Oil-stained Sandstone

Consortium Phase II Proposal: Lacustrine Systems: Stratigraphy, Facies Distribution, Reservoir Architecture, Source Rock Formation

Microbial Bioherm

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Purpose:
Integrated lacustrine stratigraphic and reservoir studies, including source rock analysis and characterization of reservoir type and heterogeneity.

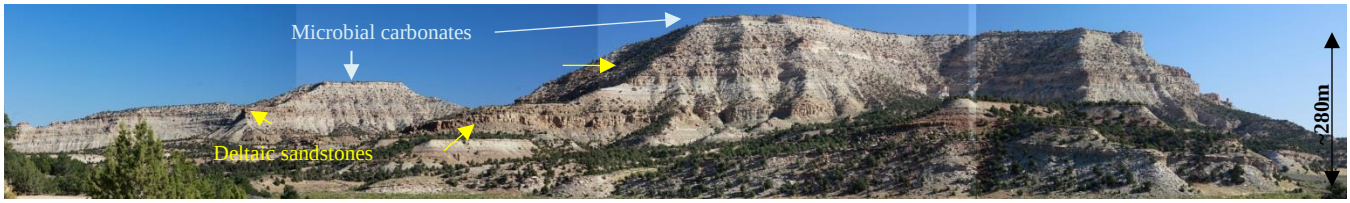

Figure 1. Architecture and lateral continuity of siliciclastic and carbonate intervals in the Upper Wasatch/Colton and Green River formations, White Face Butte (length of outcrop is ~4 km).

Project Rationale (Why?):
Predictive lacustrine models are few as compared with their marine counterparts. Recent discoveries in the lacustrine deposits and developments in unconventional gas and oil research have challenged existing depositional models for lake environments and understanding of the unconventional reservoir deposits. Models that have been used to characterize deposits and reservoir architecture are outdated, and there is a lack of good outcrop and subsurface analogues.

Figure 2. Location of Lake Uinta.

The Green River and Wasatch formations in the Lake Uinta, and especially in the Douglas Creek Arch (DCA) area (Figures 1 and 2), are exposed over tens of square miles. This, together with thousands of subsurface electrical well logs and core, gives a unique possibility to study shallow to deep lake deposits in strike and dip directions over long distances and throughout the subsurface of the basin. Exposed lake deposits include microbial and non-microbial carbonates, sandstones, mudstones, and oil shale (Figures 3, 4, and 5). Gilsonite veins, and carbonate and siliciclastic deposits impregnated with oil occur in the area. Organic rich intervals follow carbonate or siliciclastic units and are separated by nonporous fine grained mud rocks. This outcrop area is directly adjacent to Green River producing oil fields where dense subsurface control and core exists and which contain both conventional (carbonate and siliciclastic and unconventional (shale oil) reservoirs.

Superb exposure and continuous outcrops over long distances, core, and abundant subsurface control gives an excellent possibility for study of these mixed lake deposits both laterally and vertically and into the Uinta basin, to develop 3D depositional reservoir models for microbial and non-microbial carbonates, and for siliciclastic 100m

richness variation both laterally and vertically, and to document migration of oil in the Uinta basin area and the contribution from different source intervals to different producing fields. Nearby Wasatch and Green River producing fields allow a direct tie and comparison to subsurface reservoirs and organic-rich shale.

Figure 3. Continuous sandstone bodies, middle Green River Fm., Evacuation Creek (length of outcrop is ~2 km).

Figure 4. Biohermal microbialite, middle Green River Fm., Three Mile Canyon.

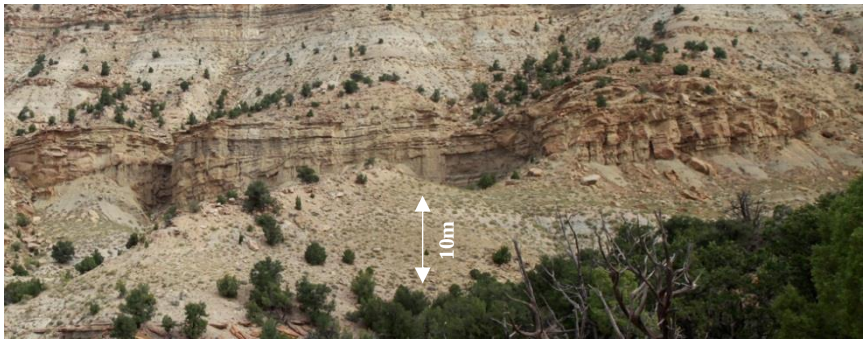

Figure 5. Thick channel deposits that cut into black shale below lower Green River Fm., White Face Butte.

Phase II Objectives:

1. Develop an integrated stratigraphic framework for the Green River-Wasatch system that includes electric logs including the PE for improved lithology prediction, and chemostratigraphy including XRF elemental profiles and stable isotopes to build a more predictive stratigraphy for lake systems. Concepts developed here will be applied to other ancient lacustrine systems.

2. Develop a depositional model for the fluvial to lake transition to improve prediction of channel and shoreline sandstones. Potential outcrops displaying this transition in the southern Uinta basin include Argyll Canyon (fluvial dominated) in Utah and Yellow Creek (wave dominated) in Colorado.

3. Conduct a comparative study with other ancient lake systems to build more predictive analogs for exploration in basins around the world. Documentation will include both chemical and sedimentary facies, lake stage history, diagenesis, and probable controls on lake development and history.

4. Extend mineralogic study to Uinta basin to compare and contrast with Piceance to better understand the chemical differences between the two lakes.

5. Complete characterization of organic-rich source rocks in the Uinta basin including 1) characterizing the suite of oils representing distinct produced fluid types (e.g., black wax, yellow wax, asphaltic, etc.); 2) comparison of these results with other global lacustrine source rocks – Is the Green River a good analog?; and 3) integrate the Green River geochemistry into stratigraphic framework to assess the percentage of charge from each source facies the effect on production.

6. Carbonate reservoirs (see addendum).

Deliverables:
1. Improved stratigraphic cross sections interpreting depositional environments utilizing cores, well logs, and outcrops with lithofacies interpretations that includes fluvial to lake transition.
2. Mineralogical-Chemical model for Uinta basin.
3. Source rock model for Uinta basin and comparison to other lacustrine basins.
4. Initial global set of global lacustrine analogs.
5. Two yearly meetings for sponsors, including core workshops and field trips.
6. Exclusive consortium website for members.

PI:
Dr. Rick Sarg, CSM, (Petroleum geology and stratigraphy of carbonates and mixed deposits)

Timetable:
Project start: January, 2016
Duration of Phase II: 3 Years
Membership: $35,000 per year per company, and/or in-kind contributions.

ADDENDUM – CARBONATE PROJECTS

For the carbonate lithofacies in the upper Wasatch and Green River Formation, the general objective is to build 3D reservoir models for microbial carbonates and non-microbial carbonate grainstones based on the superb exposures of the shallow lake carbonate bodies. Oolitic and bioclastic grainsupportstone units comprise the Cow Ridge Member of the Wasatch Fm. (Uteland Butte unit in subsurface), and crop out in a lake margin facies belt that extends over ten miles in the strike direction and on the scale of miles in the dip direction. Microbial facies are present in the Green River Fm., and are persistent over miles in both depositional strike and dip directions. The following specific projects are proposed:

1) Description of lithofacies, diagenesis, and pore architecture of the oolitic and bioclastic grainsupportstones of the Cow Ridge Member of the Wasatch Formation and construction of a 3D geo-model for these grainsupportstones. This unit crops out in three major canyons in eastern Utah (Evacuation Creek, Missouri Creek, and Hells Canyon) that comprises laterally continuous outcrops in both dip and strike directions for distances of 2-3 miles in dip direction and 10+ miles in the strike direction. This allows a unique opportunity to document the lateral and vertical facies and pore system variability over 20 square miles. Meso-pore types identified to date include interparticle, moldic, and

vuggy porosity. Pore system analysis will include high resolution QEMSCAN imaging of pore structure tied to CMS-Mercury-N gas absorption measurements to identify the macro- to nano-porosity. **Completed, 2016.**

2) Description of the lithofacies, diagenesis, and pore architecture of 1-2 of the microbial carbonate units within the Green River Formation, and construction of a 3D geo-model for these bindstone and associated breccia and pisolitic facies. These facies display a high permeability, macro-pore system of fenestral and vuggy pores. Several of these microbialite units can be traced in canyons and across almost continuous valley walls for distances of 4-5 miles in both dip and strike directions, providing the opportunity to develop a 3D depositional model for these rocks. Diagenetic analysis will include SEM and stable isotope analyses to supplement standard petrographic description. Pore system analysis as described in No. 1 above will be supplemented with serial polished slabs to help construct a 3D digital image of the macro-pore system within these microbialites**. Initial study completed 2015.**

3) Chemostraigraphic and petrographic study of the Uinta basin microbialites to understand the vertical evolution of microbial deposits and their relationship to the lake stages of Lake Uinta. Comparison of this lake with previously studied Lake Piceance. This should provide insight into changes in lake water chemistry through time. **In progress, expected completion, 2017.**

4) A number of microbial bioherms are present in the area and are on the scale of meters across and up to 15 meters thick. Detailed depositional and diagenetic study of one or two of these bioherms is proposed to understand their facies composition, growth, and diagenetic alteration. Diagenetic and pore system documentation will be as above. As these bioherms are thought to be part of more extensive sheet-like carbonate beds, results from this work will be incorporated into the 3D Petrel geo-model in No. 2 above.

5) Small microbial and non-microbial spring deposits are present in the outcrop area within the Green River Formation. These tend to occur within shoreline microbial and non-microbial grain-rich carbonate units. These provide the opportunity to document the character of these tufa and travertine deposits and to document their relationship to the adjacent non-spring carbonates. Detailed petrographic and geochemical analyses are proposed to document spring development, spring water character, and the ensuing diagenetic alterations. Pore system analysis is as above.