PSPreservation of Primary Lake Signatures in Carbonates of the Eocene Green River Wilkins Peak-Laney Member Transitional Zone*

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Abstract

Important changes in carbonate mineralogy, texture, and stable isotope composition occur at the transition from the Wilkins Peak Member to the Laney Member in the Eocene Green River Formation, Wyoming, which reflect evolution of inflow waters, lake waters, and paleoenvironments.

Alternating organic-rich laminae and primary aragonite and calcite laminae were identified from the lower Laney Member in the Bridger Basin, Wyoming. Criteria for identifying primary lacustrine aragonite include its purity, preservation of well-sorted, prismatic crystals 5-10 µm in length, micro-lamination defined by crystal size variation, and poor cementation. Primary precipitated calcite also forms laminae that are monomineralic, unconsolidated, and lack diagenetic overprints. Calcite crystals are well-sorted equant blocky polyhedra, ~10 µm in size. Primary calcite and aragonite in the lower Laney Member have $\delta^{18}O$ values that decrease upward by ~3‰ over 15 meters of stratigraphic section which suggests (1) source waters changed to high altitude foreland rivers or (2) lake waters underwent less evaporative concentration than in the underlying Wilkins Member.

The top of the Wilkins Peak Member contains heterogeneous laminae of calcite and dolomite. Evaporites associated with these layers suggest deposition in underfilled, evaporative lakes. Carbonate mineral textures include well-sorted euhedral primary-precipitated dolomite crystals <15 µm and interlocking diagenetic mosaics of calcite and dolomite 20-70 µm in size. Electron microprobe analyses indicate diagenetic overgrowths of Fe-rich dolomite on cloudy Fe-poor cores. $\delta^{18}O$ values of carbonate laminae in the upper Wilkins Peak Member vary by ~6‰ with no covariance, suggesting diagenetic overprinting. The results from this study show that understanding the primary lacustrine versus diagenetic origin of Green River carbonate minerals is essential for paleoenvironmental and paleoclimate interpretations

PRESERVATION OF PRIMARY LAKE SIGNATURES IN CARBONATES OF THE EOCENE GREEN RIVER WILKINS PEAK-LANEY MEMBER TRANSITIONAL ZONE

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Abstract

Important changes in carbonate mineralogy, texture, and stable isotope composition occur at the transition from the Wilkins Peak Member to the Laney Member in the Eocene Green River Formation, Wyoming (Figs. 1 & 2), which reflect evolution of inflow waters, lake waters, and paleoenvironments .

Alternating organic-rich laminae and primary aragonite and calcite laminae were identified from the lower Laney Member in the Bridger Basin, Wyoming (Fig. 1). Criteria for identifying primary lacustrine aragonite include its purity, preservation of well sorted, prismatic crystals 5-10µm in length, micro-lamination defined by crystal size variation, and poor cementation (Fig. 3). Primary precipitated calcite also forms laminae that are monomineralic, unconsolidated, and lack diagenetic overprints. Calcite crystals are well sorted equant blocky polyhedra, ~10µm in size (Fig. 4). Primary calcite and aragonite in the lower Laney Member have $\delta^{18}O$ values that decrease upward by ~3‰ over 15 meters of stratigraphic section which suggests (1) source waters changed to high altitude foreland rivers or (2) lake waters underwent less evaporative concentration than in the underlying Wilkins Peak Member (Figs. 9 & 10).

The top of the Wilkins Peak Member contains heterogeneous laminae of calcite and dolomite. Evaporites associated with these layers suggest deposition in underfilled, evaporative lakes. Carbonate mineral textures include well-sorted euhedral primary-precipitated dolomite crystals <15µm (Fig. 5) and interlocking diagenetic mosaics of calcite and dolomite 20-70µm in size (Fig. 6). Electron microprobe analyses indicate diagenetic overgrowths of Fe-rich dolomite on cloudy Fe-poor cores (Fig. 6B; Fig 9; Tables 1-4). $\delta^{18}O$ values of carbonate laminae in the upper Wilkins Peak Member vary by ~6‰ with no covariance, suggesting diagenetic overprinting (Fig. 9). The results from this study show that understanding the primary lacustrine versus diagenetic origin of Green River carbonate minerals is essential for paleoenvironment and paleoclimate interpretations.

Geologic Background

The Green River Formation (GRF) of Wyoming, Colorado, and Utah is an Eocene lacustrine deposit (ca 53 and ca 48 Ma) that formed in foreland basins east of the Cordilleran fold and thrust belt (Smith et al., 2008; Fig. 1). Sediments of the GRF were deposited in two large lakes: Lake Gosiute in the Bridger and Washakie Basins and Lake Uinta in the Uinta and Piceance Creek Basins (Bradley, 1964). Green River lakes periodically varied between underfilled evaporative stages (e.g. Wilkins Peak Member), balanced fill "fresher" water lakes (e.g. early Laney Member), and overfilled states.

The WPM is dominated by calcareous mudstones (commonly kerogen-rich) and quartzose and arkosic sandstones which were deposited in hydrologically-closed, saline lakes (Smoot, 1983; Fig. 2). WPM facies form well-developed meter-scale cycles which reflect lake expansion and contraction (Pietras and Carroll, 2006; Fig. 2). The overlying LaClede Bed of the basal LM represents a return to profundal lake stages fluctuating between balanced fill and overfilled conditions (Carroll et al., 2008; Doebbert et al., 2010; Fig. 2). The LaClede bed comprises organic-rich and well-laminated carbonates that suggest deposition in a meromictic lake with anoxic bottom waters. Fish fossils from this unit indicate fresher surface waters.

The transition from the WPM to the LM is a result of changing lake conditions from a hydrologically closed, and underfilled saline basin into a balanced fill to overfilled lake. Previous work by Carroll et al. (2008) and Doebbert et al. (2010) suggest decreasing salinity during this transition due to the capture of a lighter-sourced river or rivers, marked by a decrease in carbonate $\delta^{18}O$.

Methods

- Core Research & Sampling
  - ERDA 1 Blacks Fork Core (Fig. 1)
- Microscopy
  - Thin sectioning of core samples
  - Transmitted Light & Scanning Electron Microcopy (SEM)
- X-ray Powder Diffraction (XRD)
  - Micromill and XRD individual laminae
  - Rietveld refinements to quantify mineralogy using GSAS (Larson and Von Dreele, 2000)
- Electron Microprobe (EMP)
  - Mg-content of calcite & Fe-concentration of dolomite
- Stable Isotope Analyses
  - Micromill select laminae
  - $\delta^{18}O$ and $\delta^{13}C$ of individual carbonate laminae

Alkaline Earth Carbonates

Origins of alkaline earth carbonates in lacustrine settings:

1) Primary precipitates in the water column

2) Biologically produced skeletons

3) Transported detrital grains

4) Diagenetic alteration products

Locality & Stratigraphy

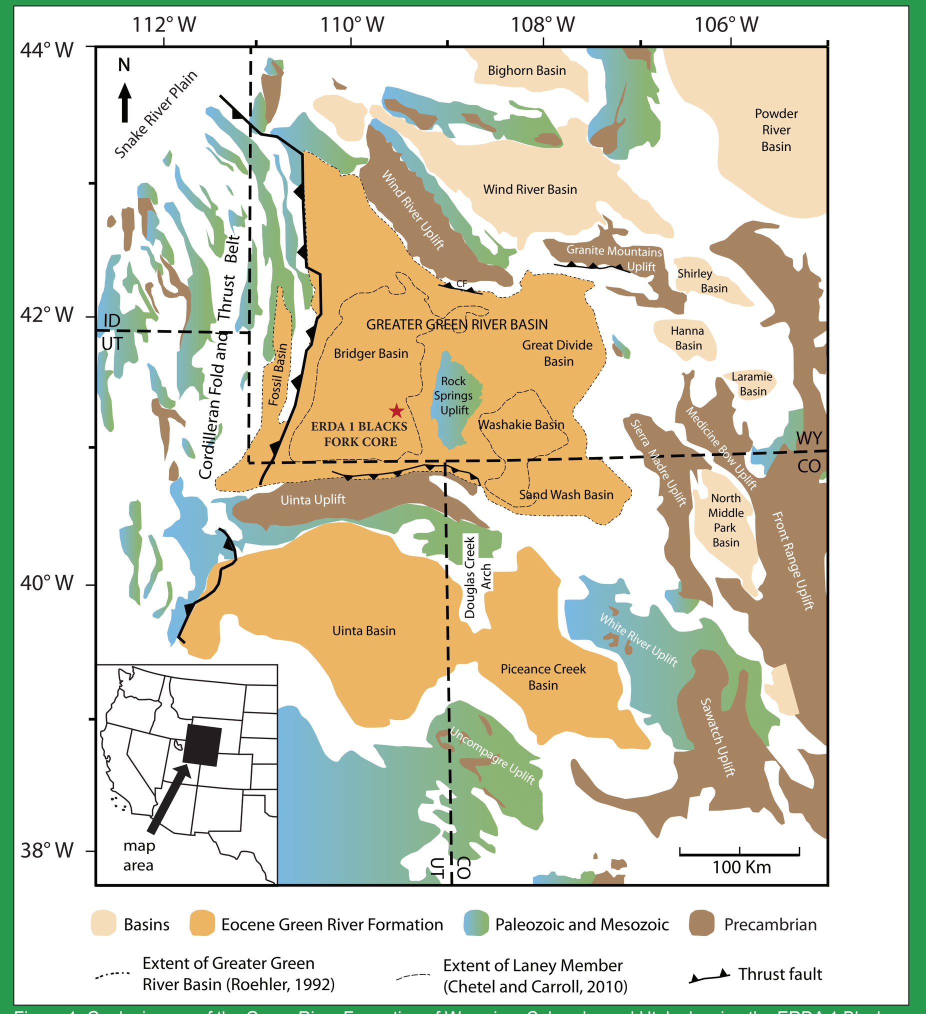

Figure 1. Geologic map of the Green River Formation of Wyoming, Colorado, and Utah showing the ERDA 1 Blacks Fork Core location. (modified from Roehler, 1992; Smith et al., 2008; and Jagniecki et al., 2013).

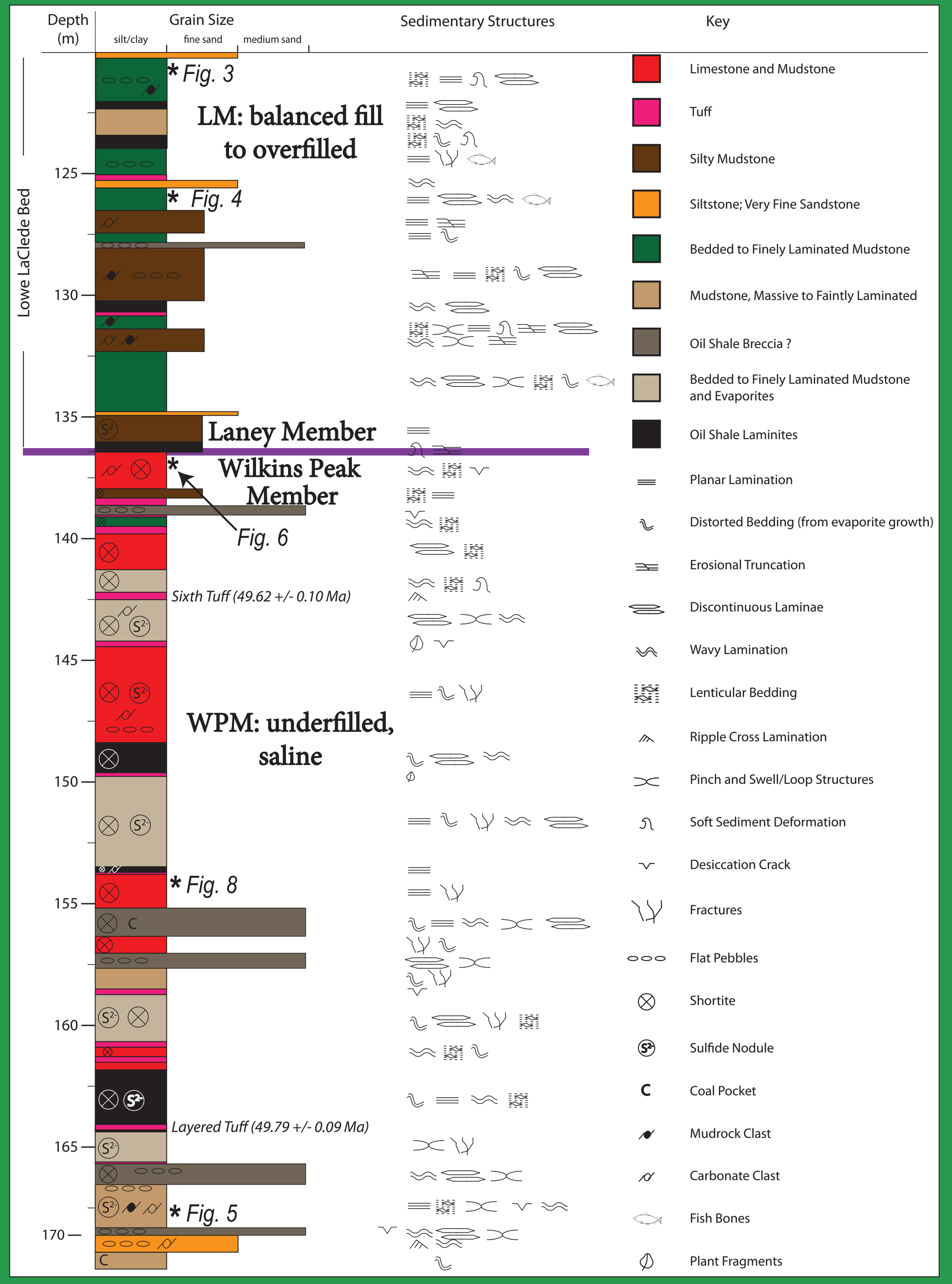

Figure 2. Stratigraphic section of the ERDA 1 Blacks Fork Core from the Wilkins Peak Member-Laney Member transitional zone from 120-170m.

Petrography & Criteria

Primary Aragonite

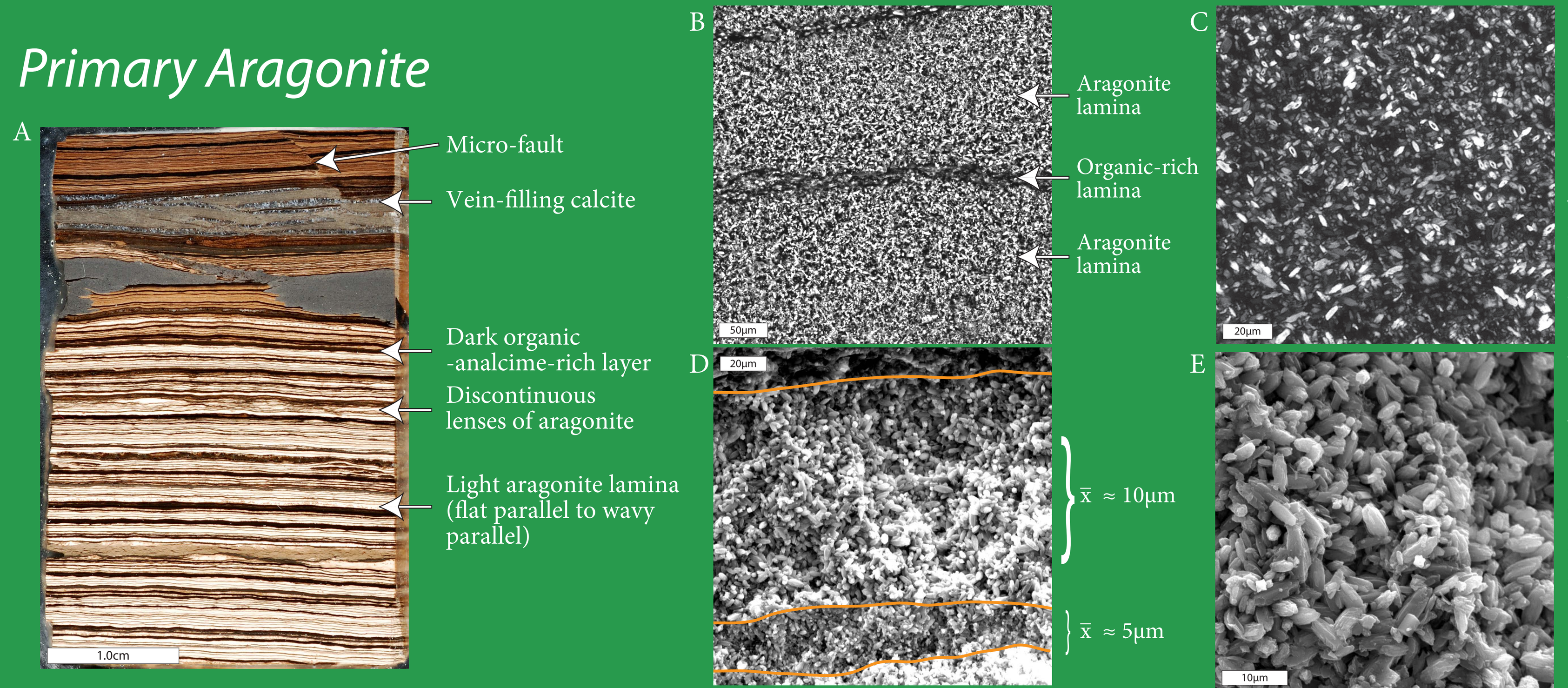

Figure 3. Hand sample (A), thin section (C), and SEM images (B,D,E) of aragonite laminae from the Laney Member of the ERDA 1 Blacks Fork Core, 121.2m. A) Hand sample image showing 100µm scale lamination defined by light aragonite layers and dark organic-analcime-rich layers. B) Backscatter SEM image showing laminae of unconsolidated needle-shaped crystals of aragonite. C) Thin section image of aragonite showing the preservation of randomly oriented ~10µm needles. D) SEM image of pure unconsolidated aragonite needles. Aragonite shows sub-lamination defined by crystal size variation E) SEM image of unconsolidated pure prismatic aragonite.

Primary Calcite

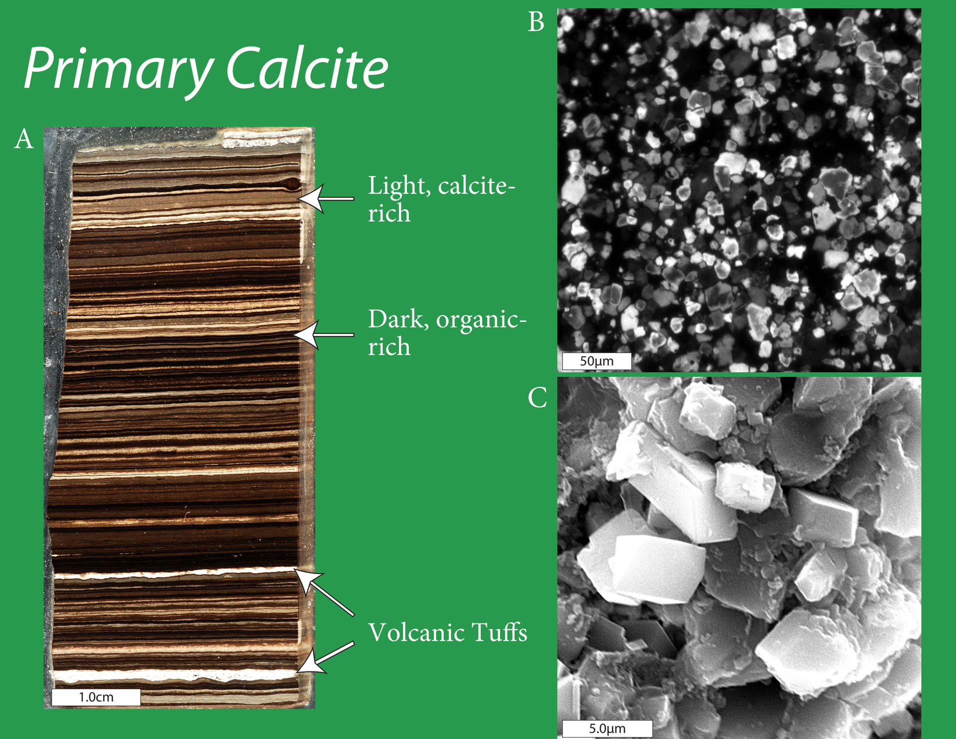

Figure 4. Hand sample (A), thin section (B), and SEM (C) images of primary precipitated calcite from the ERDA 1 Blacks Fork Core, 125.9m. A) Alternating light calcite-rich and darker, organic-rich laminae. E) Thin section image of primary equant calcite crystals. C) SEM image of unconsolidated primary calcite rhombs and minor cement.

Primary Dolomite

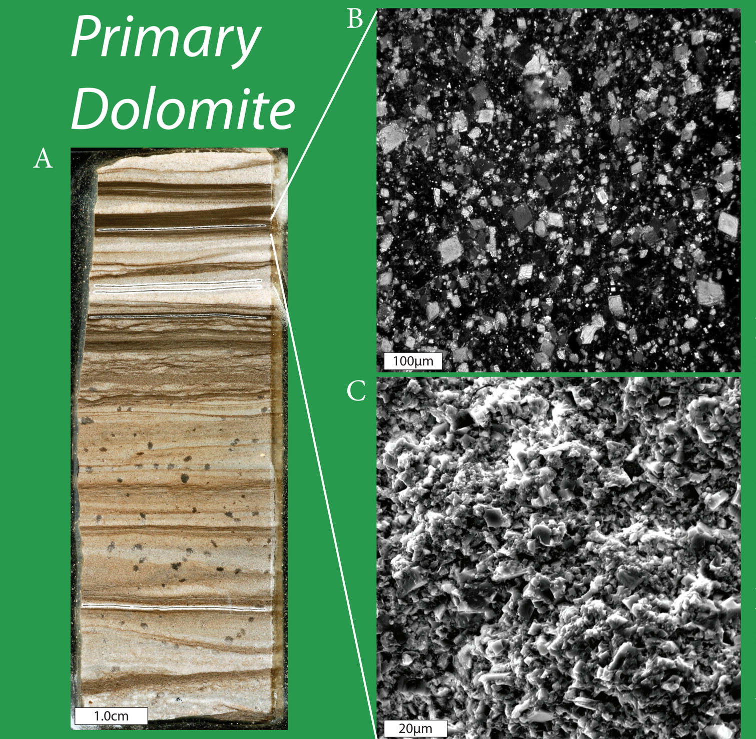

Figure 5. Hand sample (A), thin section (B) and SEM image (C) of primary dolomite laminae from the WPM. A) Alternating primary dolomite laminae (dark brown) and diagenetic carbonate (light laminae). B) Thin section image of a pure dolomite lamina. C) SEM image of a dolomite lamina showing well sorted, pure, and unconsolidated crystals.

PRIMARY CRITERIA:

1) Unstable polymorph (aragonite, Fig. 3)

2) Homogeneous, same crystal size, well-sorted

3) Micro-crystalline

4) Monomineralic

5) No cement/primary pore space

6) Sub-layers defined by crystal size variation (aragonite, Fig. 6D)

7) Other minerals hydrodynamically equivalent

8) Similar to modern lacustrine aragonite: Pyramid Lake, Nevada (Galat and Jacobsen, 1985); Waldsea Lake, Deadmoose Lake, and Little Manitou Lake, Western Canada (Last and Vance, 1997); Dead Sea, Israel and Jordan (Garber et al., 1987); and Lake Balaton, Hungary (Müller, 1971)

9) Similar to modern primary lacustrine calcite: Lake Zurich, Switzerland (Kelts and Hsü, 1978); Lake Greifen, Switzerland (Hollander et al., 1992), and Fayetteville Green Lake, NY (Thompson, 2000)

10) Similar to modern primary lacustrine dolomite: saline lakes of south and southeastern Australia (De Deckker and Last, 1988 – Western Victoria; Warren, 1990 – Coorong region lakes; Coshell et al., 1998 – Lake Walyungup); Manito Lake, Canada (Last et al., 2012)

Diagenetic Carbonate

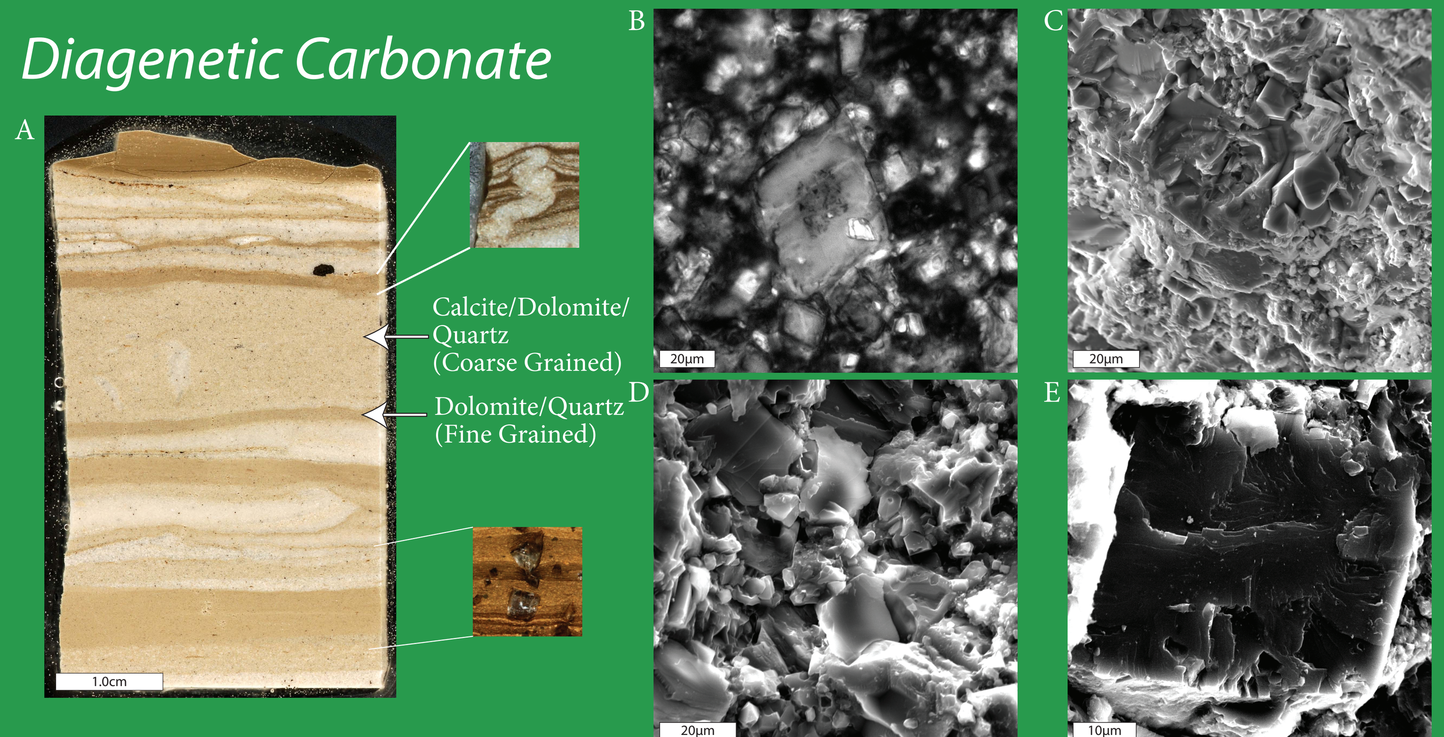

Figure 6. Hand sample (A), SEM (C, D, E) and thin section (B) images of carbonate crystals and textures observed in the Wilkins Peak Member. A) Mudcracks within the dark micro-crystalline dolomite laminae are common and filled with calcite (upper inset image). Variations in the silt-sized carbonate occur further down in the section from Na-carbonate evaporite disruption (lower inset image). B) Thin section image of a dolomite rhomb with a cloudy core and clear rims of overgrowth dolomite. C) SEM image of larger dolomite overgrowth crystals within pure-dolomite laminae. D) SEM image of a mixed calcite/dolomite layer showing diverse sizes in crystals. E) An isolated dolomite crystal from SEM.

DIAGENETIC CRITERIA:

1) Overgrowth cement nucleating from a core (Fig. 6B)

2) Fe-rich cement (Table 2)

3) Interlocking crystalline mosaics

4) Heterogeneous crystal sizes

5) Crystals larger than precipitates in same lamina

6) Euhedral crystal grains terminate into primary pores

7) Similar to diagenetic lacustrine carbonate: Lake Hayward, Western Australia (Rosen and Coshell, 1992) Minnesota lakes (Last, 1990); Devils Lake, North Dakota (Last, 1990)

Mineralogy

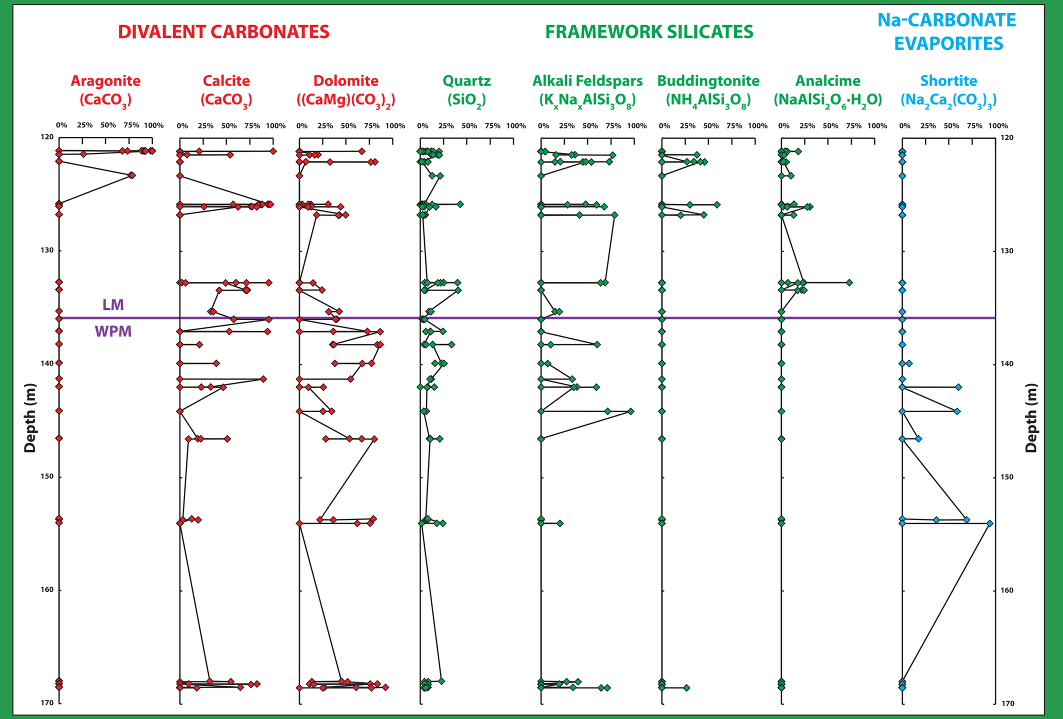

Figure 7. Mineralogy (in relative %) of select laminae from the WPM-LM transition zone in the ERDA 1 Blacks Fork Core.

Table 1. Average Mg-content of low-Mg calcite crystals from the LM and WPM. Values were obtained from electron microprobe point scans.

Sample ID	Depth (m)	# of Samples	Mg-Content (mol %)
BF-8a	125.8	4	1.09
BF-8j	125.8	5	0.78
BF-8x	125.8	4	1.28
BF-17a	136.0	5	0.67
BF-17c	136.0	6	0.39
BF-18b	137.1	5	0.23
BF-34b	168.2	8	0.22
BF-34c	168.2	5	0.21

Table 2. Electron microprobe results from dolomite crystals which varied in iron between the core and margin.

Sample ID	Depth (m)	% $FeCO_3$ (Core)	% $FeCO_3$ (Margin)
BF-18a	137.1	2.51	3.59
BF-18a	137.1	0.10	0.87
BF-18b	137.1	0.00	1.14
BF-18b	137.1	0.00	0.81
BF-18c	137.1	0.24	0.52
BF-18c	137.1	0.00	0.25
* BF-26a	154.0	0.09	0.65

* See Fig. 8 for electron microprobe line scan

Table 3. Electron microprobe results from calcite crystals which lacked significant variation in iron between the core and margin.

Sample ID	Depth (m)	% $FeCO_3$ (Core)	% $FeCO_3$ (Margin)
BF-17a	136.0	0.52	0.41
BF-18a	137.1	0.44	0.28
BF-18a	137.1	0.18	0.27
BF-18a	137.1	0.33	0.27
BF-18a	137.1	0.28	0.45
BF-18a	137.1	0.60	0.42
BF-26a	154.0	0.57	0.45
BF-34c	168.2	0.27	0.31
BF-34d	168.2	0.24	0.28

Table 4. Electron microprobe results from dolomite crystals which lacked iron in both core and margin.

Sample ID	Depth (m)	% $FeCO_3$ (Core)	% $FeCO_3$ (Margin)
BF-18a	137.1	0.00	0.20
BF-18b	137.1	0.00	0.00
BF-18c	137.1	0.09	0.11
BF-34c	168.2	0.00	0.05
BF-34d	168.2	0.19	0.13

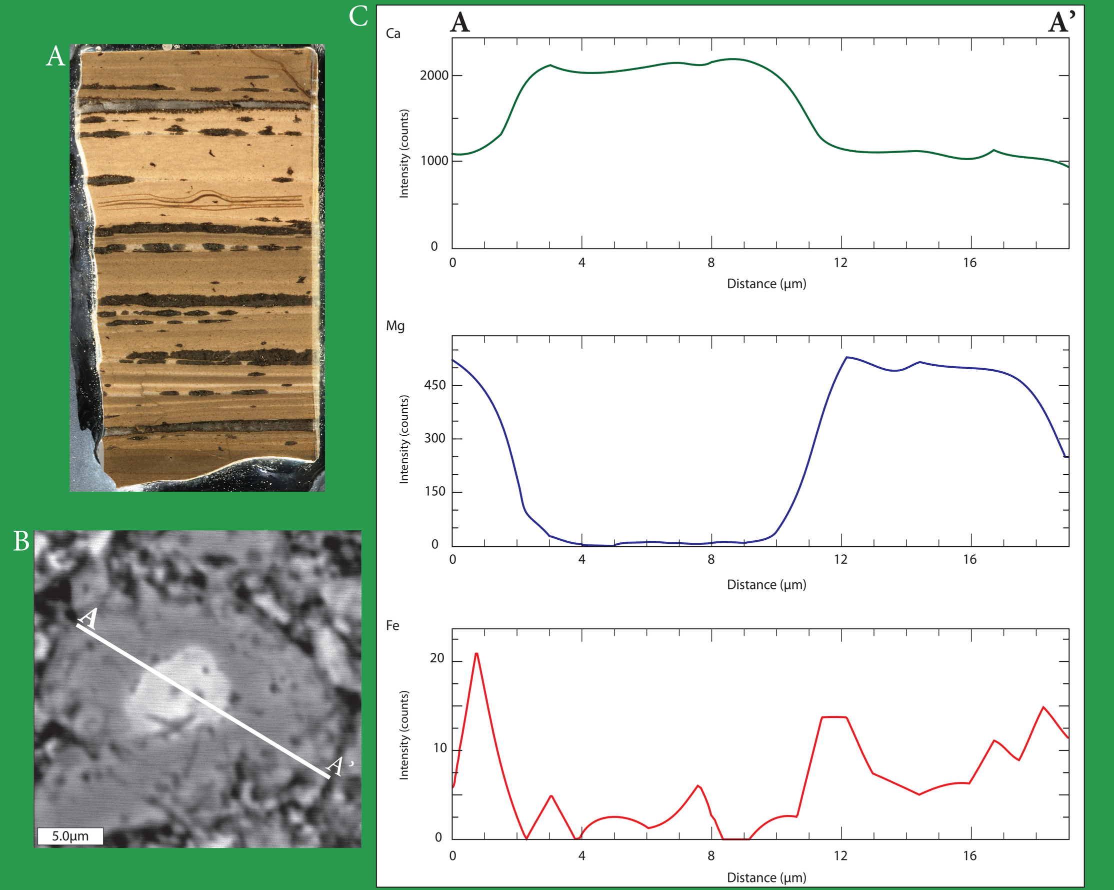

Figure 8. A) Alternating pure dolomite laminae (light to dark brown) and diagenetic shortite (dark gray laminae). B) EMP backscatter image of a carbonate grain containing a calcite core with dolomite overgrowth. C) EMP line scan through transect A-A' from through a carbonate crystalfrom a pure dolomite laminae in (A) documenting changes in calcium, magnesium, and iron concentrations.

Paleoenvironment

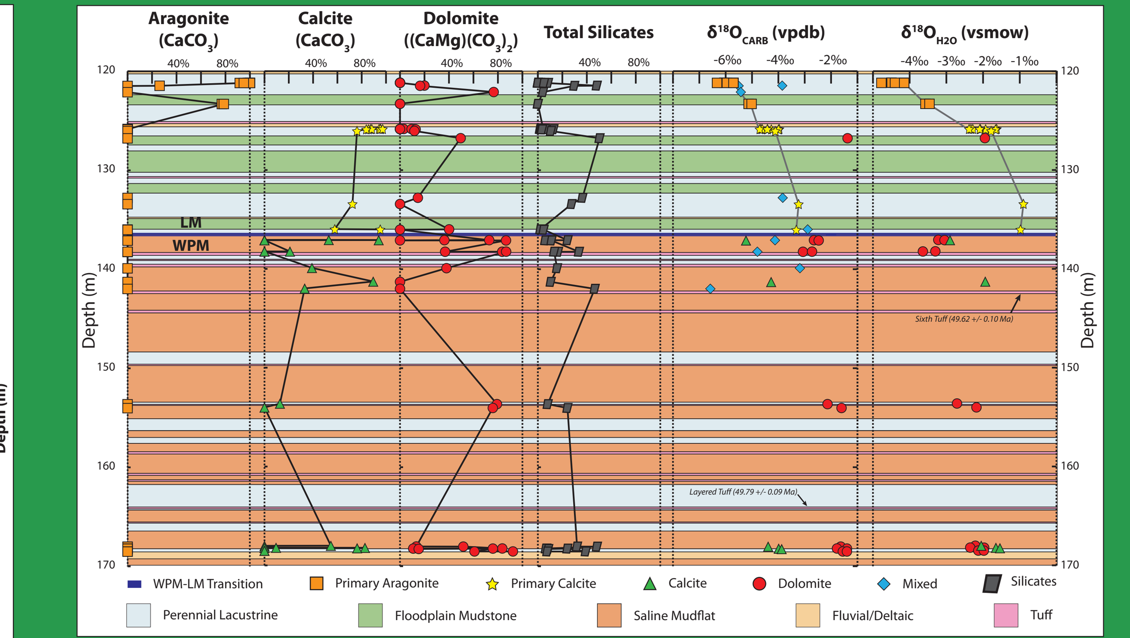

Figure 9. Generalized stratigraphic cross section with interpreted depositional environments, carbonate and silicate mineralogy (in relative percentage), and isotopic data for samples of the WP-LM transitional zone, ERDA Blacks Fork 1 Core, Bridger Basin, WY (See Fig. 1 for location). Tuff locations and ages from Smith et al. (2008). Calculation of $\delta^{18}O_{H2O}$ (vsmow) from equation 17.19 by Faure (1998).

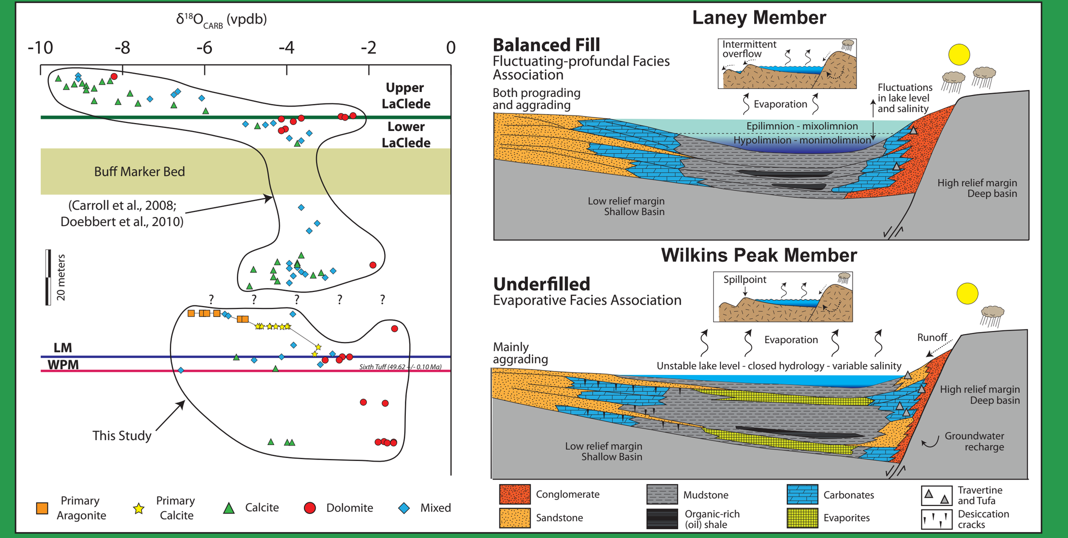

Figure 10. Compilation of data between this study and Carroll et al. (2008) and Doebbert et al. (2010) demonstrating an overall decreasing trend as lake conditions transitioned from underfilled (WPM) to balanced fill (lower LaClede) to overfilled (upper LaClede). Underfilled and balanced fill illustrations from Renaut and Gierlowski-Kordesch (2010).

Conclusions

Previous work by Carroll et al. (2008) and Doebbert et al. (2010) focused on paleoenvironmental changes from the LaClede Bed of the basal LM. Carroll et al. (2008) found a 6‰ decrease in carbonates from the Washakie Basin. This occurred across a "fill-to-spill" surface, marking a transition from a balanced fill (lower LaClede) to overfilled (upper LaClede) Lake Gosiute (Fig. 10). The interpretation of this shift was related to the capture of a lighter-sourced foreland river. Doebbert et al. (2010) verified that this transition also occurs west of the Rock Springs Uplift in the Bridger Basin (Fig 1.).

In this study, $\delta^{18}O$ trends from pristine, unaltered carbonate laminae exhibit a ~3‰ negative shift from -3‰ to -6‰ (VPDB) immediately across the WPM-LM transition from the ERDA 1 Blacks Fork Core, Bridger, Basin, WY. This shift occurs stratigraphically below previous reported values (Carroll et al., 2008; Doebbert et al., 2010). This reflects changing lake conditions from underfilled to balanced fill over ~15m of stratigraphic section (Figs. 9 & 10).

Petrographic study and stable isotope analysis at the lamina level resulted in the discovery of a new isotopic shift for Laney Member deposits in the Bridger Basin likely related to new inflow water sources (e.g. Carroll et al., 2008) or an overall freshening of the lake.

Acknowledgments

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