Facies Architecture and Mineralogy of Miocene Microbially-Dominated Carbonate Lakes of the Horse Spring Formation, Southern Nevada

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THE HORSE SPRING FORMATION

The detailed stratal geometry of microbially dominated lacustrine sequences is relatively poorly constrained, yet these rocks comprise signficant and important petroleum source rocks and reservoirs that have gained considerable recent attention. The Late Oligocene to Miocene Horse Spring Formation, exposed in the Lake Mead, Nevada region, comprises the fill of pre-extension and transtensional basins. Each member of the HSF (Fig 1.) contains significant microbial lacustrine carbonate sequences. Superb exposure of these sequences allows us to characterized in detail their meso-scale facies architecture and 2D geometry.

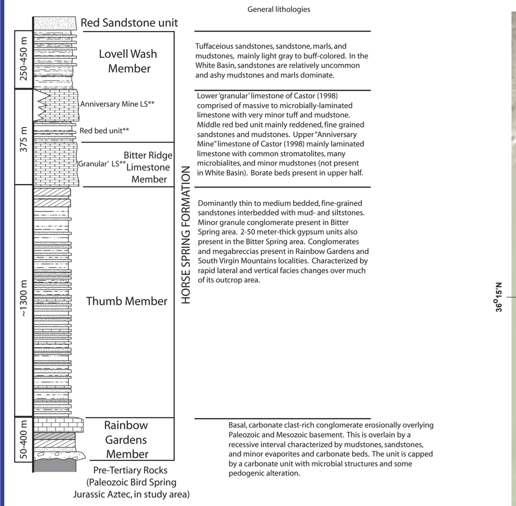


Figure 1. Horse Spring Fm. general stratigraphic column

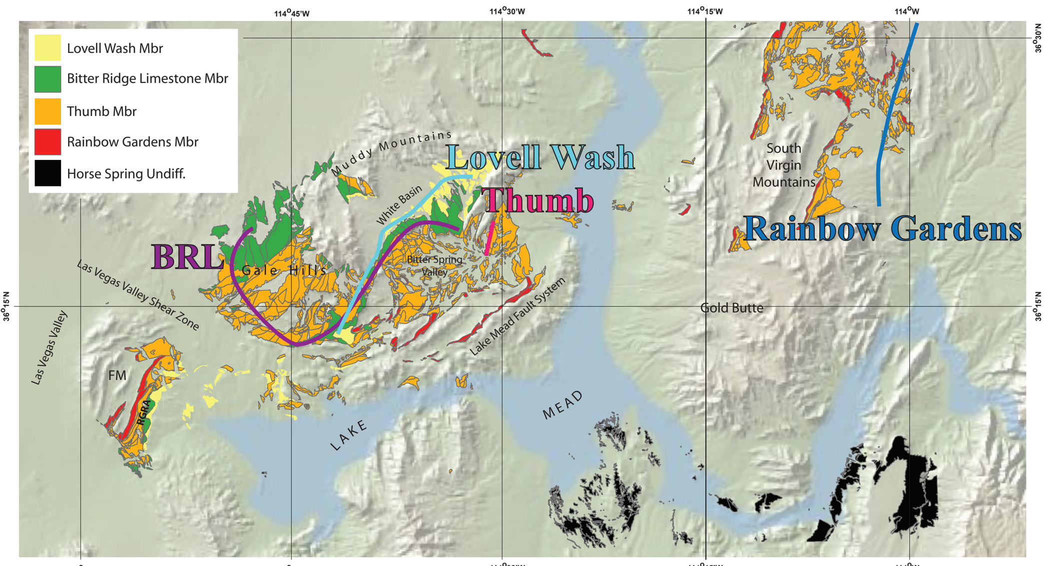
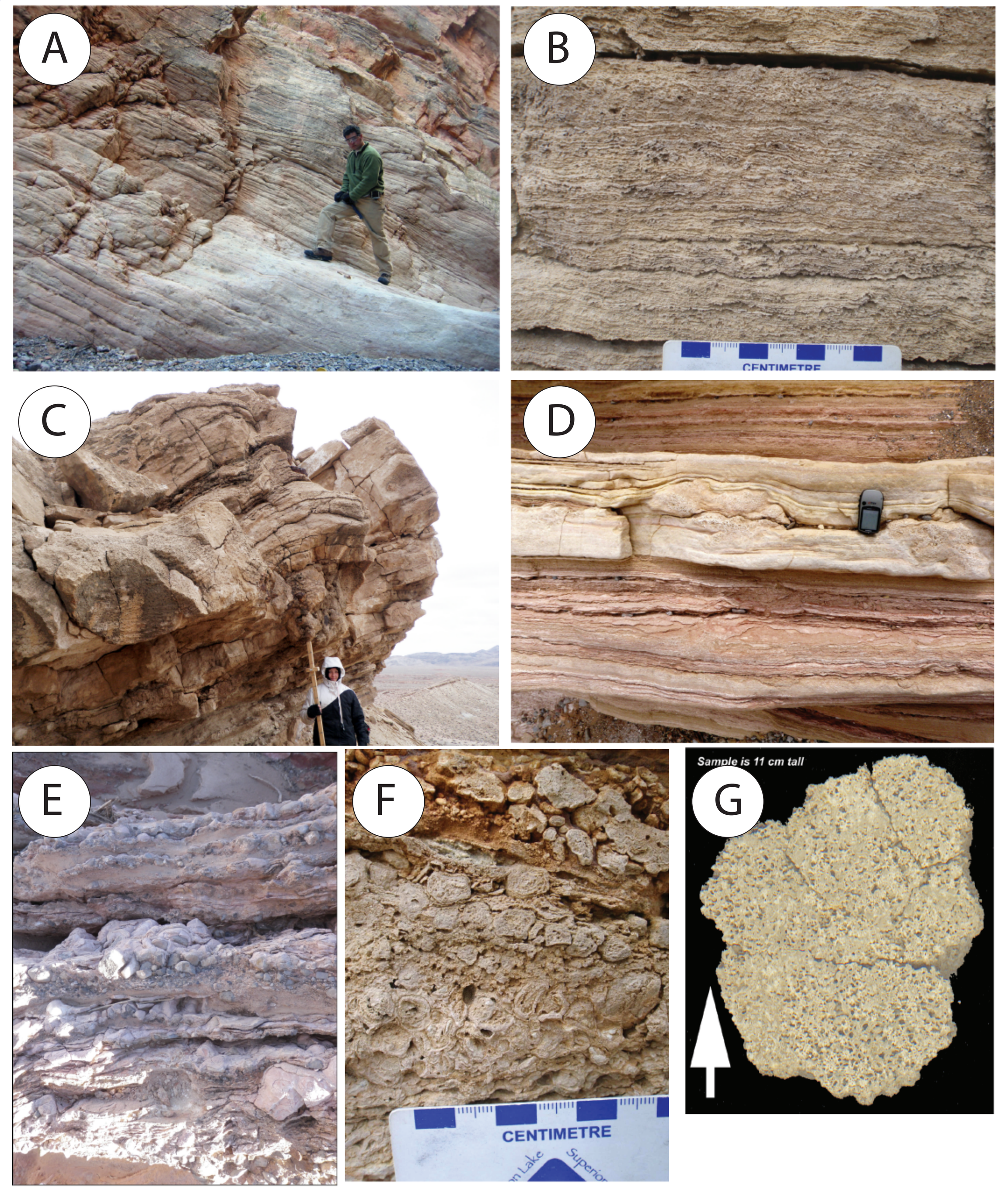


Figure 2. Outcrop distribution map of the HSF members. FM: Frenchman Mountain. Lines of stratigraphic facies architecture panels shown as colored swatches.

LACUSTRINE MICROBIALITES IN THE HSF



A. Peloidal, predominantly clastic-textured laminites with minor microbial laminae, Bitter Ridge Limestone Member, thick, tabular facies.

B. Finely-laminated preserved microbial mat fabrics, Bitter Ridge Limestone Member, thick, tabular facies.

C. Large domal stromatolites, Lovell Wash Member, Heterogeneous facies.

D. Thrombolitic mounds in peloidal grainstones, Lovell Wash Member, Marginal facies.

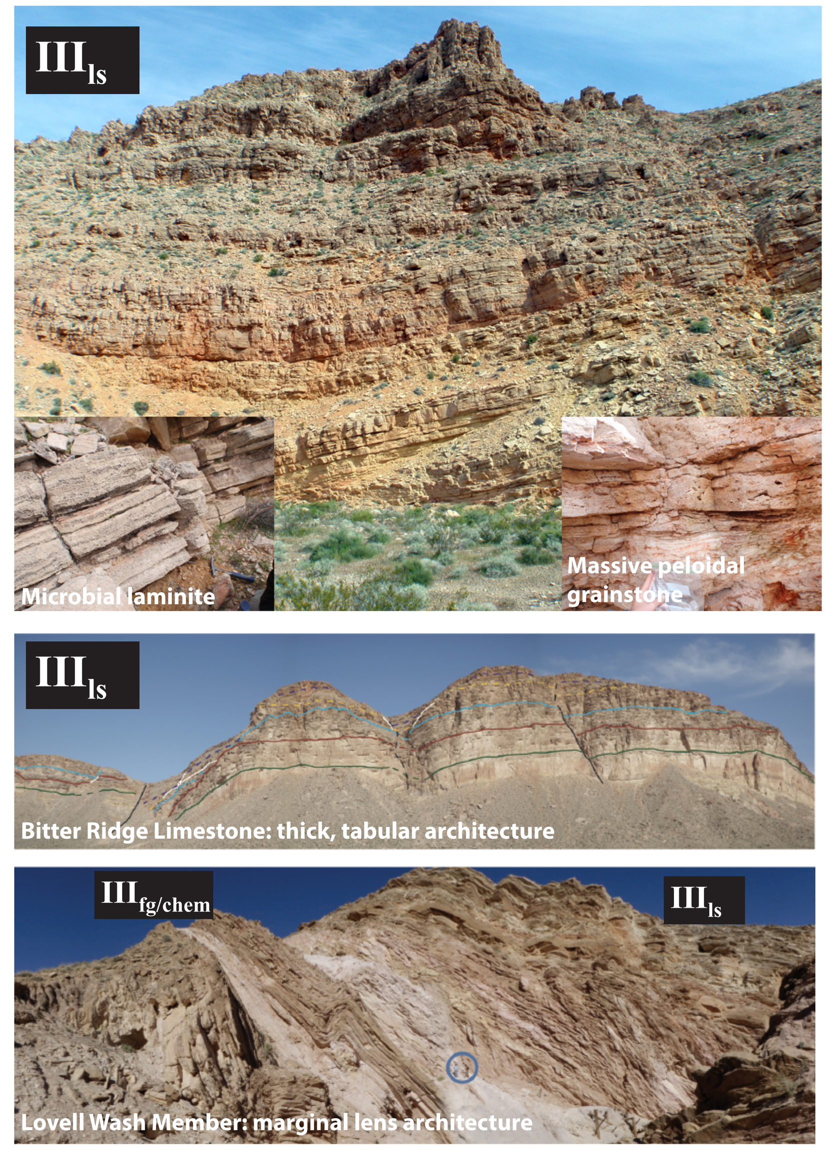
E. Small, domal stromatolites forming on conglomerate clasts, Lovell Wash member, marginal facies.

F. Oncolitic fabrics, Thumb Member, marginal facies.

G. Polished slab of thrombolite, Lovell Wash Member, marginal facies.

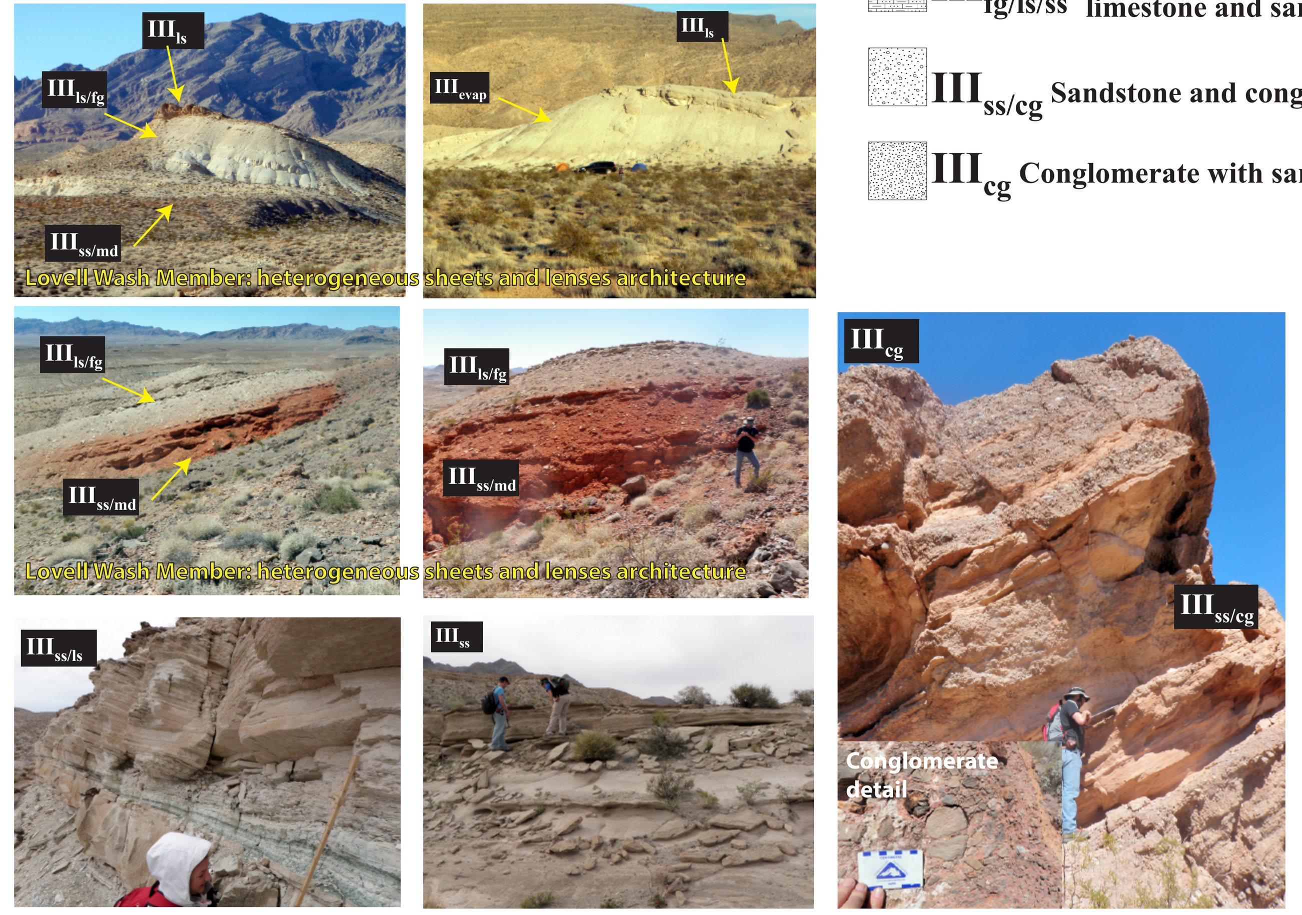
ARCHITECTURAL ELEMENTS OF THE HSF

We applied an architectural elements approach to characterizing the facies architecture of the HSF. In this approach, lower-order elements correspond to geometrically smaller features in terms of vertical and lateral continuity. Third-order elements correspond to meso-scale packages with thicknesses on the order of 10-100 m and lateral extents that vary between 1 and 30 km. We focus here on these third-order packages because they provide the most insight into seismic and reservoir scale geobodies.



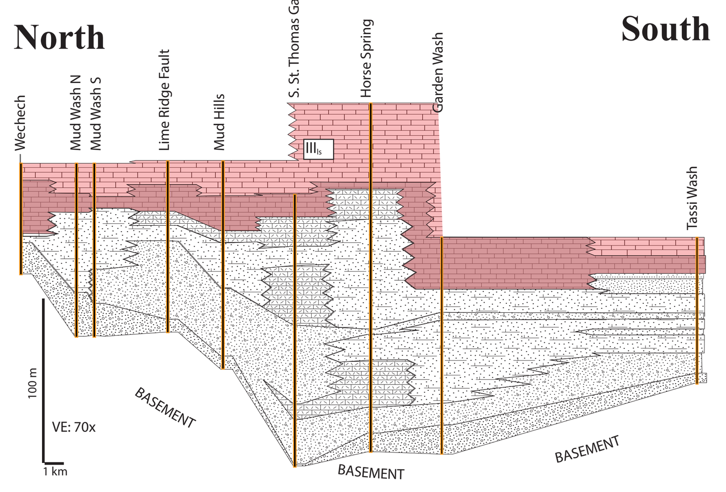
Key to Third Order Architectural Elements
First lithology is dominant, second is sub-dominant lithology

- III_{ls} Thick, tabular limestone beds
- $III_{ls/fc}$ Limestone with fine clastics
- $III_{ls(alt)}$ Limestone with pedogenic alteration
- $III_{ls/ss}$ Discontinuous limestone beds with sandy, tuffaceous interbeds
- $III_{ss/ls}$ Thick beds of fine sandstone and limestone
- $III_{ss/ls(alt)}$ Sandstone and limestone with pedogenic alteration
- III_{evap} Gypsum
- $III_{fg/chem}$ Thin limestone beds, mudstone, and gypsum
- III_{m} Mudstone with minor sandstone
- $III_{ss/m}$ Fine- medium sandstone beds with minor mudstone interbeds
- III_{ss} Sandstone
- $III_{fg/ls/ss}$ Fine-grained facies with limestone and sandstone
- $III_{ss/cg}$ Sandstone and conglomerate
- III_{cg} Conglomerate with sand lenses



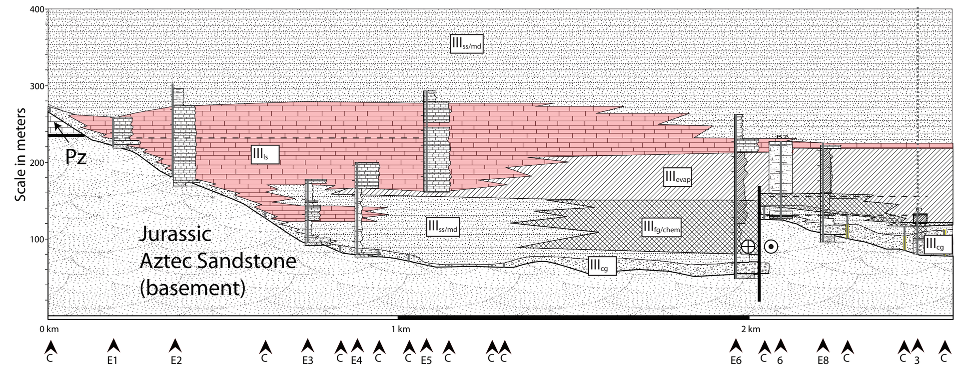
FACIES ARCHITECTURE

Rainbow Gardens Member



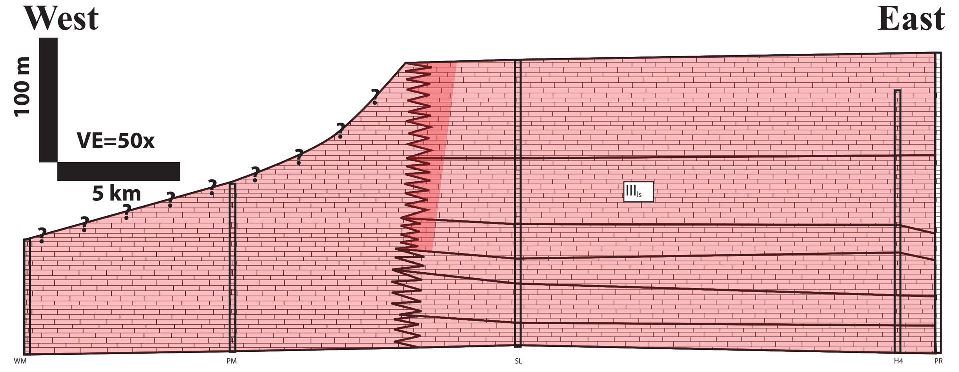
The upper-most portion of the Rainbow Gardens Mbr. is comprised of a laterally extensive (>40 km) sheet that varies in thickness from 10-60 m. This carbonate unit shows oncolitic, stromatolitic, and laminated microbial fabrics in places, but many features are obliterated by pedogenic alteration, including root traces, mottling, and petrocalcic horizons.

Thumb Member



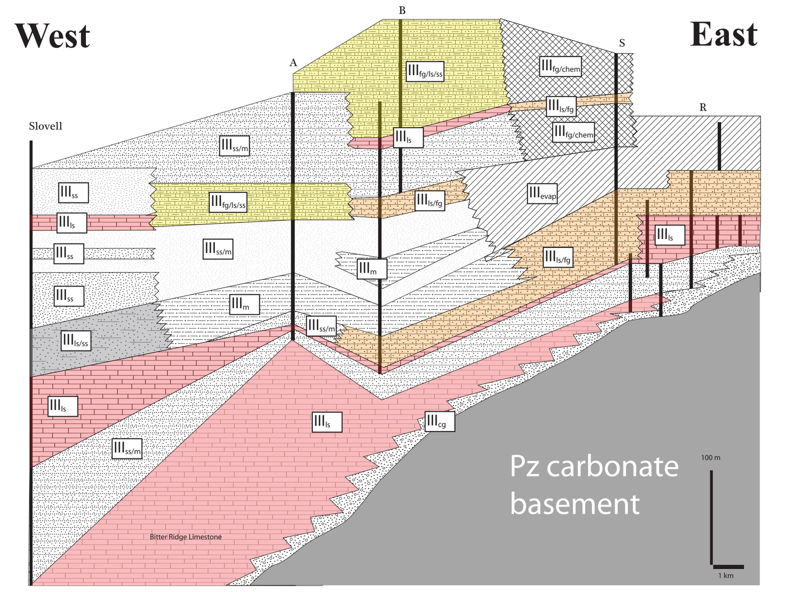
The Thumb Mbr. is predominantly comprised of siliclastics. The largest carbonate accumulation exists near a basin margin in the E. Longwell Ridge locality. Stratiform stromatolitic and oncolitic fabrics dominate this unit.

Bitter Ridge Limestone Member



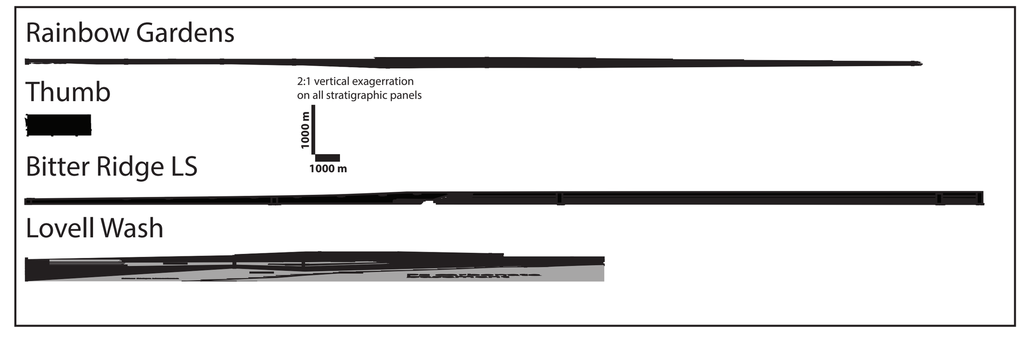
The Bitter Ridge Limestone Mbr. exhibits the thickest and most laterally extensive lacustrine microbialite. It is essentially a thick (100-200 m) laterally continuous (40-50 km) sequence of stratiform stromatolites, minor thrombolites, and peloidal grainstones.

Lovell Wash Member



The Lovell Wash Mbr. shows the most heterogeneous carbonate architectures, from marginal lenses to thin, discontinuous sheets. These also show the widest range in stromatolite morphologies: domal, digitate, and stratiform at many scales, as well as thrombolites and localized bioherms.

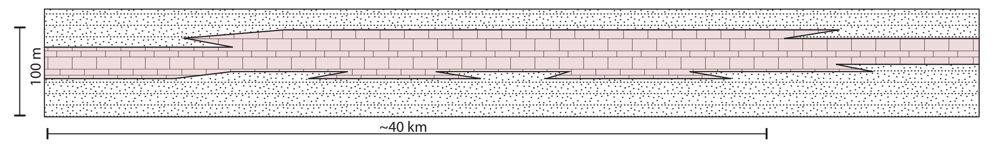
SCALE COMPARISONS



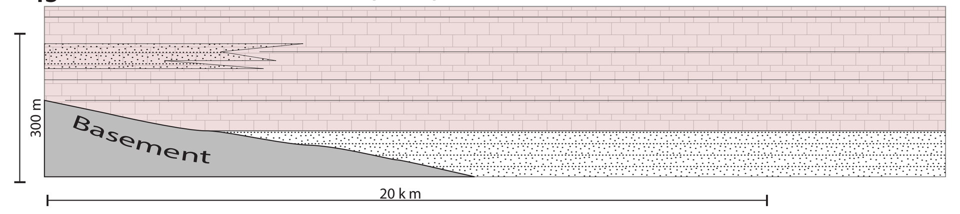
Lacustrine microbialite limestones of the HSF vary considerably in their dimensions. The stratigraphic panels to the left have been converted to the same vertical and horizontal scale in the image above for comparison.

SIMPLIFIED ARCHITECTURAL STYLES

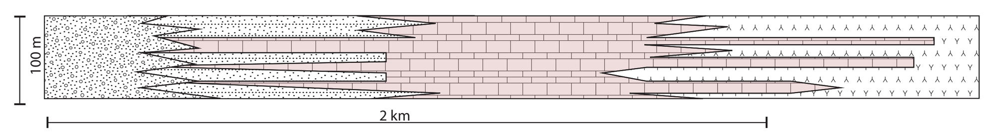
III_{ls}: Thin, tabular sheet (Rainbow Gardens)



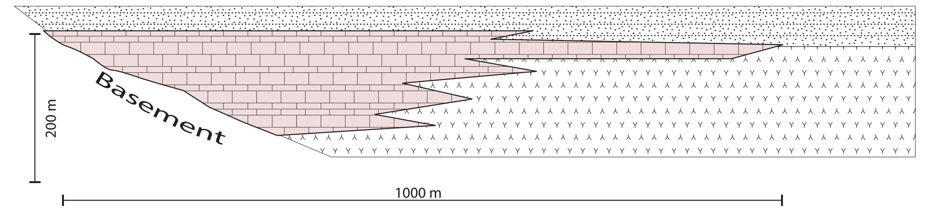
III_{ls}: Thick tabular sheet (BRL)



III_{ls}: Heterogeneous discontinours sheets and lenses (LW)

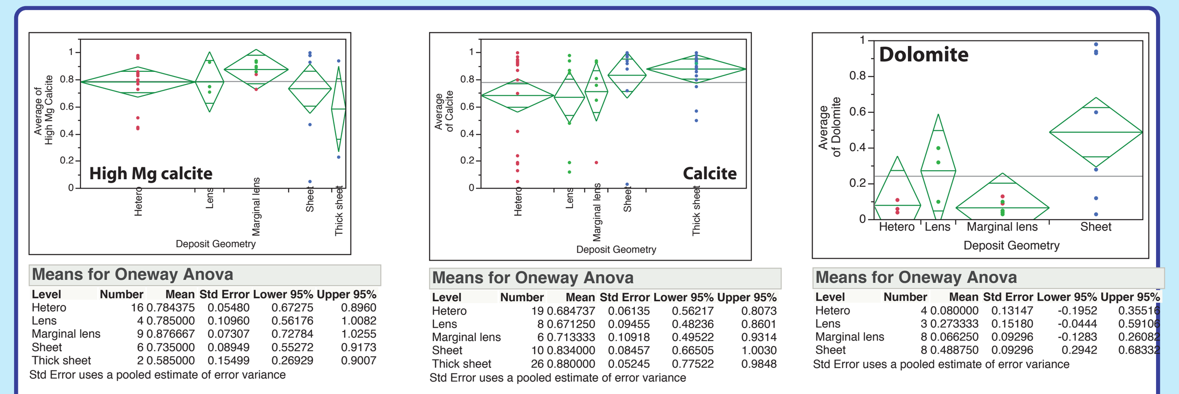


III_{ls}: Basin Margin Lens (Thumb)

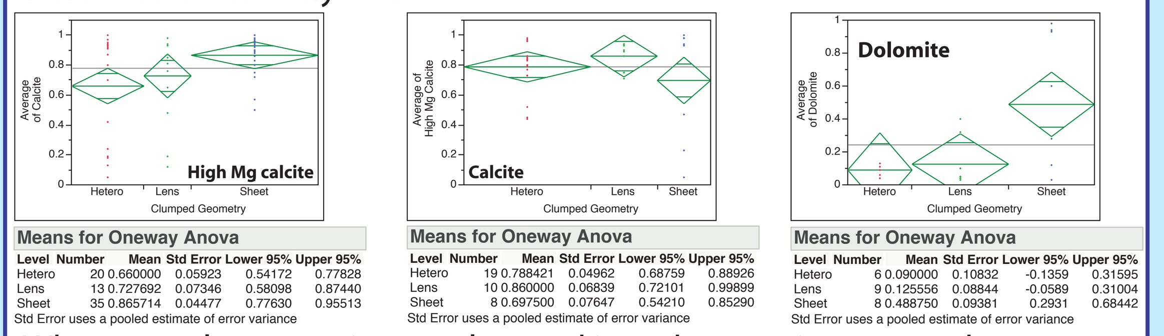


We recognize three general architectural styles of microbialite limestone in the HSF: tabular sheets (thick and thin), lenses (marginal and basinal), and discontinuous, heterogeneous thin sheets and lenses.

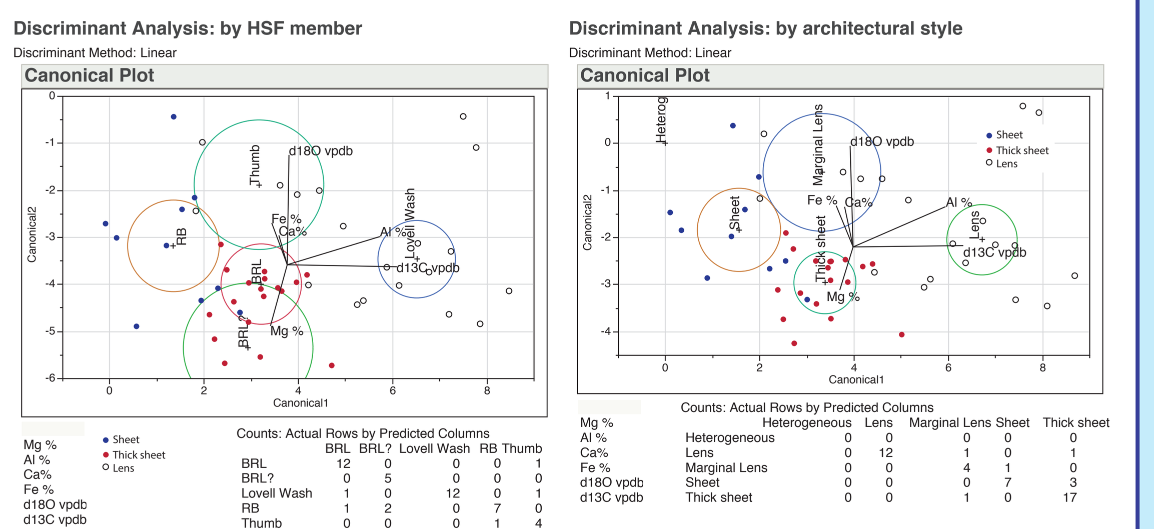
MINERALOGY AND GEOCHEMISTRY OF MICROBIAL PACKAGES



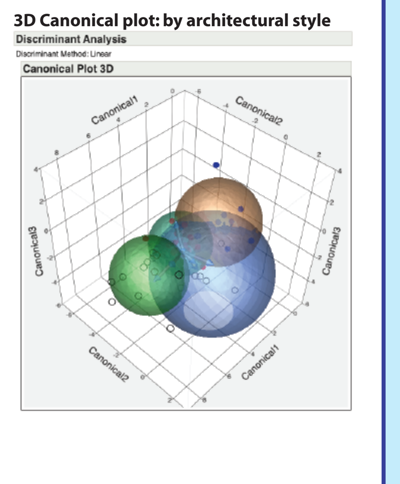
X-ray diffraction analysis of samples from the different architectural geometries shown on the left show very little variability, except that sheet type geometries have somewhat less high Mg calcite than the other geometries. Dolomite is relatively rare.



When stratal geometries are clumped into three main groups, there appears to be an increase in calcite from heterogeneous deposits to lenses to sheets and a concomitant reduction in high Mg calcite.



Integrating ICP-OES major element and oxygen and carbon isotopic data for microbial carbonate samples, each of the members of the HSF appears to have a distinctive geochemical signature based on discriminant analyses. However, when a similar analysis is performed using deposit architecture as the grouping variable, these geochemical signatures are far stronger (there is more discriminatory power). In descending order, the geochemical variables with the most discriminatory power are $\delta^{13}C$, Al, $\delta^{18}O$, Mg, Fe, and Ca. This suggests that each of the different architectural styles are related to different lake chemistries with variable carbon inputs ($\delta^{13}C$), provenance signatures (Al), and precipitation/evaporation ratios ($\delta^{18}O$).



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