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Lacustrine Carbonates – Facies Evolution, Diagenesis: Eocene Green River Formation, Piceance Creek Basin, Colorado

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The lacustrine carbonates of the Eocene Green River Formation crop out on the western margin of the Piceance Creek basin, in Douglas and Baxter Passes. Carbonate lithofacies can be linked to the large-scale lake basin evolution from an initial fresh to brackish lake, a middle highly fluctuating saline lake, to a final stable saline lake. In the initial fresh lake, carbonates consist of littoral to sub-littoral lithofacies characterized by quartz-skeletal-oolitic packstones to grainstones, and oolitic packstone/grainstones. Lithofacies of the middle saline lake are a mix of interbedded oolitic grainstones, intraclast rudstones, and microbialite stromatolites and thrombolites. Carbonates in the final stable lake phase are thin, laminated microbialites deposited in deeper sublittoral environments.

Lake carbonates commonly form thin, 10-30m thick, upward-deepening cycles (Fig. 1). Sequences start with fluvial, deltaic, or shoreline quartz sandstones that are overlain by carbonates of varying facies depending on the lake stage. These can include molluscan coquina layers, and/or intraclast rudstone or oolitic grainstone; followed in restricted, high salinity lake times by 1-5m thick coarse-agglutinated stromatolites or thrombolites that are capped by fine-grained laminated stromatolites. The carbonates are overlain by and cycles are completed by sublittoral lean oil shale or mudstone. Absolute age dates suggest that these sequences are 400Ky eccentricity cycles.

The overall vertical succession of carbonate deposits correlates well with medium-scale lake evolutionary stages as defined by Tanavsuu-Milkeviciene and Sarg, 2011, in press. The carbonate succession starts with coquina limestones composed of quartzose mollusk ostracod lime grainstones and skeletal-oolitic lime grainstone deposits that occur in an initial Fresh Lake Stage 1. An abrupt change to more restricted saline conditions occurs at the base of the Transitional Stage 2. Nahcolite and dawsonite are deposited as crystals and nodules in profundal areas. Microbialite limestone bioherms and biostromes are deposited along the lakeshore and are composed of thrombolitic mounds capped by coarse-agglutinated stromatolites or fine-grained laminated stromatolites. The Highly Fluctuating Stage 3 lake phase commences with deposition of very rich oil shale, and is distinguished by the onset of nested high frequency depositional sequences of various scales, but similar in character to the 400Ky depositional cycles (Fig. 1). Periodic hypersalinity occurred during low lake level periods, and nahcolite and halite were deposited as beds, nodules and crystals in profundal areas. The uppermost part of the carbonate bearing section is dominated by thin, laminated microbialites that correlate with an overall deepening of the lake, and the beginning of the Rising Lake Stage 4. The lake remains restricted during this period and nahcolite is common. Nahcolite precipitation continues into the ensuing

High Lake Stage 5, and is accompanied by widespread, organic-rich oil shale deposition (Mahogany Zone).

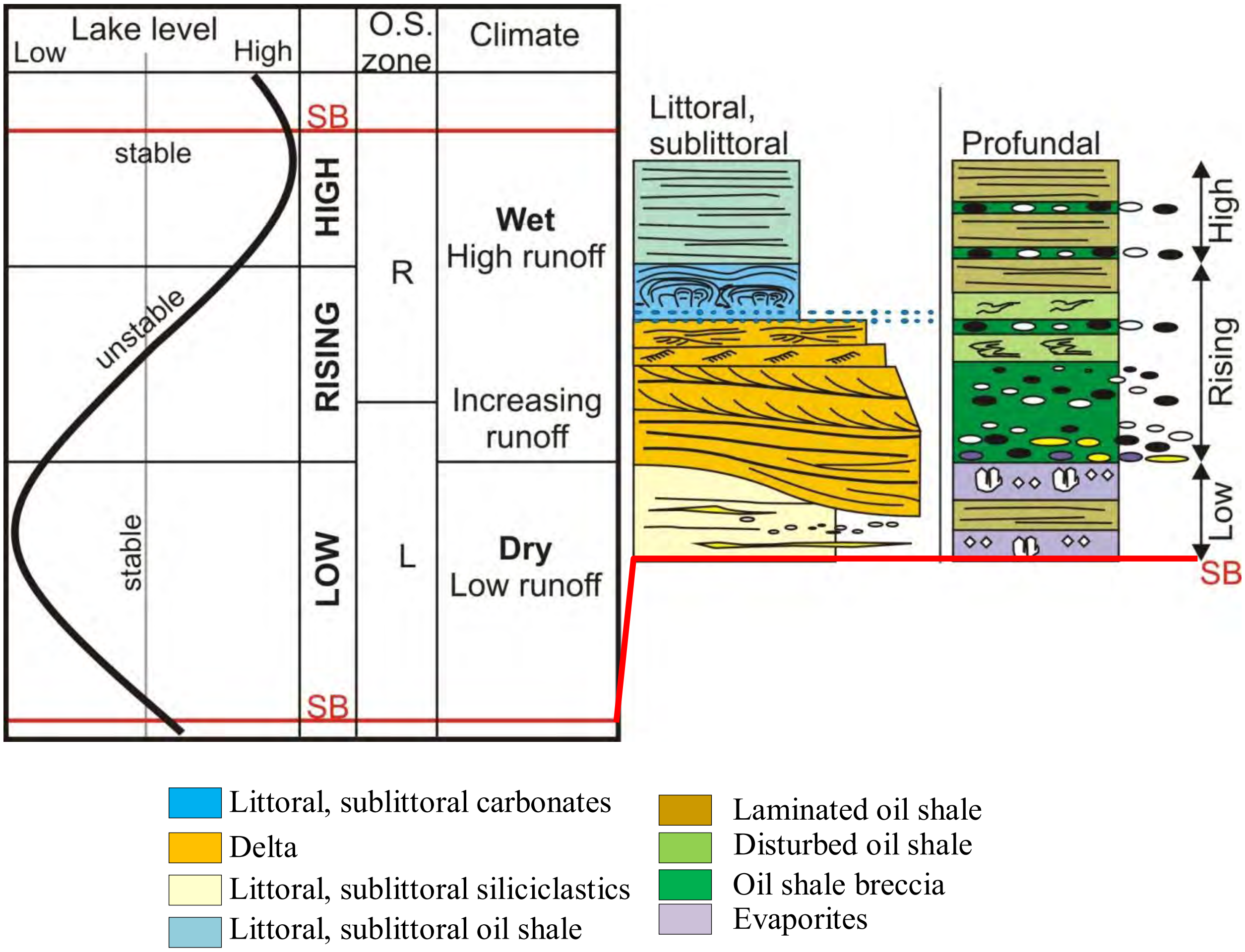

Figure 1. Deepening upward cycles within Green River Formation at lake margin (littoral/ sublittoral) and lake interior (profundal).

Changes in Carbon and Oxygen stable isotope values reflect changes in lake chemistry and correspond well with Lake Stages. Stable isotope $\delta^{18}O$ and $\delta^{13}C$ range from -8 to +0.8 ‰ and -3 to +5 ‰, respectively. In general, the $\delta^{18}O$ and $\delta^{13}C$ co-vary. Periods of lake-level fluctuation are recorded as positive and negative excursion in carbonate $\delta^{18}O$. The trends to heavier $\delta^{18}O$ reflect increased evaporation and higher salinity, and trends to lighter $\delta^{18}O$ indicate increased inflow and freshening of the lake. The $\delta^{13}C$ values show a similar trend. Respiration processes related to decomposition of organic matter, dissolved inorganic carbon replenishment by water inflow, and/or atmosphere to water CO_2 exchange process result in negative excursions of $\delta^{13}C$ values, corresponding to lake-level rises. Positive excursion of $\delta^{13}C$ values may have resulted from increased photosynthesis and high organic productivity.

The Green River Formation carbonates have undergone a complex diagenetic history including, in paragenetic order: micritization, dissolution, neomorphism, siderite cementation, mechanical and chemical compaction, dolomite cementation, fracturing, shallow burial dolomitization, cementation (equant, blocky, and poikilotopic cements), late burial dolomitization, and dedolomitization. Porosity is controlled by original depositional fabric and modified by diagenesis. Packstones, grainstones, and rudstones have interparticle, moldic, and meso-vuggy porosity that ranges from 2-20%. Microbialite porosity (Fig. 2) can be high, > 10%, and consists of fenestral, vuggy, interparticle porosity within trapped grainstone fill, and intergrowth porosity between individual thrombolites.

Figure 2. Microbialite mound and polished slabs showing shrub-like thrombolitic and laminar stromatolitic structures. Porosity types include vuggy, inter-shrub, and fenestral. Large tubular vugs are embedment structures.