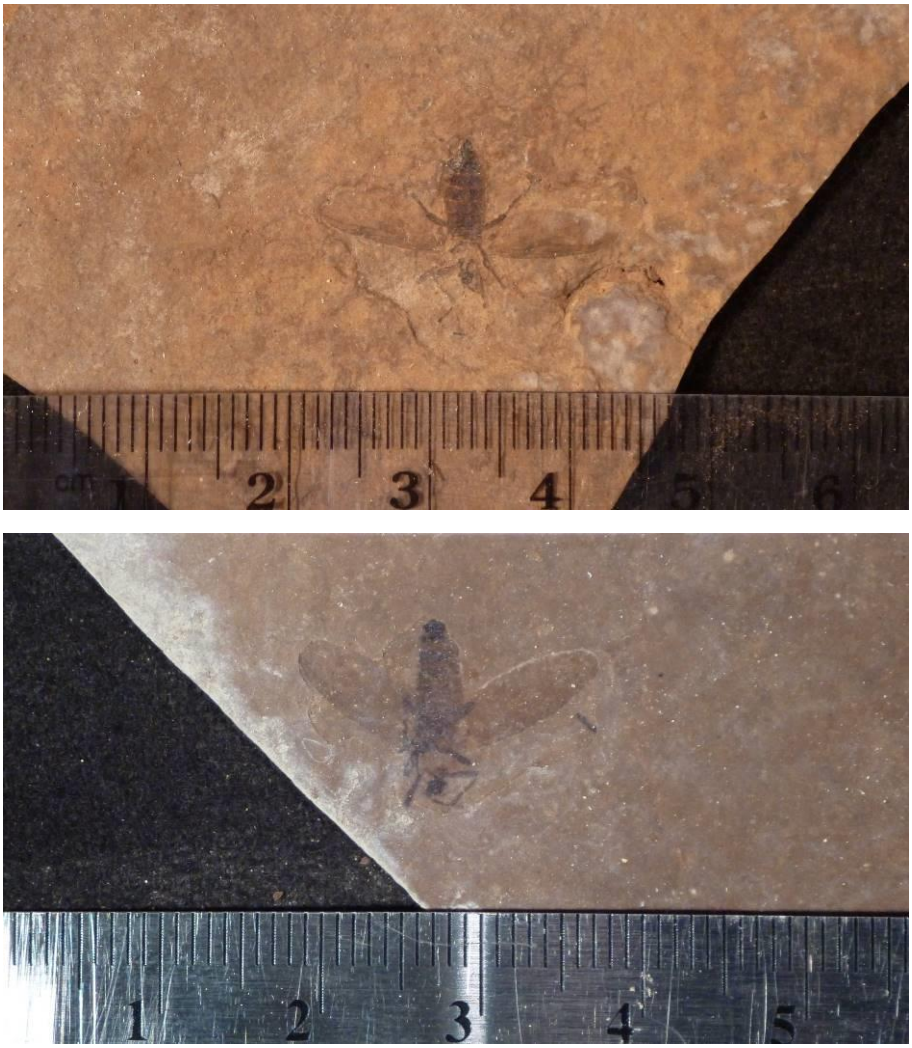

Figure 29: Photographs of March Flies preserved as carbonaceous compressions.

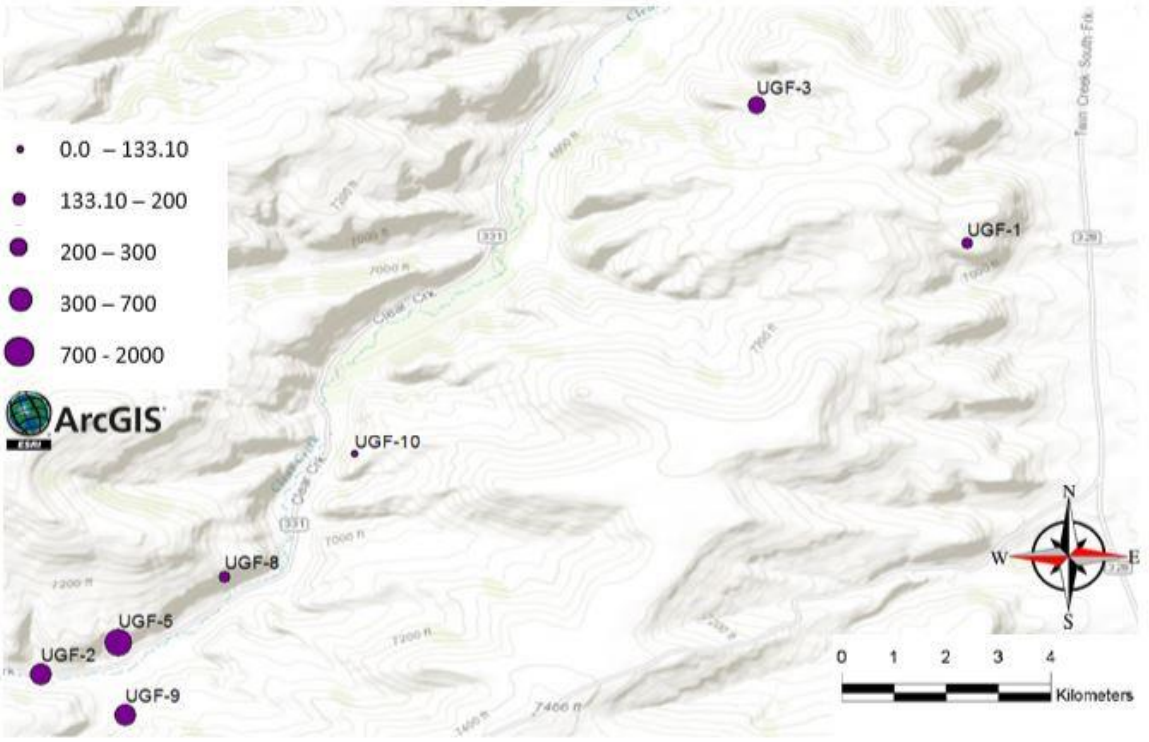

Figure 30: Upper Ghost Fish bed displaying estimated number of fish per m^3. Values were calculated using the number of fish recorded per volume of rock and then extrapolated to 1 m^3. Fish abundance is highest in the SW region of the study area.

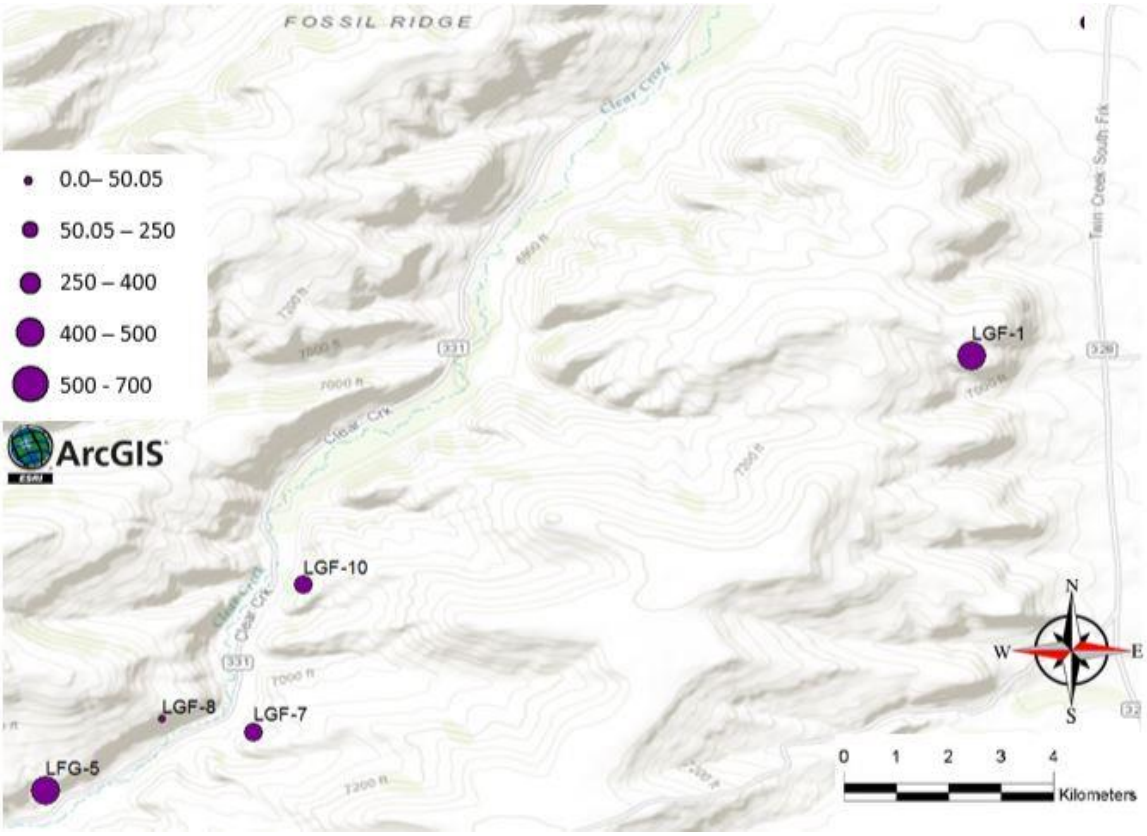

Figure 31: Lower Ghost Fish bed displaying estimated number of fish per m^3. Values were calculated using the number of fish recorded per volume of rock and then extrapolated to 1 m^3. Fish abundance is highest in the margins of the study area.

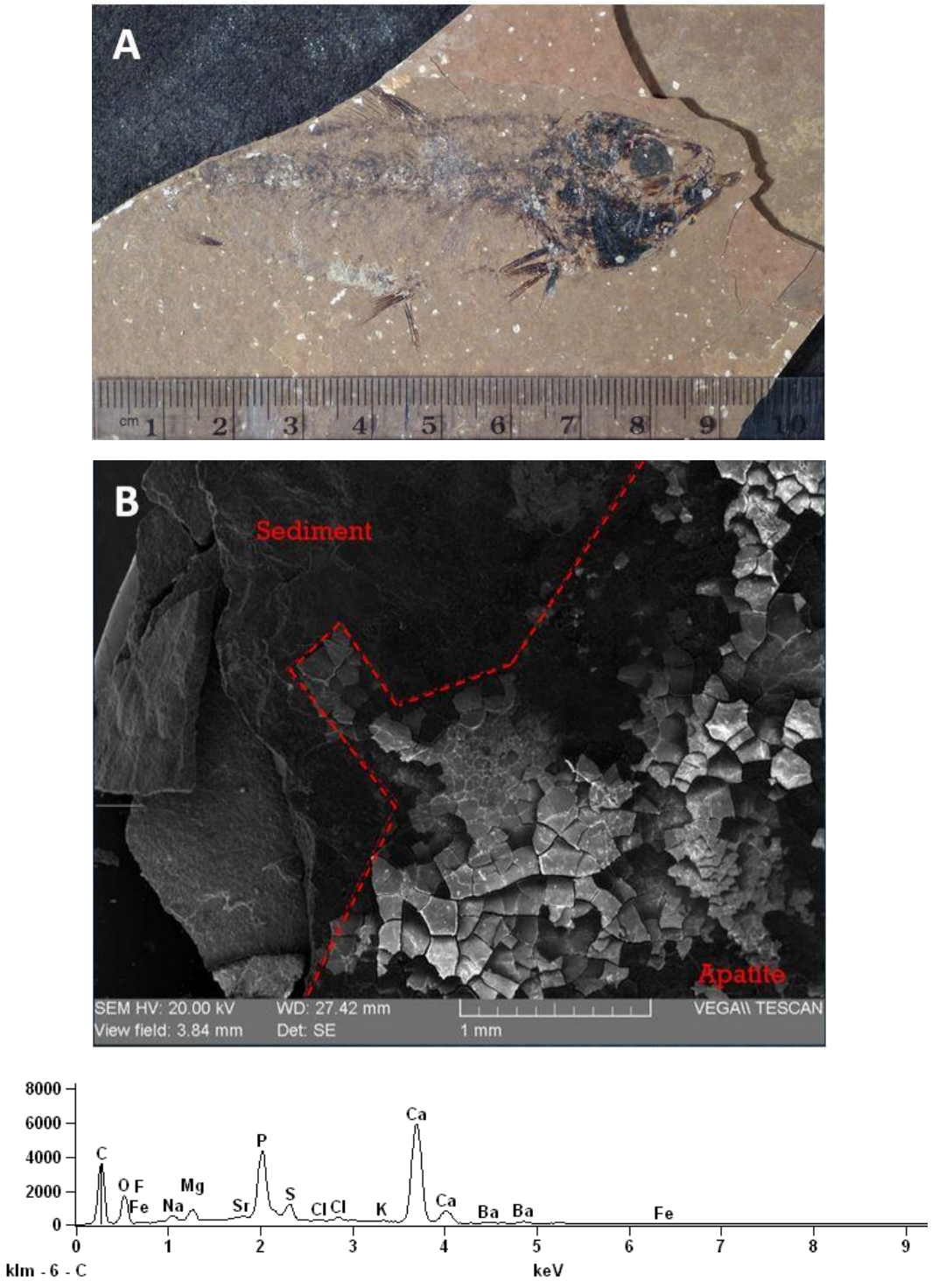

Figure 32: Type 1 fossil preservation: bone with high amounts of carbon. The SEM image shows the boundary between the fish head and sediment. The EDS plot shows element content of the bottom right corner which is high in carbon and apatite ($Ca_5(PO_4)_3(OH,F,Cl)$). Au/Pd coating values were removed from the plot.

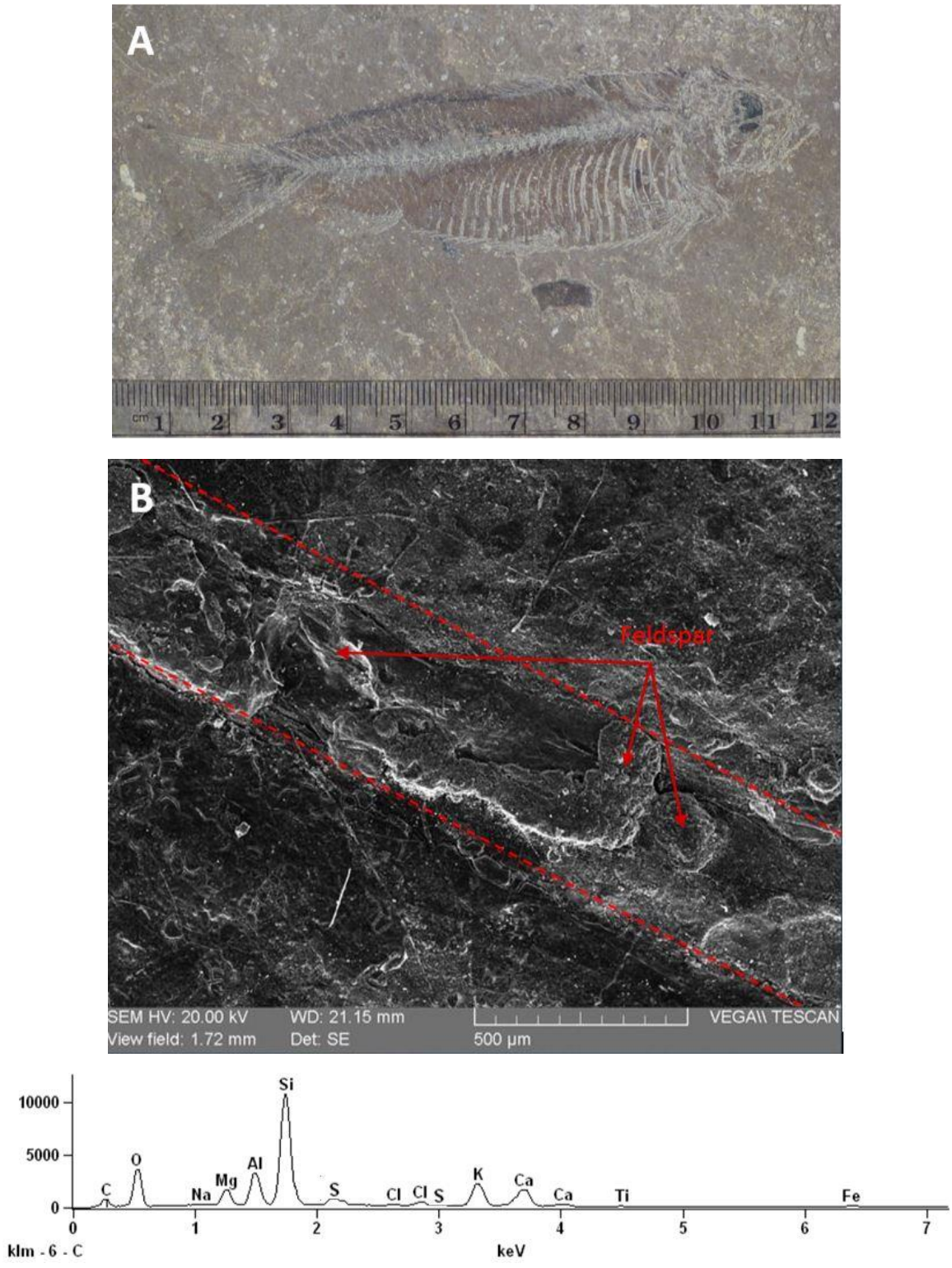

Figure 33: Type 2 preservation: bone replaced by feldspar. The SEM image shows feldspar where a rib bone previously existed. The EDS plot shows element content of the rib area which is high in feldspar ($KAlSi_3O_8$). Au/Pd coating values were removed from the plot.

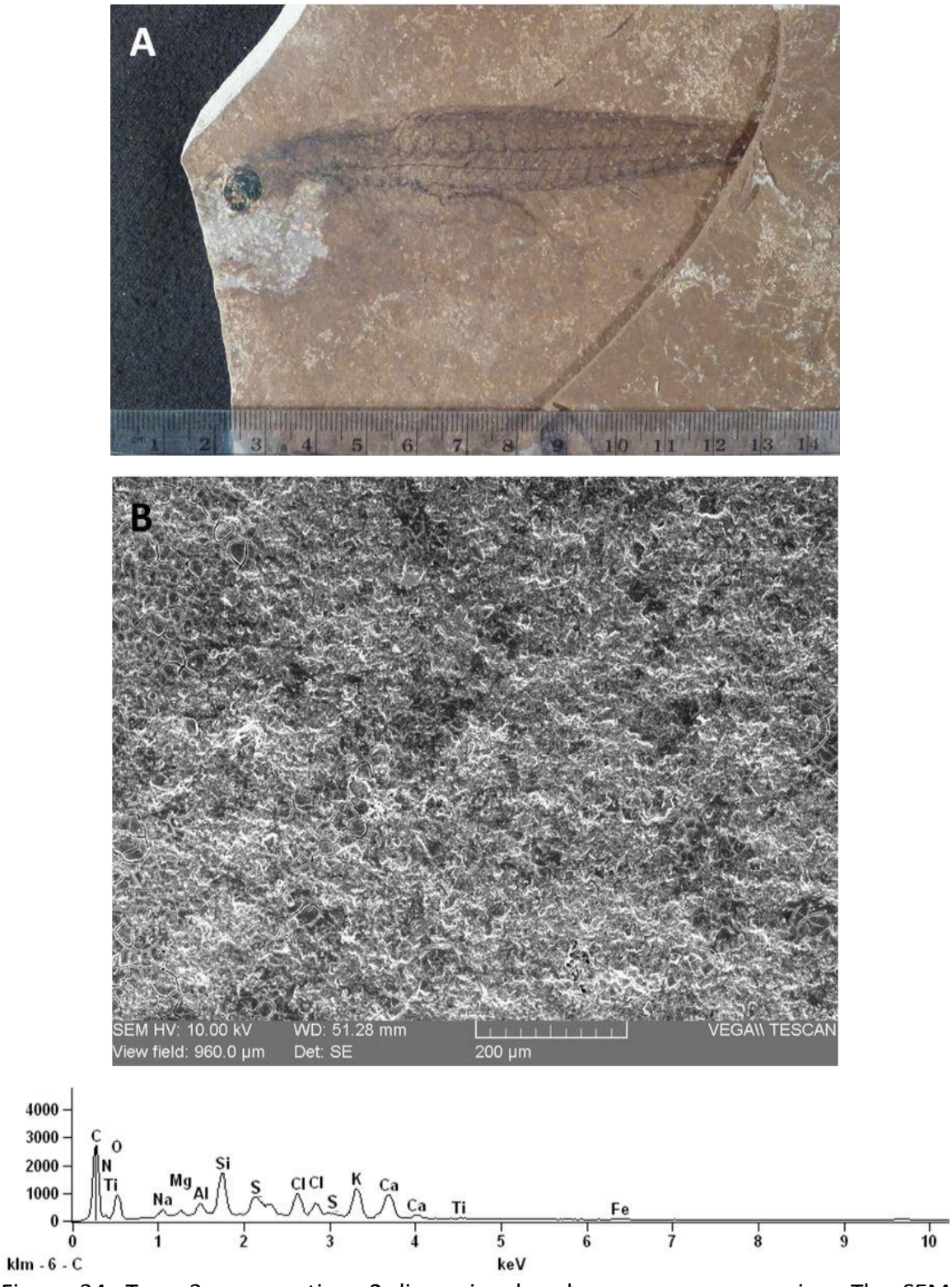

Figure 34: Type 3 preservation: 2-dimensional carbonaceous compression. The SEM image shows no 3-dimensionality. The EDS plot shows element content, with the highest peak as carbon. Au/Pd coating values were removed from the plot.

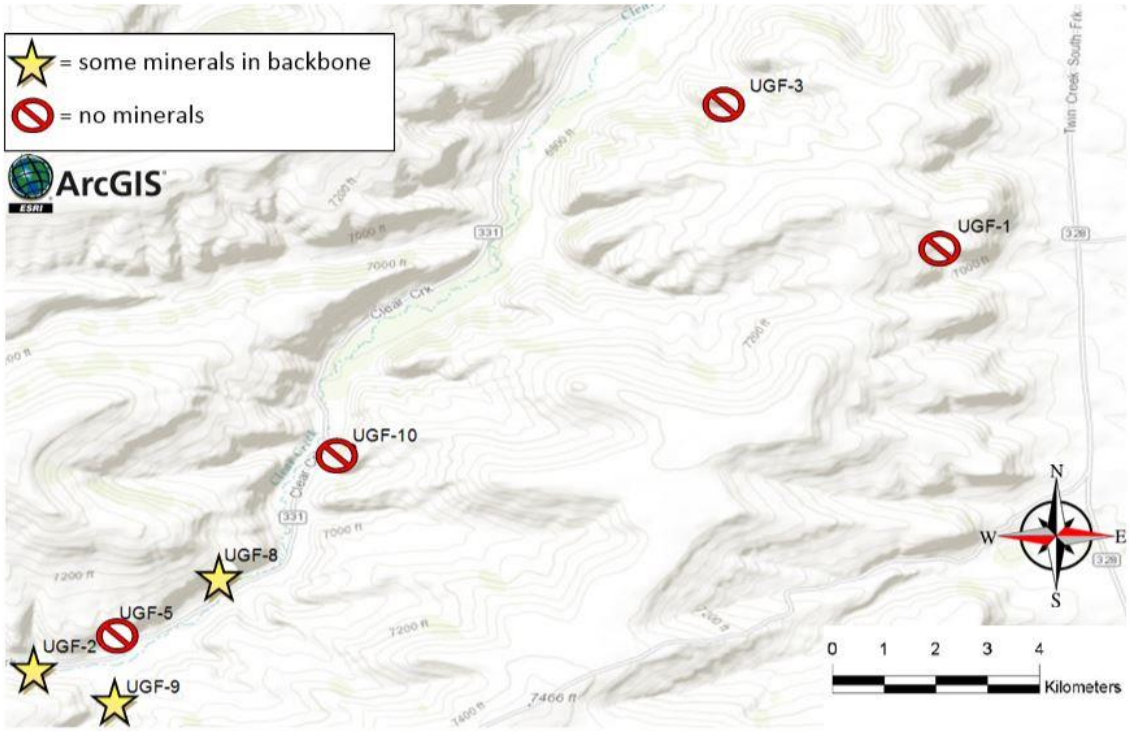

Figure 35: Map displaying types of preservation. Only three localities (UGF-2, UGF-8, UGF-9) in the Upper Ghost Fish Bed contain fossils with minerals in the backbones. No fish in the Lower Ghost Fish Bed have minerals. These values were determined using field observations.

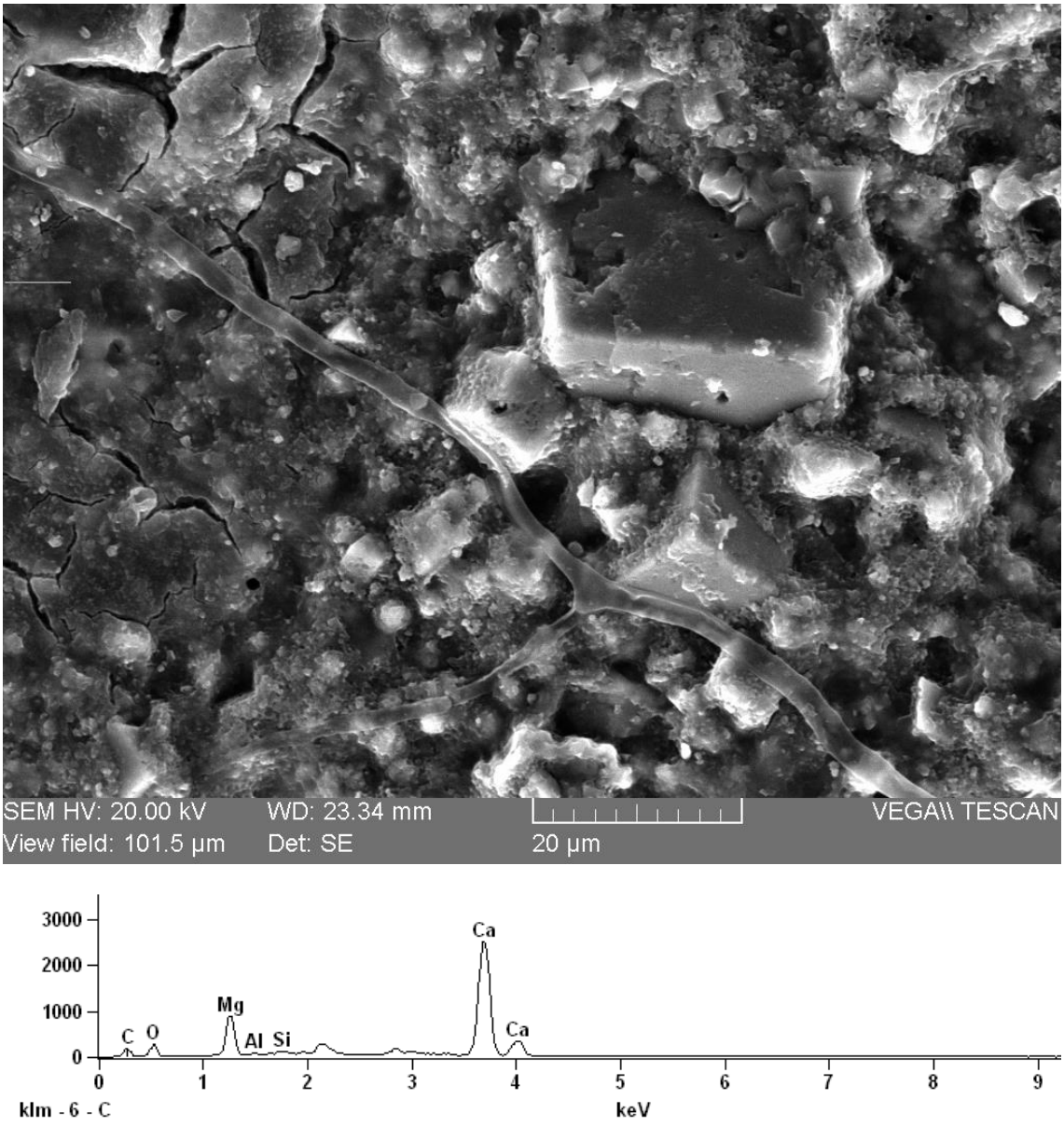

Figure 36: Authigenic dolomite in matrix. The rhombohedral shape implies that dolomite was precipitated within the lake rather than being transported into the lake. The sample is from UGF-9.

CHAPTER 4

DISCUSSION

Fossil Lake, including the Angelo Member, is recognized as a hydrographically closed basin through most of its existence (Buchheim, 1994a). Talbot (1990) has used isotopic covariance of oxygen and carbon in carbonates to determine whether lakes are hydrographically open or closed. R values of ~0.7 or higher are indicative of hydrographically closed basins. Isotopic covariance diagrams from the Ghost Fish beds have R values of ~0.7, suggesting that at the time of deposition, Fossil Lake was a hydrographically closed basin.

The Angelo Member time is also recognized as a hypersaline period during Fossil Lake's history (Amato, 2008). Fewer known fossils were preserved during this period than the Fossil Butte Member, one exception being a layer in the White Marker Bed. This layer recorded a period of increased P/E (precipitation/evaporation ratio) and lake freshening that allowed for organism habitation, and ultimately, fossil preservation (Amato, 2008). This project suggests that the Ghost Fish beds were also deposited during periods of higher P/E in a hypersaline lake. Supporting the hypothesis of an increase in fresh water is the presence of large amounts of carbonate mudstone. These mudstone layers often occur directly below both beds, and at times, replacing the LGF bed and/or replacing or mixing with the tuff at the base of the UGF bed (Appendix B). This mud may have washed into the lake during a heavy rain or flooding event.
The presence of fish and calcite in Fossil Lake is indicative of freshwater conditions while other variables suggest a hypersaline environment. Authigenic dolomite (Figure 36)

confirms the hypothesis that dolomite was precipitated within the lake. This often occurs in a hypersaline lake environment (Wolfbauer and Surdam, 1974). Chemoturbated sediments also support the hypersaline hypothesis and are especially common in the NW half of the study area (Figure 26). Another indicator supporting a hypersaline lake is the presence of tuff beds composed of K-feldspar, most likely an authigenic mineral that was created through syndepositional alteration of the original volcanic ash. For this to occur, Fossil Lake would have to be highly saline and alkaline, with a pH of 10 or greater (Buchheim, 1994a). The presence of freshwater and hypersaline indicators is most likely due to a stratified water column with a freshwater upper layer and hypersaline bottom layer. It could also be due to a freshwater hypopycnal flow from the lake margins, flowing over a hypersaline lake.

A distinctive difference in the sediment's elemental composition was observed in XRF results with a much larger amount of Si, Ti, Al, Fe, Mg, K, Ni, Cr, Ba, Zr, Ga, Cu, and Zn and a much smaller amount of P than the famous 18-inch layer (Appendix B). These differences in element concentrations may be attributed to a combination of two things. First, the 18-inch layer was deposited in fresh water (Buchheim & Eugster, 1984), resulting in a 93% calcite composition whereas the Ghost Fish beds typically contain 70 % or less calcite (Appendix: Table 3). In order to better compare element compositions, data values need to be normalized in relation to calcium. Second, the presence of tuff at the base of both the upper and lower Ghost Fish beds, a 0.25 cm tuff in the middle of the UGF bed, and tuff interbedded with the carbonate layers at some locations may have contributed to elemental differences.

In the LGF bed, calcite is highest near the center of the study area (Figure 11). $\delta^{18}O$ values are more negative, also near the center of the study area (Figure 15). Fish count is highest in the margins of the study area (Figure 29). The results suggest that in the LGF bed, water was fresher in the center of the study area rather than more saline. Fish abundance, however, is compatible with the presence of inflow along the lake margins, providing freshwater regions. Previous research supports a saline lake center with freshwater margins (Loewen, 1997). This is most likely the same in the lower Ghost Fish bed.

Laterally across the UGF bed, calcite percentages are higher in the SW half of the study region (Figure 10). $\delta^{18}O$ values are more negative near the center of the study region (Figure 14). Fish count is highest in the SW region of the study area (Figure 28). Chemoturbation is most prevalent in the NW half of the study area (Figure 27). Large amounts of mudstone and the occasional absence of the LGF bed are observed in the SW region of the study area. This may be due to a freshwater stream entering the lake from the SW, resulting in a higher fish abundance, more negative $\delta^{18}O$ values, higher calcite percentages, and thick mudstone beds. These results suggest water was most fresh in the SW region of the study area and most saline in the NW. This is compatible with research completed by Trivino (1996) and Amato (2008), concluding that Fossil Lake was fresher in the south and hypersaline in the north.

Vertically in the UGF bed, dolomite and $\delta^{18}O$ values are consistent from the base to the top of the bed (Figure 37). These values are based on data from GF-7 in the south section of the study area and may vary from other locations. Values from UGF-7 may

not reflect original lake conditions accurately due to secondary calcite crystal growth, especially in the top of the section.

Vertically in the LGF bed, dolomite, $\delta^{13}C$, and $\delta^{18}O$ values are consistent from the base of the bed to the top of the bed (Figure 38). These values are based on data from GF-7 in the south section of the study area and may vary from other locations.

Fossil preservation differs between the lower and upper Ghost Fish beds. The LGF bed contains only Type 3 preservation: 2-dimensional carbonaceous compressions. The UGF bed contains all three types of preservation. Most UGF quarry locations contain only Type 3 preservation except for UGF-2, UGF-8, and UGF-9. These three quarries are all located in the SW region of the study area, the same region displaying high amounts of calcite and high fish abundance. This preservation with bone present correlates with fresher water conditions, like those observed with other fish preserved in Fossil Basin.

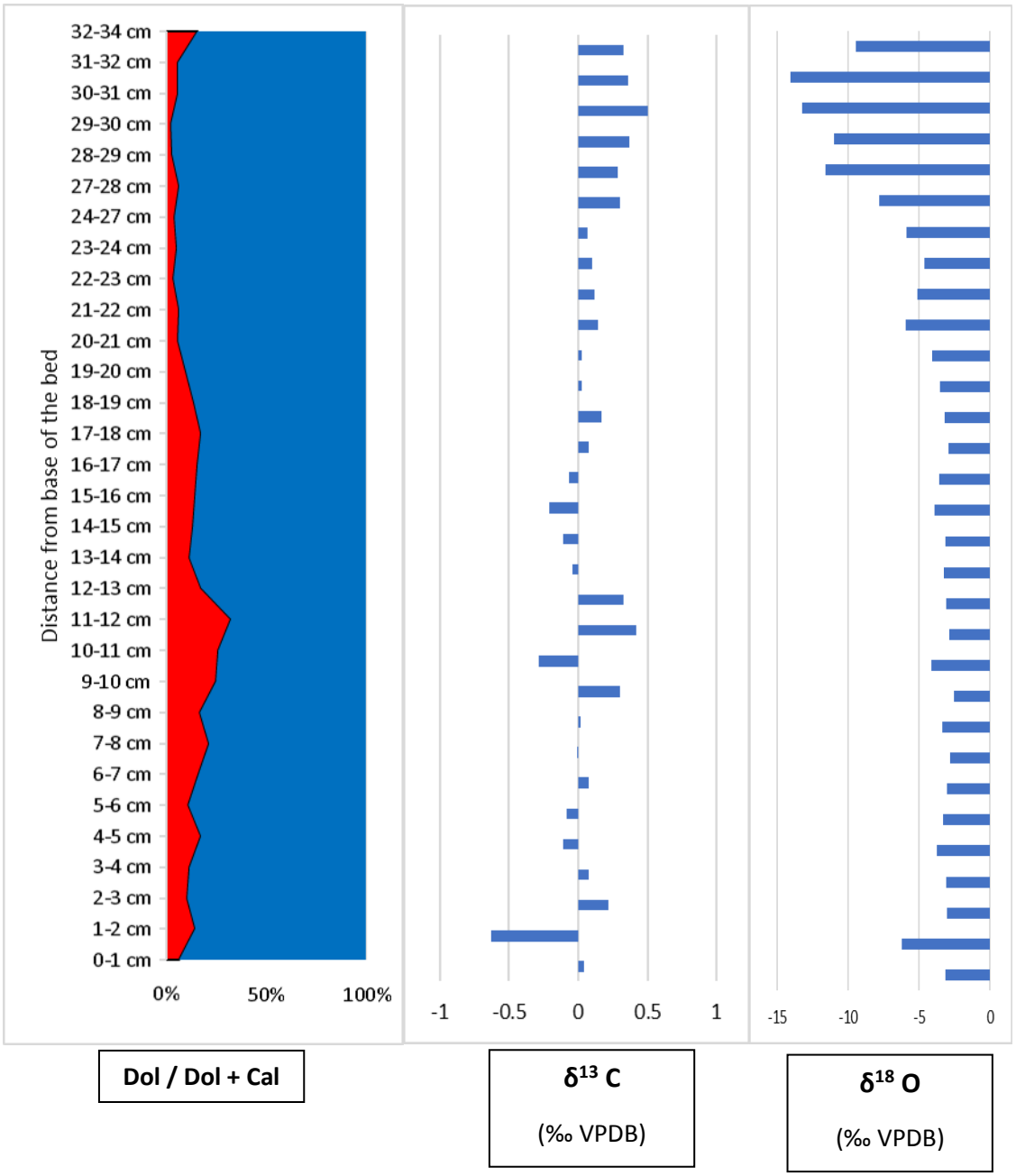

Figure 37: Upper Ghost Fish bed summary diagram from UGF-7. Values are fairly consistent with the exception of $\delta^{18}O$ which becomes more negative at the top of the UGF most likely due to calcite replacing evaporite casts.

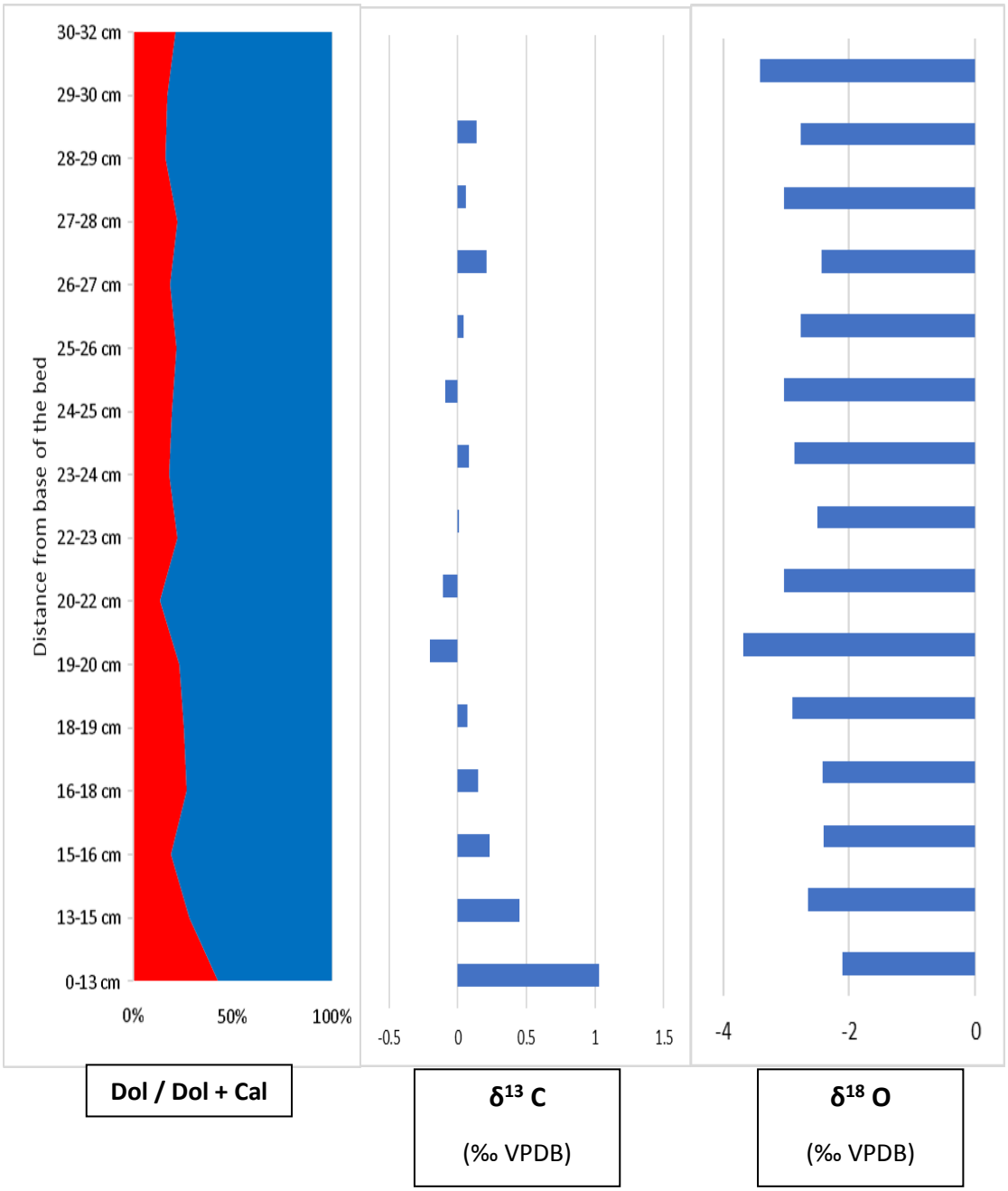

Figure 38: Lower Ghost Fish bed summary diagram from LGF-7. Values are fairly consitent.

Alkaline lakes are characterized by a combination of conditions including a closed basin, low P/E rates, a limited supply of soluble calcium and magnesium, and the presence of photosynthesizing organisms (Grant, 2006). Many alkaline lakes are stratified, hosting a fresher, oxygenated upper layer and a saline, anoxic lower layer (Buchheim & Surdam, 1977). These are the conditions that this project's data suggests existed within Fossil Lake during the deposition of the Ghost Fish beds.

Research by Bell, Mika, and Krueger (1978) and Wilby (1996) suggest that a highly alkaline and saline solution with the presence of dissolved carbonate can cause hydroxyapatite to become unstable and dissolve. Research by Parsons-Hubbard et al. (2008) suggests these same conditions also have the ability to preserve soft tissue. In addition, a high pH would aid in suppressing bacterial activity causing soft tissue decay (Parsons-Hubbard et al. 2008). Similar conditions to those studied in these experiments existed during the deposition of the Ghost Fish beds and are thought to be the explanation behind the lack of bone and preservation of soft tissues.

Microbial mats on Fossil Lake's bottom may also have aided in bone dissolution and soft tissue preservation. Research by Iniesto (2015), Dupraz (2009), and Wilby (1996) all demonstrate the ability of microbial mats to create unique mini-environments, including the alteration of pH and oxygen levels. This may have affected the water chemistry surrounding the fossil fish and aided in bone dissolution. The presence of microbial mats may also have protected soft tissues from decay. Wilby (1996) suggested that microbial mats act as a seal, protecting soft tissues. Iniesto (2015) demonstrated the difference in articulation with and without microbial mats, showing

their ability to aid in preservation. The dominant percentage of Ghost Fish preserved fully articulated is most likely a result of the presence of microbial mats.

CHAPTER 5

CONCLUSIONS

Interpretation of this data suggests that overall, Fossil Lake was more hypersaline and alkaline during the LGF bed deposition than the UGF bed deposition. This conclusion was made primarily through the analysis of $\delta^{18}O$ values and dolomite content. The presence of authigenic dolomite and fully articulated fish suggest the presence of microbial mats present during the deposition of both the UGF and LGF beds.

Overall, this research suggests that a combination of high salinity, high alkalinity, and the presence of microbial mats are key environmental conditions that result in preserving fossil fish with detailed soft tissues and no bones. These unique conditions simultaneously protected soft tissues from decay while causing bones to become unstable and dissolve.

This conclusion provides a starting point in to this unique fossil preservation and Fossil Lake's dynamic system during the time of deposition. However, to confirm hypotheses presented by this research and better understand the methods by which they occur, further studies covering a larger area and similar fossil beds will be required. Additional data correlating fish preservation and geochemical indicators through quarrying will also clarify trends and relationships, especially the affect that microbial mats and tuff beds may have had on the geochemistry. Further research on tuff beds near the Ghost Fish beds and their alteration will also provide further insight into alkalinity.

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APPENDICES

These sections include all data charts compiled in this thesis project.

APPENDIX A

QUARRY & SAMPLE LOCATIONS

Location	Latitude (N)	Longitude (W)	Thickness of carbonates (cm)	Thickness of base (cm)	Type of base	Notes
UGF-1	41°46'50.57"	110°41'56.98"	54	7	tuff	ostracods
LGF-1	41°46'50.57"	110°41'56.98"	36	2.5	tuff	ostracods
UGF-2	41°45'17.76"	110°45'16.78"	32	4.9	tuff	ostracods
LGF-2	41°45'17.76"	110°45'16.78"	mudstone	3.5	tuff	
UGF-3	41°47'20.46"	110°42'42.26"	30	3.5	tuff w/ mudstone between laminated and tuff	
LGF-3	41°47'20.46"	110°42'42.26"	10 cm SSD laminated limestone	5	tuff	
UGF-4	41°46'39.06"	110°42'56.10"			tuff/mudstone	
LGF-4	41°46'39.06"	110°42'56.10"			tuff/mudstone	
UGF-5	41°45'24.56"	110°45'0.07"	29	7	tuff	
LGF-5	41°45'24.56"	110°45'0.07"	30	7	tuff	ostracods
UGF-6	41°47'49.14"	110°44'14.22"	41	5	tuff	
LGF-6	41°47'49.14"	110°44'14.22"		4	tuff	
UGF-7	41°45'36.21"	110°44'18.91"				
LGF-7	41°45'36.21"	110°44'18.91"	32	4	tuff	
UGF-8	41°45'38.70"	110°44'37.03"	36		SSD tuff mixed w/mudstone	
LGF-8	41°45'38.70"	110°44'37.03"	32	4	tuff	
UGF-9	41°45'8.86"	110°44'58.45"	25	3.5	tuff	ostracods
LGF-9	41°45'8.86"	110°44'58.45"	mudstone	2.5	tuff	
UGF-10	41°46'5.30"	110°44'9.17"	32		mudstone w/tuff specks	
LGF-10	41°46'5.30"	110°44'9.17"	30	5	tuff	

Location	Latitude (N)	Longitude (W)	Thickness of carbonates (cm)	Thickness of base (cm)	Type of base	Notes
S1L	41°47'27.52"	110°42'32.71"			tuff	
S2U	41°47'1.97"	110°41'50.57"			tuff	
S2L	41°47'1.97"	110°41'50.57"			tuff	
S3U	41° 47' 16.22"	110° 41' 58.74"			tuff/mudstone	
S3L	41° 47' 16.22"	110° 41' 58.74"			tuff	
S4U	41°44'59.03"	110°45'4.97"	23	4	tuff	ostracods
S4L	41°44'59.03"	110°45'4.97"	mudstone	2.5	tuff	
S5U	41°45'13.72"	110°44'55.82"	30	4	tuff	
S5L	41°45'13.72"	110°44'55.82"	mudstone	1 to 2	tuff	
S6U	41°45'28.58"	110°45'55.73"	29	3.5	tuff	
S6L	41°45'28.58"	110°45'55.73"	mudstone	1.5	tuff	
S7U	41°45'58.75"	110°44'6.76"			mudstone/tuff	
S7L	41°45'58.75"	110°44'6.76"			tuff w/SSD	
S8U	41°46'1.70"	110°44'6.14"			mudstone	
S8L	41°46'1.70"	110°44'6.14"				
S9U	41°46'3.94"	110°44'10.28"			mudstone/tuff	
S9L	41°46'3.94"	110°44'10.28"				
S10U	41°46'11.21"	110°44'5.71"				ostracods
S10L	41°46'11.21"	110°44'5.71"			tuff	
S11U	41°46'15.49"	110°44'7.48"			mudstone/tuff	
S11L	41°46'15.49"	110°44'7.48"				
S12U	41°46'30.07"	110°43'46.02"			mudstone/tuff	

Location	Latitude (N)	Longitude (W)	Thickness of carbonates (cm)	Thickness of base (cm)	Type of base	Notes
S13U	41°46'34.79"	110°43'29.89"				
S13L	41°46'34.79"	110°43'29.89"			mudstone/tuff	SSD
S14U	41°46'41.45"	110°44'7.04"		0.25	tuff	
S14L	41°46'41.45"	110°44'7.04"				
S15U	41°47'52.22"	110°43'20.89"		3	tuff	
S15L	41°47'52.22"	110°43'20.89"			tuff interbedded w/laminated	
S16U	41°50'5.14"	110°44'26.68"	32	4	tuff interbedded w/laminated	
S16L	41°50'5.14"	110°44'26.68"	42	5	tuff	
S17U	41°45'54.00"	110°42'11.45"	18	4	tuff	
S17L	41°45'54.00"	110°42'11.45"	14	5	tuff	

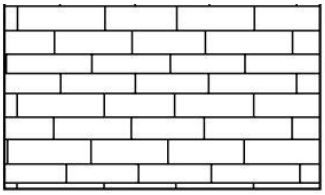
APPENDIX B

STRATIGRAPHIC SECTIONS

A stratigraphic section for each quarry was created including at least 2 m above and 2 m below the Ghost Fish beds. Color fill represents actual color in outcrop.

LGF: Lower Ghost Fish bed

UGF: Upper Ghost Fish bed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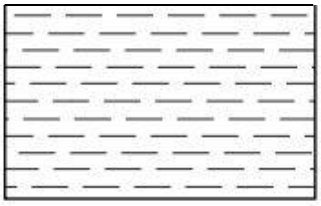
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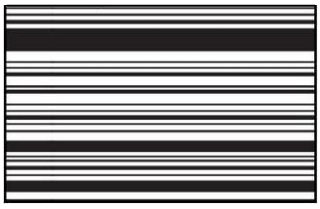
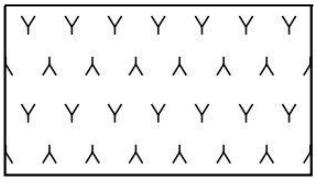
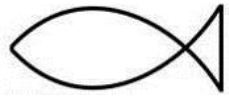

Oil Shale

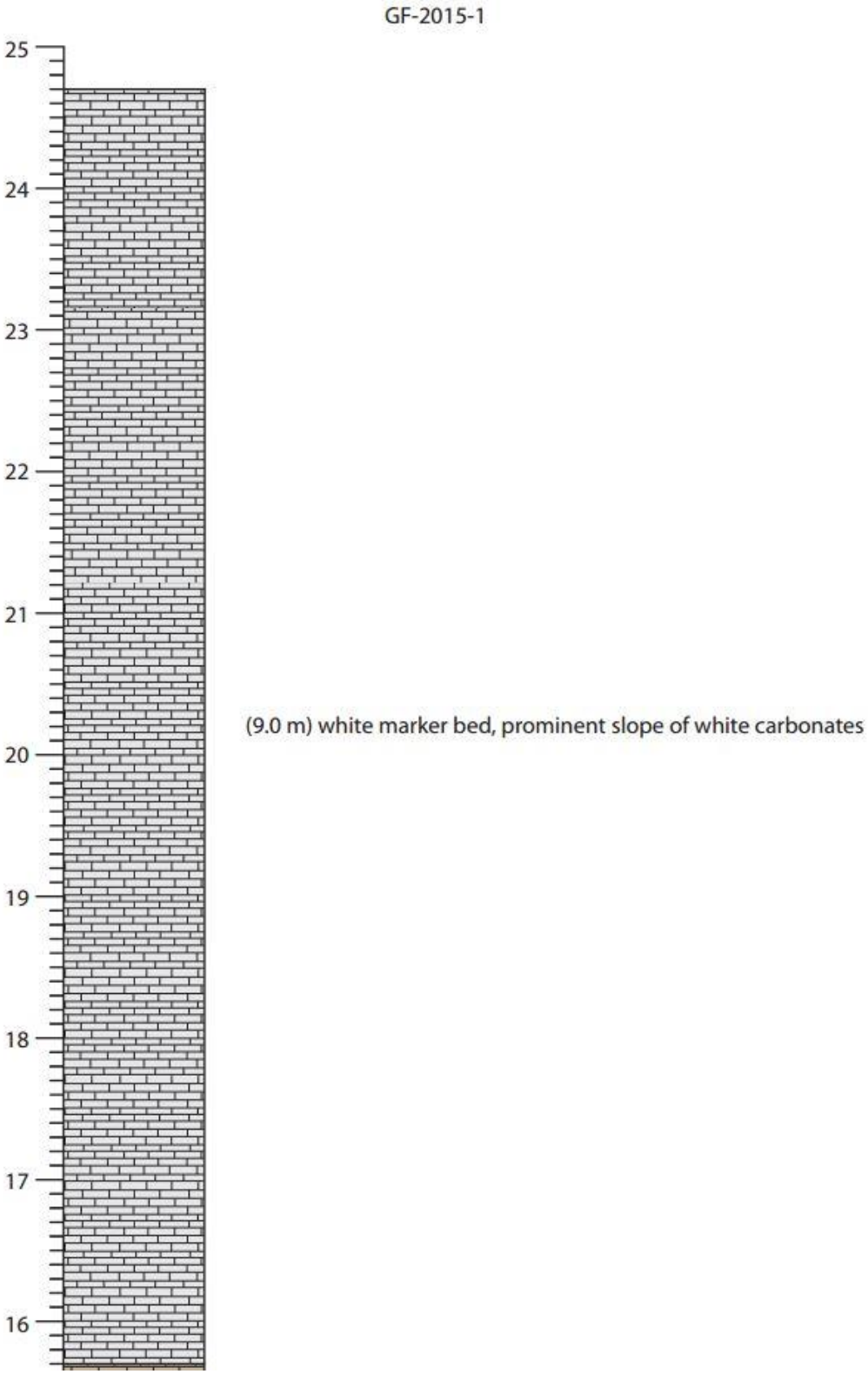

Tuff


Ghost Fish


Chemoturbation


Base of Ghost Fish bed

GF-1 Stratigraphic Section



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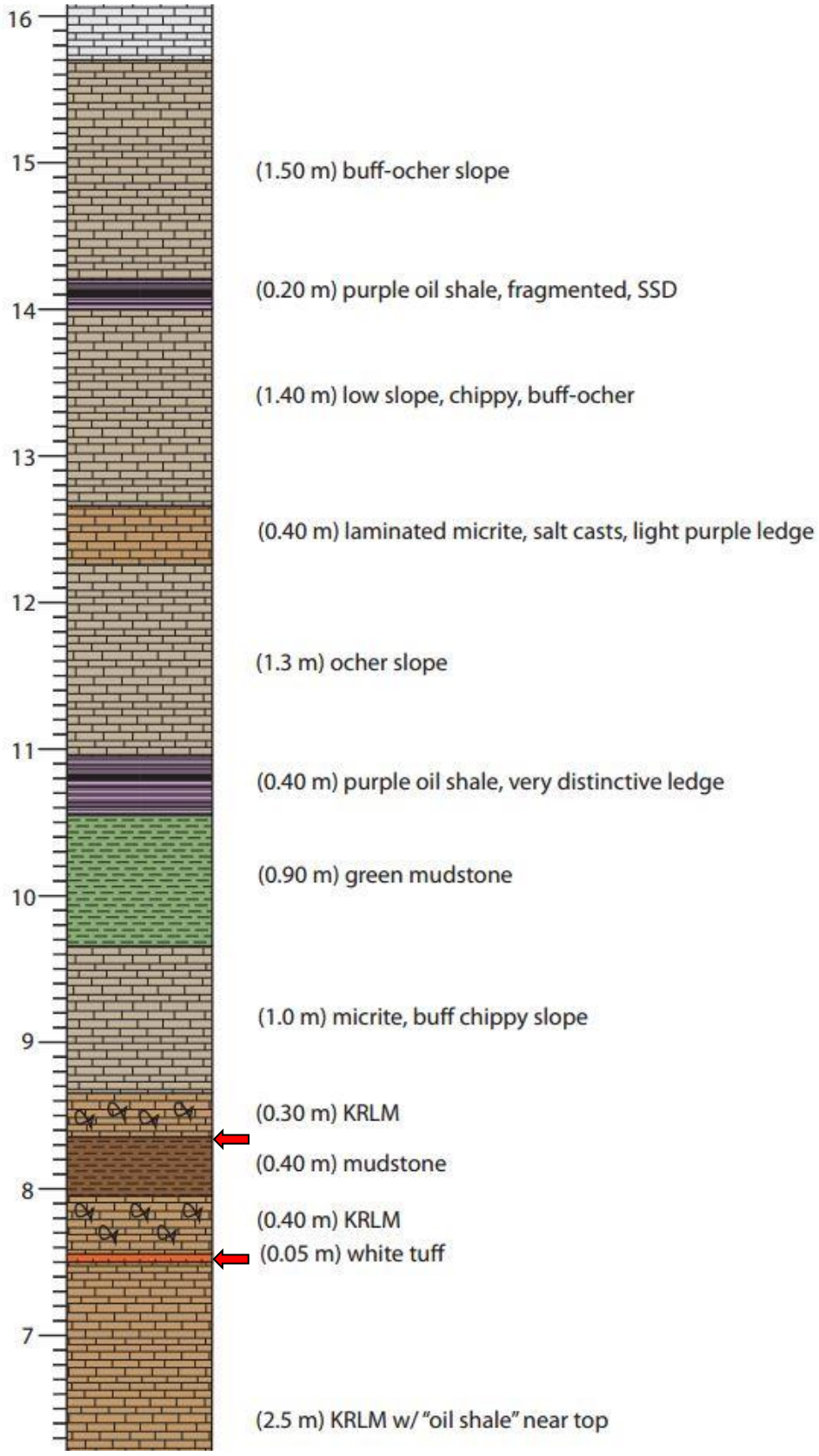

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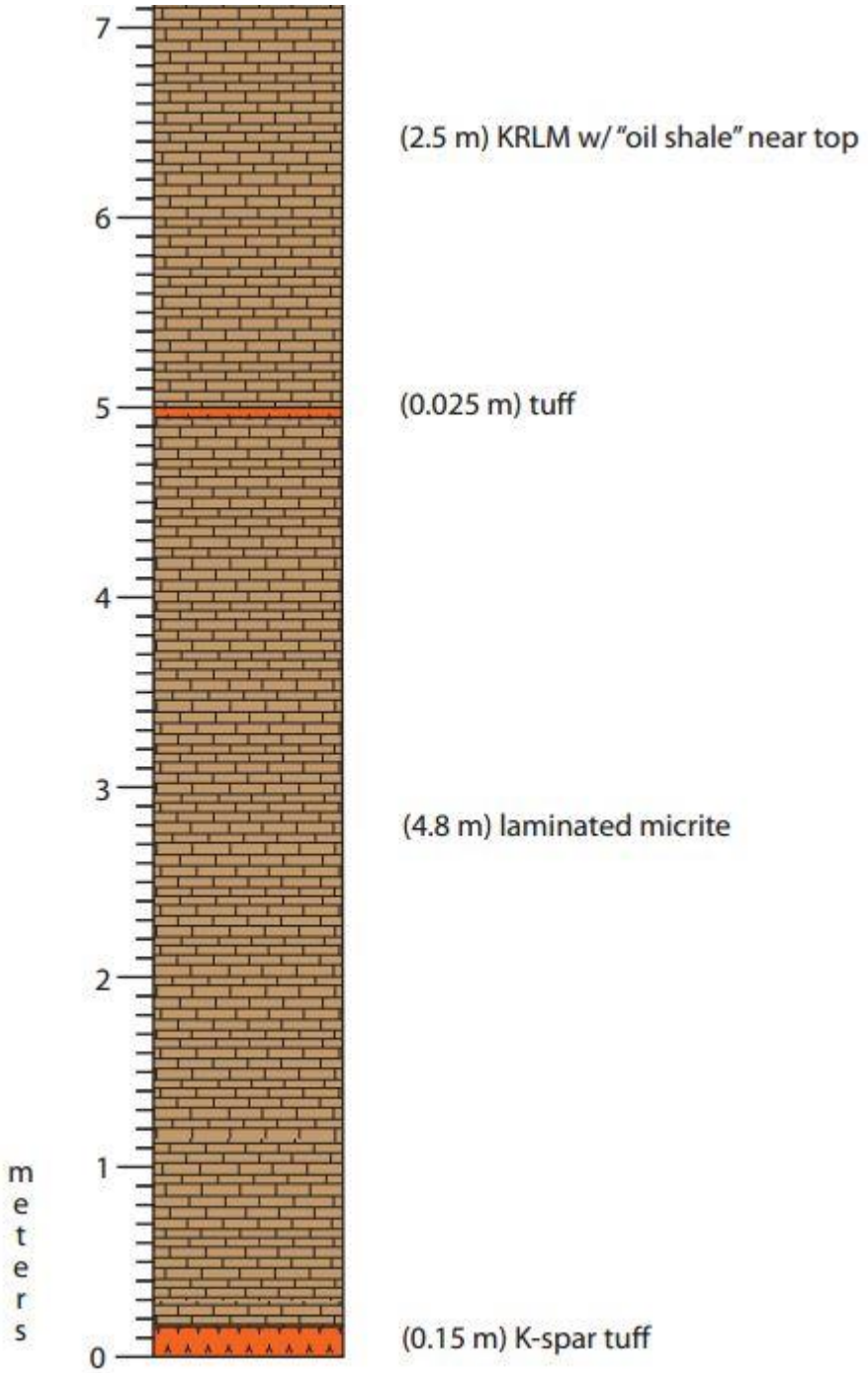

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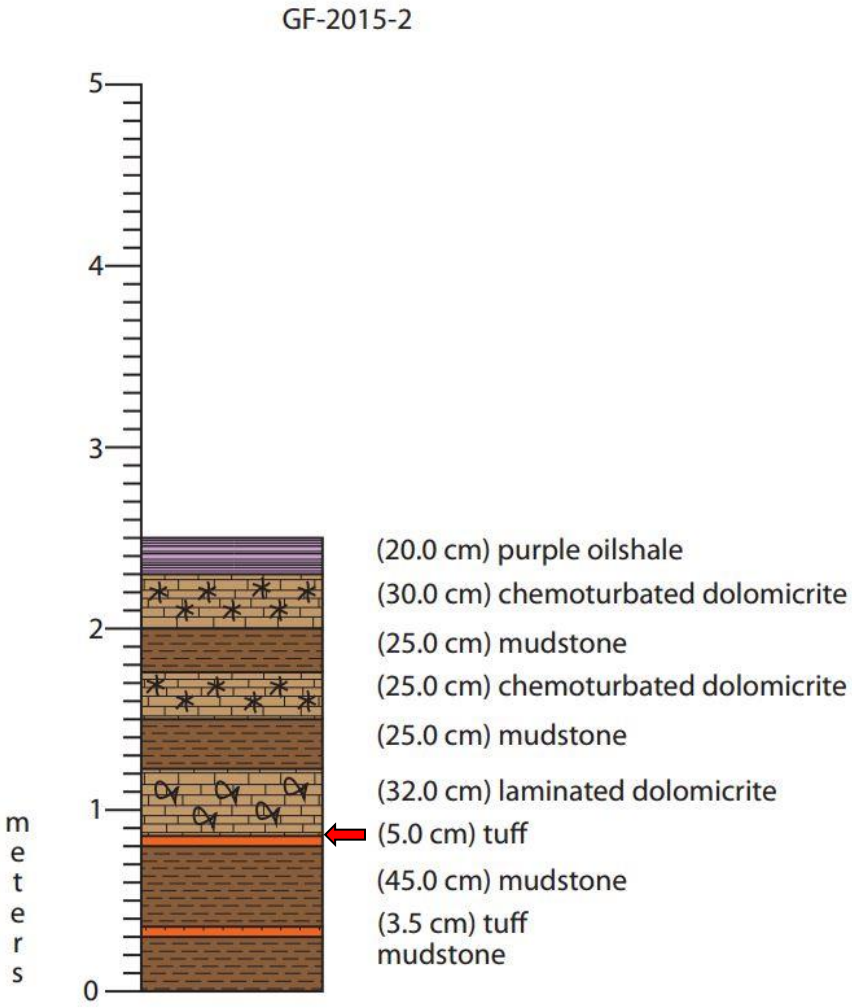

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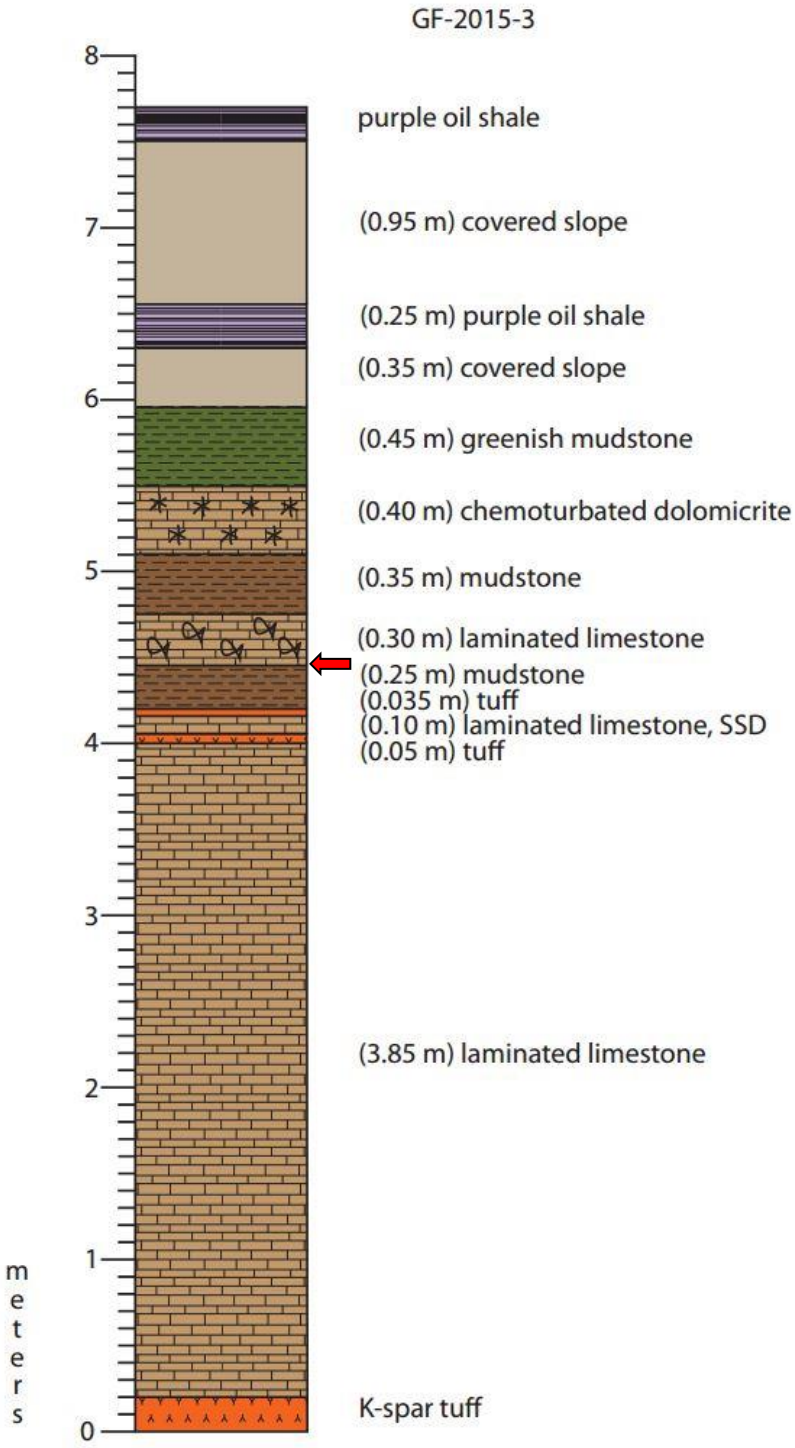

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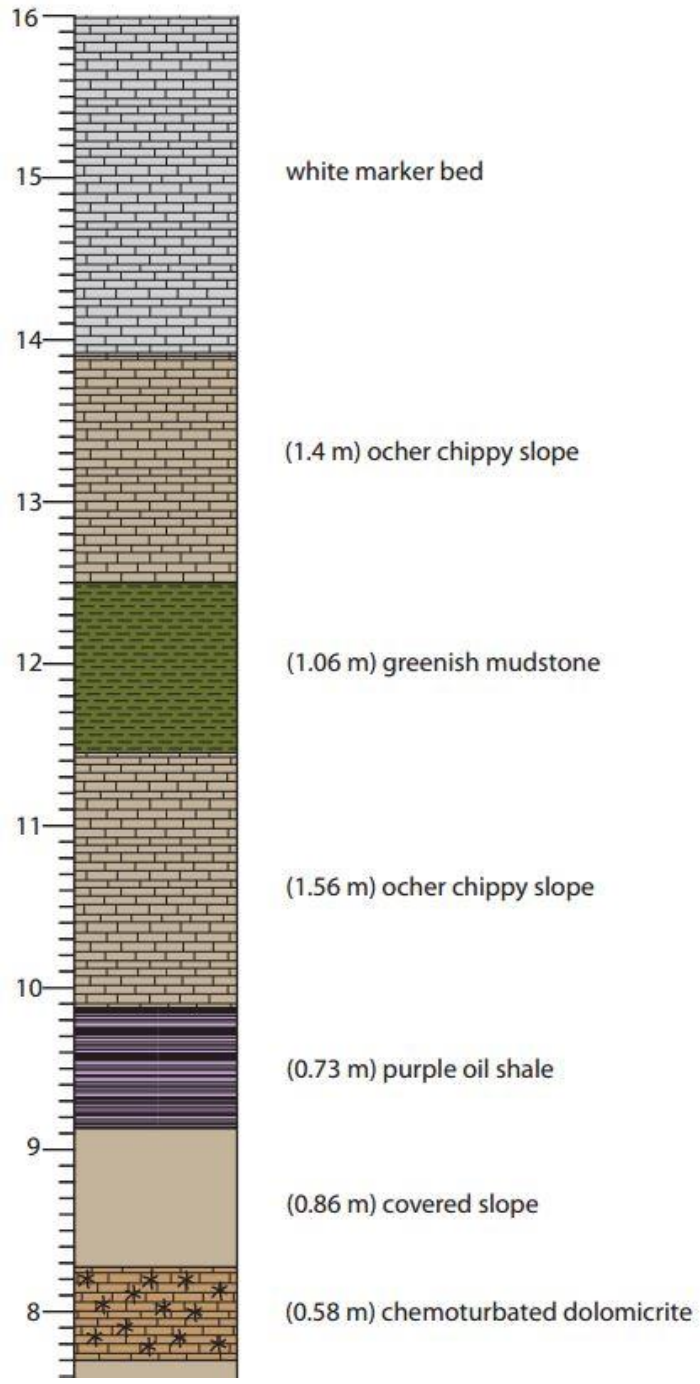
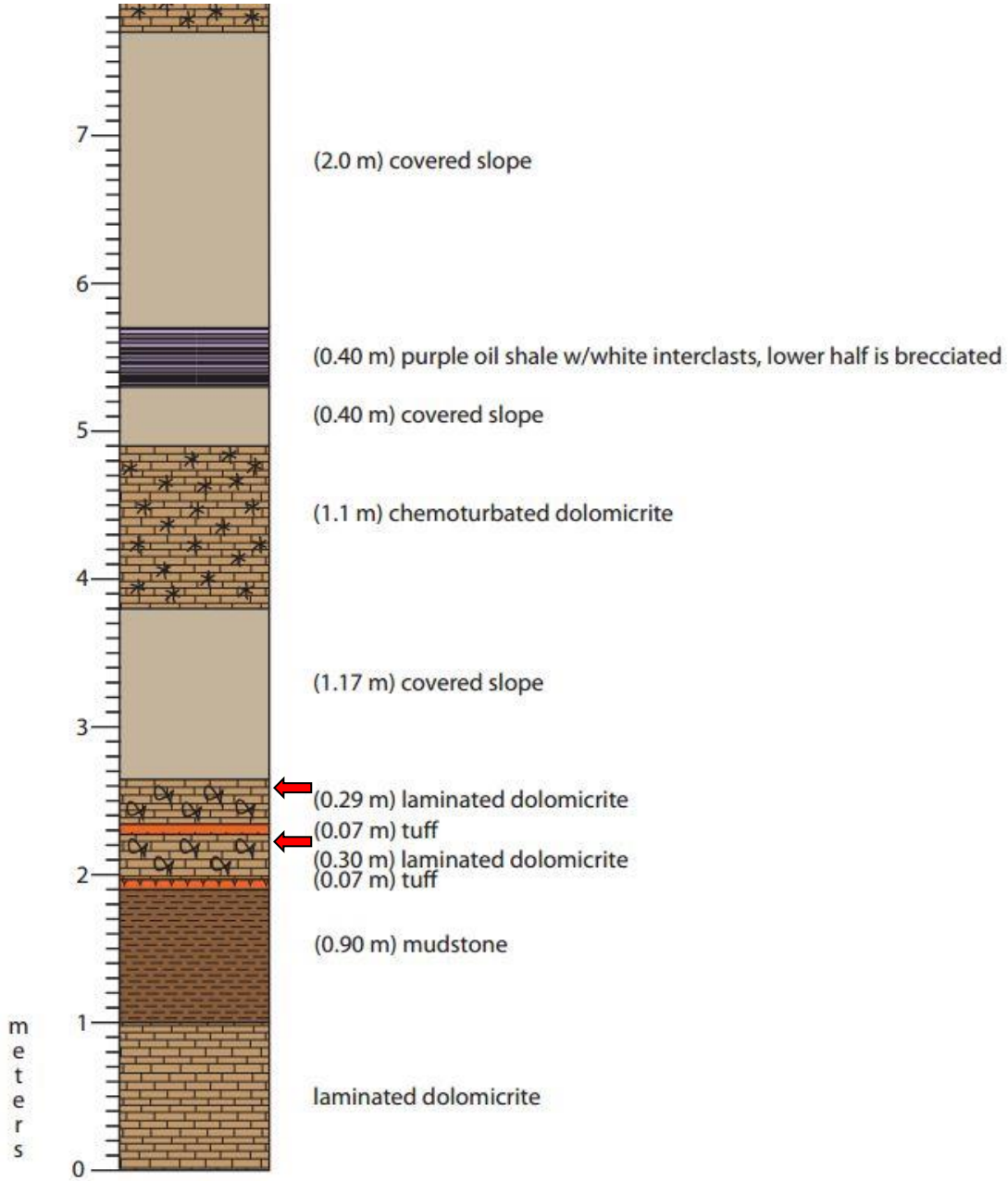
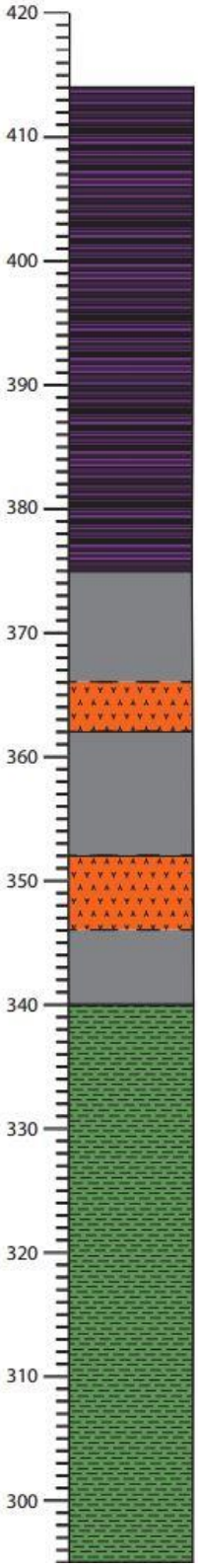


GF- 5 continued



GF-6 Stratigraphic Section

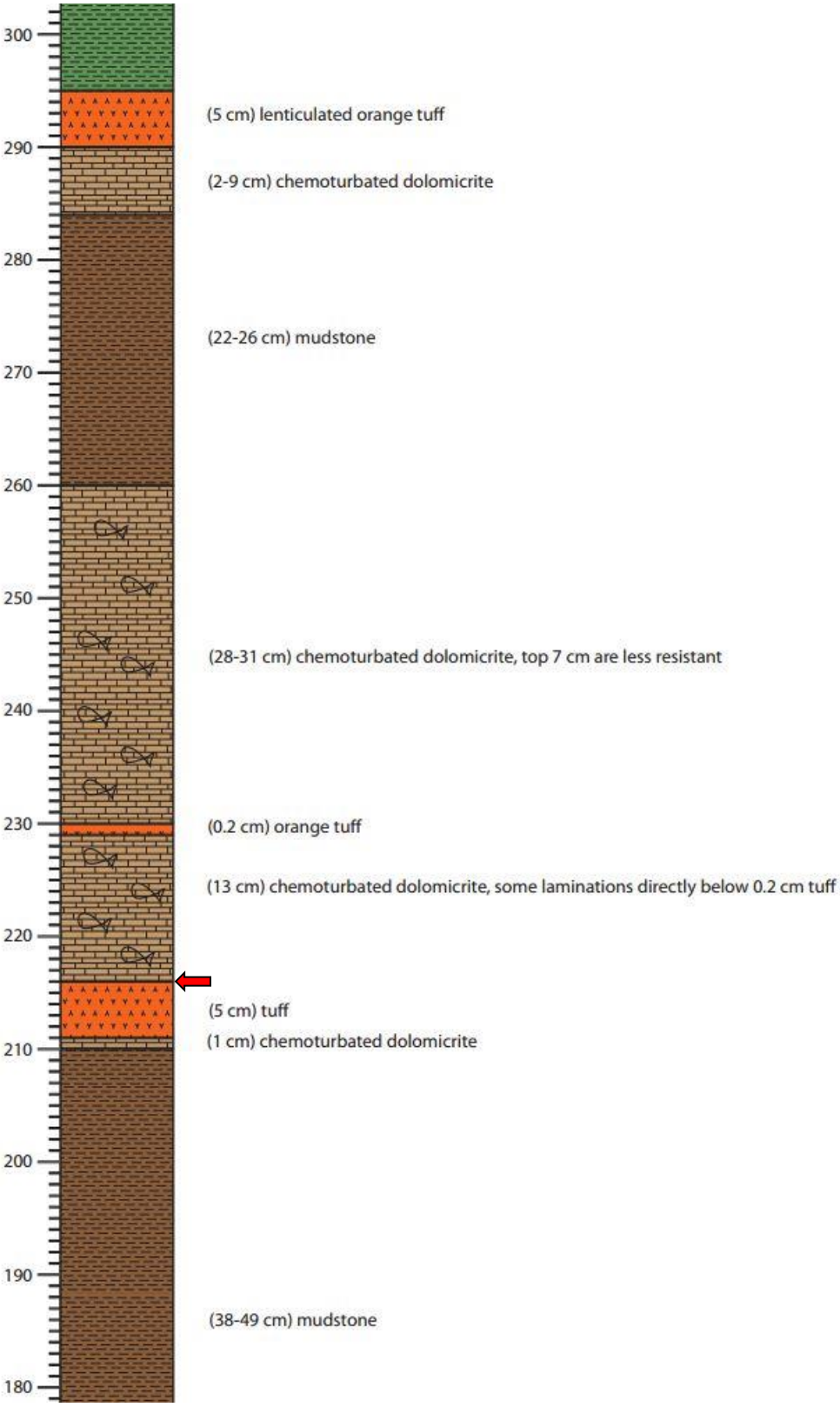


(39 cm) purple oil shale, wavy, small white specks

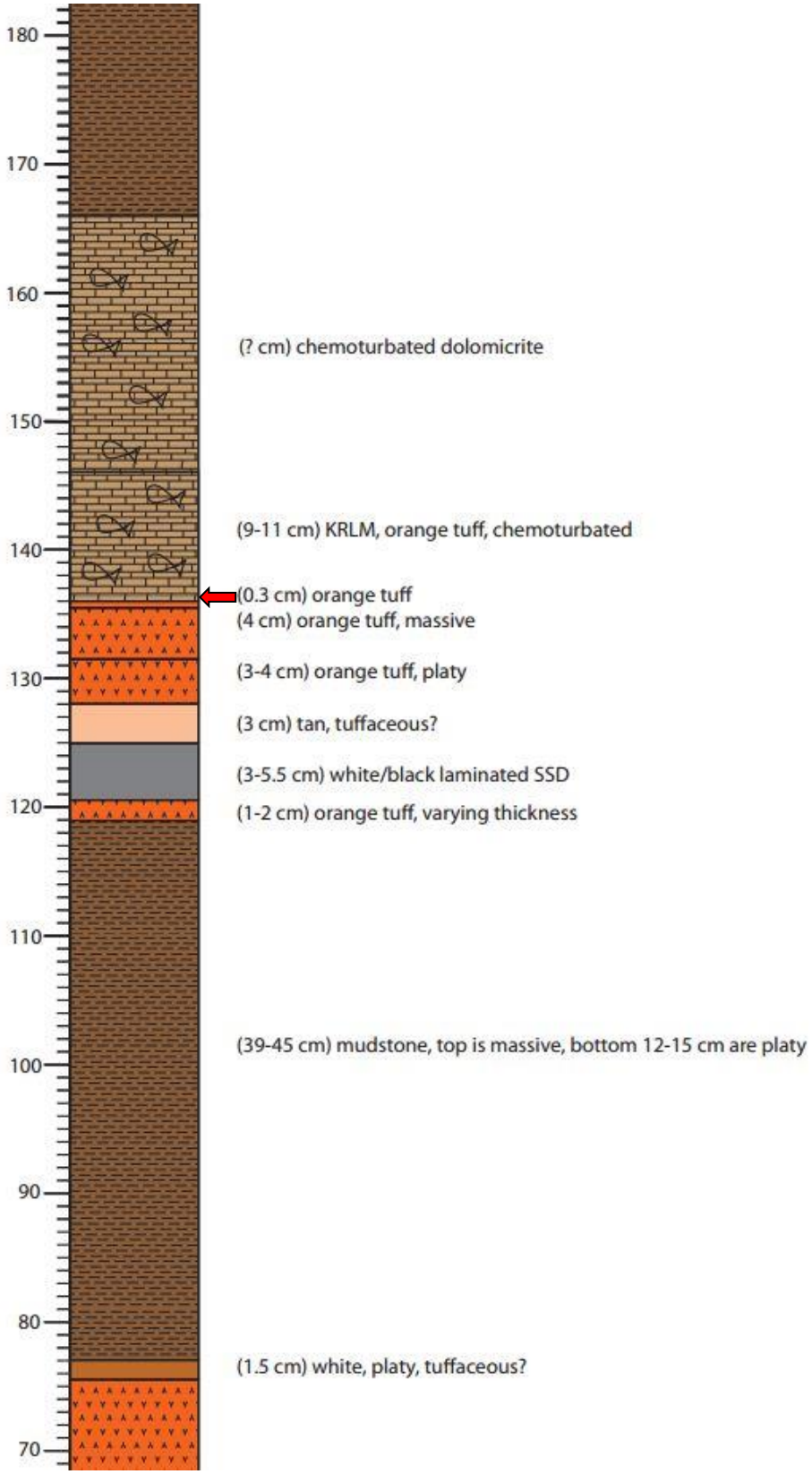
(35 cm) black/white platy w/ 2 orange tuff layers (0.5-13 cm) thick in middle, top is platy

(39-50 cm) green mudstone, base has mix of laminated layers, tuff, and chemoturbation

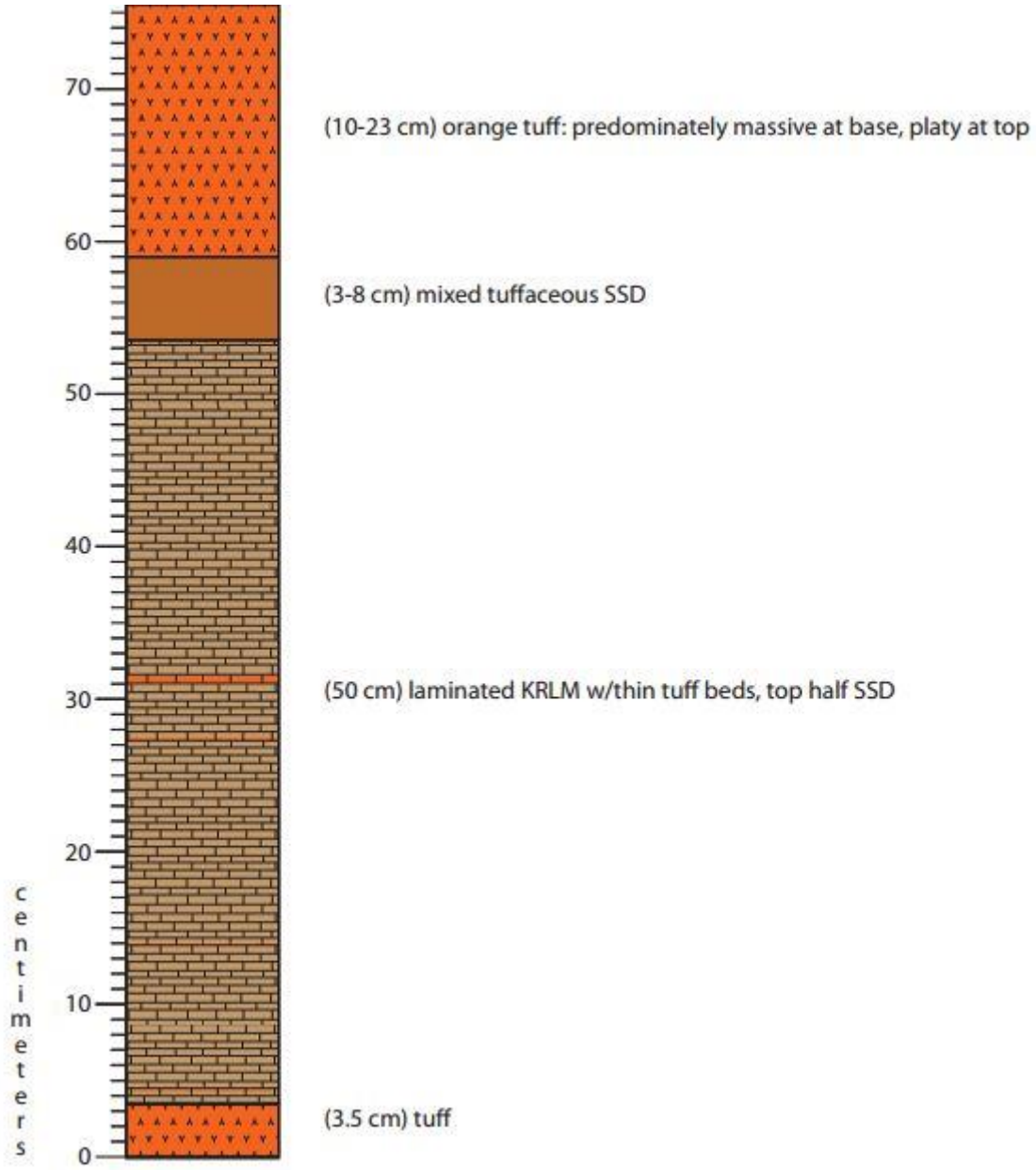
GF-6 continued



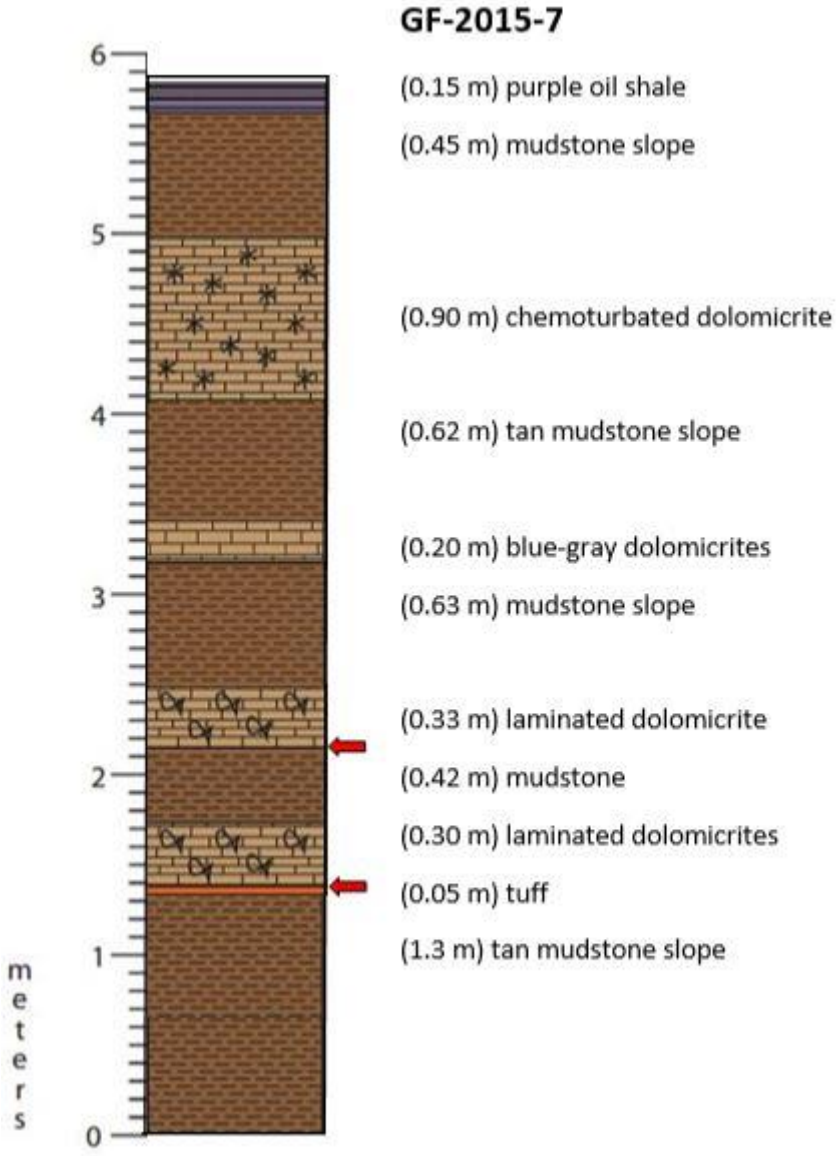
GF-6 continued



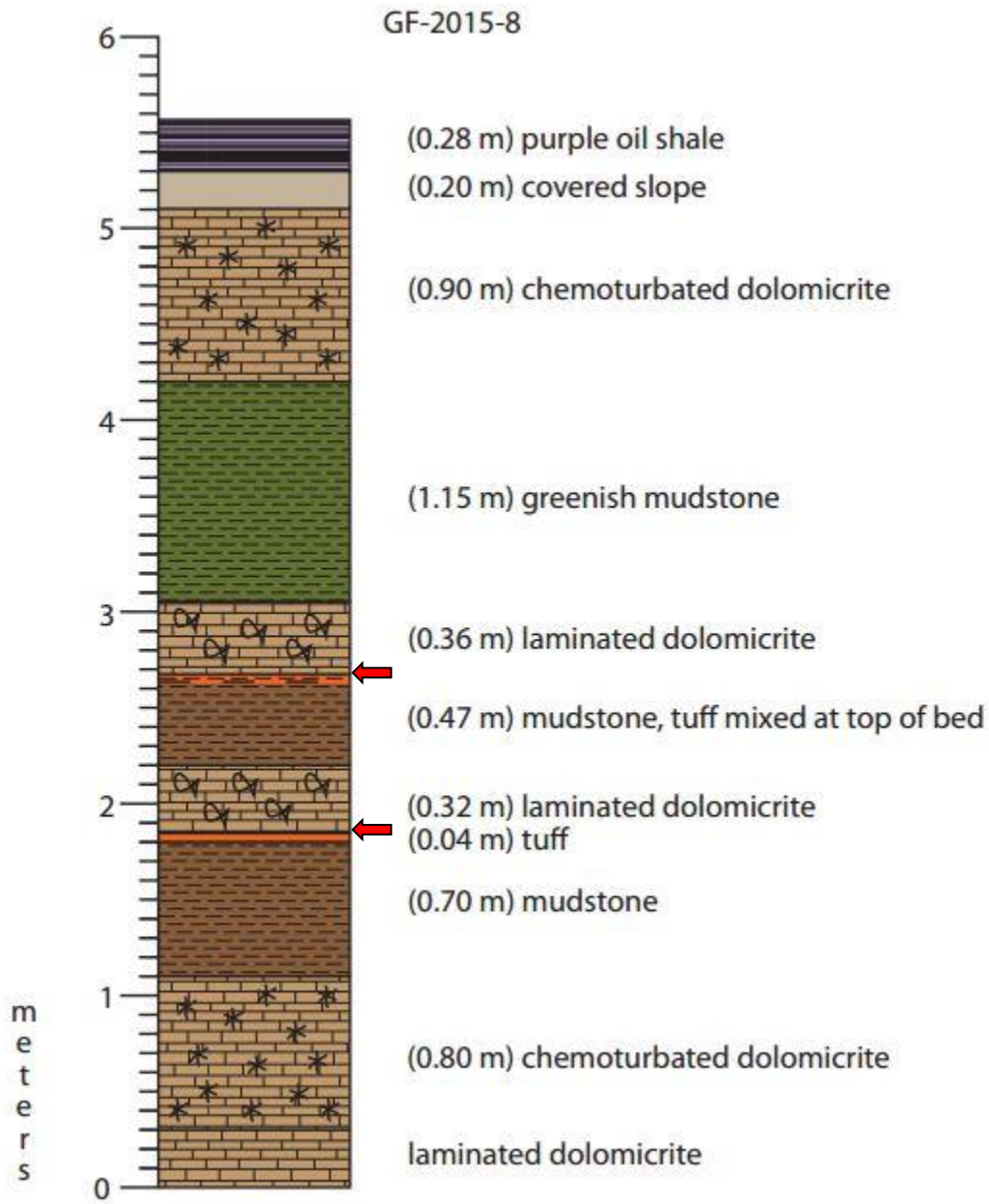
GF-6 continued



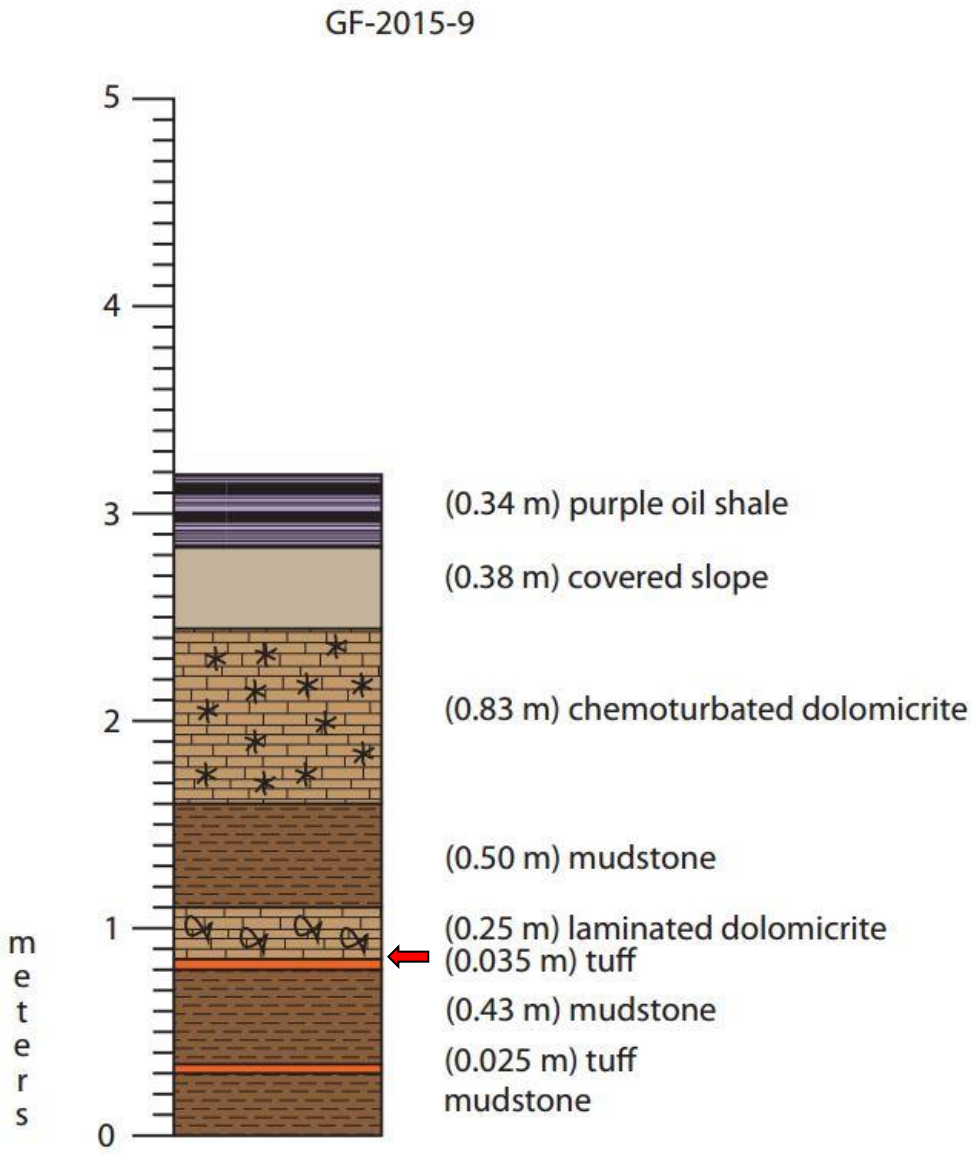
GF-7 Stratigraphic Section



GF-8 Stratigraphic Section

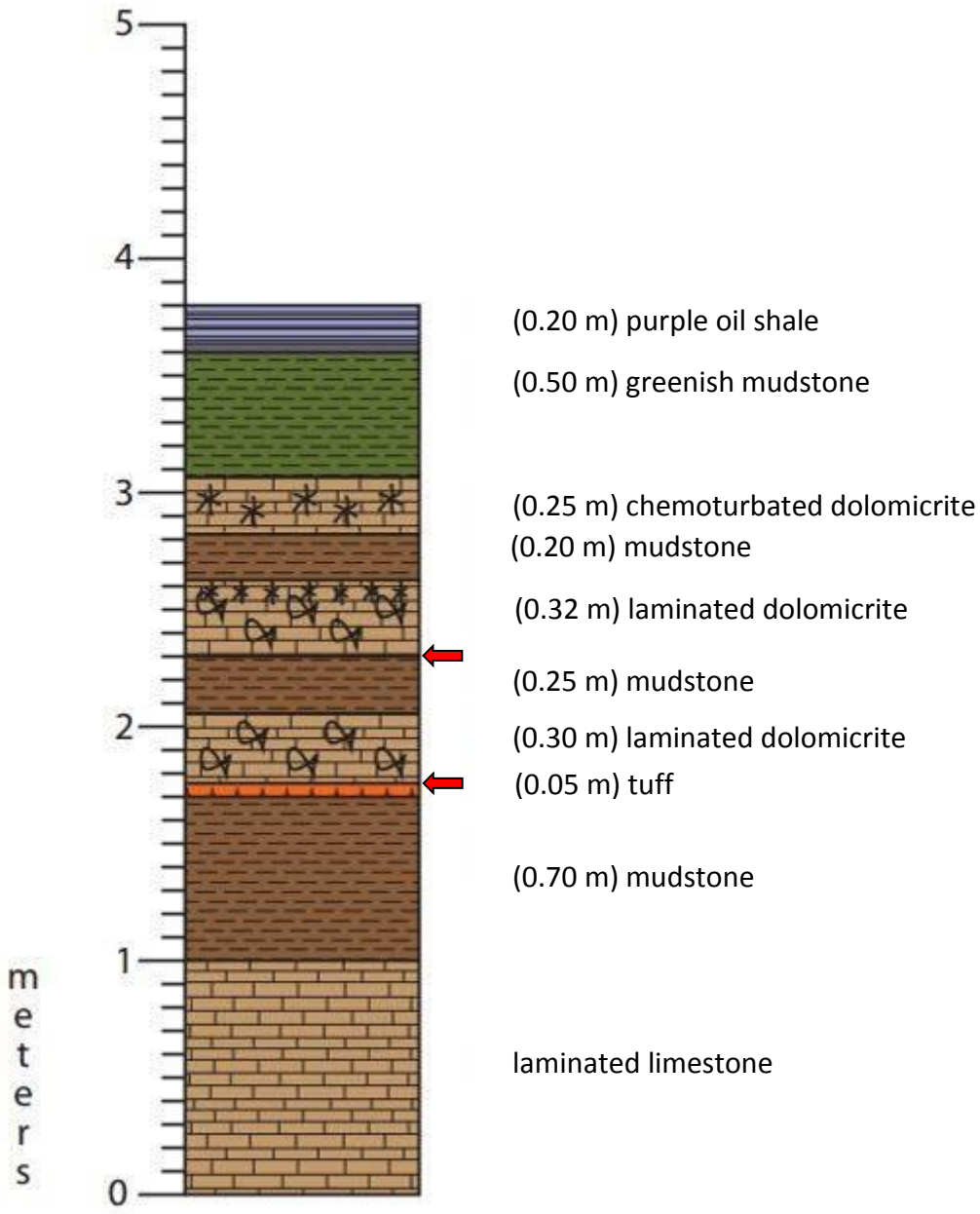


GF-9 Stratigraphic Section



GF-10 Stratigraphic Section

GF-2015-10



APPENDIX C

XRD MINERALOGY

Values are normalized based on the 5 main minerals and have been rounded to the nearest integer.

Location	Calcite	Dolomite	Aragonite	K-feldspar	Quartz
LGF-1	51	22		22	5
UGF-1	58	10		26	5
UGF-2	67	10		20	4
UGF-3	66	16		14	4
LGF-4	67	18		12	4
UGF-4	30	37		28	6
LFG-5	66	17		14	3
UGF-5	66	7		24	3
UGF-6	76	10		7	7
LGF-7	54	24		17	6
UGF-7	70	8		17	4
LGF-8	49	28		24	0
UGF-8	82	5		10	3
UGF-9	59	17		21	4
LGF-10	65	17		14	4
UGF-10	77	10		11	3
S1L	76	10		10	4
S1U	67	16		15	2
S2L	58	21		15	6
S2U	74	10		13	4
S4L	26	48		22	5
S4U	80	1		17	3
S5U	42	4		40	14
S6lam	43	19		33	5
S6Uchem	64	9		23	4
S7L	71	13		15	2
S7U	87	6		4	3
S8L	63	19		13	5
S8U	55	17		21	7
S9L	84	5		9	1
S9U	86	5		8	1
S10L	62	14		20	3
S10U	86	8		4	3
S11L	65	12		18	5

Location	Calcite	Dolomite	Aragonite	K-feldspar	Quartz
S11U	84	9		5	2
S12L	59	17		17	6
S12U	77	4		14	6
S13U	65	11		20	4
S14L(20)	39	21	12	18	11
S14U(20)	44	21		26	10
S15L(20)	48	20		25	7
S15U(20)	56	12		21	11
S16L	4	64		32	0
S16U(10-0)	0	4		82	13
S16U(32-10)	63	17		16	4
S17C	59	21		17	3
S17E	77	9		11	3
Gastropod	94	0		4	3
Upper Splits	92	6		1	1
Sandwich	82	9		0	9
Asiniops	56	36		4	4
Minifish	88	8		4	0
18'' layer	93	3		3	2
S15U(tuff)				88	12
LGF-8 (tuff)				97	3
S16L tuff				99	1
S16U tuff	0	52		48	0
LGF-7 (tuff)				95	5
LGF-7 (13-0)	8	24		58	11
LGF-7 (15-13)	50	33		13	5
LGF-7 (16-15)	57	18		19	6
LGF-7 (18-16)	49	29		19	3
LGF-7 (19-18)	49	26		18	6
LGF-7 (20-19)	54	24		17	6
LGF-7 (22-20)	70	13		12	5
LGF-7 (23-22)	56	23		20	0
LGF-7 (24-23)	65	19		13	4
LGF-7 (25-24)	60	20		16	4
LGF-7 (26-25)	57	23		16	4
LGF-7 (27-26)	59	18		19	4
LGF-7 (28-27)	59	24		14	3
LGF-7 (29-28)	68	17		12	4
LGF-7 (30-29)	71	19		8	3
LGF-7 (32-30)	62	23		13	2
UGF-7 (tuff)				77	23
UGF-7 (1-0)	69	5		26	0

Location	Calcite	Dolomite	Aragonite	K-feldspar	Quartz
UGF-7 (2-1)	25	5		63	7
UGF-7 (3-2)	71	10		18	2
UGF-7 (4-3)	71	11		17	2
UGF-7 (6-5)	65	9		23	3
UGF-7 (7-6)	67	16		14	2
UGF-7 (8-7)	55	21		21	3
UGF-7 (9-8)	57	14		25	5
UGF-7 (10-9)	46	23		27	4
UGF-7 (11-10)	40	22		34	4
UGF-7 (12-11)	39	36		21	4
UGF-7 (1/4 tuff)	10	6		84	0
UGF-7 (13-12)	49	13		35	3
UGF-7 (14-13)	68	10		19	4
UGF-7 (15-14)	69	12		16	3
UGF-7 (16-15)	66	14		16	4
UGF-7 (17-16)	67	15		15	3
UGF-7 (18-17)	65	18		14	4
UGF-7 (19-18)	65	12		19	4
UGF-7 (20-19)	70	9		17	4
UGF-7 (21-20)	79	5		12	4
UGF-7 (22-21)	82	6		9	3
UGF-7 (23-22)	86	3		9	3
UGF-7 (24-23)	84	5		7	3
UGF-7 (27-24)	87	4		6	3
UGF-7 (28-27)	79	6		12	3
UGF-7 (29-28)	89	3		6	3
UGF-7 (30-29)	85	3		10	2
UGF-7 (31-30)	82	6		10	3
UGF-7 (32-31)	80	5		12	3
UGF-7 (34-32)	48	11		36	5

APPENDIX D

STABLE ISOTOPES & TOC

All values are sampled from 20 cm above the base of the bed unless otherwise specified.

Location	$\delta^{13}C$ (‰VPDB)	$\delta^{18}O$ (‰VPDB)	TOC (%)
LGF-1	0.32	-1.98	8.83
LGF-4	-0.09	-2.69	13.85
LFG-5	-0.21	-3.09	12.94
LGF-7	-0.20	-3.67	
LGF-8	0.10	-2.23	2.76
LGF-10	-0.16	-3.01	4.9
S1L	0.89	-2.53	
S2L	0.15	-2.83	
S4L	1.77	-3.16	
S6 (lam)	0.89	-11.48	
S7L	0.28	-7.68	
S8L	0.28	-7.67	
S9L	0.03	-8.41	
S10L	-0.41	-2.97	
S11L	0.90	-11.03	
S12L	-0.15	-4.11	
S13L	0.84	-10.77	
S14L	1.25	-19.87	
S15L	1.55	-20.76	
S16L	2.79	-1.00	0.27
S17 ("C")	0.06	-3.04	
UGF-1	0.38	-2.66	13.8
UGF-2	-0.02	-3.23	6.57
UGF-3	0.26	-2.96	0
UGF-4	0.38	-2.55	25.75
UGF-5	-0.36	-2.69	6.78
UGF-6	0.05	-2.27	
UGF-7	0.08	-3.05	3.38
UGF-8	0.17	-3.32	9.28
UGF-9	-0.21	-3.17	3.25
UGF-10	0.38	-7.19	0.7
S1U	0.14	-2.35	
S2U	0.30	-2.58	

Location	$\delta^{13}C$	$\delta^{18}O$	TOC
S4U	-0.02	-3.41	
S5U	-0.13	-3.11	
S6U (chemo)	2.09	-16.43	
S7U	-0.50	-12.45	
S9U	0.39	-11.80	
S10U	1.15	-18.40	
S11U	0.53	-11.94	
S12U	0.05	-10.23	
S13U	0.02	-14.96	
S14U	2.00	-18.33	
S15U	2.00	-19.51	
S16U(10-0)	1.78	-2.84	
S16U(32-10)	0.77	-5.65	3.14
S17E	0.17	-3.80	

APPENDIX E

XRF

SAMPLE NAME	S15LGF	S13LGF	S15LGF	S13LGF	S14LGF	UGF-10	18" LAYER	S16UGF(32-10)	UGF-8	LGF-7	UGF-7
fraction sample	0.83	0.82	0.83	0.82	0.83	0.81	0.78	0.82	0.82	0.82	0.78
Fraction UHP Qtz	0.17	0.18	0.17	0.18	0.17	0.19	0.22	0.18	0.18	0.18	0.22
Normalized Majors undiluted (Wt. %)											
SiO2	25.15	23.49	25.15	23.49	28.29	13.76	0.53	22.17	15.08	23.93	23.16
TiO2	0.27	0.21	0.27	0.21	0.21	0.16	0.08	0.21	0.16	0.23	0.25
Al2O3	5.79	4.94	5.79	4.94	5.11	3.41	0.88	5.78	3.61	4.85	5.74
FeO*	1.88	1.60	1.88	1.60	0.99	1.44	0.23	1.67	1.38	1.64	2.01
MnO	0.04	0.02	0.04	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02
MgO	4.99	5.36	4.99	5.36	6.01	3.39	1.43	4.51	1.77	7.83	2.84
CaO	56.71	59.63	56.71	59.63	54.72	74.32	95.18	61.28	74.31	57.04	61.24
Na2O	0.44	0.51	0.44	0.51	0.66	0.20	0.25	1.63	0.23	0.23	0.27
K2O	4.15	3.72	4.15	3.72	3.44	2.72	0.83	2.10	2.76	3.74	3.94
P2O5	0.02	0.04	0.02	0.04	0.00	0.04	0.28	0.02	0.04	0.04	0.08
Total	99.44	99.50	99.44	99.50	99.44	99.45	99.68	99.39	99.36	99.54	99.55
SO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SAMPLE NAME	S15LGF	S13LGF	S15LGF	S13LGF	S14LGF	UGF-10	18" LAYER	S16UGF(32-10)	UGF-8	LGF-7	UGF-7
Normalized Traces undiluted (ppm)											
Ni	14.62	5.64	14.62	5.64	10.64	6.08	0.00	0.00	3.88	7.55	5.80
Cr	40.19	31.95	40.19	31.95	33.70	32.44	10.05	37.92	29.13	24.54	42.51
Sc	14.62	7.52	14.62	7.52	12.42	6.08	17.59	7.58	7.77	13.21	15.46
V	58.46	50.74	58.46	50.74	46.11	40.55	50.25	43.61	36.89	39.64	48.31
Ba	1057.82	964.07	1057.82	964.07	675.75	918.36	304.02	767.84	1466.09	692.72	562.31
Rb	65.77	54.50	65.77	54.50	60.30	58.79	50.25	43.61	54.37	67.95	71.50
Sr	3211.84	2839.59	3211.84	2839.59	3534.83	3318.65	2057.78	3987.07	3584.63	2702.92	2747.76
Zr	48.81	42.77	48.81	42.77	45.63	50.15	4.97	22.51	46.11	54.16	51.62
Y	51.16	31.95	51.16	31.95	33.70	18.25	20.10	41.71	27.19	26.43	17.39
Nb	12.79	11.28	12.79	11.28	12.42	12.16	17.59	11.38	11.65	11.33	11.59
Ga	7.31	7.52	7.31	7.52	8.87	4.05	0.00	11.38	3.88	5.66	9.66
Cu	18.27	20.67	18.27	20.67	8.87	28.38	0.00	17.06	23.30	20.76	28.98
Zn	38.37	28.19	38.37	28.19	21.28	26.35	2.51	18.96	38.84	41.53	42.51
Pb	12.79	3.76	12.79	3.76	12.42	4.05	10.05	5.69	5.83	1.89	7.73
La	0.00	15.03	0.00	15.03	10.64	0.00	10.05	3.79	31.07	26.43	15.46
Ce	63.94	65.77	63.94	65.77	69.17	56.76	65.33	54.98	52.43	67.95	63.77
Th	23.75	15.03	23.75	15.03	33.70	10.14	35.18	20.85	15.53	7.55	9.66
Nd	10.96	5.64	10.96	5.64	39.02	6.08	20.10	39.81	9.71	32.09	46.38
U	10.96	1.88	10.96	1.88	23.06	0.00	12.56	11.38	5.83	1.89	3.86
Cs	3.65	1.88	3.65	1.88	12.42	26.35	30.15	22.75	19.42	0.00	34.78
As	1.83	1.88	1.83	1.88	3.55	20.27	17.59	5.69	19.42	9.44	0.00
W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX F

FOSSIL FIELD DATA

Fossils were all measured during collection in the field. Percent of bone preserved is a rough estimate based on field observations.

Fossil Field Data: UGF-1

UGF-1	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.780715 N	54-46	1	fish		100	0	
-110.69916 W	54-46	2	fish		100	0	not collected
	36-28	3	plant				
120 x 50 cm	36-28	4	fish		100	0	
54 cm laminated	36-28	5	fish	5.2	100	0	
	36-28	6	fish		100	0	
	36-28	7	fish		100	0	
	31	8	seed				
	28-25	9	fish		100	0	
	28-25	10	fish		100	0	
	25-16	11	fish		100	0	
	25-16	12	stem				
	25-16	13	fish	4.8	100	0	
	25-16	14	fish		100	0	
	25-16	15	fish		100	0	
	25-16	16	fish	8	100	0	
	25-16	17	fish		100	0	
	25-16	18	fish		100	0	
	25-16	19	fish	~4	100	0	
	25-16	20	fish	~3	100	0	
	25-16	21	fish		100	0	
	25-16	22	fish		100	0	
	25-16	23	fish		100	0	
	25-16	24	fish		100	0	
	25-16	25	stem				
	16	26	fish	6.5	100	0	
	16	27	fish		100	0	
	16	28	fish		100	0	
	16	29	fish		100	0	
	16	30	fish		100	0	
	16	31	fish		100	0	
	16	32	fish		100	0	
	16	33	fish		100	0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
16	35	fish		100	0	
16	36	fish		100	0	
25-16	37	fish		100	0	
25-16	38	fish		100	0	
25-16	39	fish		100	0	
25-16	40	fish	4	100	0	
25-16	41	fish		100	0	
25-16	42	fish		100	0	
25-16	43	fish		100	0	
25-16	44	fish		100	0	
25-16	45	fish		100	0	
25-16	46	fish		100	0	
25-16	47	fish		100	0	
16-14.5	48	fish		100	0	
16-14.5	49	fish	9	100	0	
16-14.5	50	fish		100	0	
16-14.5	51	fish		100	0	not collected
16-14.5	52	fish		100	0	
16-14.5	53	fish		100	0	not collected
16-14.5	54	fish		100	0	
16-14.5	55	fish		100	0	
14-12.5	56	fish		100	0	
14-12.5	57	fish		100	0	
16-14.5	58	fish		100	0	
16-14.5	59	plant		100	0	
9.0-0	60	fish		100	0	
12.5-9	61	fish		100	0	
12.5-9	62	fish		100	0	
9.0-0	63	fish		100	0	
14-12.5	64	fish		100	0	not collected
16-14.5	65	fish		100	0	

Fossil Field Data: LGF-1

LGF-1	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
							not
41.78007 N	36-33	1	stem				collected
-110.69922 W	36-33	2	fish		100	0	
	36-33	3	stem				
90 x 30 cm		4	fish		100	0	
36 cm							
laminated	36-33	5	fish	8.5	100	0	
							not
2.5 cm tuff	36-33	6	insect		100		collected
	33-27	7	fish	8	100	0	
	33-27	8	fish		100	0	
							not
	33-27	9	fish		100	0	collected
							not
	33-27	10	plant				collected
	33-27	11	plant				2 pieces
	33-27	12	seed				
							not
	33-27	13	fish		100	0	collected
	33-27	14	fish	7.5	100	0	
	33-27	15	fish	6	100	0	
							not
	27-19	16	plant				collected
							not
	27-19	17	fish		100	0	collected
							not
	27-19	18	fish		100	0	collected
	27-19	19	fish		100	0	
							not
	27-19	20	fish		100	0	collected
							not
	27-19	21	fish		100	0	collected
							not
	27-19	22	fish		100	0	collected
	27-19	23	fish		100	0	
	27-19	24	fish		100	0	
							not
	27-19	25	fish		100	0	collected
	27-19	26	plant				

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
22-19	28	fish		100	0	
22-19	29	fish		100	0	
22-19	30	fish		100	0	
22-19	31	fish		100	0	
22-19	32	fish		100	0	
22-19	33	fish		100	0	
22-19	34	fish				
22-19	35	fish		100	0	
22-19	36	fish		100	0	
22-19	37	fish		100	0	
22-19	38	fish		100	0	
22-19	39	fish		100	0	6 fish
22-19	40	fish		100	0	
22-19	41	fish		100	0	
22-19	42	fish	7.2	100	0	
22-19	43	fish		100	0	
22-19	44	fish		100	0	
22-19	45	fish	5.5	100	0	
22-19	46	fish	6	100	0	
22-19	47	fish		100	0	
22-19	48	fish		100	0	
22-19	49	fish	7.5	100	0	
22-19	50	fish		100	0	
22-19	51	fish		100	0	
22-19	52	fish		100	0	
22-19	53	fish		100	0	
22-19	54	fish		100	0	
19-11	55	fish		100	0	not collected
19-11	56	stem				not collected

Fossil Field Data: UGF-2

UGF-2	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.754933 N	32-25	1	fish		100	50	2 pieces
-110.75466 W	32-25	2	fish	4.5	100	0	
	32-25	3	fish	4.5	100	0	
80 x 50 cm	32-25	4	plant				not collected
32 cm laminated	25-20	5	fish		100	0	2 pieces
3.7 tuff	25-20	6	plant				
1.2 crumbly tuff	25-20	7	plant				
	20-17	8	fish		100	0	not collected
	20-17	9	leaf				2 pieces
	20-17	10	fish	7.2	100	30	2 pieces
	20-17	11	fish	8.4	100	0	
	20-17	12	fish			0	tail only, not collected
	20-17	13	fish		100	0	2 pieces
	20-17	14	fish		100	0	2 pieces
	20-17	15	fish			0	tail only, not collected
	20-17	16	fish	8.7	100	30	
	20-17	17	fish			0	
	17-13	18	fish	7.2	100	0	
	17-13	19	fish		100	20	
	17-13	20	fish		100	0	2 fish
	17-13	21	fish	7.8	100	50	
	17-13	22	fish	7.5	100	30	
	17-13	23	fish			20	*look at vertebrae
	17-13	24	fish			0	not collected
	17-13	25	fish		100	20	
	17-13	26	fish			0	
	17-13	27	fish	7.3	100	0	
	17-13	28	fish		100	0	
	17-13	29	fish			0	
	17-13	30	fish		100	20	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes	Layer (cm from base)
	17-13	31	fish		100	0	
	17-13	32	fish		100	0	
	17-13	33	plant				
	13-10	36	fish	7.5	100	20	
	13-10	37	fish	7.5	100	20	
	13-10	38	fish		100	0	
	13-10	39	fish		100	0	
	13-10	40	fish	6.5	100	20	2 pieces
	13-10	41	fish	6.5	100	20	
	13-10	42	fish			0	
	13-10	43	fish	5.4	100	0	
	13-10	44	fish		100	0	
	13-10	45	fish		100	0	
	13-10	46	fish		100	20	
	13-10	47	fish		100	20	
	13-10	48	fish		100	10	
	13-10	49	fish		100	0	
	13-10	50	fish		100	10	
	13-10	51	fish		100	0	
	13-10	52	fish		100	0	
	13-10	53	fish		100	0	
	13-10	54	fish		100	0	
	13-10	55	fish		100	0	
	13-10	56	fish	~8	100	10	
	13-10	57	fish		100	10	
	13-10	58	fish		100	10	
	13-10	59	fish		100	10	
	13-10	60	fish		100	0	
	13-10	61	fish		100	5	
	13-10	62	fish				
	13-10	63	fish		100	0	
	13-10	64	fish		100	0	
	13-10	65	fish		90	0	neck is broken
	13-10	66	fish	~7	100	0	
	13-10	67	fish			0	

Fossil Field Data: UGF-3

UGF-3	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.789018 N	30-28.5	1	plant	1			not collected
-110.71174 W	28.5-26.5	2	seed	1			2 pieces
	30-28.5	3	stem	1.5			not collected
59 x 60 cm	28.5-26.5	4	fish	12+	100	0	3 pieces
30 cm laminated	26.5-24.5	5	plant				not collected
15 cm crumbly ash/mudstone	26.5-24.5	6	insect				
	26.5-24.5	7	leaf	2			not collected, oval leaf
	26.5-24.5	8	flying insect				
	26.5-24.5	9	leaf	2			similar to specimen #7
	26.5-24.5	10	stick	9			not collected
	24.5-22.5	11	flying insect				2 pieces
	24.5-22.5	12	fish				
	24.5-22.5	13	fish		100	0	
	24.5-22.5	14	fish	6.3	100	0	
	24.5-22.5	15	fish		100	0	
	24.5-22.5	16	fish		30	0	
	24.5-22.5	17	seed				
	24.5-22.5	18	Knightia		100	0	
	24.5-22.5	19	Knightia		100	0	2 pieces
	24.5-22.5	20	fish		100	0	3 pieces
	24.5-22.5	21	fish		100	0	
	24.5-22.5	22	leaf				
	24.5-22.5	23	insect				
	24.5-22.5	24	fish		100	0	
	24.5-22.5	25	fish		100	0	
	24.5-22.5	26	insect				
	17-14.5	27	seed				
	17-14.5	28	fish			0	
	14.5-12	29	fish			0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes	Layer (cm from base)
	14.5-12	30	fish	8.5			
	14.5-12	31	fish				
	14.5-12	32	fish			0	only the head
	14.5-12	33	insect				
	14.5-12	35	fish			0	2 fish ?
	14.5-12	36	fish			0	not collected, only tail
	12-9.5	37	fish			0	
	12-9.5	38	fish			0	2 pieces
	12-9.5	39	fish		100	0	not collected
	9.5-7	40	fish		100	0	only tail visible
	9.5-7	41	stick				
	9.5-7	42	fish		100	0	
						0	
	9.5-7	44	fish		100	0	
	9.5-7	45	fish		100	0	
	9.5-7	46	fish		100	0	
	9.5-7	47	stem			0	not collected
	9.5-7	48	fish		100	0	not collected
	9.5-7	49	fish			0	

Fossil Field Data: UGF-5

UGF-5	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.756821 N - 110.75002 W	29-27	1	fish		100	0	
	29-27	2	fish		100	0	3 pieces
	27-21	3	seed				2 pieces
90 x 18 cm	27-21	4	fish			0	
29 cm laminated	27-21	5	plants				3 pieces
7 cm tuff	27-21	6	fish		100	0	both eyes
mudstone below	27-21	7	fish	7.5			both eyes, tail is separate
	27-21	8	leaf				
	27-21	9	fish			0	only tail
	27-21	10	fish	7	100	0	scales?
	27-21	11	fish				only tail
	27-21	12	fish			0	only tail
	27-21	13	fish		100	0	4 pieces
	27-21	14	fish		100	0	
	27-21	15	fish		100	0	2 pieces
	21-14	16	plant				
	21-14	17	plant				
	21-14	18	plant				2 pieces
	21-14	19	fish			0	not collected
	21-14	20	fish			0	2+ fish
	21-14	21	insect				
	21-14	22	fish				
	21-14	23	fish		100	0	
	21-14	24	fish		100	0	
	21-14	25	fish		100	0	
	21-14	26	fish		100	0	
	21-14	27	fish		100	0	2 fish
	21-14	28	fish		80	0	
	21-14	29	fish			0	
	21-14	30	Diplomystus	10	100	0	crystals in vertebrae

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes	Layer (cm from base)
	21-14	31				0	not collected
	21-14	32				0	not collected
	21-14	33	fish		100	0	2 pieces
	21-14	35	fish		100	0	
	21-14	36	Diplomystus		100	0	
	21-14	37	fish		100	0	
	21-14	38	fish		30	0	bone pool
	21-14	39	fish			0	tail only, not collected
	21-14	40	Knightia		100	0	
	21-14	41	plant				
	14-10	42	fish		100	0	not collected
	14-10	43	fish			0	
	14-10	44	Knightia		100	0	
	14-10	45	fish		100	0	
	14-10	46	fish		100	0	2 fish
	14-10	47	fish			0	only tail, not collected
	14-10	48	fish		100	0	2 fish
	14-10	49	Knightia			0	tail only, not collected
	8.0-0	50	Phareodus	21+	100	0	
	8.0-0	51	Diplomystus	8	100	0	
	8.0-0	52	Diplomystus		90	0	
	8.0-0	53	fish			0	
	8.0-0	54	fish		100	0	2 fish
	8.0-0	55	Diplomystus	6.3	100	0	
	8.0-0	56	Knightia	6.8	100	0	
	8.0-0	57	fish			0	
	8.0-0	58	fish			0	
	8.0-0	59	fish			0	
	8.0-0	60	fish		100	0	
	8.0-0	61	fish		100	0	3 fish, fry
	8.0-0	62	fish		100	0	2 fish, fry
	8.0-0	63	fish		100	0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes	Layer (cm from base)
	8.0-0	64	fish		100	0	
	8.0-0	65	fish		100	0	not collected
	8.0-0	66	fish		100	0	
	8.0-0	67	fish				
	8.0-0	68	fish		100	0	
	8.0-0	69	fish			0	
	8.0-0	70	fish			0	
	8.0-0	71	fish		100	0	
	8.0-0	73	fish			0	
	8.0-0	74	fish	8	100	0	
	8.0-0	75	fish			0	
	8.0-0	76	fish			0	
	8.0-0	77					
	8.0-0	78	fish		100	0	not collected
	8.0-0	79	fish		100	0	
	8.0-0	80	fish		100	0	
	8.0-0	81	fish		100	0	fry
	8.0-0	82	Knightia		100	0	3 fish, not collected
	21-14	83	fish		100	0	
	14-10	84	fish		100	0	
	14-10	85	fish		100	0	
	14-10	86	fish		100	0	

Fossil Field Data: LGF-5

LGF-5	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.756821 N	30-28	1	leaf				2 pieces
-110.75002 W	28-25	2	march fly		100		2 pieces
	28-25	3	seed				
88 x 38 cm	30-28	4	plant				2 pieces
30 cm laminated	28-25	5	plant				
7 cm tuff	28-25	6	fish		100	0	2 pieces
	28-25	7	seed				
	28-25	8	?				
	25-22	9	fish		100	0	2 pieces
	25-22	10	fish		100	0	2 pieces
	25-22	11	fish		100	0	
	25-22	12	fish		100	0	4 pieces
	25-22	13	Phareodus		100	0	2 pieces
	25-22	14	fish	9.5	100	0	2 pieces
	25-22	15	seed				2 pieces
	25-22	16	insect				
	22-19	17	plant				
	22-19	18	branch	3 cm wide			not collected
	22-19	19	fish			0	only head
	22-19	20	fish			0	only head
	22-19	21	plant				2 pieces
	22-19	22	plant				2 pieces
	22-19	23	fish			0	2 pieces
	22-19	24	plant				2 pieces
	22-19	25	plant				2 pieces
	22-19	26	fish			0	
	19-16	27	leaf	8.3	100		2 pieces
	19-16	28	fish		100	0	
	19-16	29	fish			0	2 pieces
	19-16	30	fish			0	2 pieces
	19-16	31	fish		100	0	
	19-16	32	fish			0	
	19-16	33	fish			0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
19-16	35	fish		100	0	
19-16	36	fish			0	
19-16	37	fish		100	0	2 pieces
16-12	38	fish		100	0	2 pieces
16-12	39	fish			0	2 pieces
16-12	40	fish		100	0	
16-12	41	plant				2 pieces
16-12	42	fish	7.5	100	0	
16-12	43	fish			0	2 pieces
16-12	44	fish			0	
16-12	45	?				2 pieces
16-12	46	fish		100	0	3 pieces
16-12	47	leaf				
12.0-8	48	plant				2 pieces
12.0-8	49	fish		100	0	2 pieces
12.0-8	50	fish	6.7	100	0	2 pieces
12.0-8	51	leaf				2 pieces
12.0-8	52	fish		100	0	2 pieces
12.0-8	53	fish			0	2 pieces
12.0-8	54	leaf				
12.0-8	55	fish			0	
12.0-8	56	fish			0	
12.0-8	57	fish			0	
12.0-8	58	fish	6	100	0	
12.0-8	59	fish		100	0	
12.0-8	60	fish		100	0	
12.0-8	61	fish			0	
12.0-8	62	fish		100	0	
12.0-8	63	fish			0	
12.0-8	64	fish				
12.0-8	68	fish		100	0	
12.0-8	69	fish	7.5	100	0	
12.0-8	70	leaf				
12.0-8	71	fish		100	0	
8.0-5	72	plant				
12.0-8	73	fish			0	2 pieces

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
12.0-8	75	fish			0	
12.0-8	76	fish				
12.0-8	77	fish			0	
12.0-8	78					
12.0-8	79	fish		100	0	
12.0-8	80	plant				
12.0-8	81	fish	4.3	100	0	
12.0-8	82	fish	5.5	100	0	
12.0-8	83	fish		100	0	
12.0-8	84	fish		100	0	
12.0-8	85	fish		100	0	
12.0-8	86	fish		100	0	
12.0-8	87	fish		100	0	
12.0-8	88	fish	5.5	100	0	
12.0-8	89	seed				
12.0-8	90	fish				
12.0-8	91	fish		100	0	
12.0-8	92	fish			0	
12.0-8	93	fish		100	0	
12.0-8	94	fish	~7	100	0	
12.0-8	95	fish	7.2	100	0	
12.0-8	96	fish	~6	100	0	
12.0-8	97	fish		100	0	not collected

Fossil Field Data: LGF-7

LGF-7	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41°45'36.21"N	32-30	1	fish	~10	100	0	
110°44'18.91"W	32-30	2	fish			0	
	32-30	3	fish			0	not collected
90 x 60 cm	32-30	4	stem				not collected
32 cm laminated	28-27	5	fish	4.5	100	0	2 pieces, floater
4 cm tuff	28-27	6	fish		100	0	not collected
	28-27	7	seed				
	26-25	8	stem				
	25-24	9	leaf				
	25-24	10	fish	10.5	100	0	
	25-24	11	fish	8	100	0	
	25-24	12	stem				not collected
	24-23	13	fish		100	0	not collected
	23-22	14	fish		100	0	not collected
	23-22	15	fish		100	0	not collected
	23-22	16	fish		100	0	
	23-22	17	fish		100	0	
	22-20	18	fish		100	0	
	22-20	19	fish		100	0	
	22-20	20	fish	8	100	0	
	20-19	21	fish	2	100	0	
	20-19	22	seed				
	20-19	23	fish		100	0	
	20-19	24	fish		100	0	
	20-19	25	fish	8.5	100	0	
	20-19	26	fish		100	0	
	20-19	27	fish		100	0	
	20-19	28	fish		100	0	
	20-19	29	fish		100	0	not collected
	20-19	30	fish		100	0	not collected
	19-18	31	fish		100	0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes	Layer (cm from base)
	20-19	32	stem				not collected
	18-16	33	fish		100	0	
	18-16	34	fish		100	0	
	18-16	35	fish		100	0	
	18-16	37	fish		100	0	not collected
	18-16	38	stem				not collected
	16-15	39	fish		100	0	
	16-15	40	fish		100	0	
	16-15	41	fish		100	0	
	16-15	42	fish		100	0	not collected
	16-15	43	fish		100	0	
	16-15	44	fish		100	0	
	16-15	45	fish		100	0	
	16-15	46	fish		100	0	
	16-15	47	fish		100	0	
	16-15	48	fish		100	0	
	16-15	49	stem				
	16-15	50	fish		100	0	
	16-15	51	fish		100	0	
	16-15	52	fish		100	0	
	16-15	53	fish		100	0	

Fossil Field Data: UGF-8

UGF-8	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41°45'38.70" N	35-30	1	fish		60	60	
110°44'37.03" W	35-30	2	fish	9	100	30	not collected
	35-30	3	fish		40	20	
81 x 69 cm	35-30	4	fish		100	10	
26 cm laminated tuff at base is SSD, mixed into mudstone	35-30	5	fish			0	not collected
	35-30	6	fish			0	not collected
	35-30	7	fish			0	not collected
	35-30	8	fish			0	not collected
	35-30	9	fish			0	not collected
	35-30	10	fish			0	not collected
	35-30	11	fish		0	10	not collected
	35-30	12	plant				not collected
	35-30	13	fish		0	10	not collected
	35-30	14	fish		100	10	not collected
	35-30	15	fish		100	0	not collected
	35-30	16	fish		100	0	
	35-30	17	fish		100	0	not collected
	35-30	18	fish		50	0	head blown
	35-30	19	fish		0	0	
	35-30	20	fish		80	0	
	35-30	21	fish		100	10	
	35-30	22	fish		20	10	
	35-30	23	fish		100	0	
	35-30	24	fish		100	10	
	35-30	25	fish		0	10	
	35-30	26	fish		100	20	

35-30	27	fish	100	0	
30-24	28	stem			not collected
30-24	29	stem			not collected
30-24	30	Knightia	100	0	
30-24	31	fish	80	10	not collected
24-22	32	fish	100	0	
24-22	33	plant			
22-17	34	fish	100	0	not collected
22-17	35	insect			
22-17	36	fish	100	0	
17-12	37	fish	100	0	not collected
12.0-6	38	fish	100	0	
12.0-6	39	fish	100	0	
12.0-6	40	fish	100	0	
12.0-6	41	fish	100	0	
12.0-6	42	stem			not collected
12.0-6	43	stem			not collected
6.0-4	44	Knightia	100	0	not collected
6.0-4	45	fish	100	0	
6.0-4	46	fish	100	0	
6.0-4	47	fish	100	20	

Fossil Field Data: LGF-8

LGF-8	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41°45'38.70" N	28-25	1	fish		100	0	
110°44'37.03" W	25-21	2	fish	~7	100	0	2 pieces
	25-21	3	fish		100	0	
111 x 90 cm	25-21	4	seed				
32 cm laminated	21-17	5	fish		100	0	
4 cm tuff	21-17	6	fish	~8.5	100	0	2 pieces
	21-17	7	insect				
	21-17	8	fish		100	0	
	25-21	9	fish		100	0	not collected
	21-17	10	fish		100	0	not collected
	21-17	11	fish		100	0	not collected
	21-17	12	fish		100	0	not collected
	21-17	13	fish		100	0	
	21-17	14	plant				
	21-17	15	plant				not collected
	17-13	16	fish		100	0	
	17-13	17	fish			0	
	11.0-8	18	fish		100	0	2 pieces
	11.0-8	19	insect		100		2 pieces
	11.0-8	20	fish		100	0	2 pieces
	11.0-8	21	fish		100	0	2 pieces

Fossil Field Data: UGF-9

UGF-9	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.75246 N	23-22	1	plant				2 pieces
-110.74957 W	19	2	Knightia	8.8	100	0	
	19-18	3	stem				not collected
90 x 38 cm	19	4	fish	~10	100	0	2 pieces
25 cm laminated	19	5	fish		100	0	
3.5 cm tuff	19-18	6	plant				2 pieces
	19-18	7	fish		100	0	2 pieces
	19-18	8	fish		100	0	
	19-18	9	fish	6.2	100	0	2 pieces
	19-18	10	fish	8.2	100	0	2 pieces
	19-18	11	plant				
	17-16	12	fish		100	0	2 pieces
	18-16	13	fish	9.2	100	0	3 pieces
	17-16	14	fish		100	0	
	18-16	15	fish		100	0	
	18-16	16	fish		100	0	2 pieces
	18-16	17	fish			0	2 pieces
	18-16	18	fish	~8.5	100	0	
	18-16	19	fish	4.2	100	0	2 pieces
	18-16	20	fish		100	0	
	17-16	21	fish		100	0	
	13-12	22	fish	~6.5	100	0	2 pieces
	13-12	23	fish		100	0	
	13-12	24	seed				2 pieces
	13-12	25	fish		100	0	2 pieces
	13-12	26	fish		100	0	2 pieces
	13-12	27	fish		100	0	
	12.0-11	28	fish		100	10	
	12.0-11	29	fish		100	0	
	12.0-11	30	fish		100	0	
	12.0-11	31	fish		100	10	
	12.0-11	32	fish		100	0	not collected
	12.0-11	33	fish		100	0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
12.0-11	35	fish		100		2 pieces
9.0-8	36	fish		100	10	
11.0-10	37	fish		100	0	
10.0-9	38	fish		100	0	
10.0-9	39	fish	6.4	100	10	
10.0-9	40	fish			0	
10.0-9	41	fish			10	
10.0-9	42	fish		100	10	
8	43	fish		100	10	
9.0-8	44	fish		100	10	
9	45	fish		100	10	
10.0-9	46	fish	5.9	100	10	
10.0-9	47	fish		100	0	not collected
8.0-7	48	fish		100	10	
8.0-7	49	fish		100	0	
8.0-7	50	fish	6.1	100	10	
9.0-8	51	fish	3.9	100	0	
9.0-8	52	fish		100	10	
9.0-8	53	fish			0	
9.0-8	54	fish			0	
9.0-8	55	fish		100	0	
9.0-8	56	fish		100	10	2 fish
7.5-0	57	fish		100	0	
7.5-0	58	fish		100	0	
17	59	fish		100	0	2 pieces
18-16	60	fish		100	0	not collected
13-12	61	fish		100	0	
9.0-8	62	fish			0	
9.0-8	63	fish		100	0	
9.0-8	64	fish		100	0	

Fossil Field Data: UGF-10

UGF-10	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.76814 N	23.5-22.5	1	fish		100	0	
-110.73588 W	22.5-19.5	2	fish				only eyes
	19.5-18	3	fish		100	0	
90 x 60 cm	16-14.5	4	insect				
32 cm laminated mudstone w/tuff specks	16-14.5	5	fish		100	0	
	16-14.5	6	fish		100	0	
	16-14.5	7	fish		100	0	
	14.5-13	8	Phareodus		100	0	
	14.5-13	9	stem				
	13-10	10	stem				
	13-10	11	seed				
	13-10	12	fish		100	0	
	10-8.5	13	fish		100	0	
	10-8.5	14	fish	8.5	100	0	
	10-8.5	15	fish		100	0	
	10-8.5	16	fish		100	0	
	10-8.5	17	fish		100	0	
	10-8.5	18	fish		100	0	
	10-8.5	19	fish		100	0	
	10-8.5	20	fish		100	0	
	10-8.5	21	fish		100	0	
	10-8.5	22	fish		100	0	
	8.5-7.5	23	fish		100	0	
	7.5-6	24	fish		100	0	
	6-4.5	25	fish		100	0	
	6-4.5	26	fish		100	0	
	4.5-0	27	fish		100	0	

Fossil Field Data: LGF-10

LFG-10	Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
41.76814 N	24.5-23	1	fish		100	0	
-110.73588	24.5-23	2	fish		100	0	
	23-21	3	fish	~10.5	100	0	
80 x 60 cm	23-21	4	fish		100	0	
30 cm laminated	23-21	5	fish		100	0	aspiration
5 cm tuff	23-21	6	fish		100	0	
	23-21	7	fish		100	0	
	21-19.5	8	stem				
	21-19.5	9	fish	8	100	0	
	21-19.5	10	fish		100	0	
	21-19.5	11	fish		100	0	
	21-19.5	12	fish		100	0	
	21-19.5	13	leaf				
	21-19.5	14	fish		100	0	
	21-19.5	15	fish		100	0	
	21-19.5	16	stem				
	19.5-18.5	17	fish		100	0	
	19.5-18.5	18	leaf				
	19.5-18.5	19	fish		100	0	
	19.5-18.5	20	fish	8.5	100	0	
	18.5-17	21	fish		100	0	
	18.5-17	22	fish			0	
	18.5-17	23	fish		100	0	
	18.5-17	24	fish			0	
	17-16	25	fish	7.2	100	0	only eyes
	18.5-17	26	fish		100	0	
	17-16	27	fish		100	0	
	17-16	28	fish		100	0	
	17-16	29	fish	9	100	0	
	17-16	30	fish		100	0	
	17-16	31	fish		100	0	
	17-16	32	fish		100	0	

Layer (cm from base)	Specimen #	Name	Length (cm)	% Articulation	% bones	Notes
17-16	34	fish		100	0	
16-14.5	35	plant				
16-14.5	36	fish		100	0	
16-14.5	37	fish	8.5	100	0	
14.5-13	38	fish		100	0	
14.5-13	39	fish		100	0	
14.5-13	40	fish		100	0	
14.5-13	41	fish		100	0	
14.5-13	42	fish		100	0	
14.5-13	43	fish		100	0	
14.5-13	44	fish		100	0	
14.5-13	45	fish		100	0	
14.5-13	46	fish		100	0	
21-19.5	47	fish		100	0	
11.5-0	48	fish		100	0	
11.5-0	49	fish		100	0	
13-11.5	50	fish		100	0	
11.5-10	51	fish		100	0	
11.5-10	52	fish		100	0	
11.5-10	53	fish		100	0	
11.5-10	54	fish		100	0	
11.5-10	55	fish		100	0	
11.5-10	56	fish		100	0	
11.5-10	57	fish	~8	100	0	
11.5-10	58	fish		100	0	
11.5-10	59	fish		100	0	
10-8.5	60	fish	~6.5	100	0	
10-8.5	61	fish		100	0	
10-8.5	62	fish		100	0	
10-8.5	63	stem				
8.5-7	64	fish		100	0	
8.5-7	65	fish		100	0	
28-18.5	66	insect				

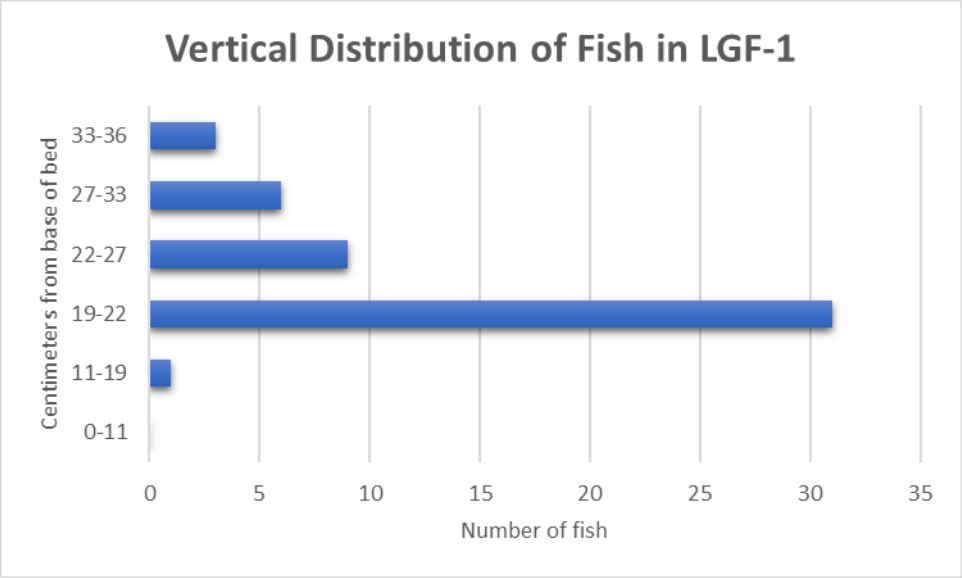
APPENDIX G

FOSSIL STATISTICS

Number of fish per one-meter cubed is based on fossils collected divided by volume of rock. Preservation types are, for the most part, based on naked eye observation.

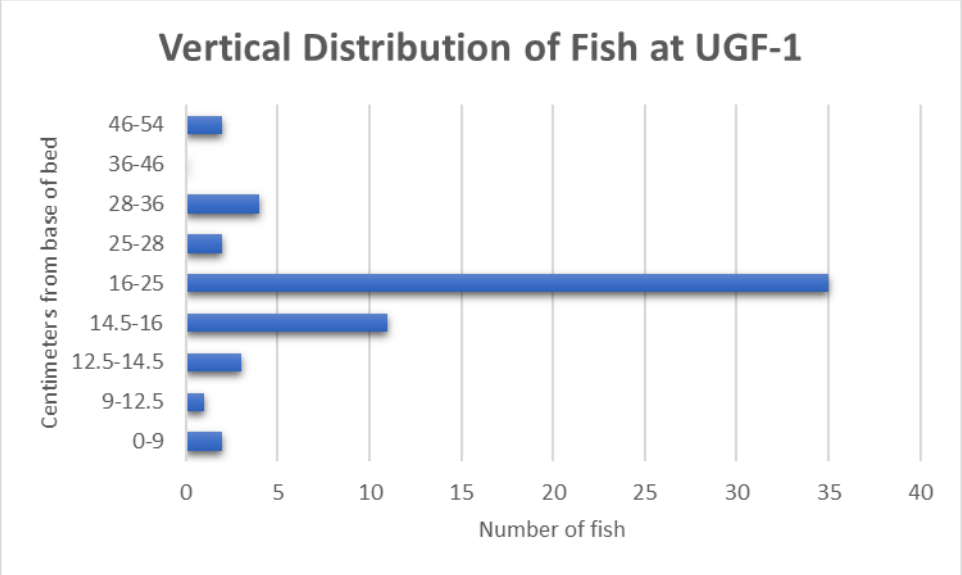
LGF-1

LGF-1	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	36-33	3			No bone
	33-27	6			
	27-22	9			
	22-19	31			
	19-11	1			
	11-0.0	0			
	Total	50	0.097	515	



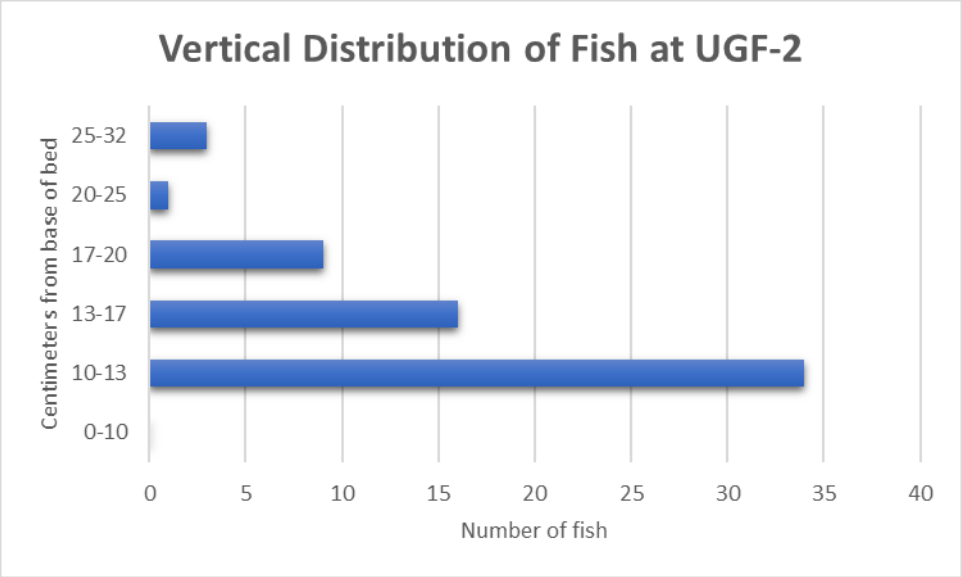
UGF-1

UGF-1	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	54-46	2			No bone
	46-36	0			
	36-28	4			
	28-25	2			
	25-16	35			
	16-14.5	11			
	14.5-12.5	3			
	12.5-9	1			
	9-0.0	2			
	Total	60	0.324	185	



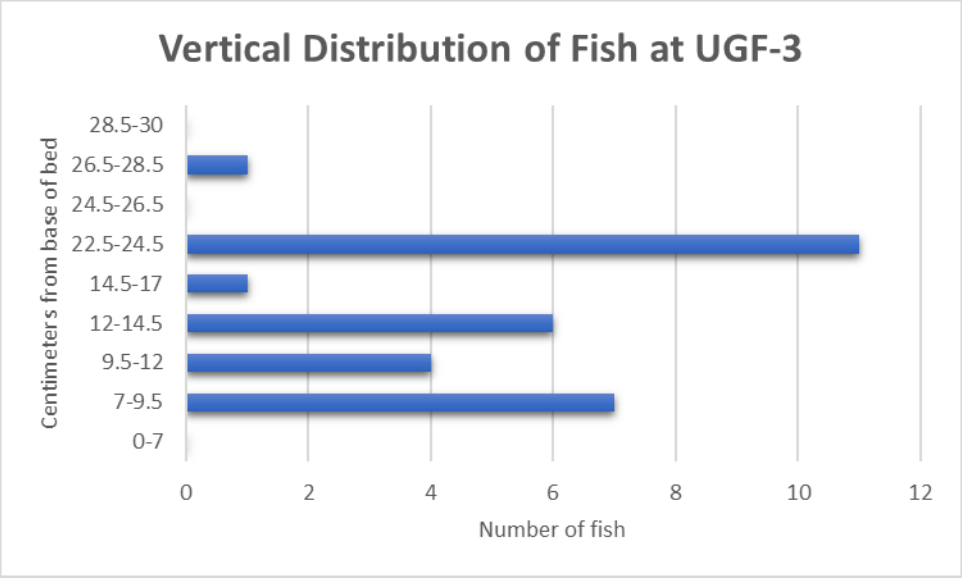
UGF-2

UGF-2	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	32-25	3			Some bone
	25-20	1			
	20-17	9			
	17-13	16			
	13-10	34			
	10-0.0	0			
	Total	63	0.128	492	



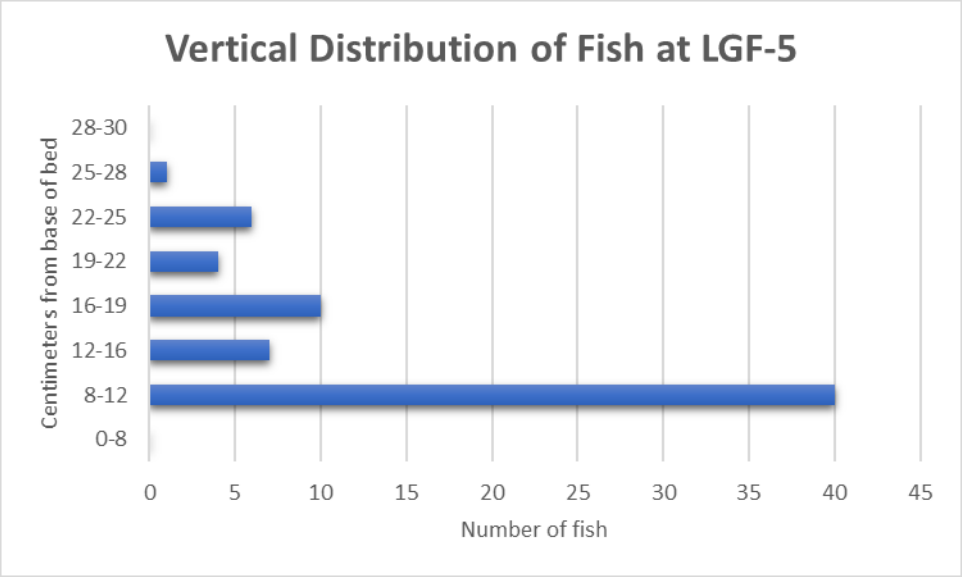
UGF-3

UGF-3	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	30-28.5	0			No bone
	28.5-26.5	1			
	26.5-24.5	0			
	24.5-22.5	11			
	17-14.5	1			
	14.5-12	6			
	12-9.5	4			
	9.5-7	7			
	7-0.0	0			
	Total	30	0.106	283	



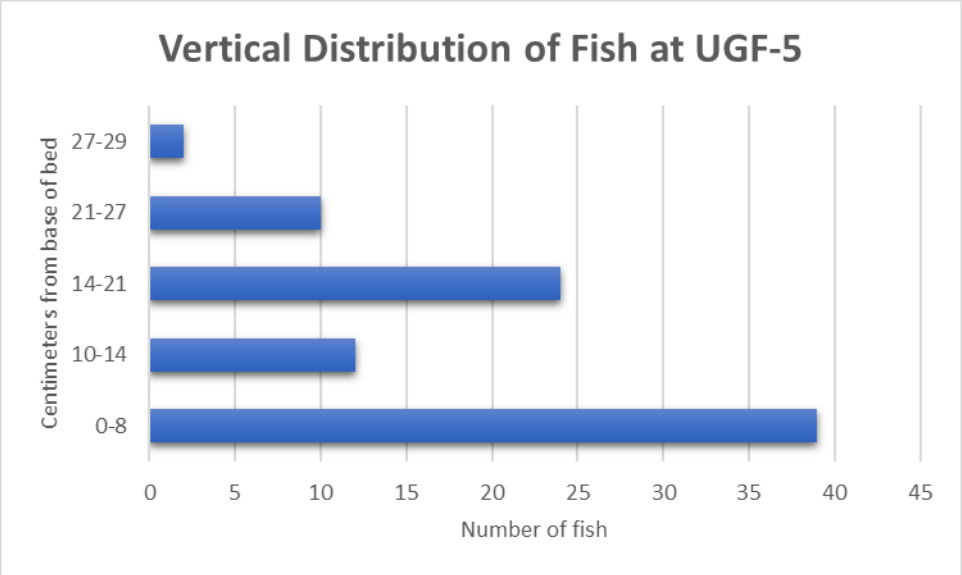
LGF-5

LFG-5	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	30-28	0			No bone
	28-25	1			
	25-22	6			
	22-19	4			
	19-16	10			
	16-12	7			
	12-8.0	40			
	8-0.0	0			
	Total	68	0.1	680	



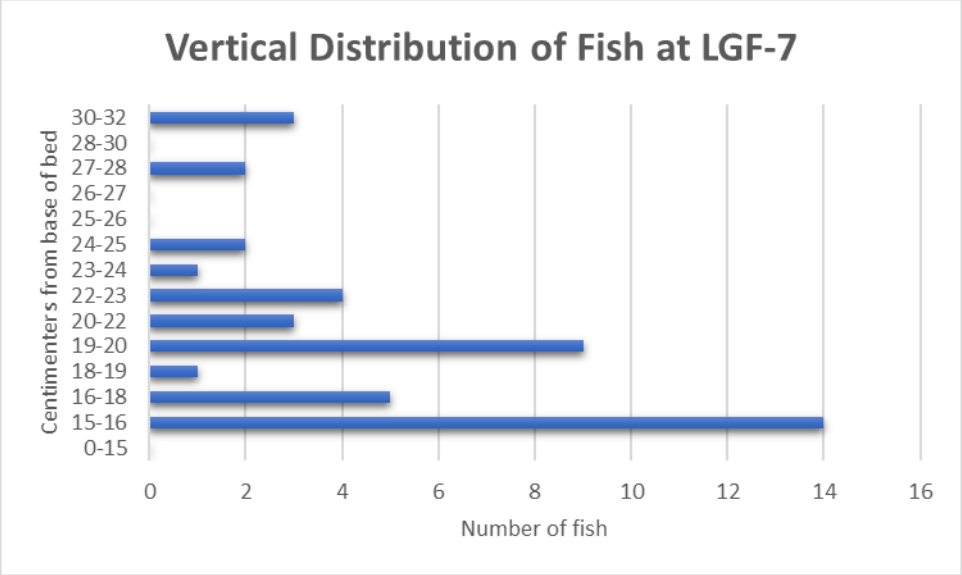
UGF-5

UGF-5	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	29-27	2			No bone
	27-21	10			
	21-14	24			
	14-10	12			
	8-0.0	39			
	Total	87	0.047	1851	



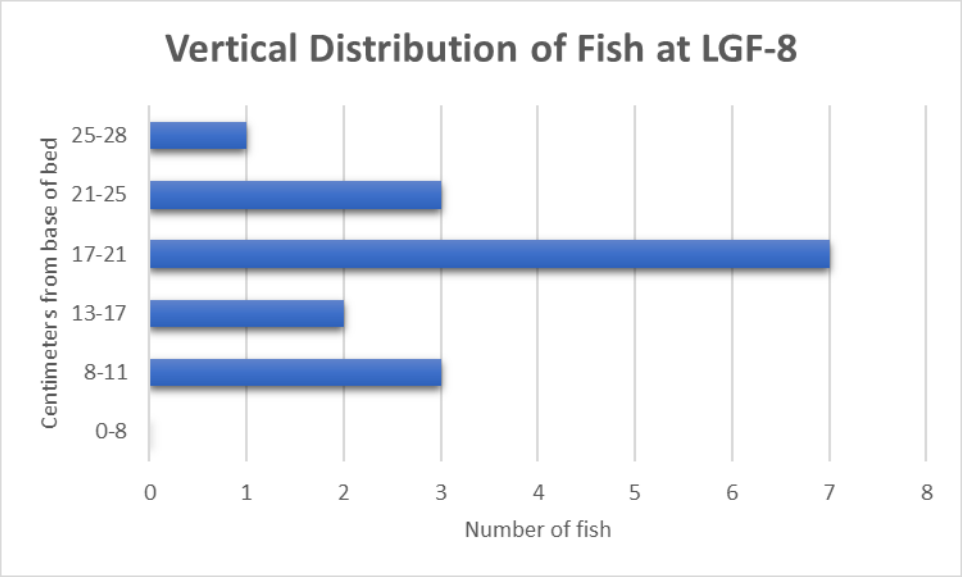
LGF-7

LGF-7	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	32-30	3			No bone
	30-28	0			
	28-27	2			
	27-26	0			
	26-25	0			
	25-24	2			
	24-23	1			
	23-22	4			
	22-20	3			
	20-19	9			
	19-18	1			
	18-16	5			
	16-15	14			
	15-0	0			
	Total	44	0.173	254	



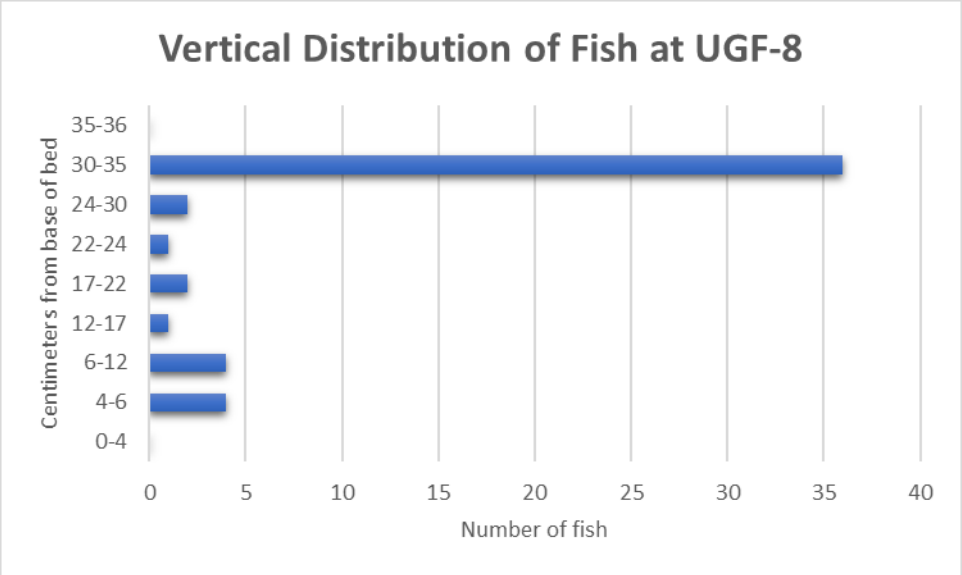
LGF-8

LGF-8	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	28-25	1			No bone
	25-21	3			
	21-17	7			
	17-13	2			
	11-8.0	3			
	8-0.0	0			
	Total	16	0.32	50	



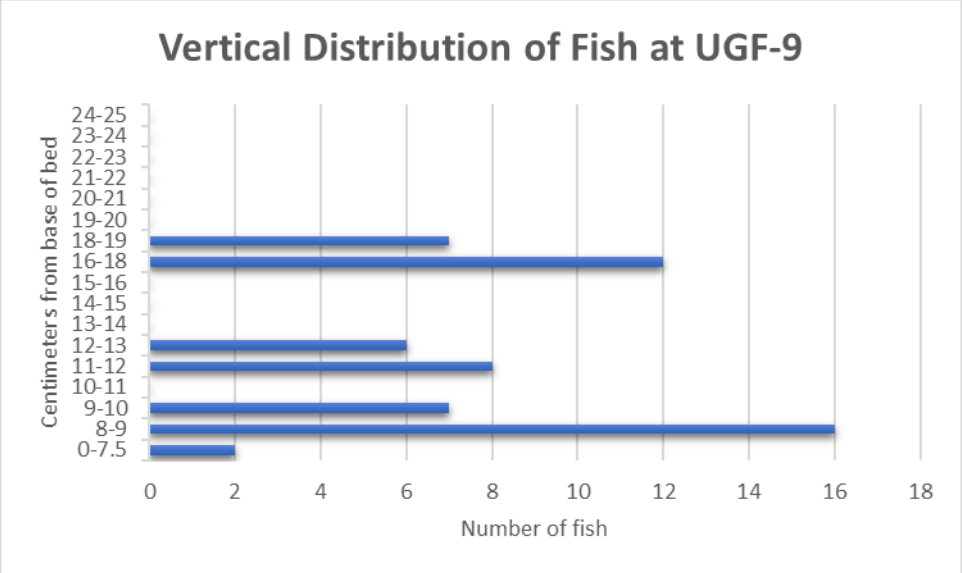
UGF-8

UGF-8	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	36-35	0			Some bone
	35-30	26			
	30-24	2			
	24-22	1			
	22-17	2			
	17-12	1			
	12-6.0	4			
	6-4.0	4			
	4-0.0	0			
	Total	40	0.145	276	



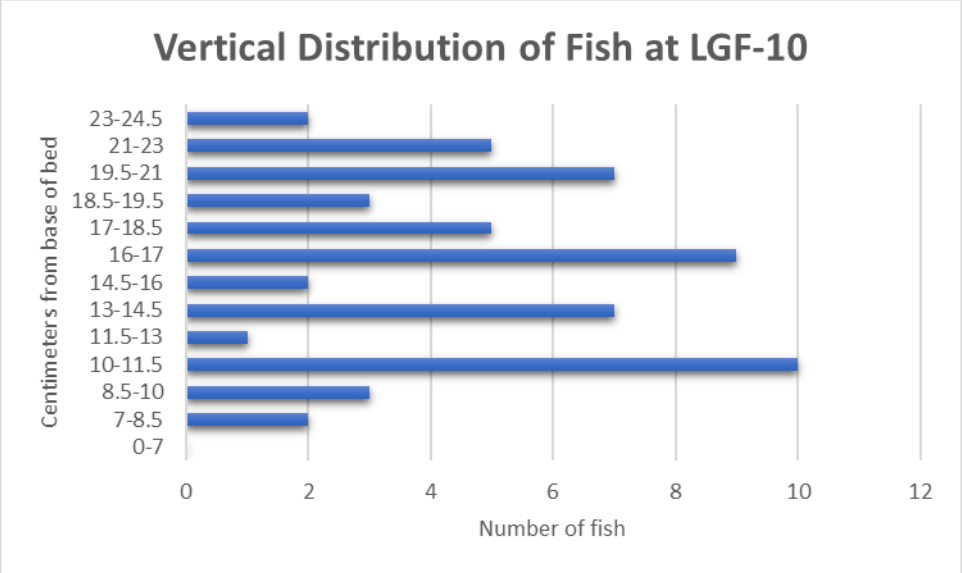
UGF-9

UGF-9	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	25-24	0			Some bone
	24-23	0			
	23-22	0			
	22-21	0			
	21-20	0			
	20-19	0			
	19-18	7			
	18-16	12			
	16-15	0			
	15-14	0			
	14-13	0			
	13-12	6			
	12-11.0	8			
	11-10.0	0			
	10-9.0	7			
	9-8.0	16			
	7.5-0	2			
	Total	58	0.086	674	



LGF-10

LGF-10	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	24.5-23	2			No bone
	23-21	5			
	21-19.5	7			
	19.5-18.5	3			
	18.5-17	5			
	17-16	9			
	16-14.5	2			
	14.5-13	7			
	13-11.5	1			
	11.5-10	10			
	10-8.5	3			
	8.5-7	2			
	7-0.0	0			
	Total	56	0.144	389	



UGF-10

UGF-10	Layer	# of fish	Volume of rock (m)	Fish/m^3	Type of preservation
	23.5-22.5	1			No bone
	22.5-19.5	1			
	19.5-18	1			
	18-16	0			
	16-14.5	3			
	14.5-13	1			
	13-10	1			
	10-8.5	10			
	8.5-7.5	1			
	7.5-6	1			
	6-4.5	2			
	4.5-0	1			
	Total	23	0.173	133