

ENABLING EASY ACCESS TO ANALOGS FOR CARBONATE DEPOSITION IN EARLY RIFT SETTINGS

Paul M. (Mitch) Harris (Chevron Energy Technology Company, San Ramon, CA, USA), James Ellis (Ellis GeoSpatial, Walnut Creek, CA, USA), and Samuel J. Purkis ((National Coral Reef Institute, Nova Southeastern University, Dania Beach, FL, USA)



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 analog examples show a spectrum of sizes, shapes and styles of deposition for lacustrine and marine settings, wherein the types of carbonates that are inferred from seismic and cores (emphasis on microbialites and tufas) can be illustrated.

Early Rift Lake, Other Lake, and Marine Basin examples illustrate the location and various styles of carbonate deposition within each of the examples. Landsat images, DEMs and available literature can be used to delineate present and past lake/basin margins, assess changes over time, and investigate spatial patterns of carbonate deposition.

The set of analogs is available to you as SEPM Short Course Notes No. 55, wherein the analogs are assembled into a GIS db accessed via ArcGIS or ArcGIS Explorer. Shared data folders for each example, which contain satellite images, maps, photos, and selected papers, will facilitate further study.

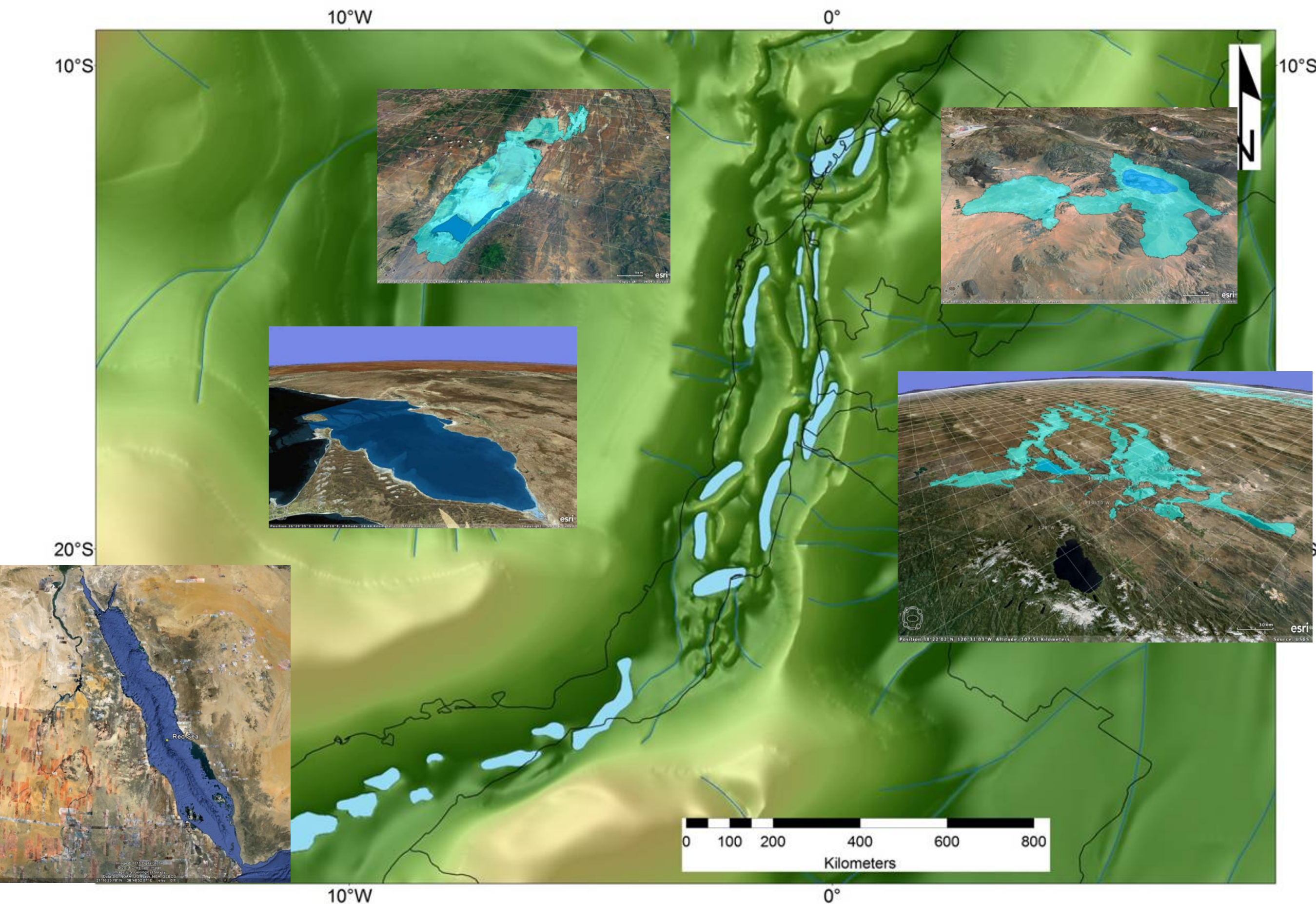


The examples can serve as lacustrine carbonate analogs from a variety of perspectives --

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		
Marine Basins							
Shark Bay		X			X		X
Red Sea	X	X	X				X

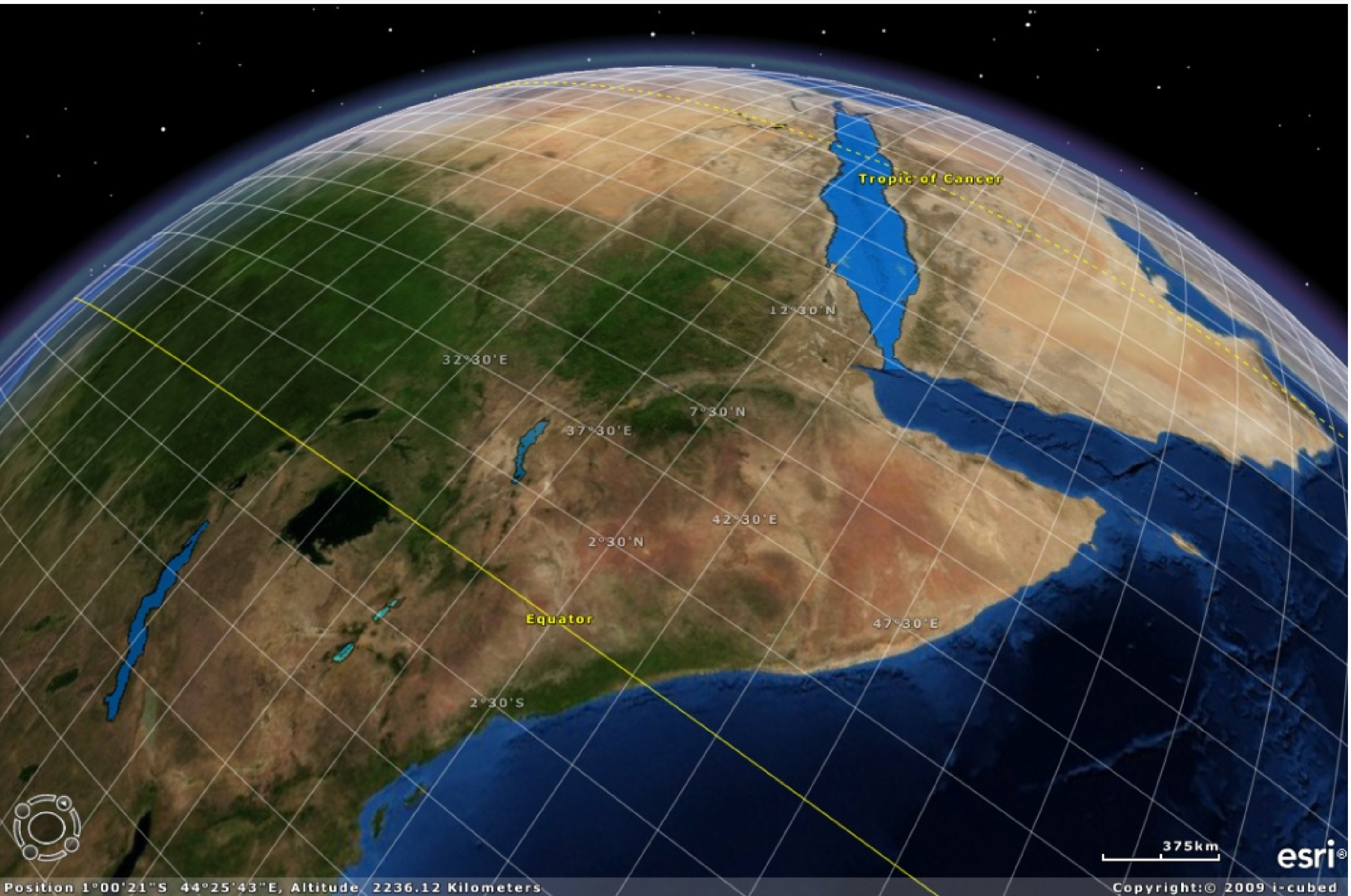
Spatial distribution at a variety of scales for better mapping and interpretation of seismic and well data at the regional, sub-regional, and prospect scale

Development and characteristics to better interpret the nature of the carbonate deposition from seismic and cores, and identify the variability of carbonates and associated reservoir heterogeneity.

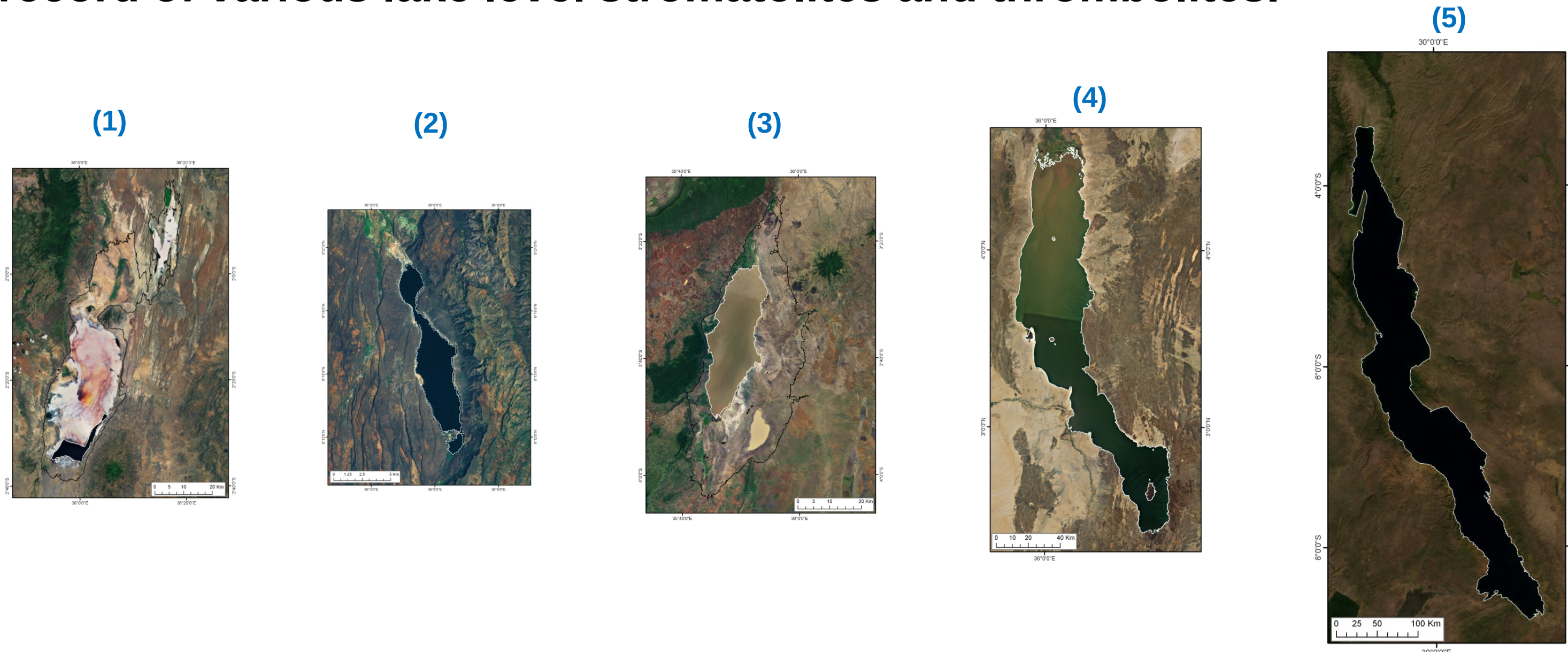


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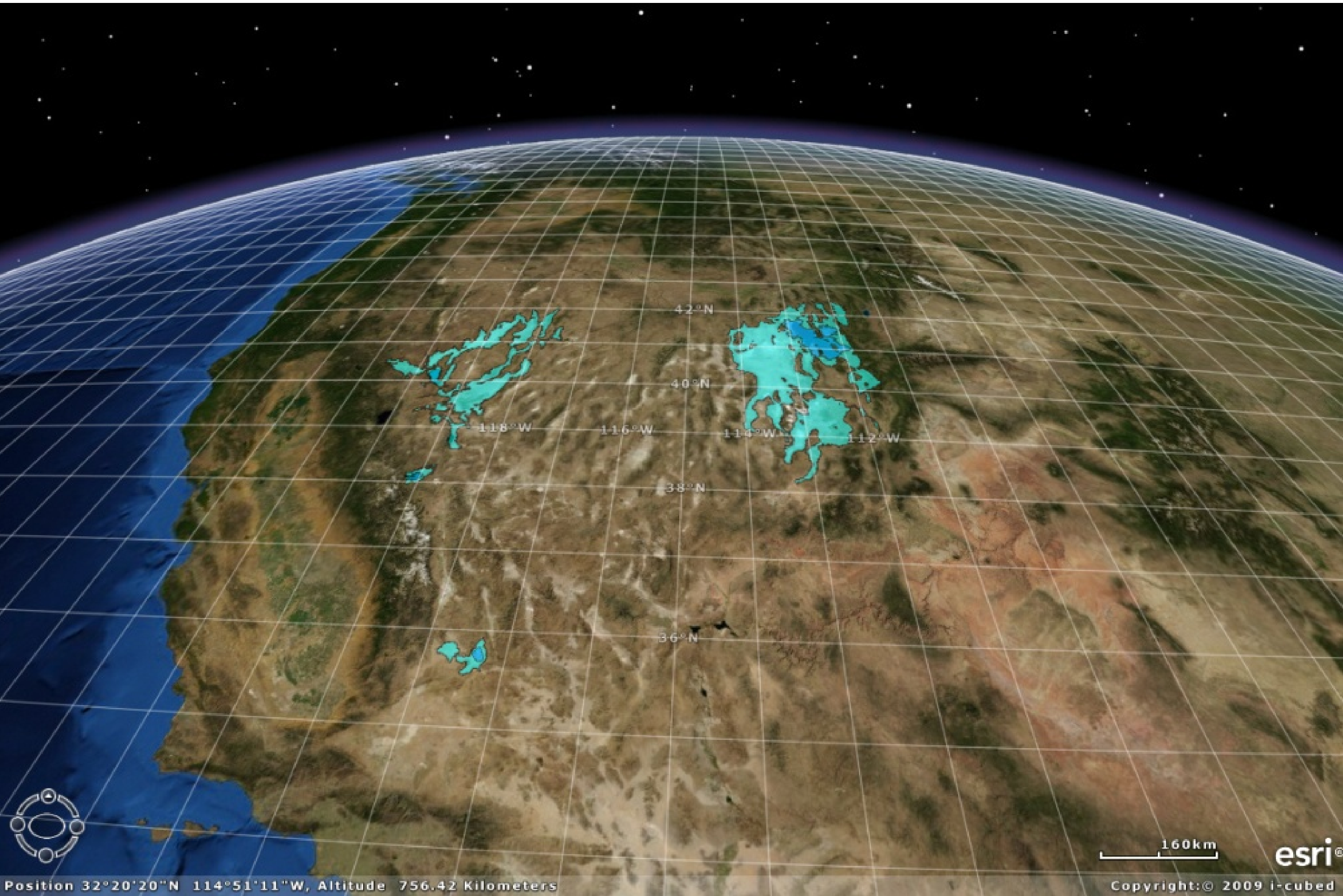
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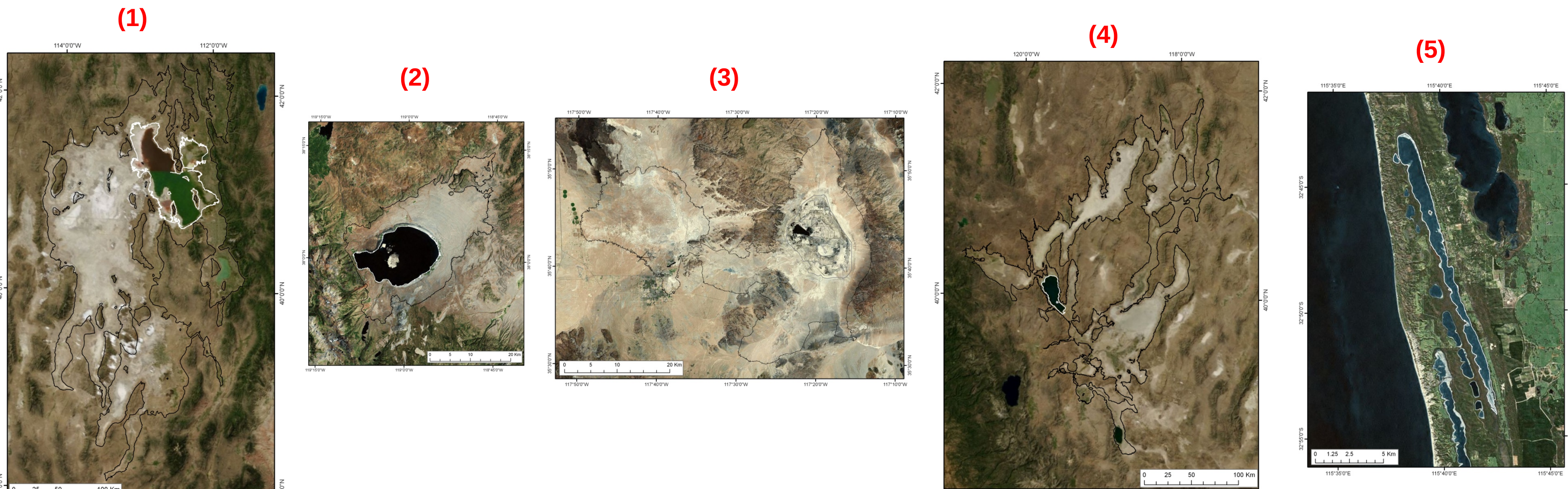
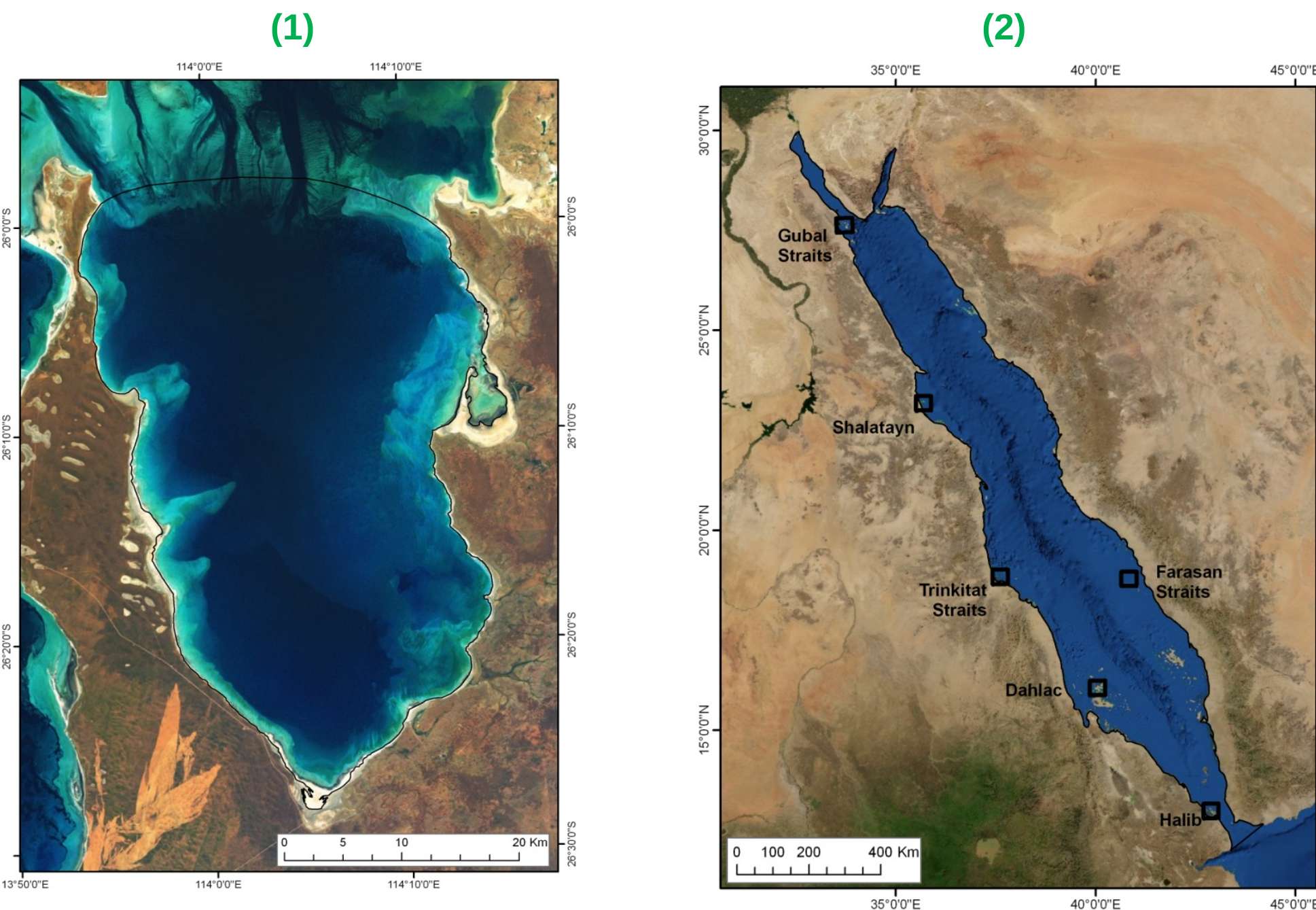
Early Rift Lakes includes five examples from the East African Rift System: (1) Lake Natron – Lake Magadi, (2) Lake Manyara, and (3) Lake Bogoria which contain stromatolites, local travertines, and an outcrop record of high lake level stromatolites; (4) Lake Turkana with shoreline carbonates, local travertines, and an outcrop record of high lake level stromatolites; and (5) Lake Tanganyika showing shoreline carbonates and an outcrop record of various lake level stromatolites and thrombolites.



Other Lakes with six diverse examples: (1) Great Salt Lake (and high lake level Lake Bonneville), Utah with shoreline carbonates including oolites, and modern and Pleistocene microbial bioherms; (2) Mono and (3) Searles Lakes, California, and (4) Pyramid Lake (and high lake level Lake Lahontan), Nevada, containing widespread spring-related tufas; and (5) Lakes Clifton and (6) Lake Thetis, Australia, with stromatolites and thrombolites).



Marine Basins with two examples: (1) Shark Bay, Australia, with nearshore restricted marine stromatolites; and the (2) Red Sea illustrating nearshore coral reefs and related marine carbonates.

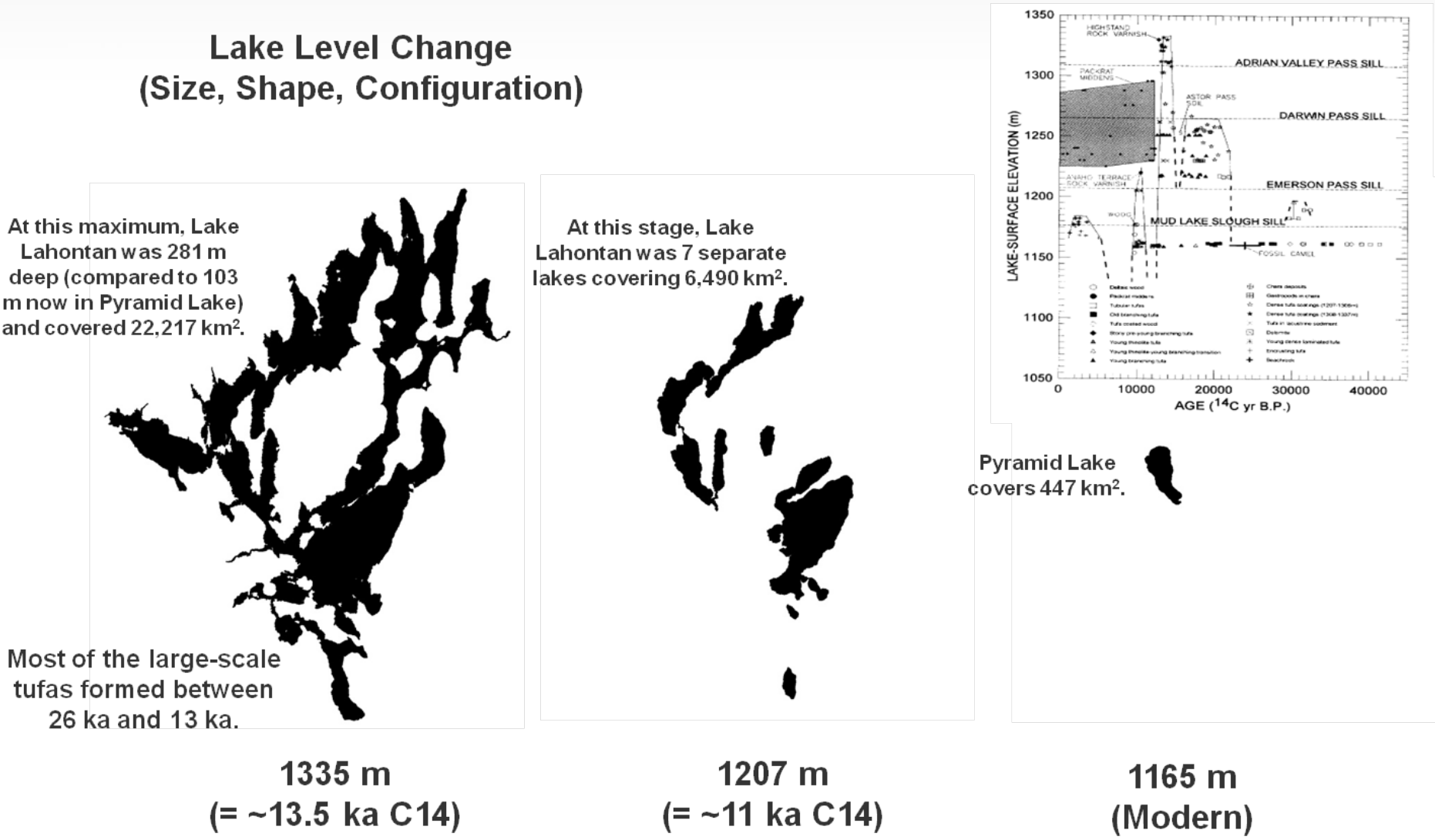
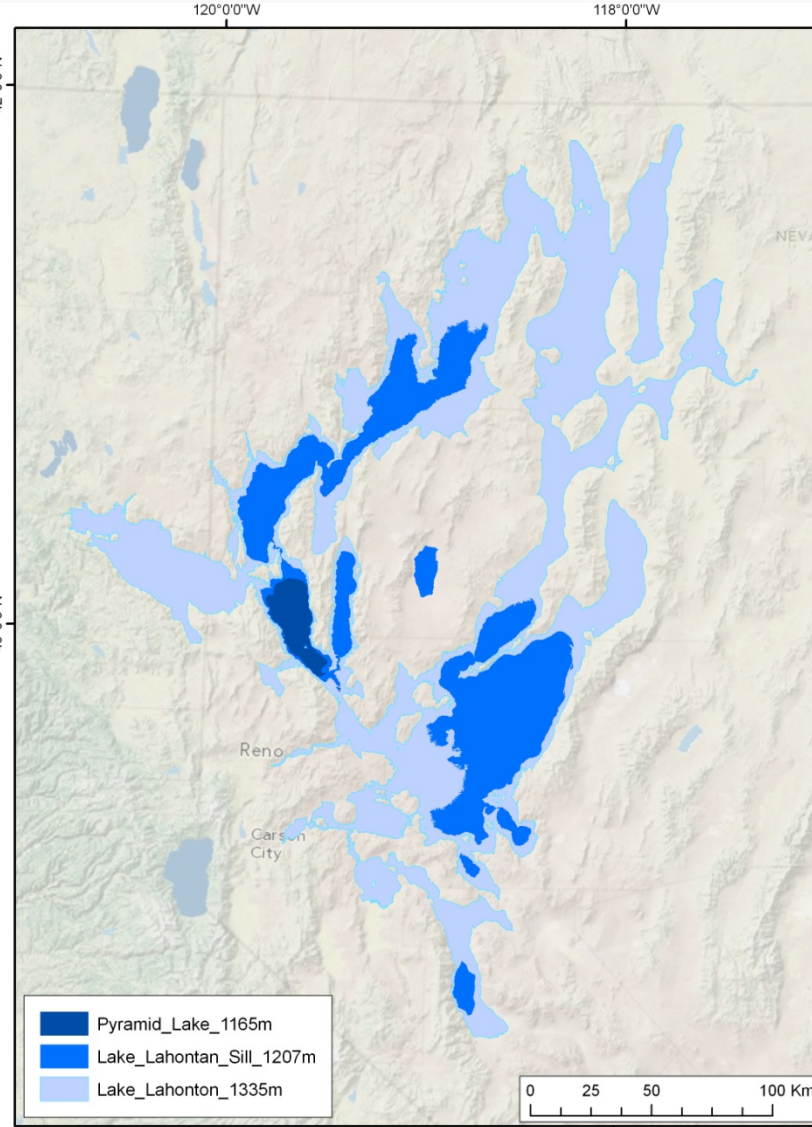
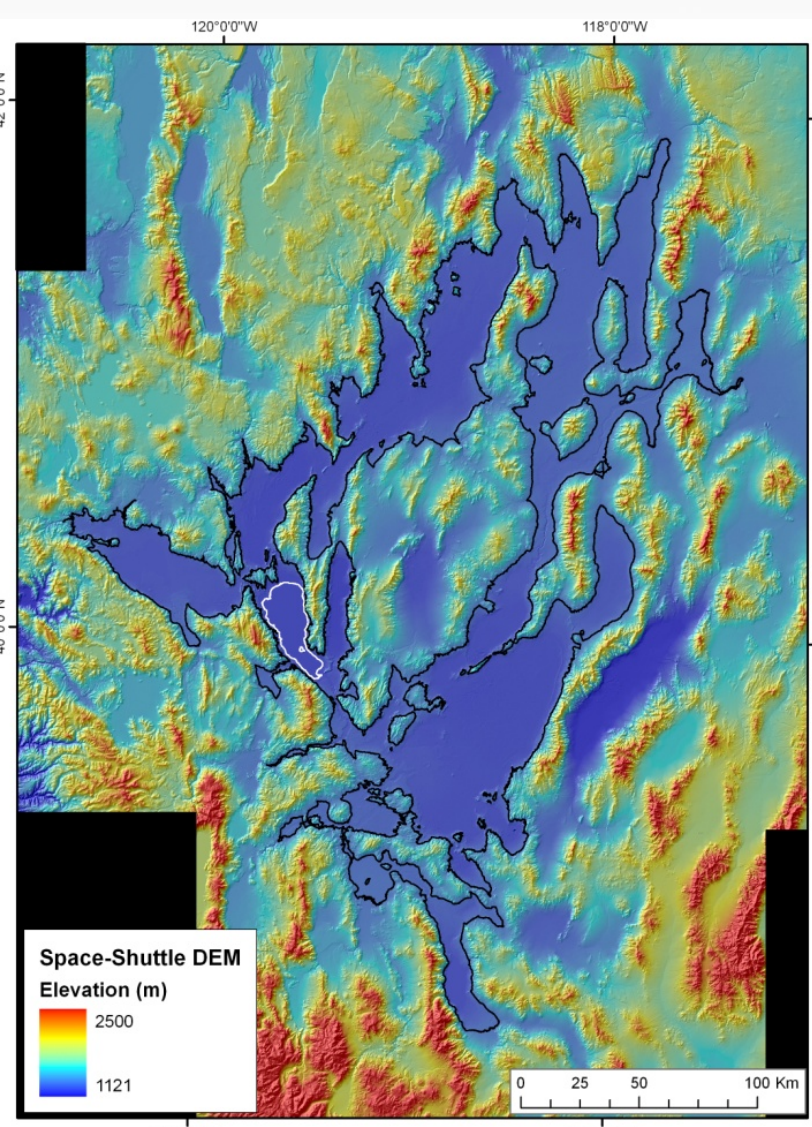


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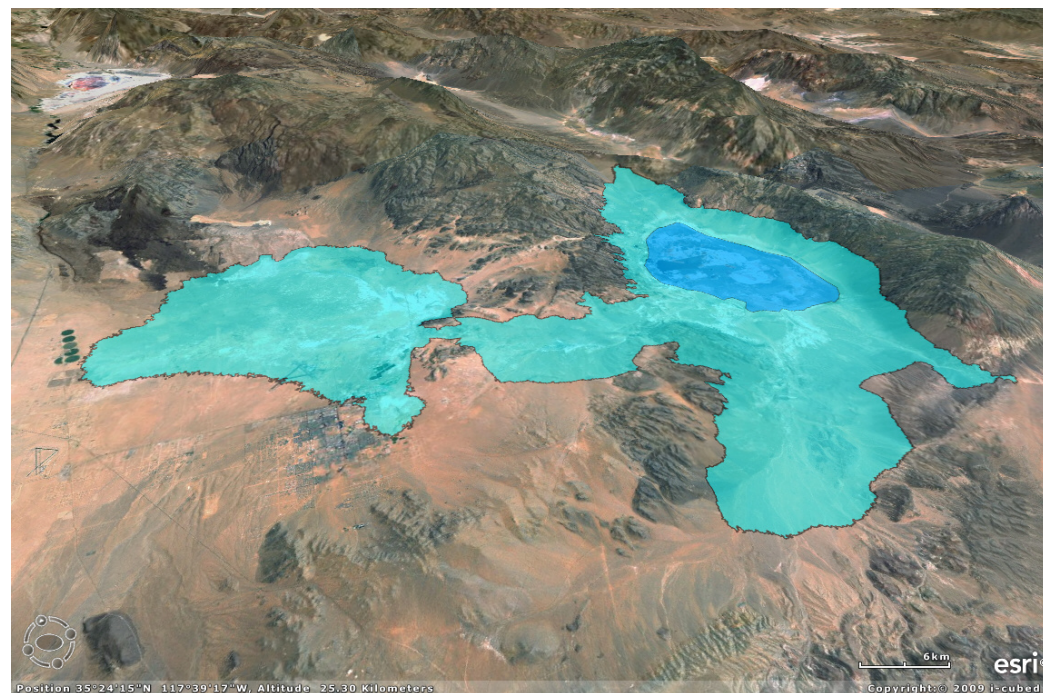
Lake Lahontan shows the magnitude of change in size, shape and complexity that a lake repeatedly undergoes and assesses the impact of this change on carbonate formation.



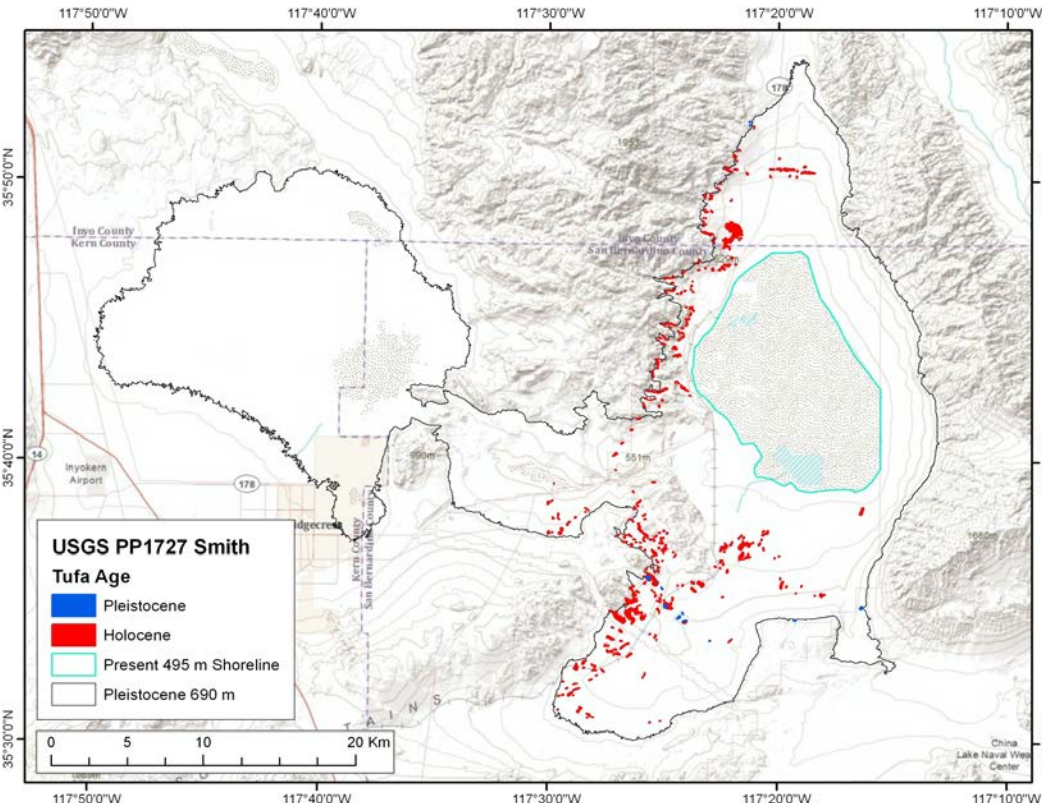
The changes in lake level and configuration directly impact the **potential for carbonate precipitation** by:

- Varying the amount and composition of **runoff** that drains into the lake,
- Varying the **connectivity** of the various sub basins across sills and thereby determining if a particular sub basin is an **open or closed system**, and
- Affecting the amount of **groundwater flow** and therefore potential springs into the lake.

Searles Lake offers an opportunity to assess the extent of tufa formation related to a particular lake level.

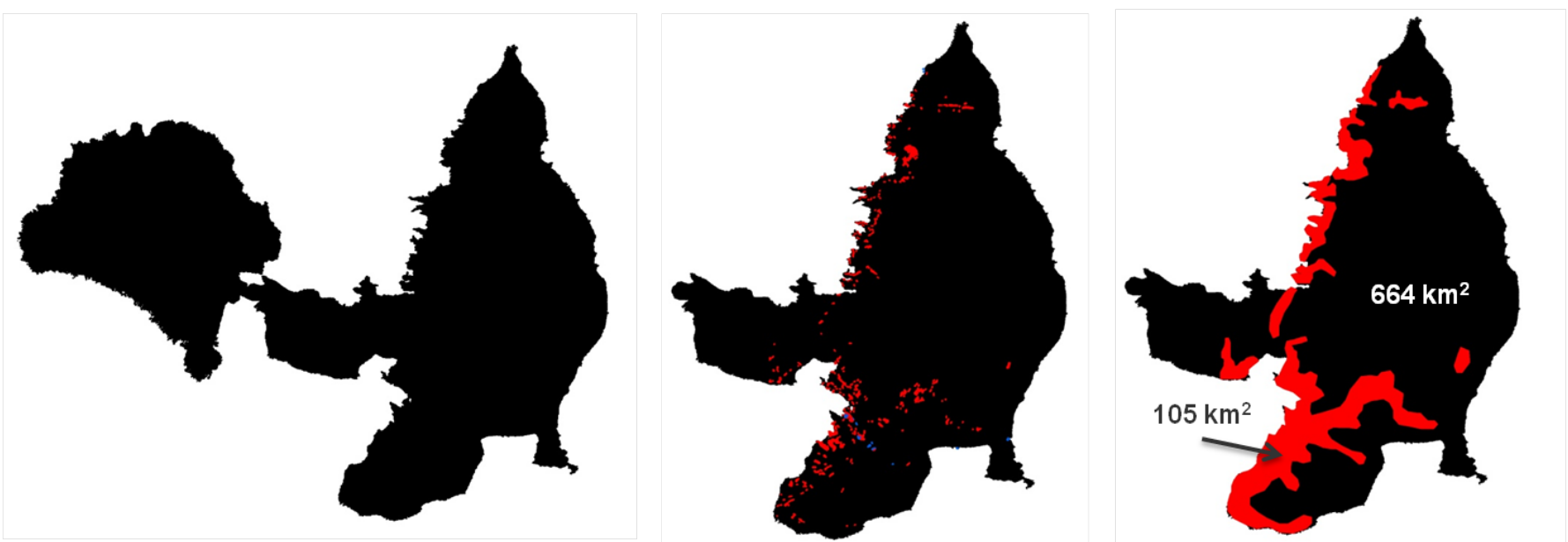


Tufas **up to 37 m high** but commonly less than half that height, and **covering up to 0.2 km²**



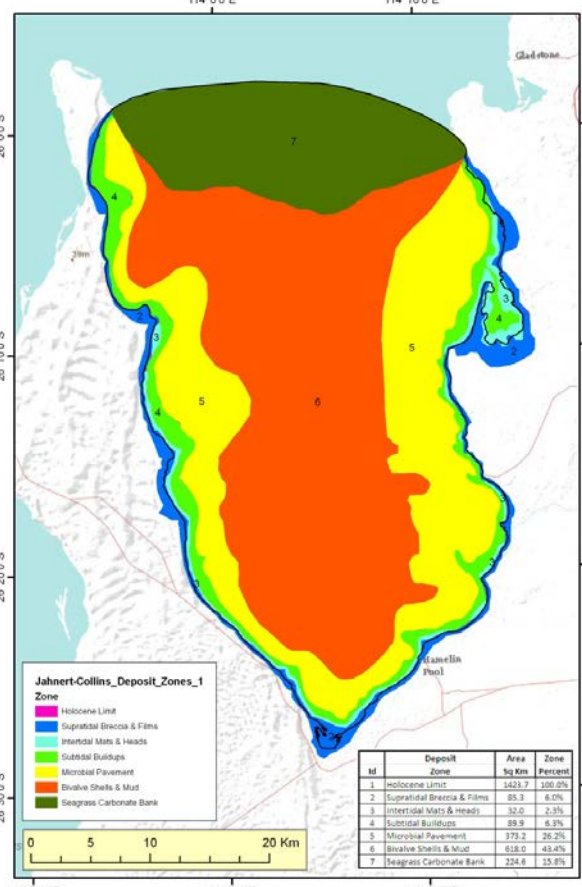
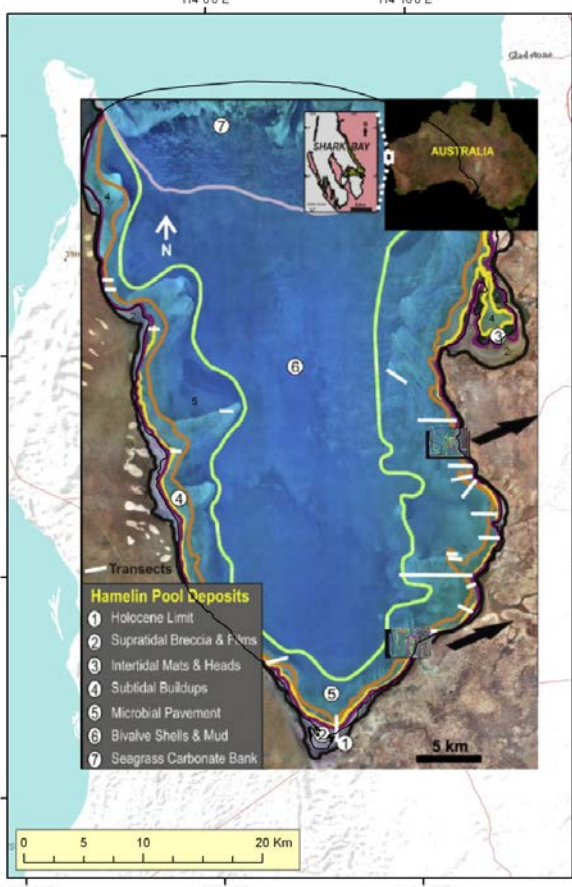
- Massive tufas are restricted to an elevation range that indicates a **deeper water sublacustrine setting**.
- Domelike shapes and local alignment suggest origin **related to springs aligned along fractures**.
- Tufas not aligned with each other or with known faults lie at or near the highest shorelines of later lakes, arguing for an **organic process in shallow water**.

Analyzing Extent of Carbonates (Tufa) Relative to Paleoshoreline(s)



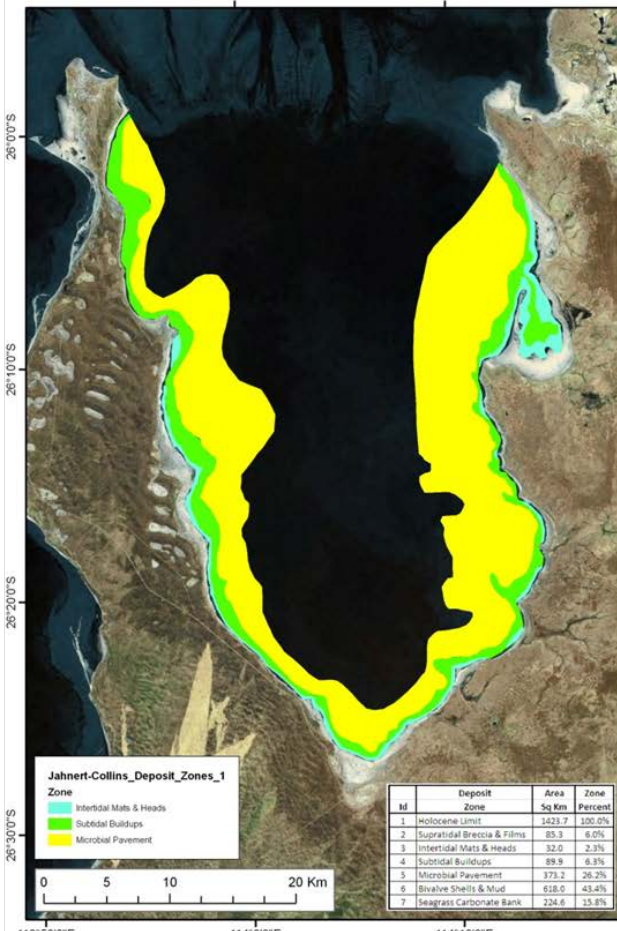
- Topography suggest the majority of the tufa deposits formed at a time when Searles Lake was not fully connected toward the west and **overflow** to the southeast was occurring.
- Spring- and fracture-related tufas formed on the lake bottom in waters up to nearly 200 m deep.
- The reduced amount of tufa along the east side is attributed to probable continuous wave action along that shore, a result of the prevailing winds out of the west.

And in a similar way, Shark Bay shows the extent and spatial distribution of different types of microbial deposits in a restricted marine basin.



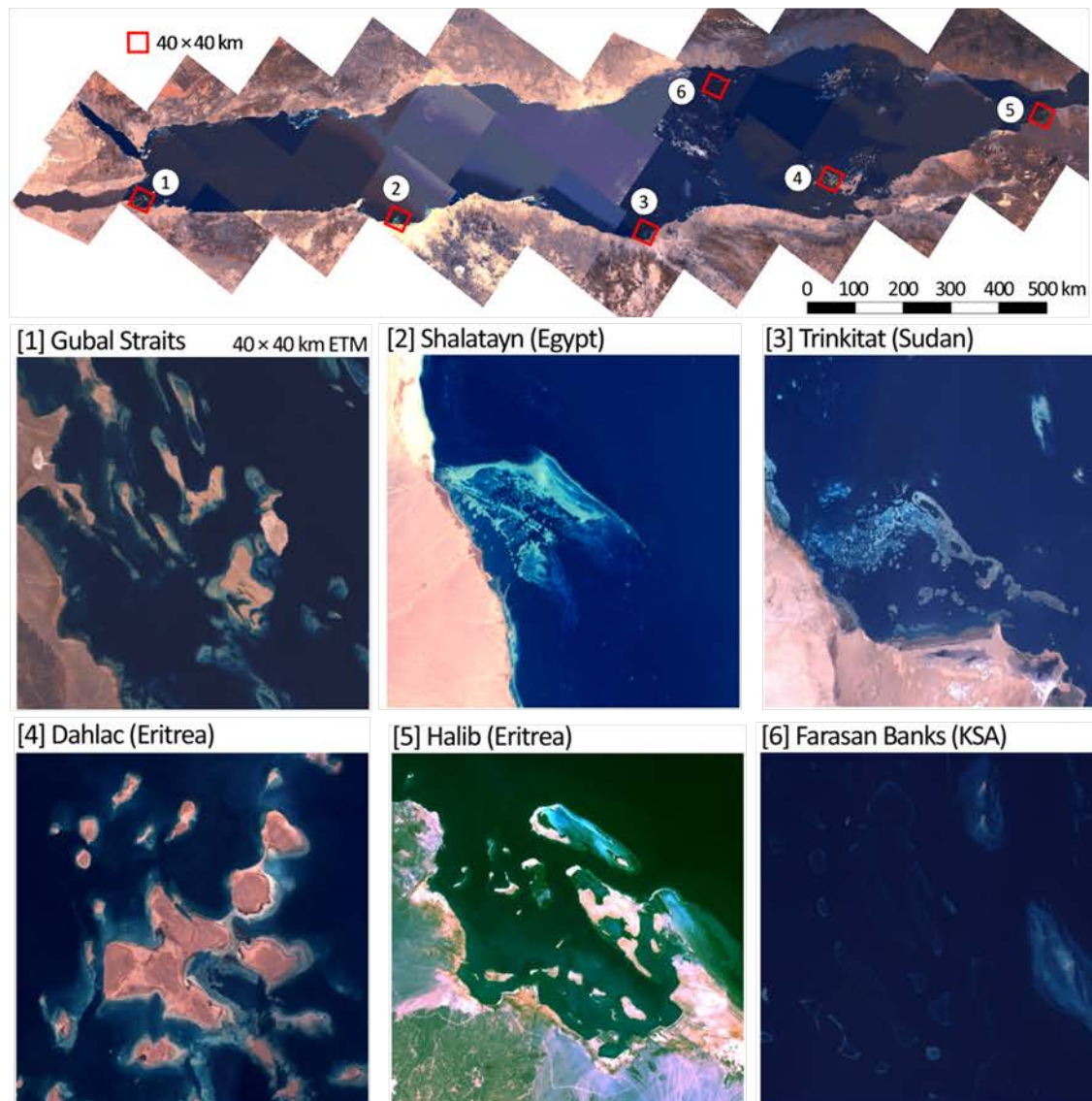
- Microbial structures grow in specific settings **according to water depth**
- **Build-ups** common between 1-2.5 m depth and pavements extending as deep as 6 m

Analyzing Extent of Carbonates (Microbialite) Relative to Shoreline



- Microbial structures and sediments in Hamelin Pool have an extensive distribution occupying **~40% of the embayment's ~1400 km² area**.
- **Subtidal** microbial deposits (pavement and buildups) occupy nearly **15 times the area of intertidal** microbial mats and heads (463 km² versus 32 km²).
- Buildups occur in an area approximately 90 km², wherein structures as high as 1.5 m are often connected laterally to form 50–500 m wide "reef" belts parallel to the shoreline.

The widespread development of modern reefs along the sides of the Red Sea marine rift serve as a robust example for quantitative interrogation of the depositional patterns formed in this case by reefs and associated skeletal sands.

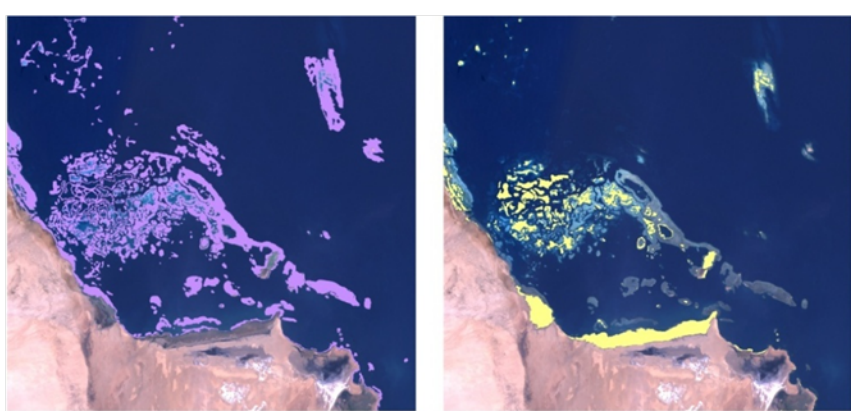
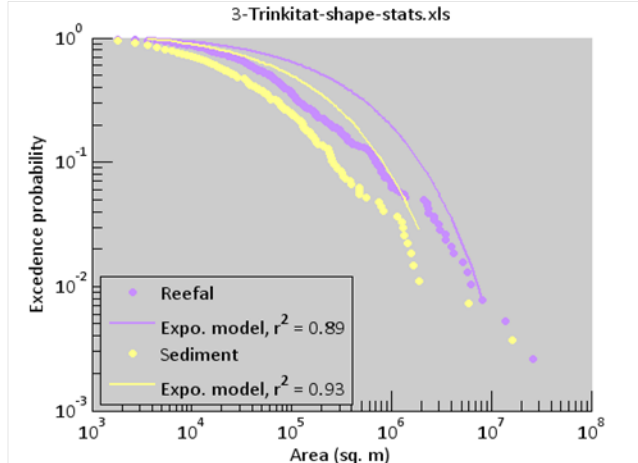


Analyzing Extent of Carbonates (Reefs) Relative to Shoreline & Comparative Morphometric Analysis

- The Red Sea can be used to explore local and regional controls on shallow-water carbonate **facies geometry** in an **extensional tectonic setting**.
- It is unique in its extent (20° of latitude) and transects a gradient in **climate**
- 6 Sites, each of 1,600 sq. km, selected to cover the range of reefal and sedimentary styles

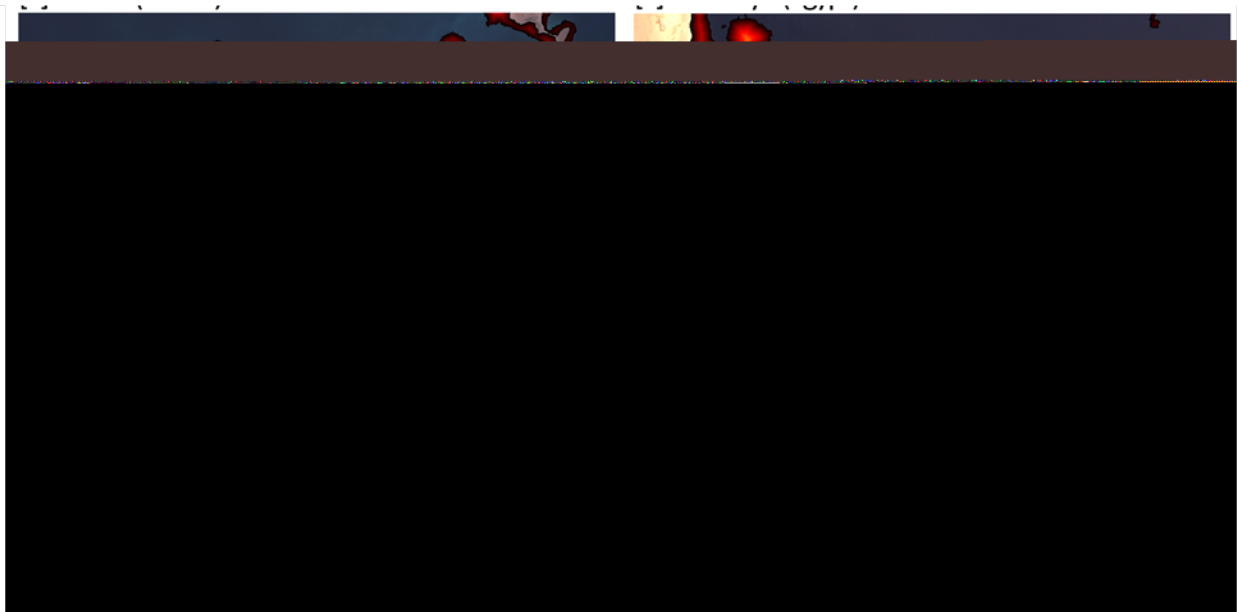
Frequency-Area Distributions

- The relationship between **size and prevalence** for reefal and sedimentary bodies is typically not power-law and in many cases closely approximates an **exponential distribution**
- Graphs of exceedence probability clearly depict that differences exist in the **relative abundance** of the reefal and sediment facies with relation to one another. (In the case of Trinkitat, for example, the two lines in the plot diverge towards the large end of the spectrum. The purple line is offset to the right of the yellow indicating how the largest reef units are approximately one order more expansive than the largest sediment bodies.)
- The **largest expected size** of a single reefal unit and sand body is ~10 - 50 km² and mean size ranges from ~1 - 5 km²
- Only two sites (Shalatayn and Farasan) report the sediments to be more abundant than reefs across the majority of the size spectrum. In all others, **reefs dominate** by area. The range for reefal facies is 6 - 18% and for sediments is 4 - 21%.



Widths-Maps of Potential Reservoir Bodies

- Abundant offshore islands provide a **topographic high** from which shallow water carbonate systems can nucleate and laterally develop
- For example, in Dahlac (Eritrea), the offshore islands form closely spaced highs, often fully or partially **knitted together** by "necking" of reefal and sedimentary facies
- However, sites such as Shalatayn are capable of building as **expansive** shallow-water carbonate fairways despite their lack of islands
- **Complex** depositional geometry and so should expect abrupt lateral and vertical **facies changes**



Orientation of Geobodies

- When offshore islands or reefs are sufficiently widely separated that sediment and reefal "necks" cannot easily develop to span their divides, there is a clear tendency for **facies belts** to align with the **strike of the rift** (red)
- Inshore reefs also are rift aligned as they are associated with the **strike of the coast**
- Closely spaced offshore islands and reef blocks serve to yield more complex depositional highs and direct the orientation of associated facies belts (see Trinkitat and Dahlac)

