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Analogs for Carbonate Deposition (Microbialites, Tufas and Travertines) In Early Rift Settings

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Driven by requests to provide carbonate analogs for subsurface hydrocarbon exploration in rift settings, we have identified and described select examples, summarized them from a carbonate perspective, and assembled them into a GIS database. The analogs (Fig. 1) show a spectrum of sizes, shapes and styles of deposition for lacustrine and marginal marine settings, wherein the types of carbonates inferred in subsurface studies from seismic and cores (emphasis on microbialites, tufas, and travertines) can be illustrated.

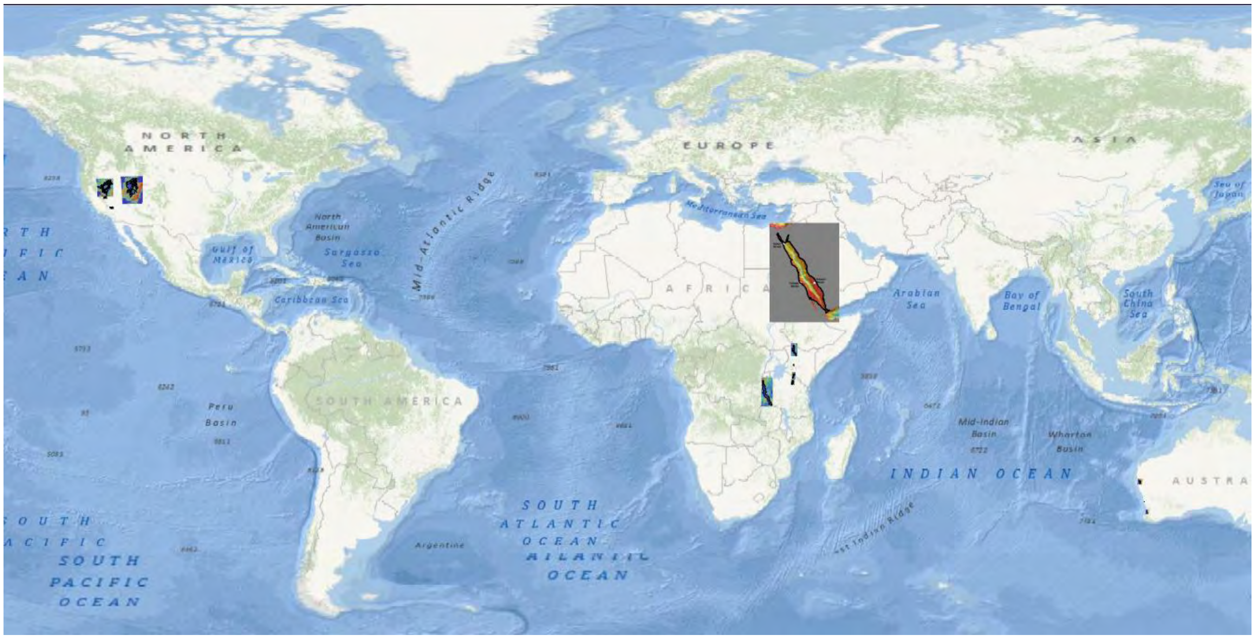

Fig. 1.- World map from ArcGIS showing analog locations by their digital elevation models.

The analogs are grouped as **Early Rift Lakes**, **Other Lakes**, and **Marginal Marine Basins**. The collection of examples was chosen to serve as analogs from a variety of perspectives, as summarized in Table 1 below.

ANALOG	RIFT SETTING	SIZE	COMPLEXITY	CHANGE OVER TIME	MICROBIAL	TUFA/ TRAVERTINE	MARINE CARBONATE
Early Rift Lakes							
Lake Turkana	X	X			X	X	
Lake Bogoria	X				X		
Lakes Natron-Magadi	X	X		X	X	X	
Lake Manyara	X				X		
Lake Tanganyika	X	X			X		
Other Lakes							
Great Salt (and Bonneville) Lake		X	X	X	X		
Mono (and Russell) Lake				X		X	
Pyramid (and Lahontan) Lake		X	X	X		X	
Searles Lake		X		X		X	
Lake Clifton					X		
Lake Thetis					X		
Marginal Marine Basins							
Shark Bay		X			X		X
Red Sea	X	X	X				X

Table 1.- Importance of examples as analogs from different perspectives.

The analogs can be used to improve our understanding of the spatial distribution of lacustrine carbonate deposits at a variety of scales (Fig. 2). For example, five Early Rift Lakes from East African Rift System show a range of characteristics to be expected in lacustrine settings during the earliest stages of rifting, whereas the Red Sea shows well advanced rifting with marine incursion and reef and associated carbonate development. The analog examples show a wide range of sizes, with several of them being large enough that they could produce carbonate deposits of potential economic interest. Three of the areas are exceedingly complex, meaning that they illustrate a large degree of potential facies heterogeneity due to their size and irregular pattern and connectivity of sub-basins within the overall lake outline. Landsat images, DEMs & available literature can be used to delineate present and past lake/basin margins, assess changes over time, and investigate spatial patterns of carbonate deposition.

Many of the examples show a wide range of microbial carbonate development in both nearshore and lake bottom environments, and several also show the distribution of tufa and travertine within the lacustrine setting. Nearshore stromatolites and thrombolites in Lake Clifton and Lake Thetis illustrate a zonation of growth forms in these small, very shallow settings. Small stromatolites occur locally only along the leeward shoreline of Lake Turkana, whereas larger ones that are spring-related are found on both sides of the lake. Spring-related travertines and minor sromatolites parallel higher lake levels shorelines of Lake Bogoria, and in Lakes Natron and Magadi similar stromatolites along highstand shorelines illustrate growth down to 14 m during times of relative lake-level stability. Similar high lake level stromatolites in Lake Manyara grew down to only 8 m depth, and are tied to paleo-shorelines that are different from those of Natron-Magadi, pointing out variability in carbonate development between adjacent basins. Lake Tanganyika has perhaps the most robust development of stromatolites of the East African examples, covering a wider depth range (6 - 60 m) and indicating growth when lake level was near balanced and had only minor fluctuations (~20 m).

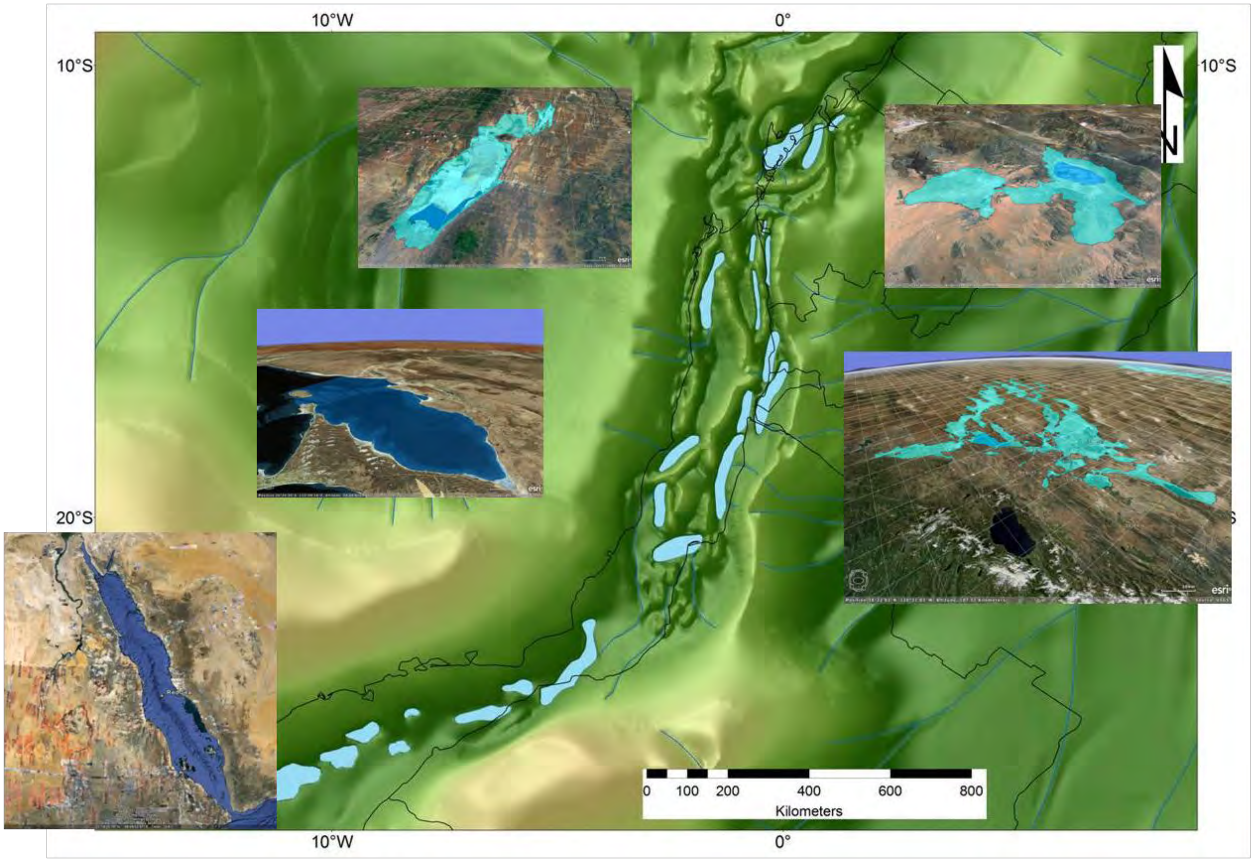

Fig. 2.- Schematic of possible lake development during initial rifting and inference of how analogs included in this study might represent the gradation from marine in the south to lacustrine in the north.

The carbonate "buildups" can be related to the modern lake outline, and in a few cases relative to paleo-shorelines associated with higher lake levels, but for almost all of the examples the buildups are not well enough exposed to be accurately mapped or to gain an appreciation of when they formed relative to lake level change. Widespread microbialite bioherms in Great Salt Lake (covering up to ~1000 km^2) are associated with small changes in topographic relief, and preliminary age dating suggests they possibly grew down to ~10 m during a time of lake level fall.

Spring-related tufa pinnacles and nearshore tufa terraces of Searles Lake show that tufas formed on the lake bottom in depths up to nearly 200 m along fault-related springs and along shorelines associated with higher lake levels. The area containing tufas covers approximately 16% of the area of the lake, and tufas are not present along the shallow eastern side due to probable wind-driven continuous wave action. Variations of tufa facies documented by indicate varying lake conditions during their growth. Different water depths may have caused differences in water residence times, water temperatures and biota. When evaporation was the main process of water loss and was accompanied by little or no water influx, i.e., a closed lake hydrologically, a longer water residence time increases the likelihood of thicker carbonate accumulations, and also affects variations in alkalinity and salinity which may have controlled tufa facies variation. Differences in water depth can also lead to different vertical temperature profiles, which also could have affected abiotic precipitation, and the biota and their activities.

Mono Lake and Pyramid Lake contain spring-related tufa towers now exposed around their shorelines. In Pyramid Lake the tufas formed during high lake level when separate sub-basins of Lake Lahontan were joined. Changes in lake level and configuration of Lake Lahontan directly impacted the potential for carbonate precipitation by varying the amount and composition of runoff that drains into the lake, varying the connectivity of the various subbasins across sills and thereby determining if a particular subbasin is an open or closed system, and affecting the amount of groundwater flow and therefore potential springs into the lake. The thickest tufa deposits formed near lake-bottom sites of ground-water discharge, and at overflow elevations where the lake was held at near-constant levels for long periods of time (hydrologically closed system, adjacent to spill points, source for Ca was thermal ground water). Deposition of large-scale tufa ended with the fall of Lake Lahontan when decreases in the discharge of lake-bottom springs may have sharply lessened the amount of calcium available for precipitation. Preservation occurred in Pyramid Lake as tufa formed at elevations not reached by subsequent lake levels, or in areas protected from subsequent surface-water runoff, or were buried by fine-grained lake sediment.

Shark Bay shows the distribution of microbial carbonates within a restricted marine setting, and the Red Sea indicates the variability of reefs and associated skeletal sands in a fully marine rift setting. Microbial deposits rim Hamelin Pool illustrating a zonation of well-formed intertidal mats, subtidal microbial buildups down to 2.5 m depth and covering 120 km^2, and subtidal microbial pavements forming to 6 m water depth. Subtidal microbial deposits (pavement and buildups) occupy nearly 15 times the area of intertidal microbial mats and heads (463 km^2 versus 32 km^2). Reefs and associated skeletal sands in the Red Sea are elongated parallel to the rift axis except where islands are present. The detailed mapping of the reefs and sands shows the amount of potential reservoir facies to be expected in a marine rift basin (up to ~20%), the size of separate reservoir geobodies (1-5 km^2 mean, 10-50 km^2 maximum), and patterns that maximum widths develop into showing varying degrees of heterogeneity.

The analogs are assembled into a GIS database accessed via ArcGIS or ArcGIS Explorer with a goal to make all of the data gathered for each analog site readily available to the reader, thereby making it “easy” to evaluate if the analog has value; and if so, to use the GIS and other spatial solutions as a starting point for further investigation.