Presalt Reservoir Analogs: Lacustrine Microbialites Fed by Shore Zone Hot Springs, Lakeside Utah*

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Abstract

Continental carbonates exposed along the Great Salt Lake shore at Lakeside (Utah) provide a unique opportunity to study fossil shorezone lacustrine microbialite bioherm reefs and genetically linked onshore alkaline spring deposits. This remarkably well-preserved and easily accessible system likely was emplaced during the fall from Lake Bonneville or the Provo stage to the Great Salt Lake level. These carbonate facies are potential analogs for reservoir rocks in systems such as the pre-salt upper sag carbonates of the South Atlantic.

We propose that the major lake level fall triggered the discharge of cool to hot geothermal groundwater from Paleozoic carbonate reservoirs at depth below the Lakeside Mountains, somewhat similarly to the hydrological model for the present-day geothermal Warm Springs Fault system (Murphy and Gwynn, 1979; Chiasson and Boyd, 2006). Springs along the shoreline were fed from conduits flowing through an older network karst in Mississippian Great Blue Limestone bedrock. Alkaline groundwater deposited travertine mostly on rocky spurs but on beaches of embayment shorelines as well. Clumped isotope Δ47 values point to temperatures from cool to mesothermal, some warmer than the cool Bonneville and Provo lake temperatures established by Mering (2015). Groundwater also flowed into the lake, mixing with lake water and promoting the development of microbialite reefs as nearshore benches and shoreline pavements. Recurrent cycles of flooding and exposure, accompanied by microkarst, pedogenesis and dolocrete formation, caused early diagenetic modifications in travertines close to the lake. Longer-term residence in the lake led to pervasive dolomitization of nearshore microbialites.

The carbonates at Lakeside are found mostly where promontories of faulted bedrock met the lake margin (Doelling, 1964, 2003), e.g. Dos Equis Point, Death Point and Atwoods Point. Deposits formed steep to flat and wavy drapes on bedrock; smaller domal forms forms grew as layers on cobbles or boulders; cm- to dm-size terracettes developed on steep walls; m-scale rimmed pools developed on low angle surfaces; m-scale complex forms suggesting flowers such as tulips grew as low-relief features while bolstered by alluvium (waterborne grainy sediment).
Subaerial, rimmed pools measuring several m² across and m-scale in height built larger terracettes (Hammer et al., 2010) on the flanks of the Death Point mound.

The facies of these carbonates exposed at Lakeside are highly similar to those of classic hot springs. Carbonates from Lakeside may be compared with hot springs in Yellowstone (e.g. Fouke et al., 2000; Fouke, 2011; de Boever et al., 2016) and in Italy (e.g. Chafetz and Folk, 1984; Pentecost, 2005; Gandin and Capezzuoli, 2014; Capezzuoli et al., 2014, Erthal et al., 2017). Microbialites at Lakeside may be compared with those from the Ries crater alkaline lake in Germany (Arp, 1995; Pache et al., 2001). Facies at Lakeside comprise four major categories: (1) Abiotic Fabrics; (2) Microbial fabrics; (3) Granular components, and (4) Subaerial exposure, microkarst and caliche. Each of these categories groups a number of different microfacies and fabrics.

Microbialites lying close to and physically connected with the alkaline spring carbonates compose small bioherms and reefs that were biologically controlled lake margin benches. The shore-parallel benches built up to a flat surface below or close to lake level. Individual 5 cm to 40 cm sized “Monk’s Head” bioherms show oval to circular “bald patches” on their caps from partial erosion of growth increments by waves and exposure. Benches, reefs or biostromes of Monk’s Head bioherms were oriented into swash-backwash directions or even into spur and groove structures. Stubby “Monk’s Tooth” microbialite forms of a similar size, more suggestive of molar teeth but with an upward branching internal structure, grew a little further out, under water in the lake. Finally, fairly simple oval to circular m-scale microbialite domes, built by successive concentric layers of carbonate, made banks further from the shore zone in deeper water.

Shorezone geomorphological criteria such as storm ridges, erosional notches (Atwood and Mabey, 2000) and sedimentological structures such as wave ripples, swash zone lamination, and microkarst erosion, characterize the zonation from exposed alkaline spring carbonate cascades meters or more above the lake down to the higher energy, grainy paleobeaches, lower energy bioherms and biostromes at average lake level, and further down into the lake with grainy shoreface flats and Monk’s Tooth bioherm reefs, and larger bioherms out on the lake floor.

Primary to very early (syndepositional) diagenetic minerals comprise aragonite, intermediate-Mg calcite, low-Mg calcite, very high-Mg calcite, and non-stoichiometric dolomite. These minerals preserved and cemented primary microbial fabrics in the travertine and the microbialites, and with them record repetitive exposure features from fluctuations in lake level with caliche and microkarst. Layers of both clotted microbial fabrics and of microkarst and caliche from soil formation are major components of the alkaline spring carbonate and the microbialites at Lakeside. The fabrics of both indicate primary microbial activity across the whole depositional system, while fenestral aragonite crystals and shrubby dendrolite growth of terracette dropwalls indicate the highly alkaline groundwater chemistry. The interbedding of layers of microkarst and caliche during bioherm growth demonstrates repeated exposure or weathering after successive phases of flooding and deposition.

While recent and fossil microbialites are common around the present day Great Salt Lake, the geothermal alkaline spring carbonate at Lakeside are the only occurrences of this type reported so far. Lakeside is the only location around the Great Salt Lake perimeter (at historic to present day lake levels) where carbonate bedrock predominates. So, it is tempting to link the alkaline groundwater related to the alkaline spring carbonate-microbialite system with the Great Blue Limestone bedrock. The fossil microbialites and bioherms at Lakeside differ in several aspects from other Bonneville, Provo, Stansbury and Great Salt Lake shoreline tufa and microbialites (Nelson et al., 2005; Felton et al., 2006; Bouton et al., 2016a, 2016b; Pace et al., 2016; Vanden Berg et al., 2016; Vennin et al., 2018). In particular, no structures similar to the Monk’s
Head or Monk’s Tooth bioherms have been described elsewhere from the lake so far, nor any tufa or travertine vent, cascade, drape and mound system such as is developed at Lakeside. However, a microbialite from Antelope Island described by Newell et al. (2017) does bear some resemblance with the domal layering of the Monk’s Head bioherms, while lacking the erosive tonsure effect. Their illustrations (Figures 3A, 3B and 6B) are comparable with bioherms from Atwoods Point, suggesting several microkarst surfaces.

A radiocarbon age of $12.5 \pm 0.1 \text{ Ka}^{14} \text{C BP}$ was measured on a sample from the 2 m tall terracette dropwall at Death Point by Pedone and Dickson (2000). Mineral and organic matter from the same layer, obtained earlier by D. Currey (Godsey et al., 2005) gave ages of $12,880 \pm 80 \text{ Ka}^{14} \text{C BP}$ ($14,448-15,921 \text{ cal yr B.P.: TOC}$) and $12,420 \pm 80 \text{ Ka}^{14} \text{C BP}$ ($14,132-15,419 \text{ cal yr B.P.: TIC}$). The convergence of these dates gives credibility to the $\text{^{14}C}$ results themselves, but their calibration gives an age between $15,385$ and $14,530$ cal yr BP (Newell et al., 2017). At that time the lake was still well above the elevation of the Lakeside deposits (Currey et al., 1984; Oviatt pers. com., 2017). This discrepancy has led Oviatt et al. (2015) and Newell et al. (2017) neither to use nor recommend these ages for the Lakeside deposits. Although the reservoir effect of lake water on the $\text{^{14}C}$ ages may have been minimal (Newell et al., 2017) the residence time of the geothermal groundwater in the bedrock aquifer would have been sufficient to lead to an apparent $\text{^{14}C}$ age being much older than the correct age (Fontes and Garnier, 1979; Pentecost 2005). A corrected age for the Lakeside travertine should therefore be somewhat younger than the measured $\text{^{14}C}$ BP ages, possibly to fall in line with a calibrated age of around 13 cal ka when the lake fell to around 1280 m.

A detailed hydrograph of the lake level over the past 15,000 years (e.g. Currey et al., 1984; McKenzie and Eberli, 1985; Murchison 1989; Patrickson et al., 2010; Oviatt et al., 2015) should allow identifying the times when the lake stood at the elevation of the Lakeside alkaline spring carbonate-microbialite paleoshoreline. Although more recent work by Oviatt (pers. com., 2017) has not substantiated the detail on these detailed graphs for the Holocene, the Lakeside system most probably deposited these alkaline spring and microbialite carbonates when the lake first fell to Great Salt Lake elevations.

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Selected References


Bouton A., E. Vennin, J. Boulle, A. Pace, R. Bourillot, C. Thomazo, A. Brayard, G. Désaubliaux, T. Goslar, Y. Yokoyama, C. Dupraz, P.T. Visscher, 2016a, Linking the distribution of microbial deposits from the Great Salt Lake (Utah, USA) to tectonic and climatic processes:


Currey, D.R., G. Atwood, and D.R. Mabey, 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geol. Survey Map 73.


Murchison, S.B., 1989, Fluctuation history of Great Salt Lake, Utah, During the last 13,000 years: United States National Aeronautics and Space Administration, Water, Paper 12, 137 p.


Newell, D.L., J.L. Jensen, C.M. Frantz, and M.D. Vanden Berg, 2017, Great Salt Lake (Utah) microbialite $\delta^{13}$C, $\delta^{18}$O, and $\delta^{15}$N record fluctuations in lake biogeochemistry since the Late Pleistocene: Geochemistry, Geophysics, Geosystems, v. 18, p. 3631-3645.


LAKESIDE, UT: WHERE IS IT?

LAKESIDE, UT: WHAT’S THERE & WHAT IS THE MESSAGE?

Great Salt Lake margin fossil geothermal springs link travertine with microbialite reefs & bioherms: GSL is all the more useful as an analog for the Presalt death point

Microbialites, travertine & tufa:
Words & their meanings as used informally here
- Microbialite: marine or lacustrine carbonate in which microbial involvement played a major role during subsequent deposition.
- Travertine: continental shoreline to lake margin carbonate deposited in the context of warm (20°C< T <40°C) to mesothermal (40°C< T <75°C) springs.
- Microbial involvement is usual.
- Tufa: continental carbonate deposited in the context of cool (T<20°C) groundwater springs, streams or pools. Microbial involvement is usual.

Usage varies between authors and from country to country: make sure you know what is meant.

Lakeside is the only GSL location with all three types of continental carbonates.

GEOLOGY

BY HELLMUT H. DOELLING

Note syncline of Mississippian Great Blue Limestone

LAKESIDE GEOTHERMAL TRAVERTINE MICROBIALITE SYSTEM

Microbialites distinguish between offshore & littoral growth patterns

Travertine carbonate were fed from mesothermal springs, formed terraced cascades, draped bedrock, coated boulders and formed mounds

The geothermal system may have been due to the lake level fall driving resurgence of deeper groundwater
numerous younger generation of larger, low-profile, crudely layered microbialite domes occur nearly 100 m offshore from the older Lakeside carbonates, close to the present lake margin.

**Microbialite Reefs & Bioherms**

**Monk’s Tooth Bioherms & Reef: Shallow Lacustrine Deposits**
- Coalescent Monk’s Tooth Bioherm
- Molar Tooth Bioherm Reef

**Monk’s Head Bioherms & Reef: Paleo Shoreline Deposits**
- Monk’s Head Bioherm or Pavement
- Monk’s Head Bioherms

**Bioherms Were Coeval With and Linked to Shoreline Travertine**
- Travertine on rock spur
- Geothermal conduit

**Monk’s Tooth Bioherms Show Repetitive Accretion & Exposure**
- Layering shows several phases of growth
- Orange and red incisions are microkarst
- Stable isotopes also show several growth phases

**Numerous Earlier Microkarst Events Were Each Followed by Deposition of More Lake Sediment After Flooding, Then Cementation & Dolomitization Again**
- Successive microkarst pockets with more or less dolomitized fill
- More recent lake sediment with ooids, coated grains & dolomite cement
- Round faceted dolomite coating micritic aragonite clots & acicular aragonite cement

**Larger, Highly Eroded Microbialite Mounds Lie Further Out on the Depositional Profile, But Close to the Monk’s Tooth Reefs**
- Monk’s Head accretion
- Monk’s Head exposure

Temperatures from Δ47 is roughly indicative of periodic flooding and exposure are revealed by microkarst solution cavities containing lacustrine sediment or pendant vadose cements.
**MOUNDS & TERRACETTES**

15m X 30m TRAVERTINE MOUND

Mound & terracette layers show microkarst, flooding with lake sediment & pedogenesis indicate a lake shore environment of the mound

**TRAVERTINE TERRACETTES ON THE FLANK OF THE MOUND**

Terraces or terracettes are formed by alkaline surface water flow in the subaerial environment

**CORING REVEALED BEDROC & FEEDER CONDUITS 1-3 FT BELOW THE PRESENT MOUND SURFACE**

The mound is asymmetrical in profile with large terracettes to the north & west, washover boulders & low mounded encrustation to the southeast. Temperatures from Δ47 are roughly indicative.

**TRAVERTINE PRIMARY MINERALS ARE MOSTLY CLOTTED & ACICULAR ARAGONITE**

Clotted fabric (1) is a consequence of microbial activity; acicular crystals (2) are chemical precipitates

**BUT LATE TERRACETTE DROPWALLS ARE SHRUBBY & CLOTTED INTERMEDIATE Mg CALCITE (=6% MgCO₃) WHILE OSTRACOD SHELLS INDICATE LACUSTRIAN FLOODING**

**DRAPES, CASCADES, MINITERRACETTES, ENCRUSTATION**

**DRAPE**

Miniterracettes coalescing to form a larger feature

**CASCADES**

Terracettes comprise an outer dropwall and an inner pond

**MINITERRACETTES & ENCRUSTATION**

Travertine draping over bedrock & progressively formed cascades & terracettes

**TRAVERTINE DRAPE, PROGRESSIVELY FORMED CASCADDS & TERRACETTES**

Miniterracettes coalescing to form a larger feature

**Travertine drape, miniterracettes, growth features encrustation & mounds**

**TRAVERTINE DRAPE, PROGRESSIVELY FORMED CASCADDS & TERRACETTES**

Miniterracettes coalescing to form a larger feature

**TRAVERTINE PONDS GREW UP TO FORM VASE SHAPED STRUCTURES**

Isolated ponds progressively build up surrounded by alluvium & form "tulip like" features

**TRAVERTINE FROM SHORELINE TO CLIFF FACE**

Wave cut mound (1), rimmed pool (2) & cemented beach gravels (3)

Truncated domes at the foot of Dos Equis cliff

Terracette cascade (1) & encrusted boulder (2)

**VENTS PROPAGATED PROGRESSIVELY FROM BEDROCK FRACTURE NETWORK KARST (A), THROUGH DRAPES & MOUNDS (B,C) TO FEED TRAVERTINE LAYERS (D)**

Fracture vent fabrics (E) show successive increments of travertine with microbially involved clotted aragonite, leaching & caliche crust from exposure, as well as dolomitization; bubble fabrics (F) are common close to and at vents
CARBONATE MINERALOGY, DOLOMITE & DOLOMITIZATION AT LAKESIDE

ARAGONITE: MICROCRYSTALLINE CLOTS & ACICULAR CEMENT

Low Mg Calcite (<1% MgCO₃): Prismatic to Botryoidal Tufa Drap

Intermediate Mg Calcite (=6.6% MgCO₃) Later Terracette Dropwalls

Calcite (Great Blue Limestone)

Poorly Ordered Calcian Dolomite (45-49% MgCO₃)

Poorly Ordered Calcian Dolomite: Occurs in Different Settings
1: Lake Margin Travertine Terracette Pool Mudstone
2: Pervasively Dolomitized Lacustrine Bioherm
3: Phreatic Zone Early Diagenetic Dolocrete Cement
4: Vadose Zone Early Diagenetic Dolocrete Cement
5: Later Crystallite Aggregates

Dolomite at Lakeside Shows Phases from Nucleation to Maturity

CONCLUSIONS

Travertine & Microbialites are Not Mutually Exclusive

Alkaline Groundwater Can Promote Growth of Both Onshore Travertine & Lacustrine Microbialites in the Same Depositional System

Different Carbonate Minerals Are Closely Linked with Specific Depositional Environments, Water Temperature & Chemistry

Significant Lake Elevation Changes Can Drive the Carbonate Factory to Produce Reservoir Facies in Unexpected Places

Bottom Line

With the Travertine & Microbialite Record at Lakeside, Great Salt Lake is All the More Useful as an Analog for Subsurface Pre-Salt Microbialite-Travertine Features