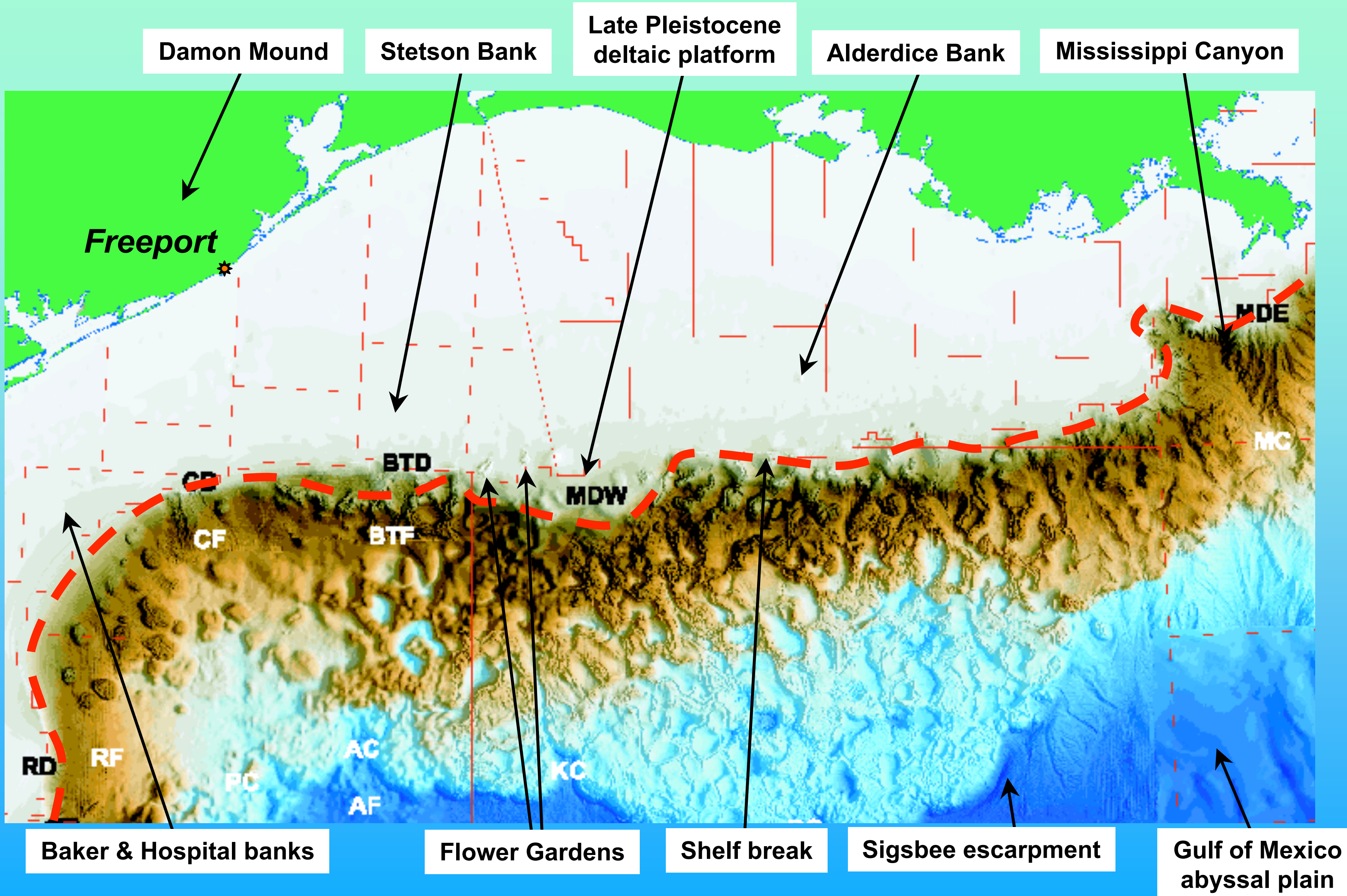
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

presented by

Mark Betts

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Northwest Gulf of Mexico physiographic setting

After Winker & Booth
GCSSEPM 2000

Two classes of shelf bathymetric highs exist on the Gulf of Mexico shelf:

- *Salt supported banks:* A majority of the banks are underlain by salt domes that push upward creating sea floor highs and providing habitat for reef forming organisms. The Flower Garden Banks and Stetson Bank are examples of these type of structures.

- *Hard-ground banks:* Some of the banks have formed on hard-grounds where the sea floor is locally sandier and provides a suitable substrate for reef growth. These hard ground banks are usually associated with slight bathymetric highs such as fault scarps on the seafloor. Baker, South Baker, and Hospital Banks are examples of these type of structures

Two classes of shelf bathymetric highs

Salt supported banks
Northwest Gulf of Mexico

Salt has many unusual properties that make it behave differently than the sand, silt, and clays that are deposited in the northern Gulf of Mexico. The two major properties are:

Density – At about 4,000' and deeper, salt becomes considerably less dense than the surrounding sediments and begins to become buoyant. This density contrast increases with depth and can cause large volumes of salt to move upward in zones of weakness in the overlying sediments.

Strength – Salt deforms in a plastic flow when put under pressure. Salt flows upward along faults and weak zones in the overlying sediments of the Gulf of Mexico. Near the surface, it becomes brittle and is able to rise up above the surrounding surface forming bathymetric highs or banks.

The importance of salt

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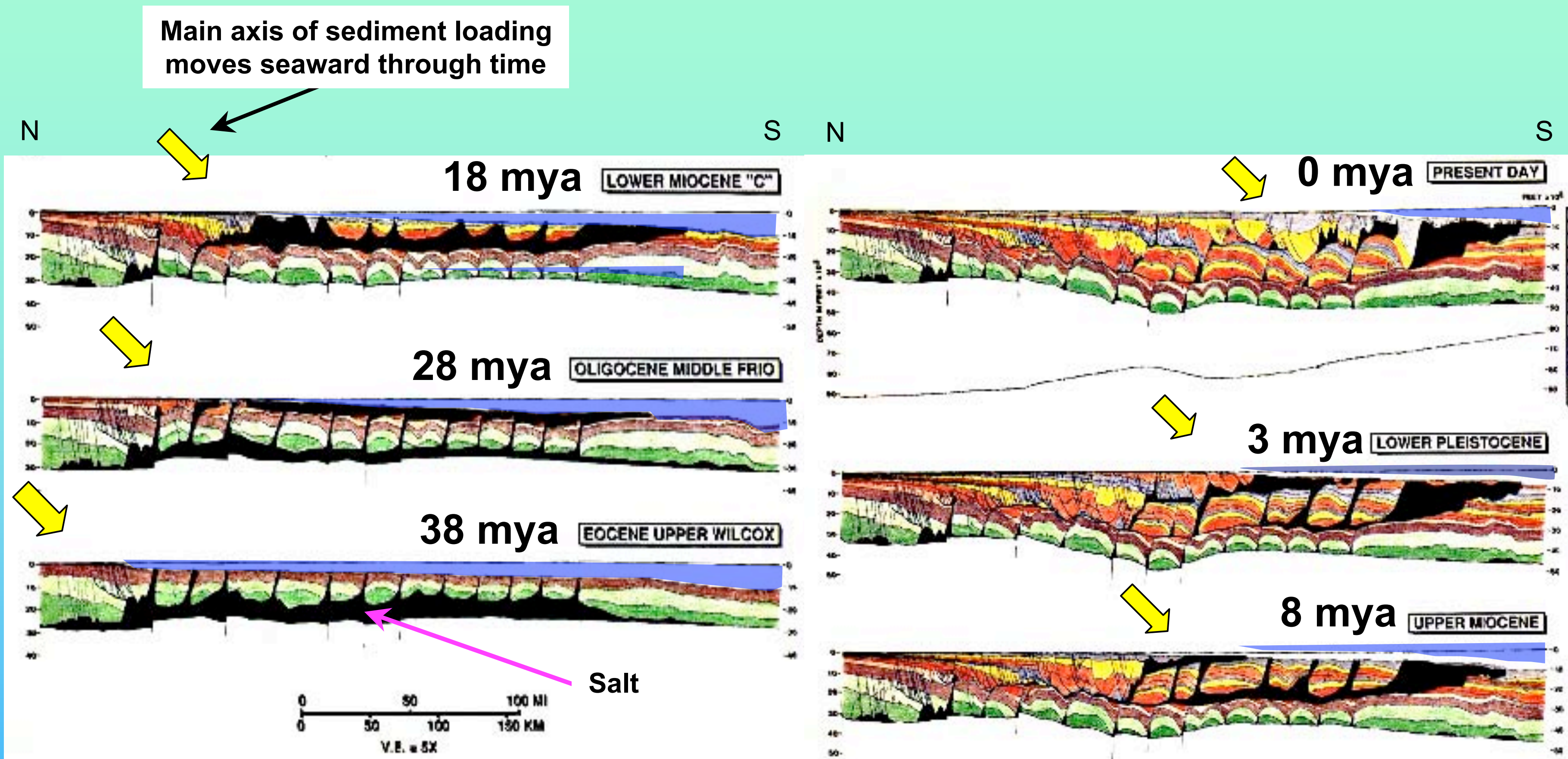
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



The salt is being "squeezed" upward and to the south by the heavier sands and shales being deposited on the shelf.

Salt - the "toothpaste" of the Gulf of Mexico

From Diegel et. al., 1995,
Salt Tectonics a Global Perspective
AAPG Memoir 65, p. 109-151

Bathymetry and subsurface analysis of East & West Flower Garden Banks Northwest Gulf of Mexico

Two major deltas dominated the western Gulf of Mexico shelf during the end of the last glacial period (late Wisconsin). The Brazos and the Trinity rivers merged and formed the Brazos - Trinity delta. This delta was smaller and occupied a position just to the west of the much larger late Pleistocene Mississippi delta.

The Mississippi river had migrated to a far western position at the end of the last glacial period and deposited a much larger delta that caused the shelf break to bulge out over the continental slope. The great weight of the sediments deposited by these deltas started a new period of salt movement (tectonics) in this area, causing salt domes to move upward in response to the loading from the sediments

The Flower Gardens are located in deeper water near the shelf edge. A closer look at the ocean bottom can reveal several key factors in their formation.

Northwest Gulf of Mexico shelf and slope setting

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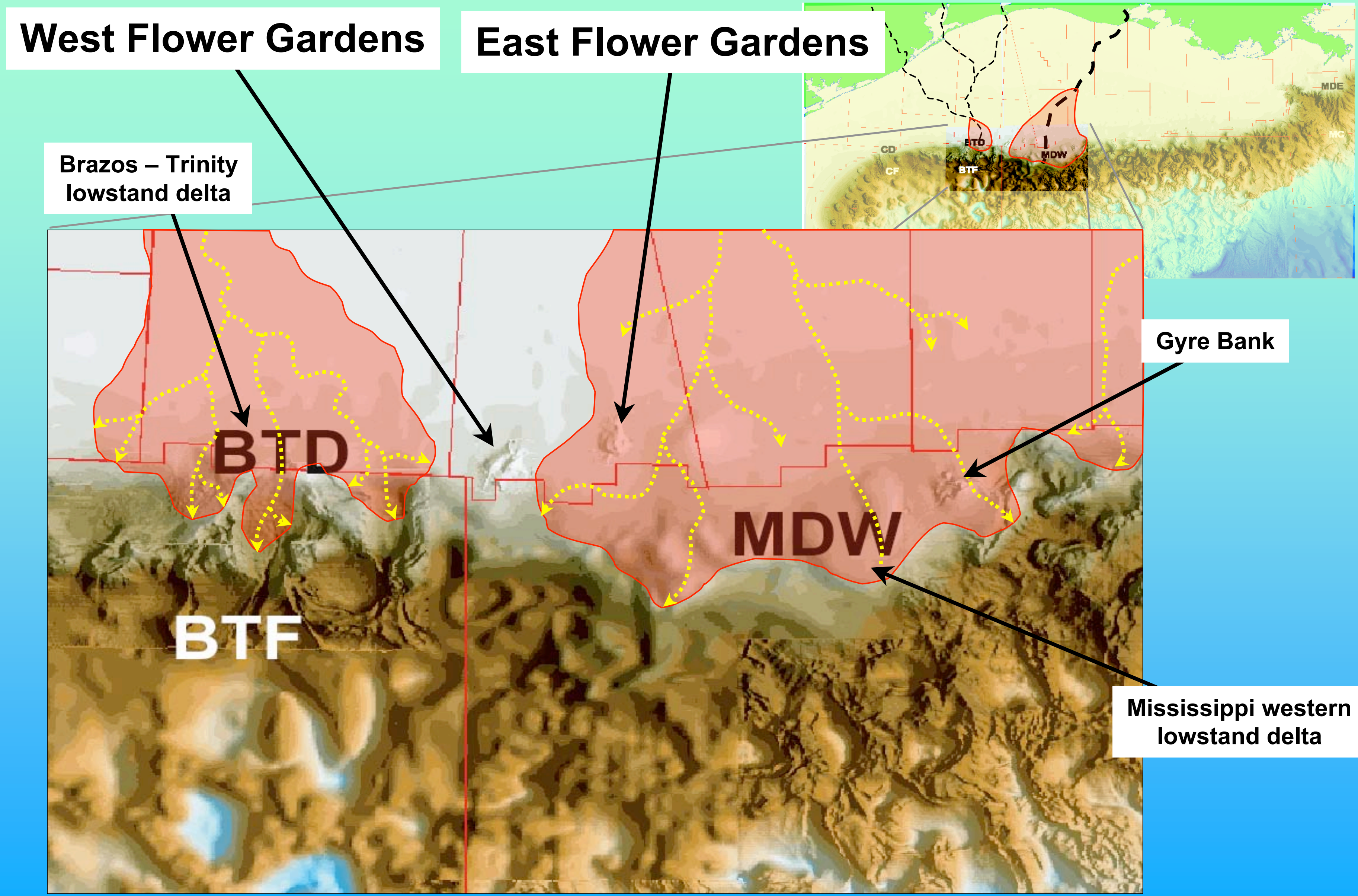
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



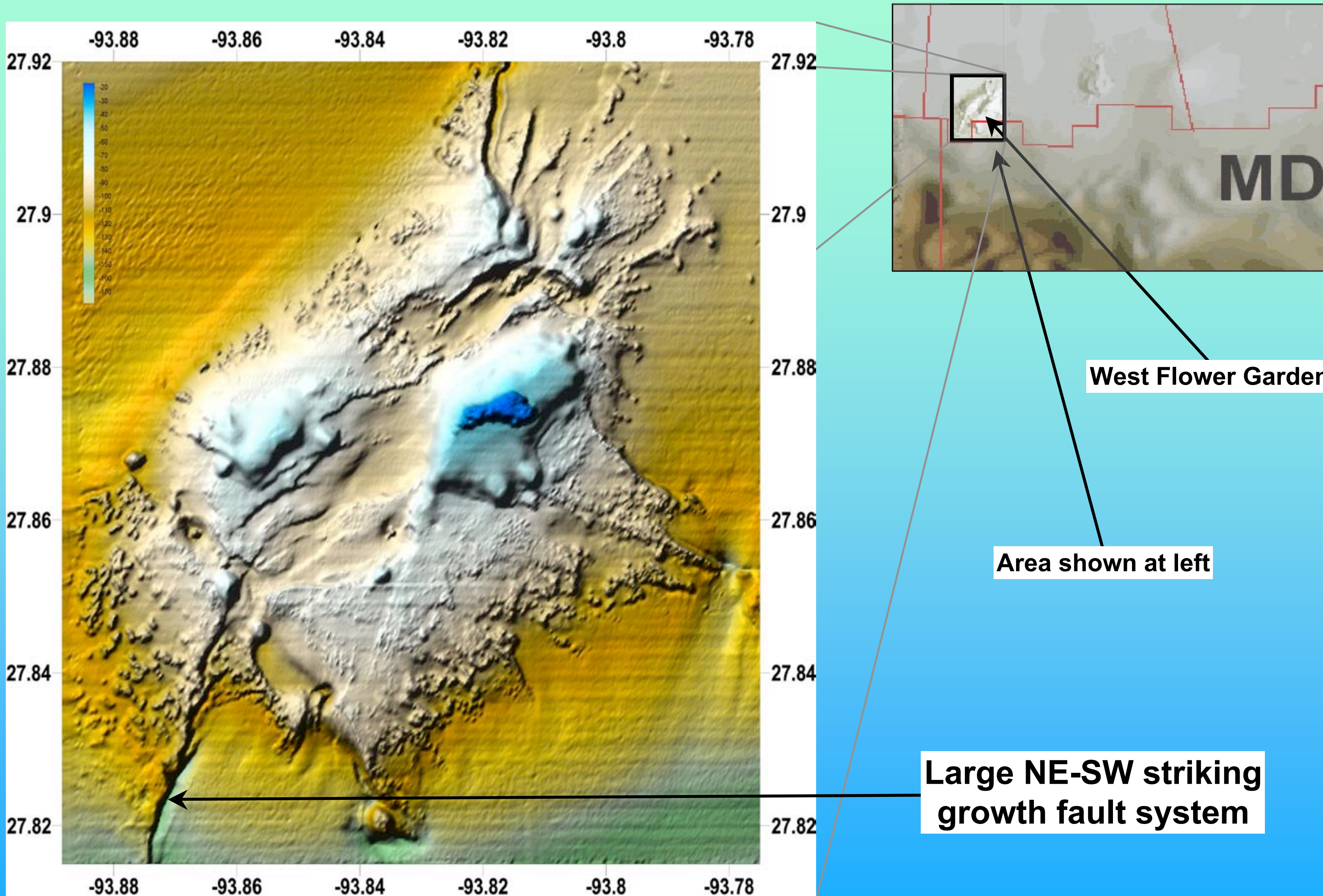
Flower Gardens setting

After Winker et. al., 2000

The Flower Gardens are located in an unique setting. They are in deeper water (540’) but their crests rise to a depth of 60’. This depth difference means that at the height of the last Wisconsin glaciation, the dome flanks were still submerged. The rising sea level flooded the exposed shelf with a huge weight of water and initiated a new period of upwelling in the salt. The dome grew, following the rising sea level upward. The rising dome kept the corals that have colonized the crest in the photic zone.

In addition, the deeper water provides a more reliable pool of warm water to sustain the true corals throughout the winter. This has led to the formation of the reefs of true corals on the crests of these domes.

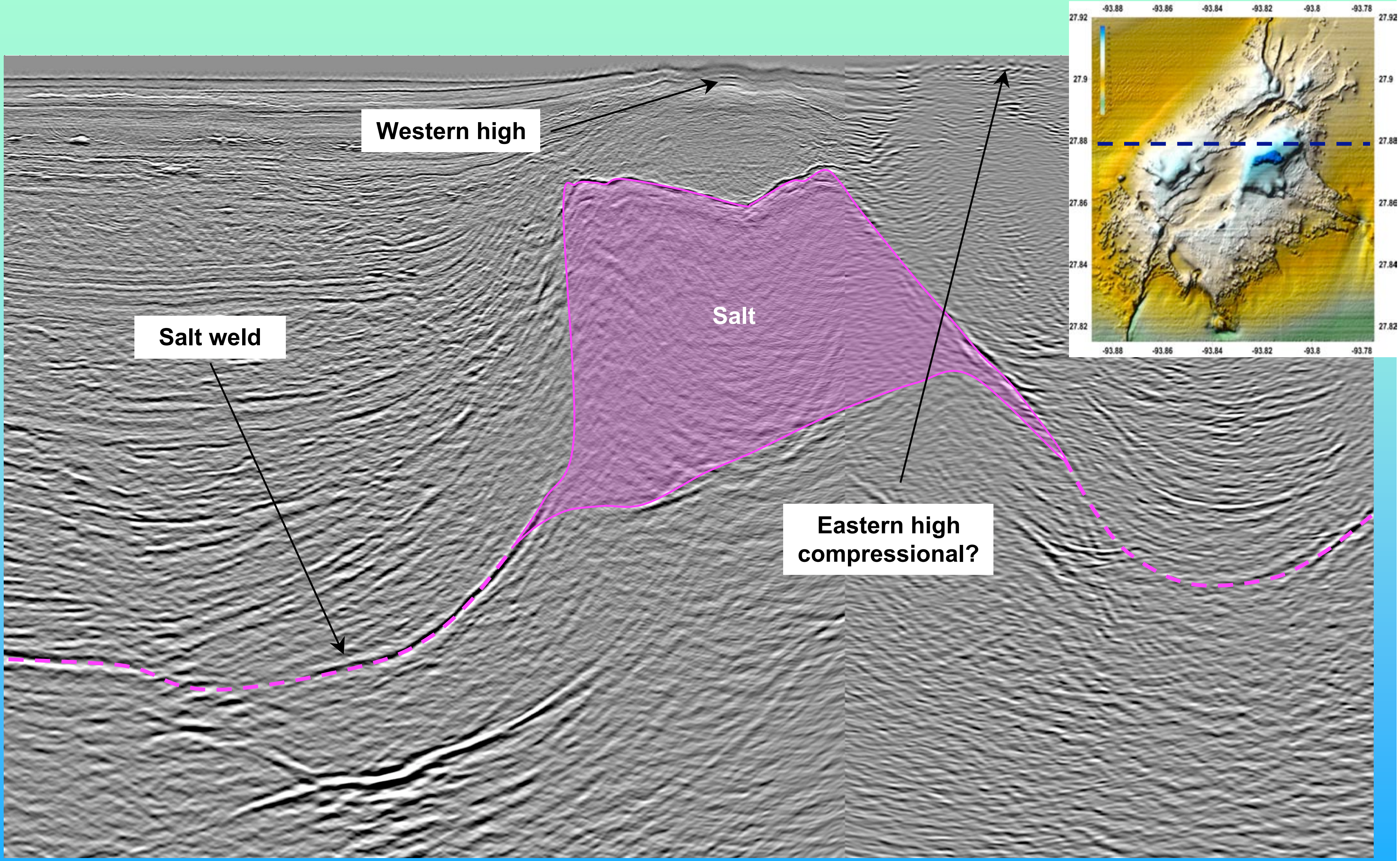
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Shaded relief image of West Flower Garden from NOAA multibeam bathymetry

Data from NOAA & USGS visualized by D. Weaver

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



W E

East – West seismic line through West Flower Garden
North of coral cap

Data courtesy of WesternGeco
Interpreted by M. Betts

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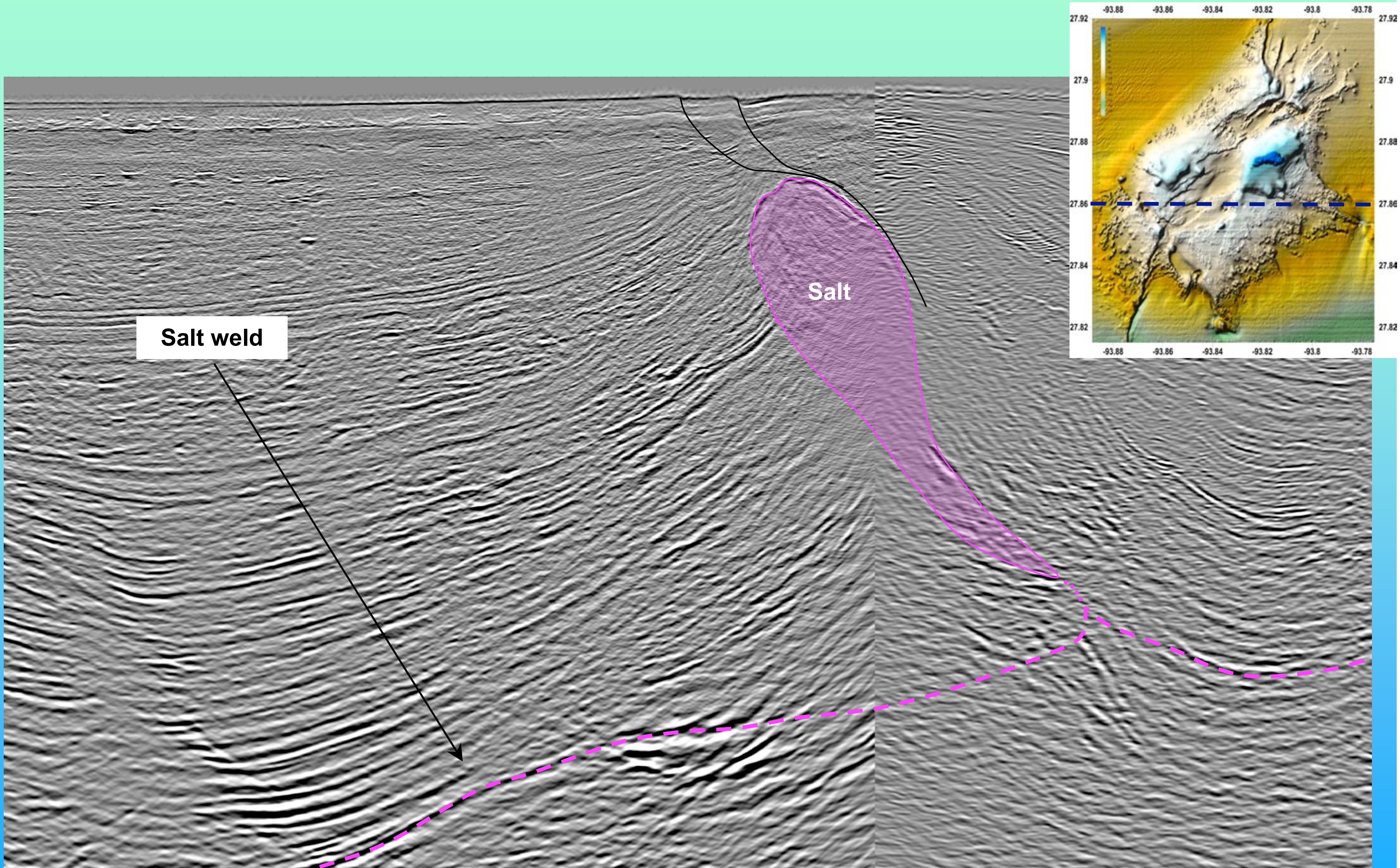
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



East – West seismic line through West Flower Garden
South of coral cap

Data courtesy of WesternGeco
Interpreted by M. Betts

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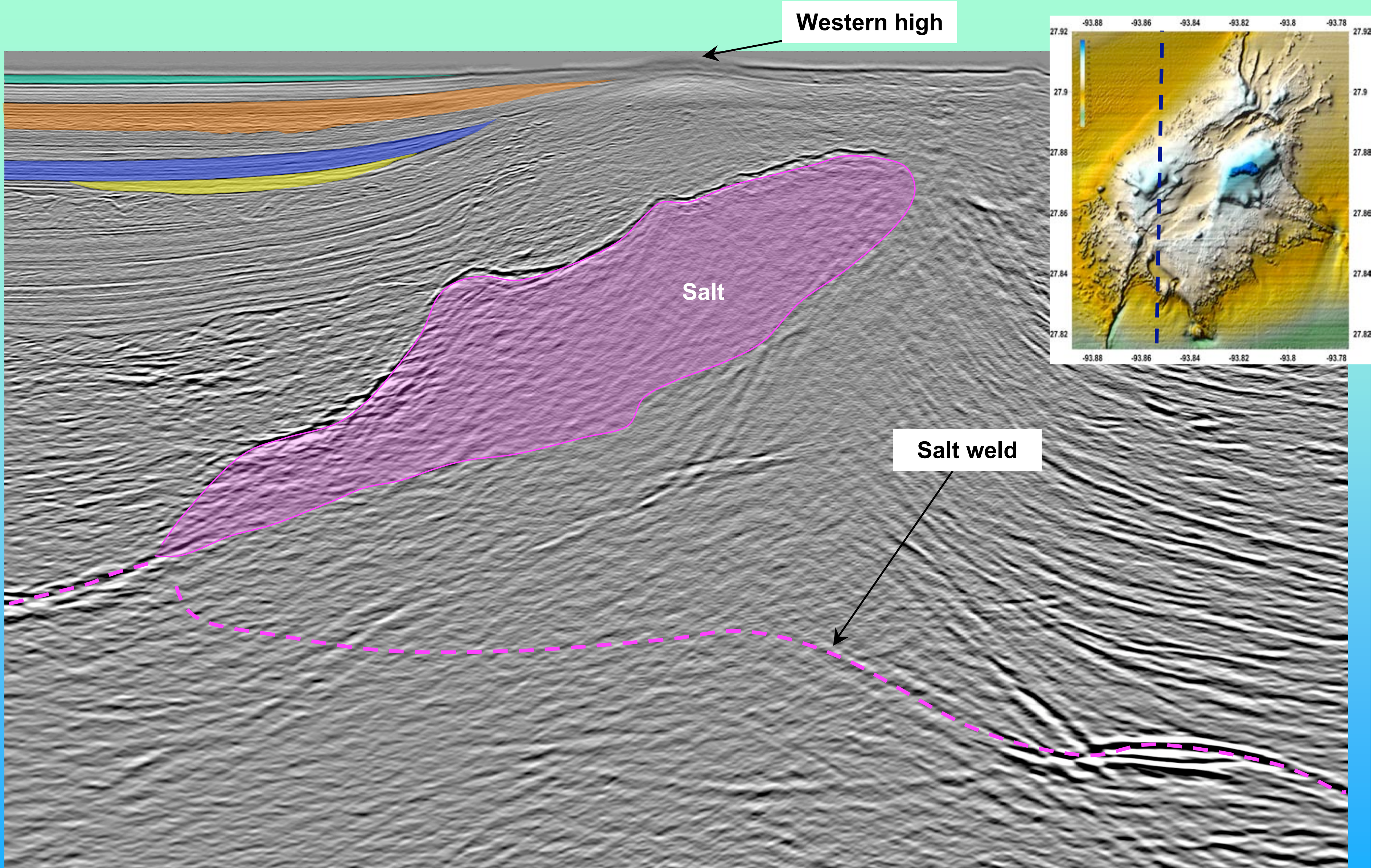
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

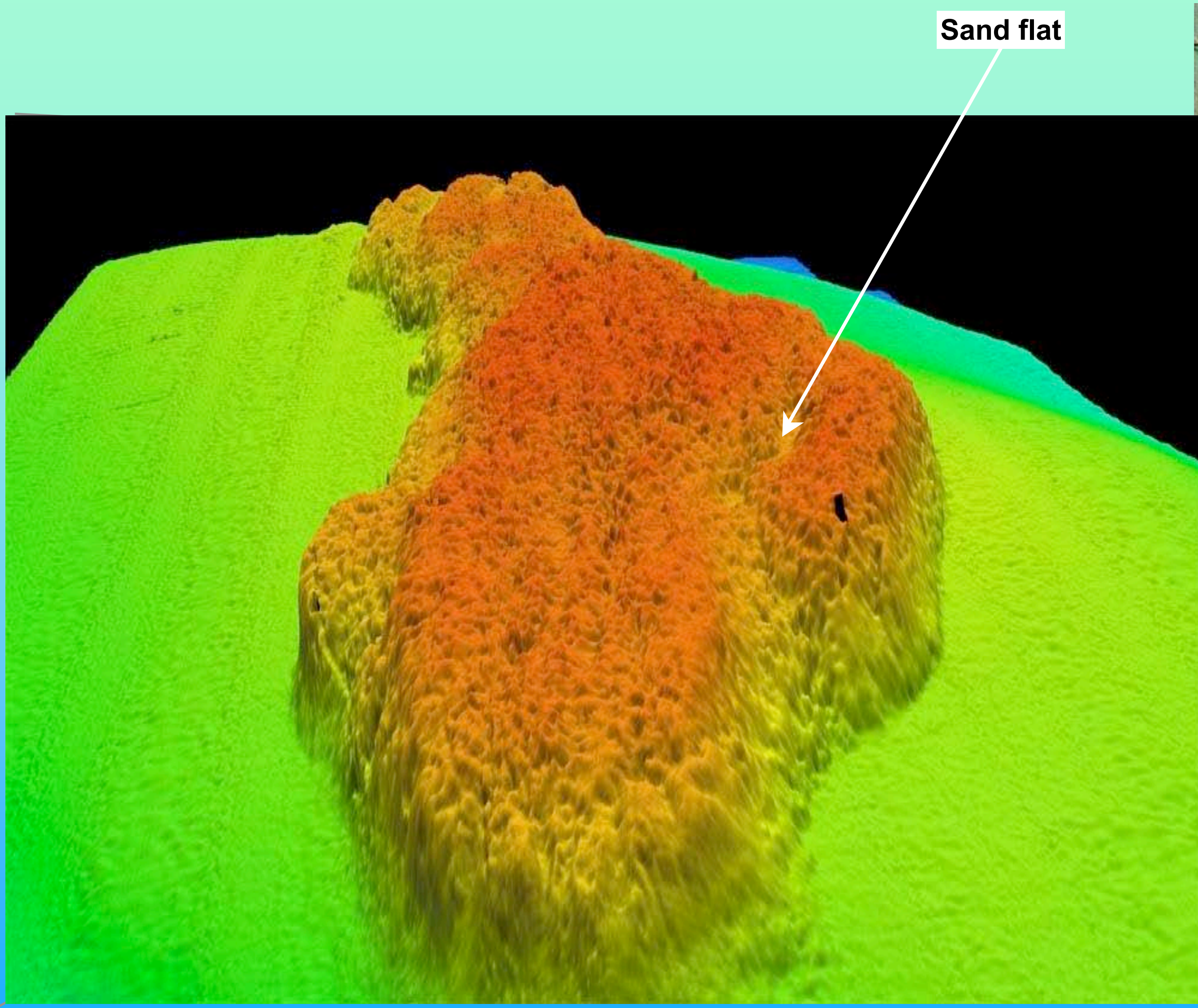


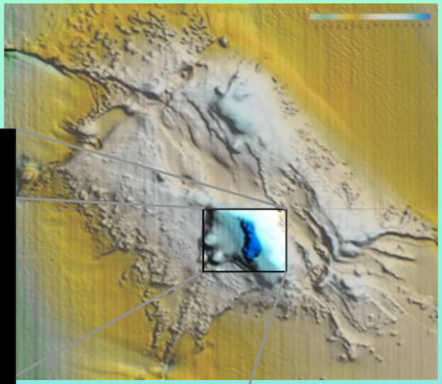
N

North – South seismic line through West Flower Garden
West of coral cap

S

Data courtesy of WesternGeco
Interpreted by M. Betts





Close – up of shaded relief image of West Flower Garden view to the west

Data from NOAA & USGS visualized by D. Weaver

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Queen triggerfish on West Flower Garden with sand flat in the background

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Yellow head jaw fish on West Flower Garden sand flat

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Sand is local, derived from the coral via bio erosion

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Typical coral assemblage on West Flower Garden Bank

Mark Betts, 2005

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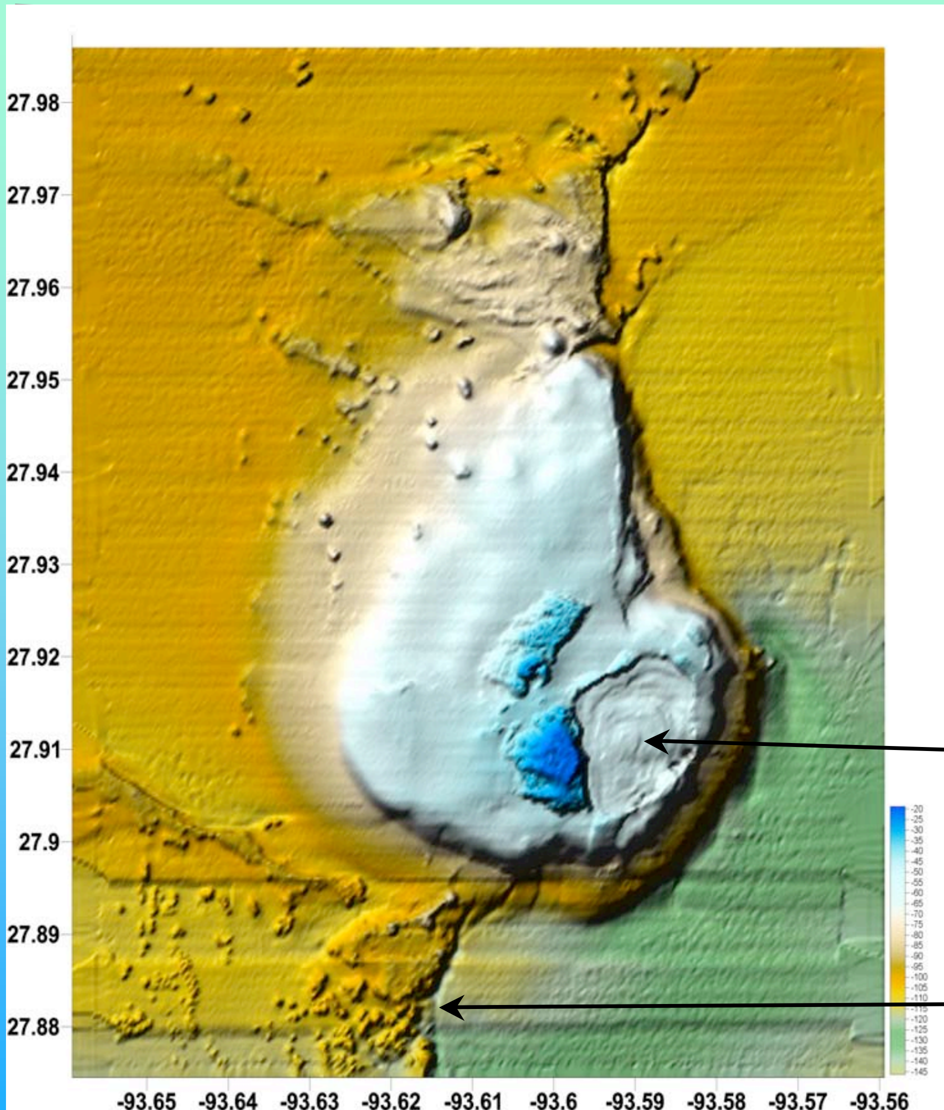
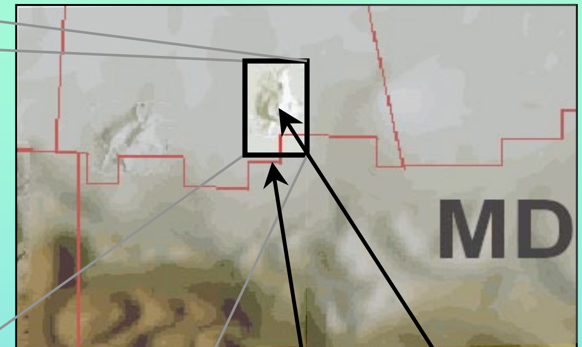
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico





East Flower Garden

Area shown at left

Salt dissolution collapse feature

Large N-S striking growth fault system

Shaded relief image of East Flower Garden from NOAA multibeam bathymetry

Data from NOAA & USGS visualized by D. Weaver

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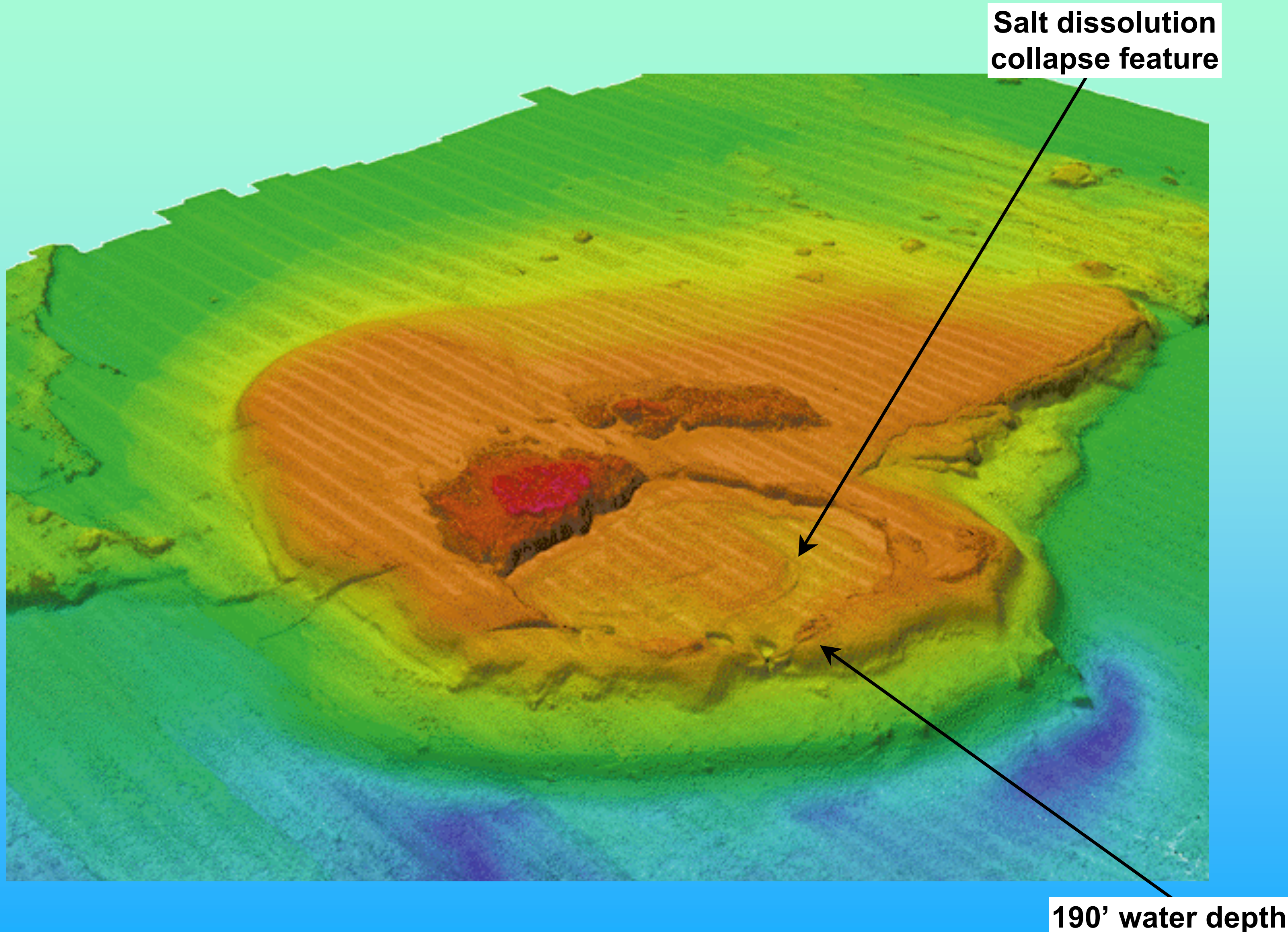
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



3D perspective image of East Flower Garden from NOAA multibeam bathymetry

Data from NOAA & USGS visualized by D. Weaver

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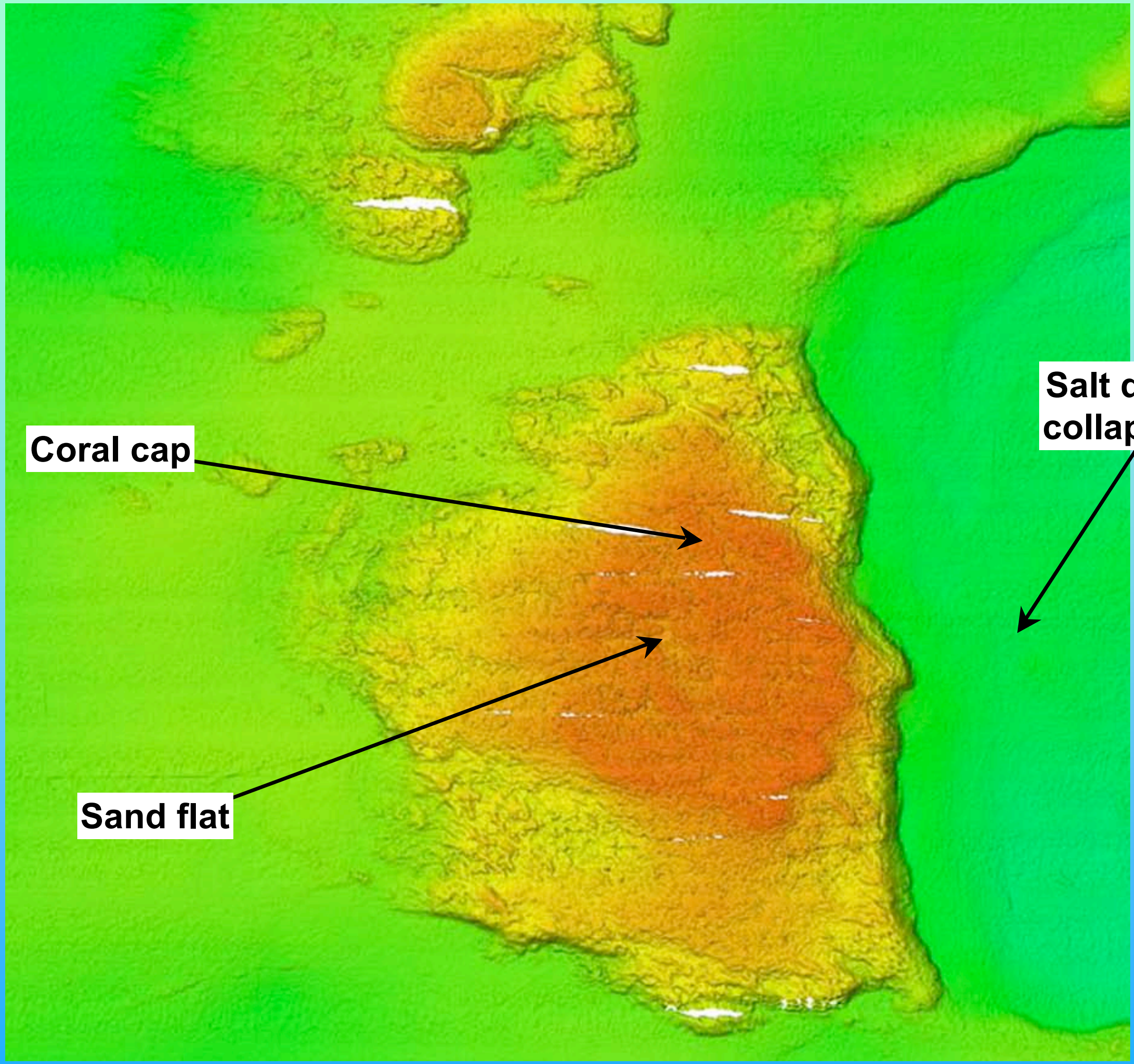
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Close – up of shaded relief image of East Flower Garden

Data from NOAA & USGS visualized by D. Weaver

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Ian McDonald at East Flower Garden Bank

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Brain coral on East Flower Garden Bank showing intense bio-erosion

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Brain coral on East Flower Garden Bank showing intense bio-erosion

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

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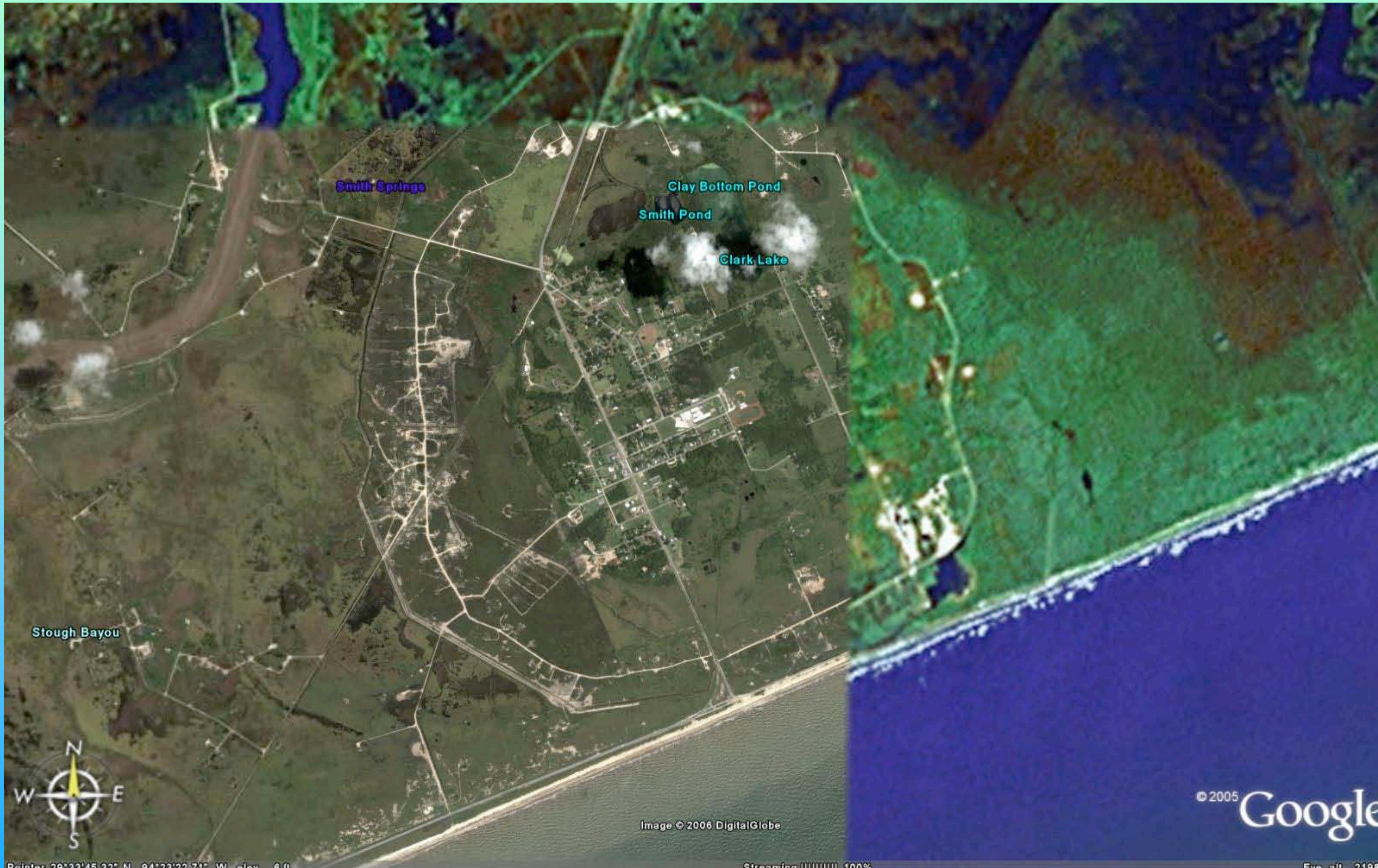
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Mark Betts, 2005

Flower Garden Banks low stand paleogeomorphology

- **Central question: What did the Flower Garden Banks look like during the last low-stand?**
  - **Edwards 1971 dissertation shows a high relief structure surrounded by a lagoon**
  - **The Banks currently have approximately 340' of relief**
  - **Modern sub-aerially exposed domes show a maximum relief of approximately 100' (Iran) and approximately 75' along the Gulf Coast**
  - **The low relief is due to susceptibility to weathering**
  - **East & West Flower Garden Banks also probably had 75' of relief during low-stand**
- **Conclusion: The Flower Garden salt stocks have undergone sudden, post low-stand, growth periods in response to loading from shelf edge delta loading and rapid sea level rise**

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



High Island salt dome on NE Texas coast
40' of relief

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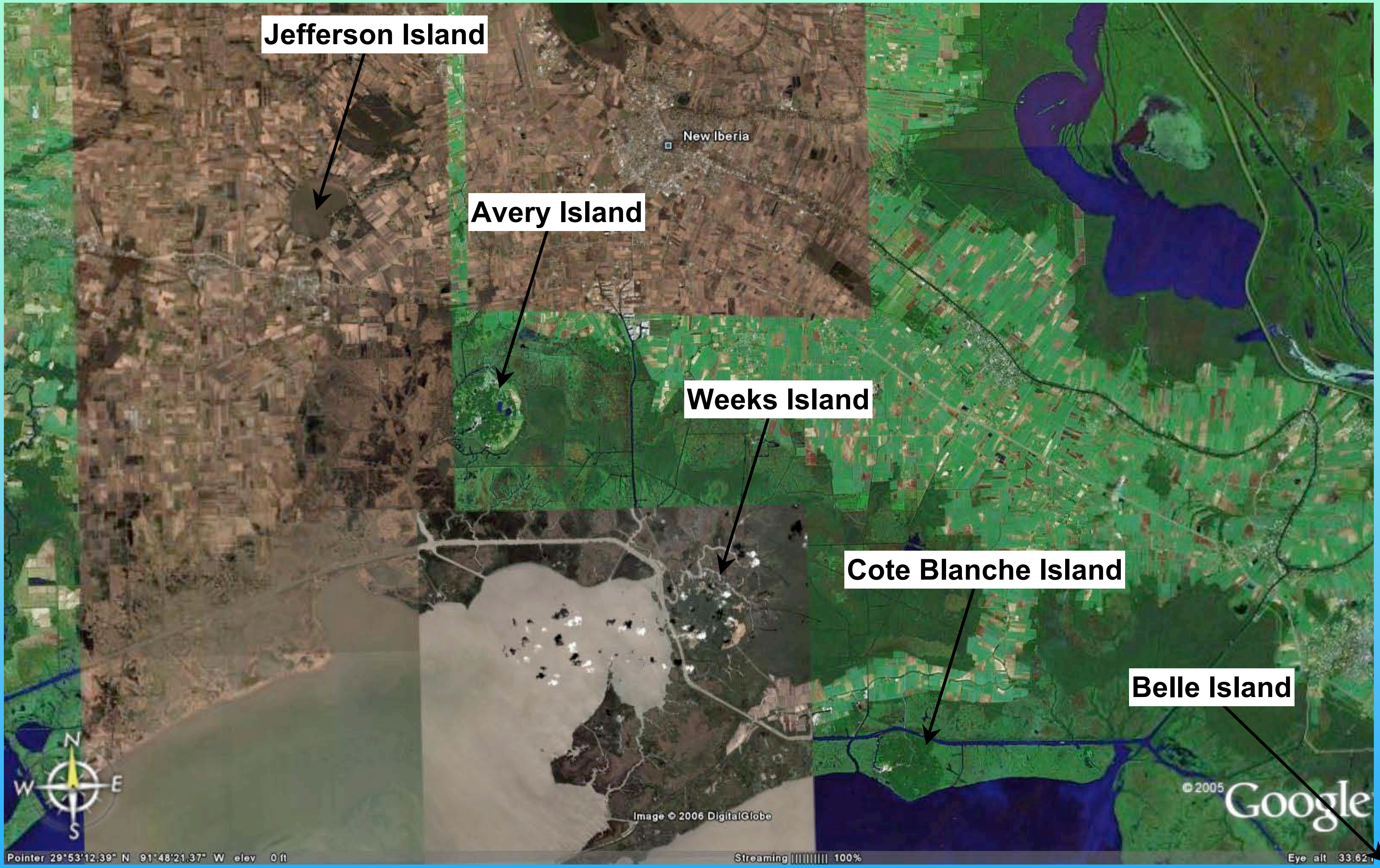
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Five Island salt dome trend on Central Louisiana coast
50' of maximum relief

Bathymetry and subsurface analysis of Stetson Bank

Stetson Bank is located well landward of the Continental shelf – slope break within the Gulf of Mexico continental shelf. It is surrounded by a relatively flat and featureless ocean bottom that was modified by wave action that has obliterated all but the most recent seafloor processes.

Stetson Bank setting

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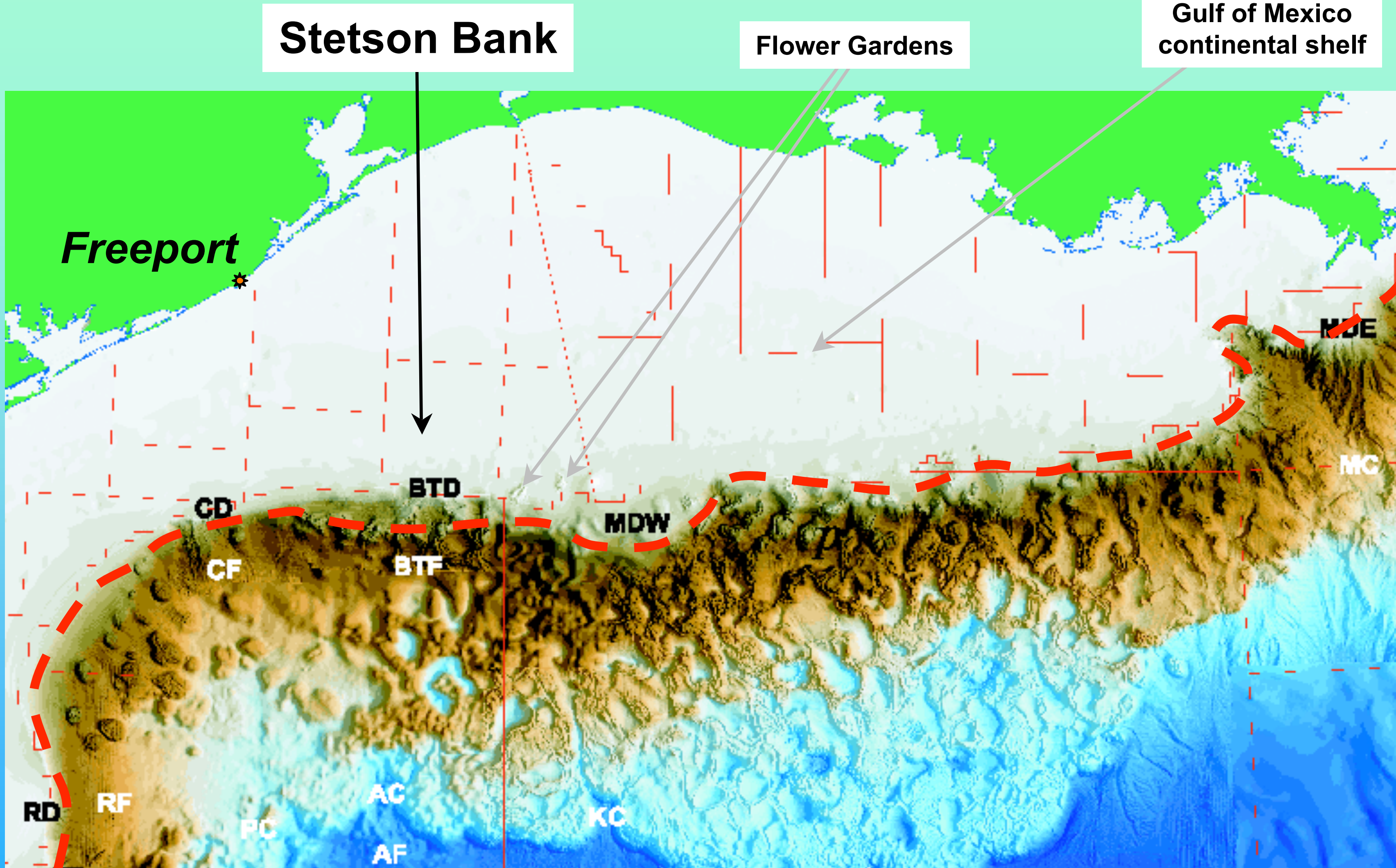
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Stetson Bank physiographic setting

From Winker & Booth
GCSSEPM 2000

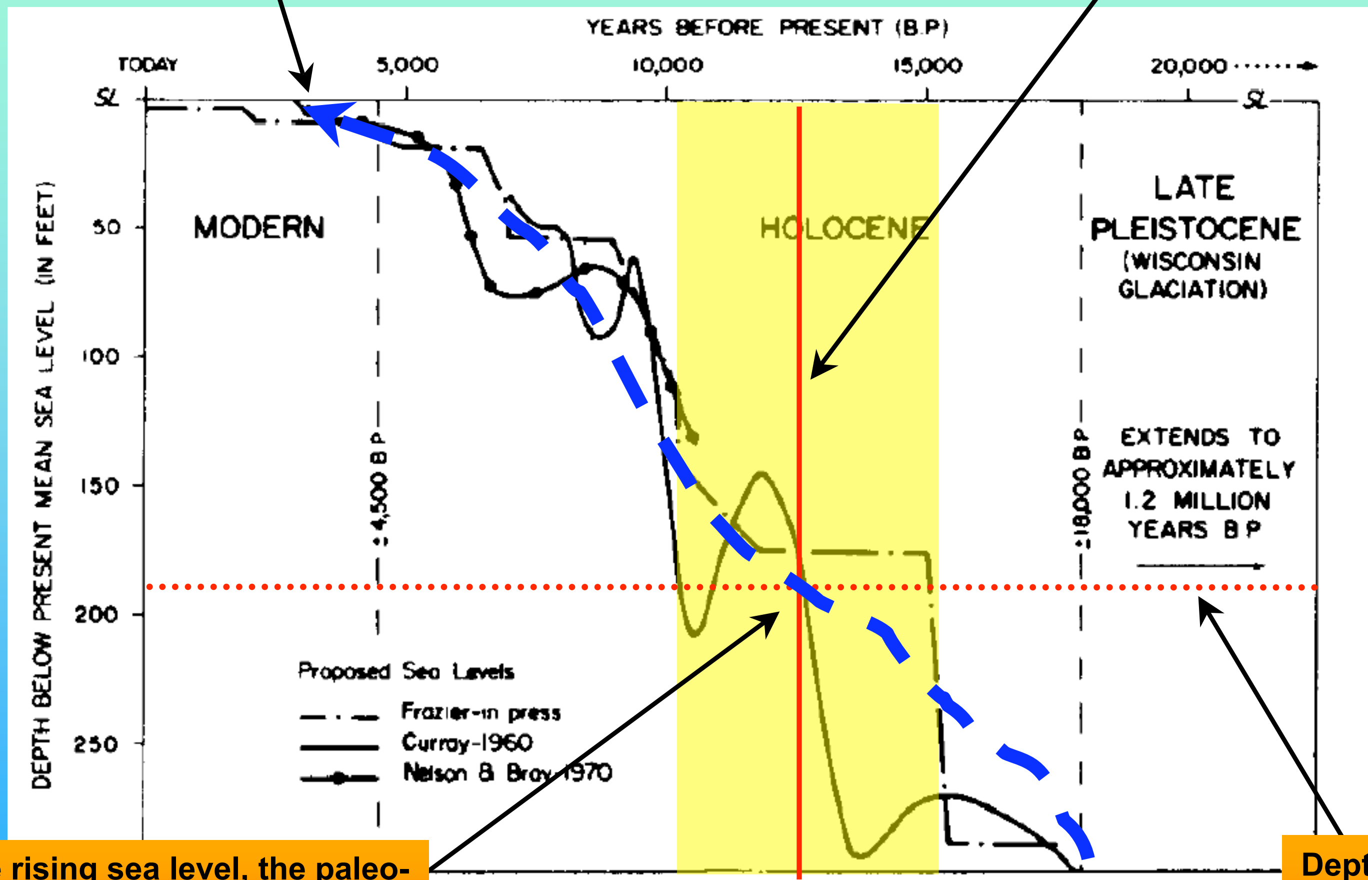
Stetson Bank has been highly modified by wave action as the sea level rose over the past 20,000 years. At one point (~12,500 years ago), the old coastline was located at Stetson Bank. The erosive action of waves flattened any pre-existing topography in this area.

The next several slides show estimates of the timing for these processes and shows when and how the Bank formed.

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Rising sea level after last glaciation (average of estimates)

Stetson Bank is probably younger than this (12,500 BP) because wave action at the coast flattened any pre-existing topography to a smooth, flat ocean bottom



Following the rising sea level, the paleo-coastline was moving inland over Stetson Bank during this time period

Depth of flat ocean bottom surrounding Stetson Bank

Sea level curves for the past 20,000 years

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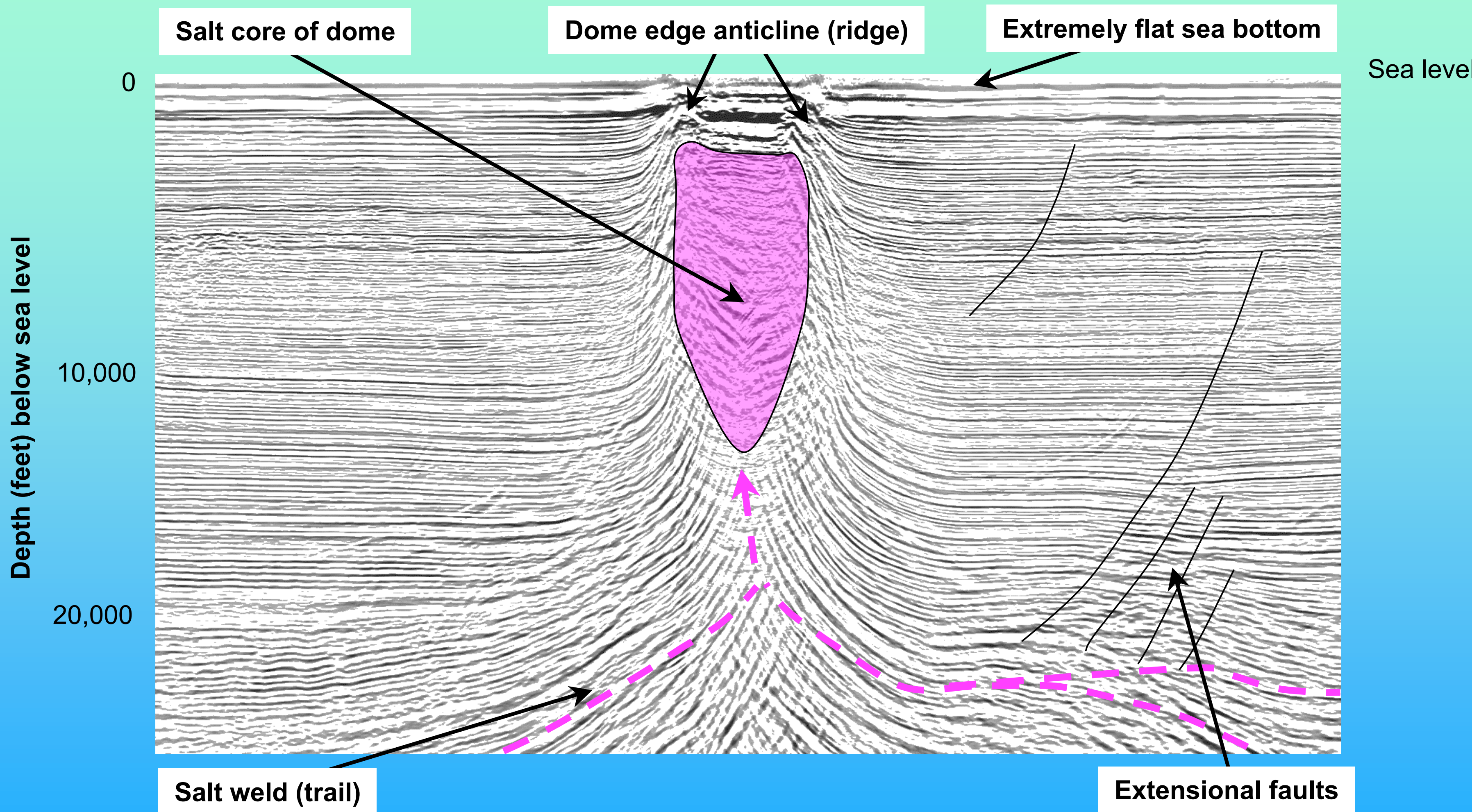
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Typical seismic line through a Galveston Area salt dome

Data courtesy TGS Nopec interpreted by M. Betts

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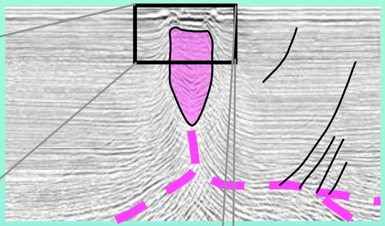
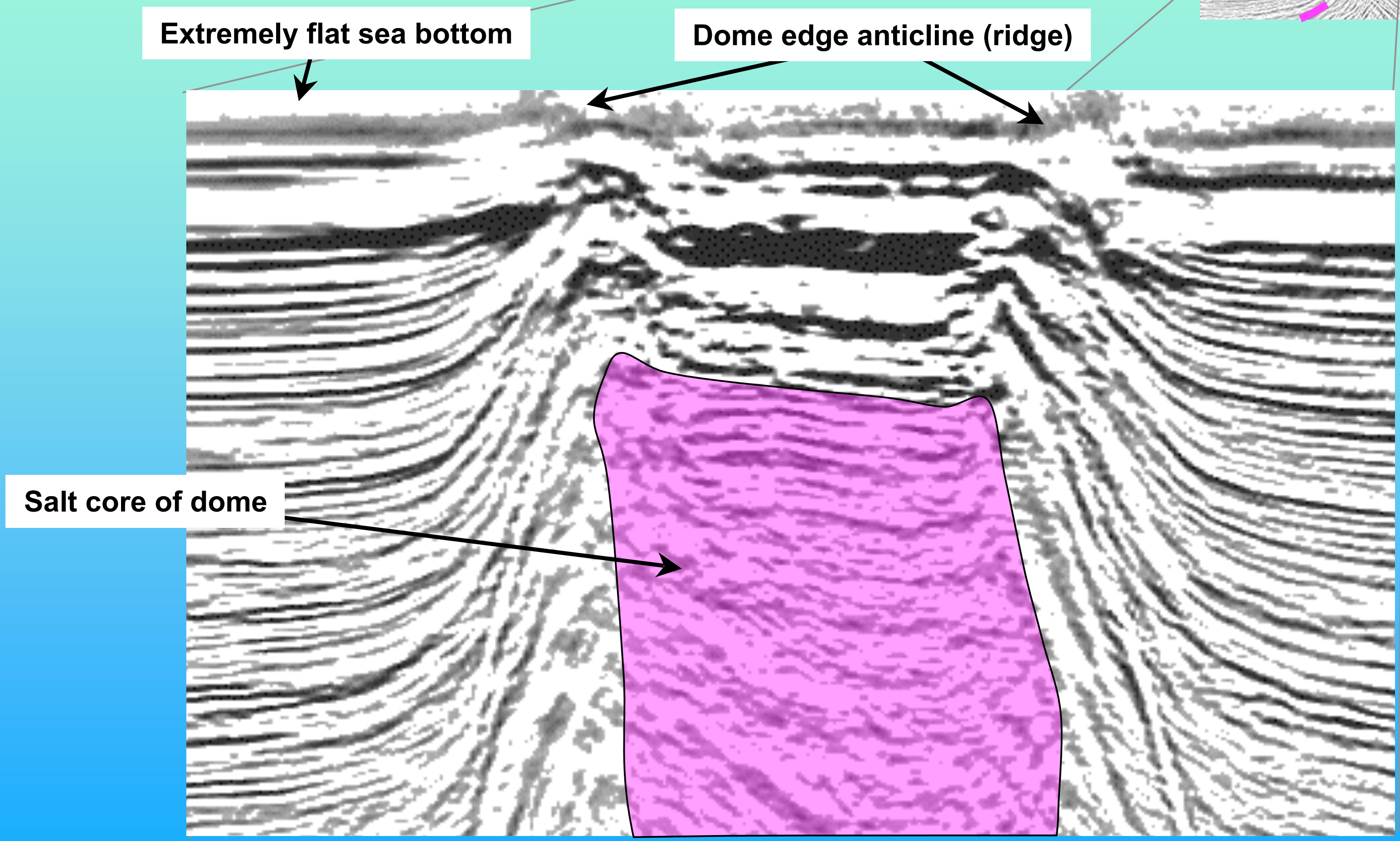
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico





Close up of typical seismic line through a Galveston Area salt dome

Data courtesy TGS Nopec interpreted by M. Betts

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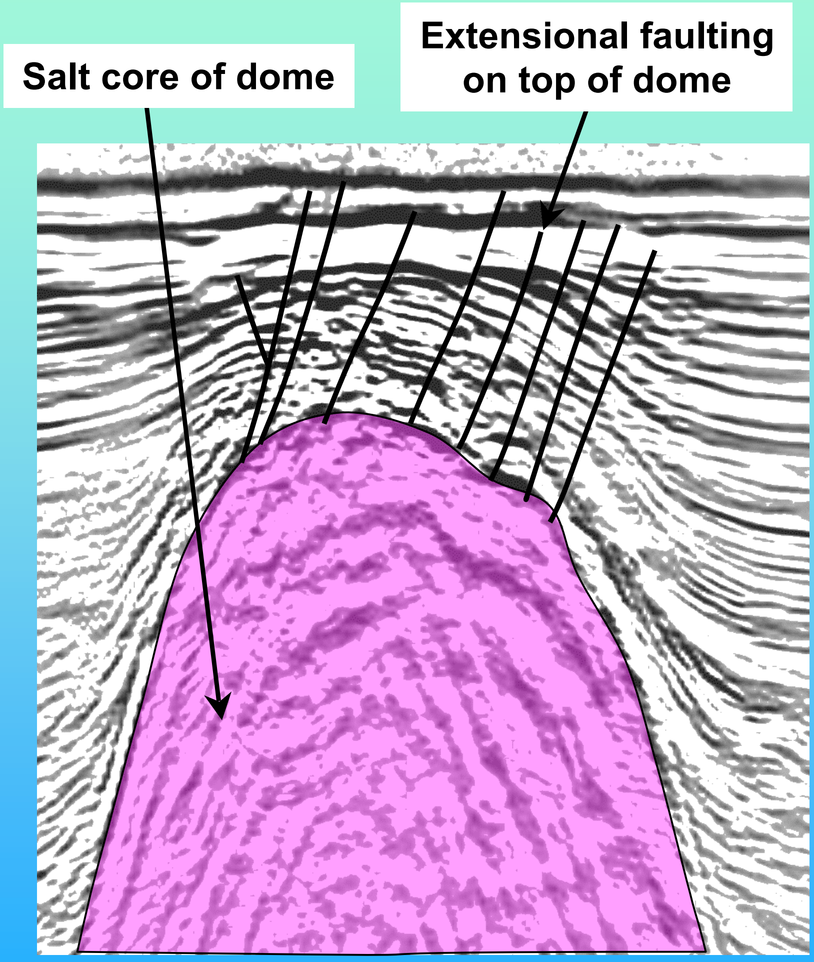
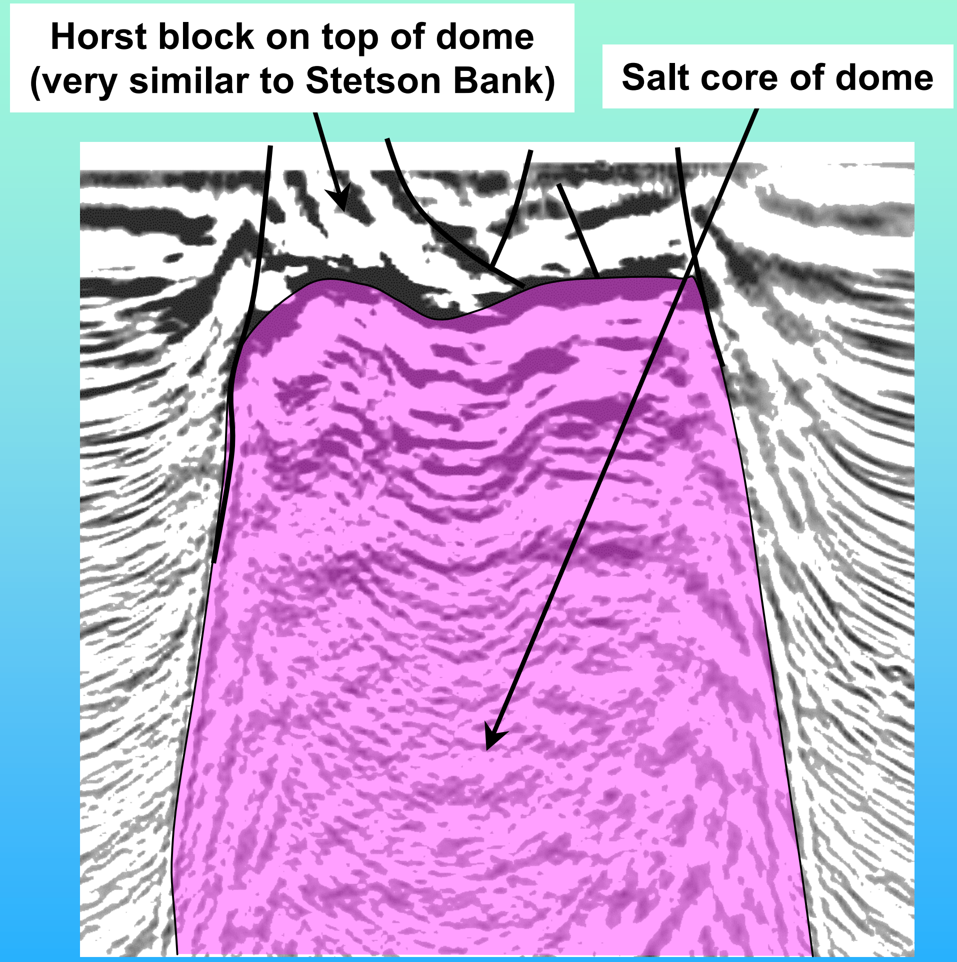
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico





Lines showing faulting and horst blocks on a typical Galveston Area salt dome

Data courtesy TGS Nopec interpreted by M. Betts

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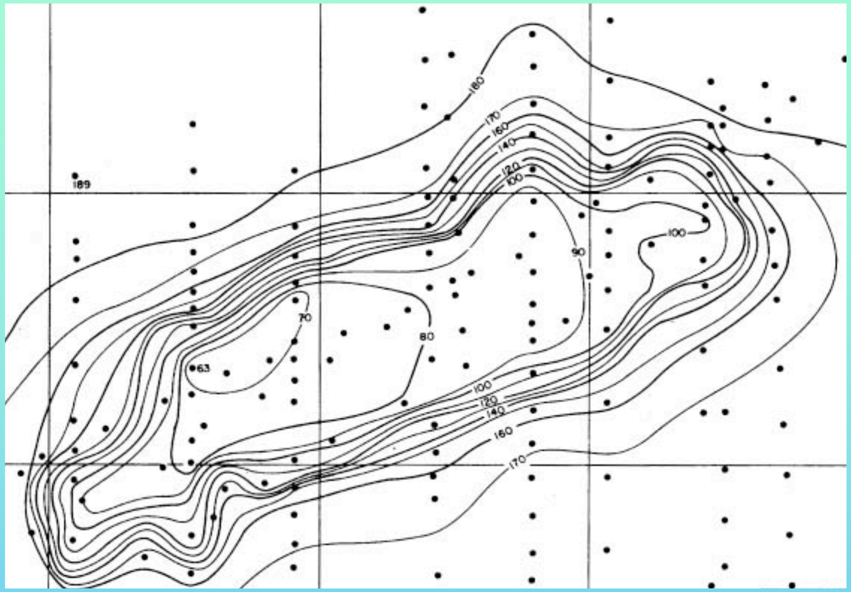
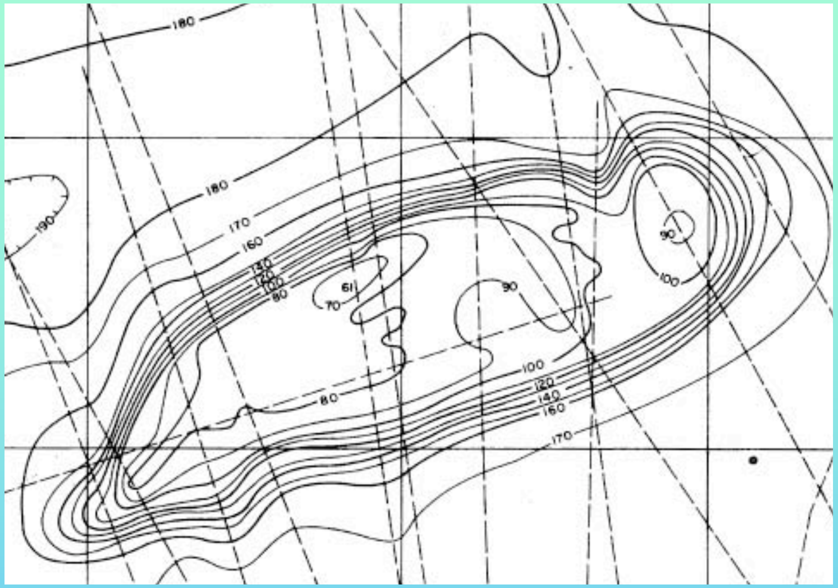
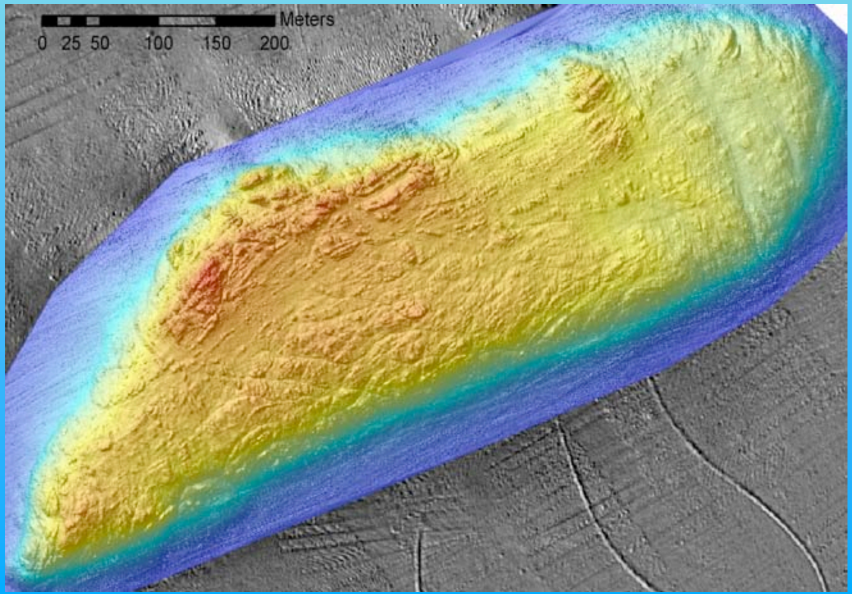
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico







Upper maps – point soundings and fathometer profiles of Stetson Bank   Conrad,1957, MS thesis, TAMU

Lower map – high resolution multibeam bathymetry of Stetson Bank D. Weaver NOAA data unpublished

Bathymetry of Stetson Bank

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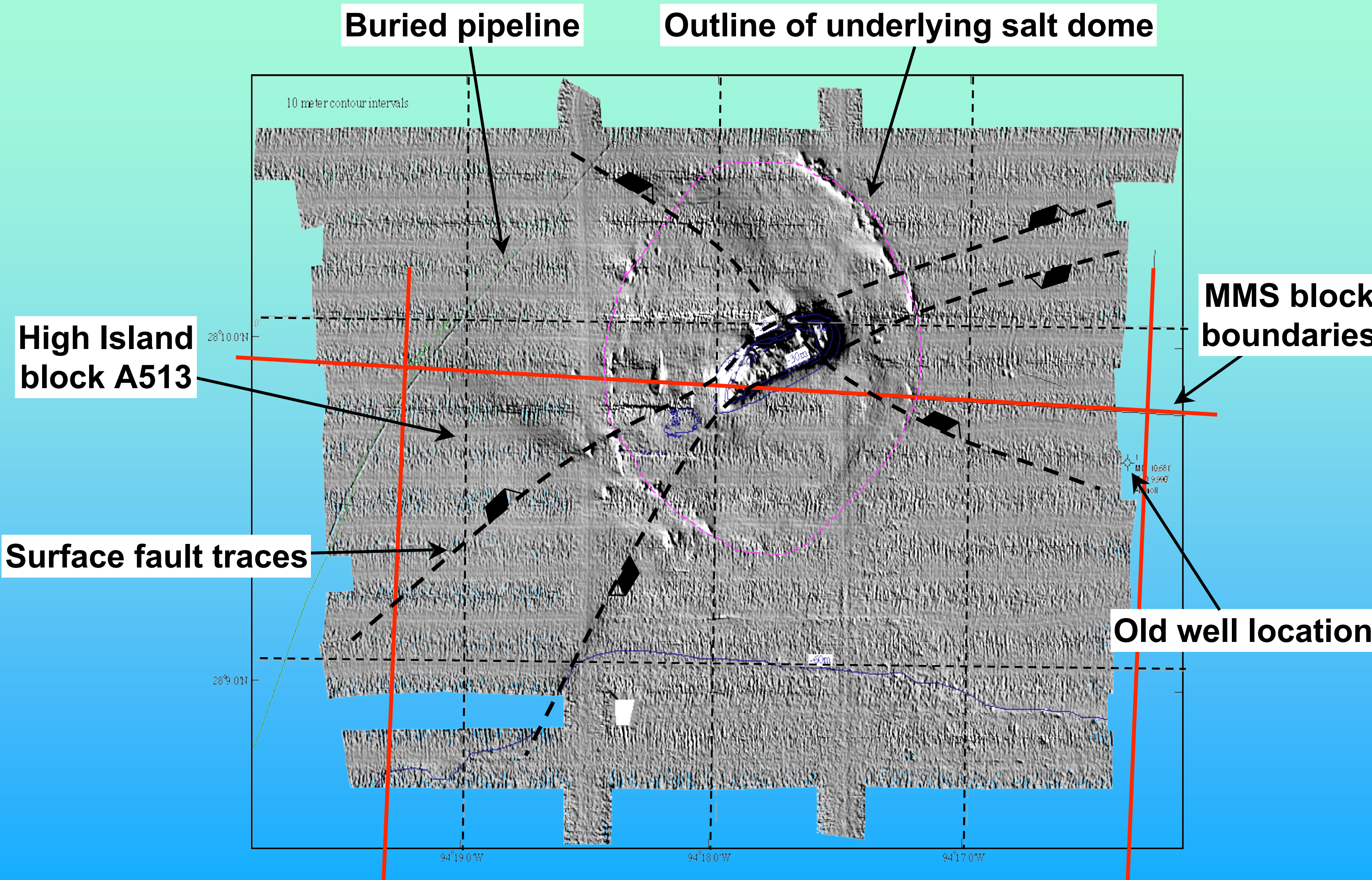

Shaded relief image of Stetson Bank from NOAA multibeam bathymetry

Data from USGS open file report 02-411, Gardner et al

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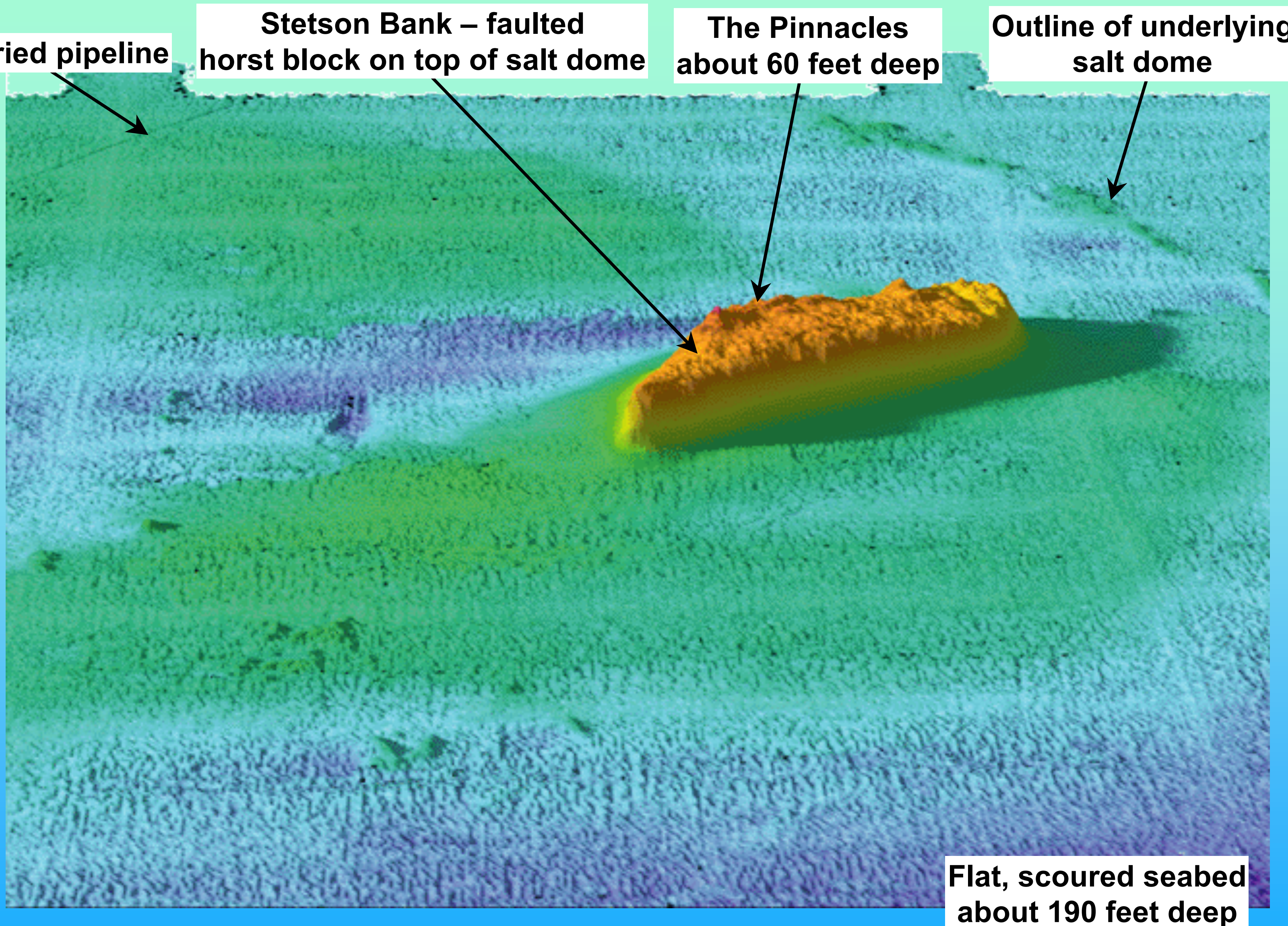
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



3D perspective image of Stetson Bank from NOAA multibeam bathymetry

Data from USGS open file report 02-411, Gardner et al

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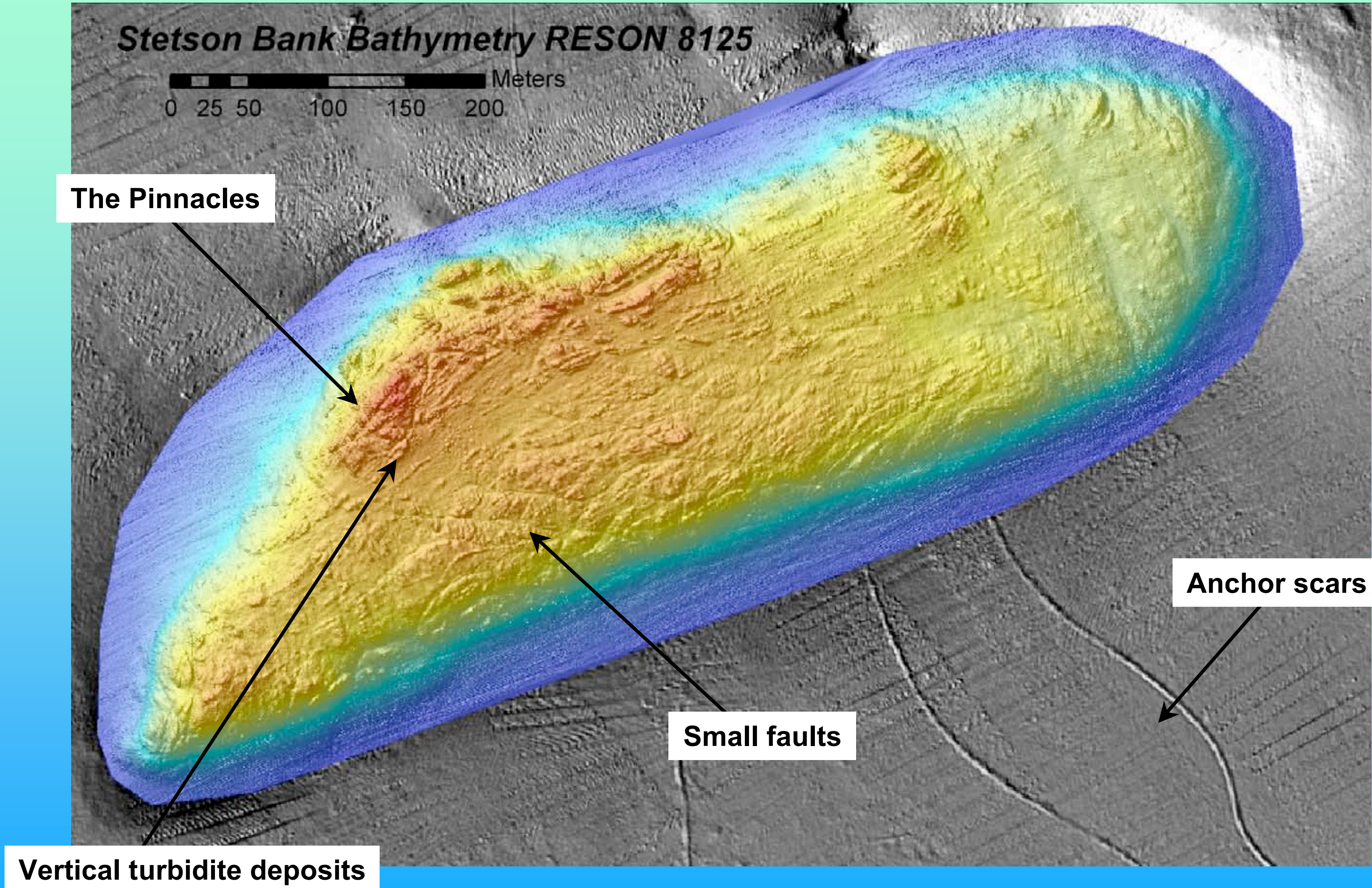
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



High resolution multibeam bathymetry of Stetson Bank

D. Weaver, NOAA data, unpublished – used by permission

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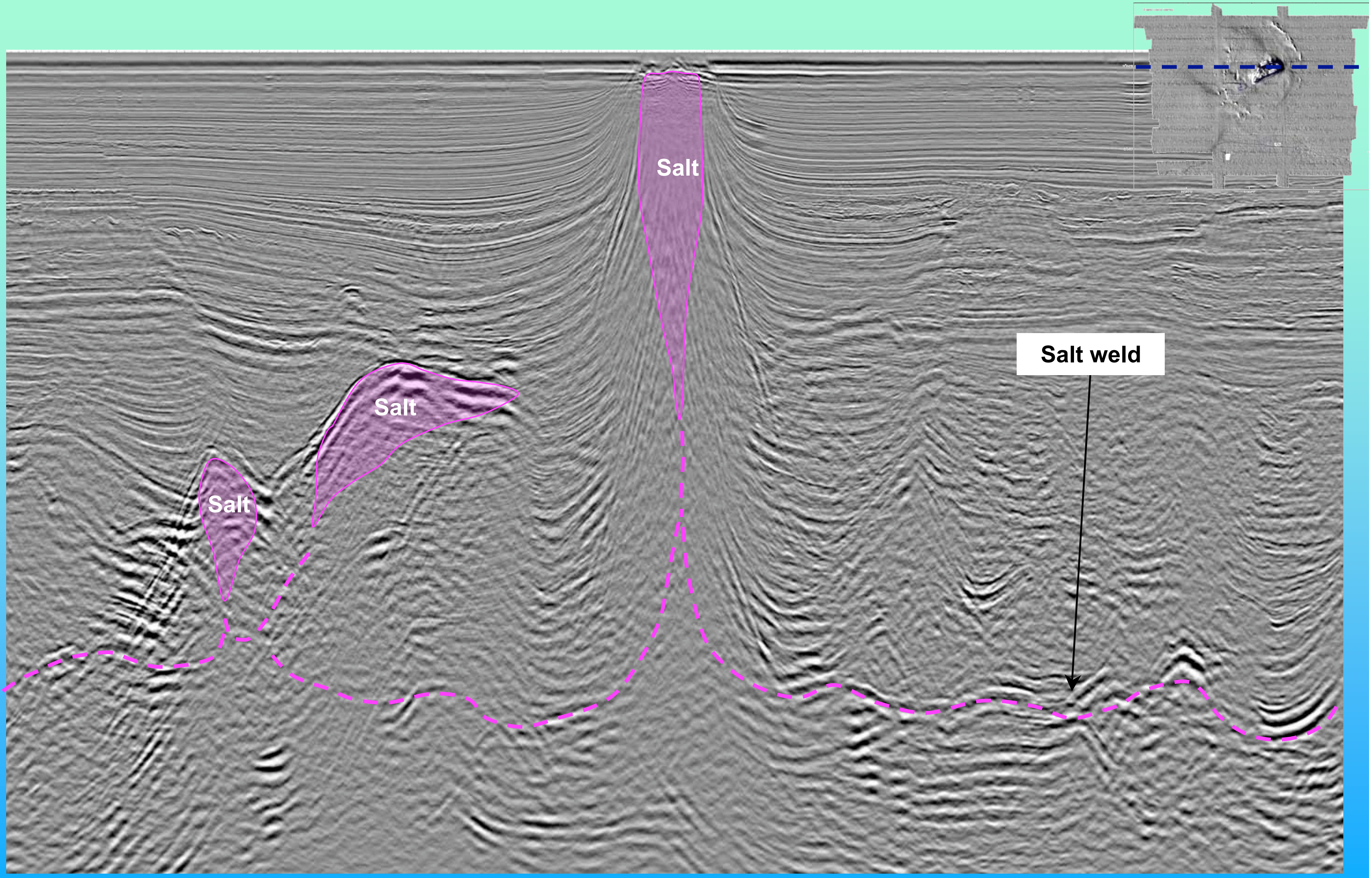
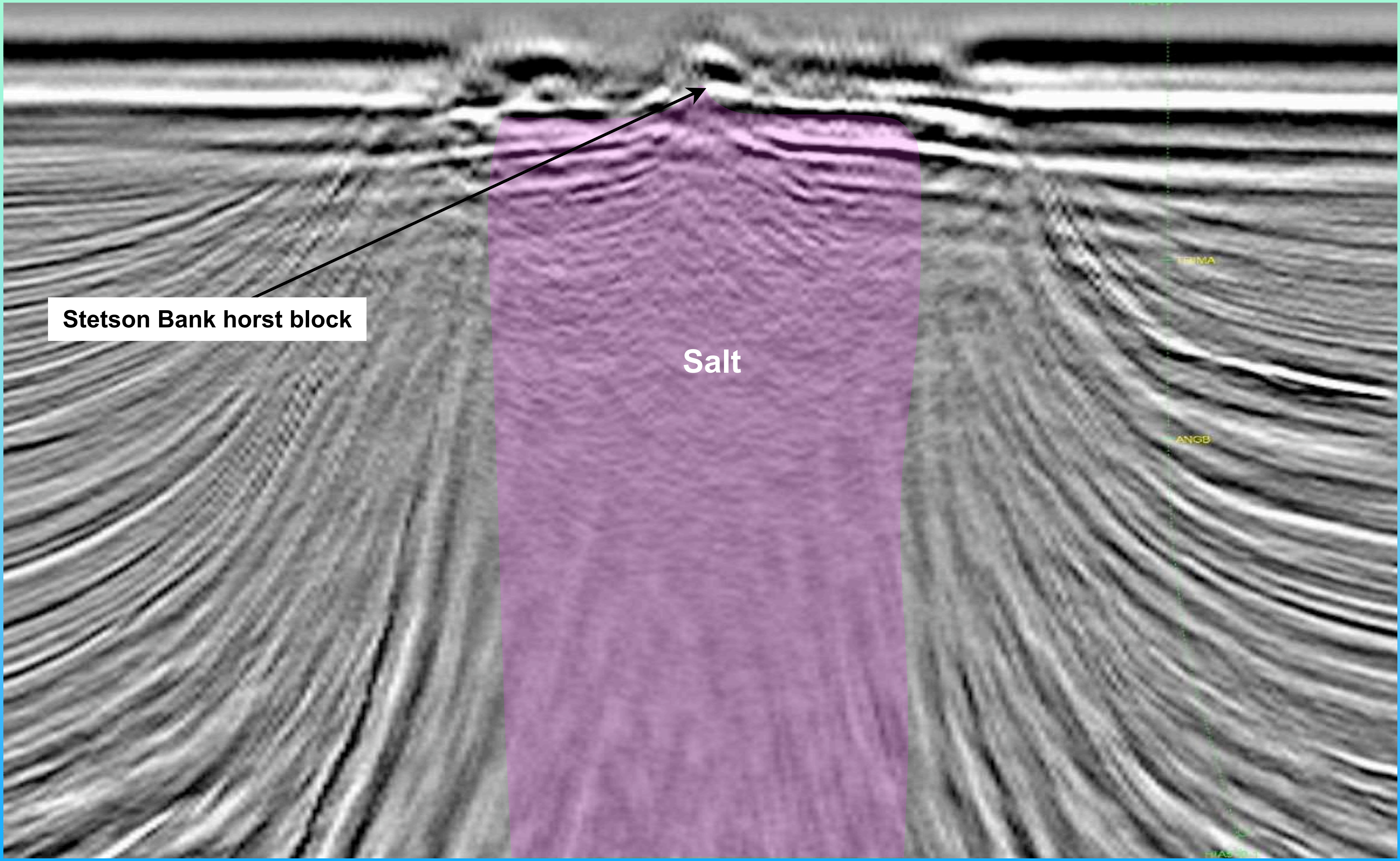
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Data courtesy of WesternGeco
Interpreted by M. Betts

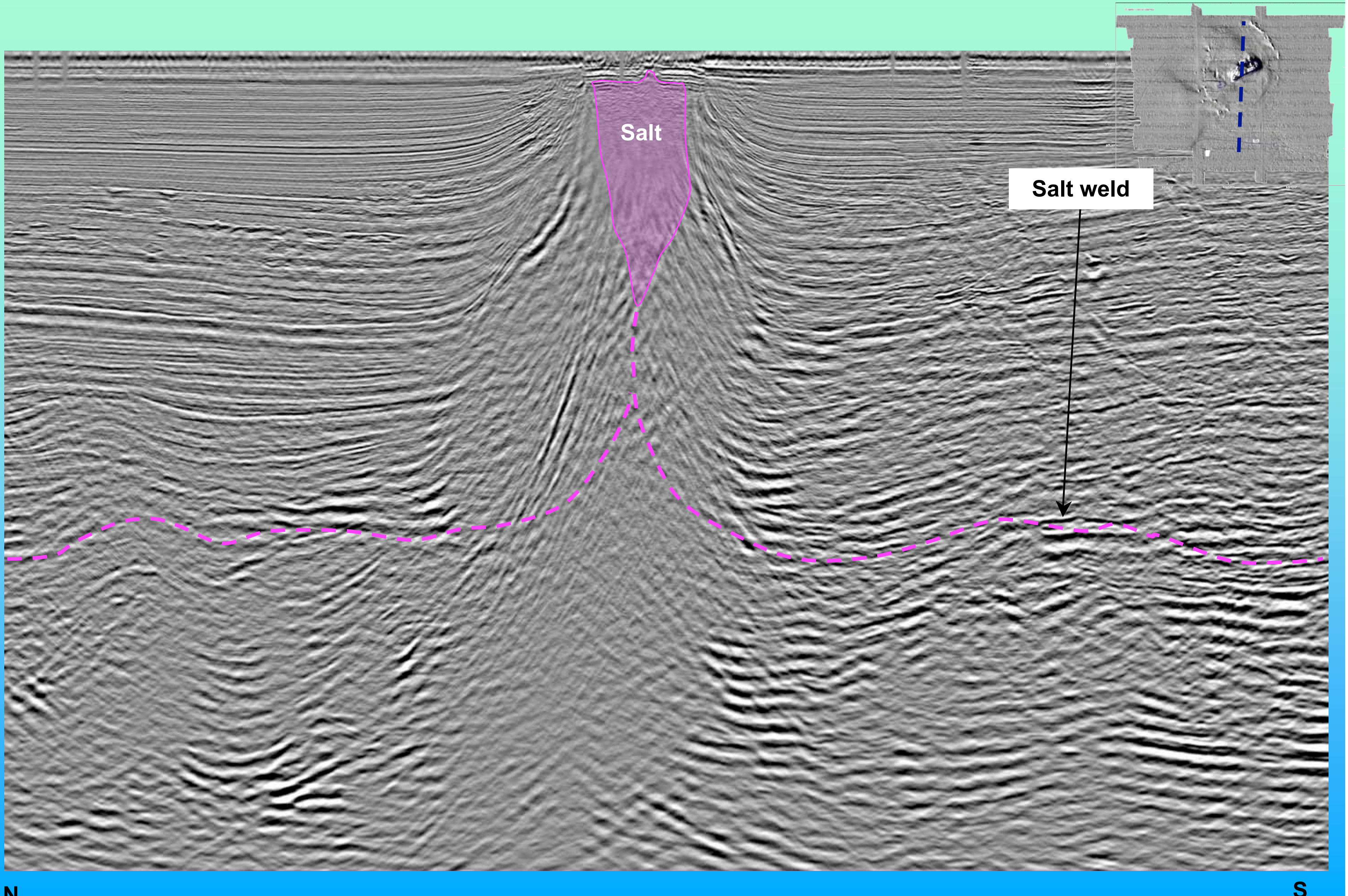
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Zoomed in portion of Stetson Bank E-W line

Data courtesy of WesternGeco
Interpreted by M. Betts

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



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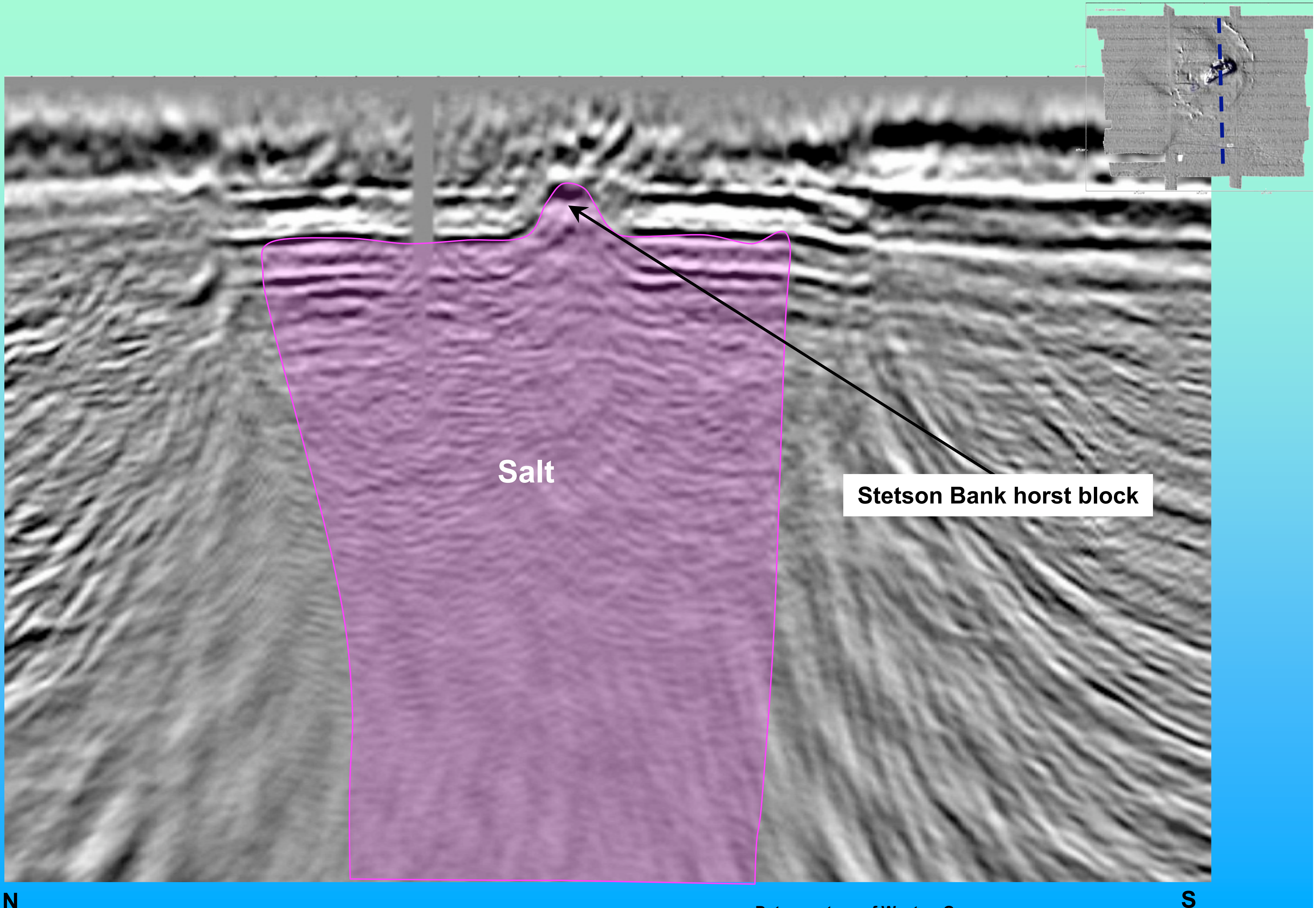
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Data courtesy of WesternGeco
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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Stetson Bank Pinnacles

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Stetson Bank showing Oligocene turbidites rotated to nearly vertical

Mark Betts, 2005

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Madracis coral on Stetson Bank

Mark Betts, 2005

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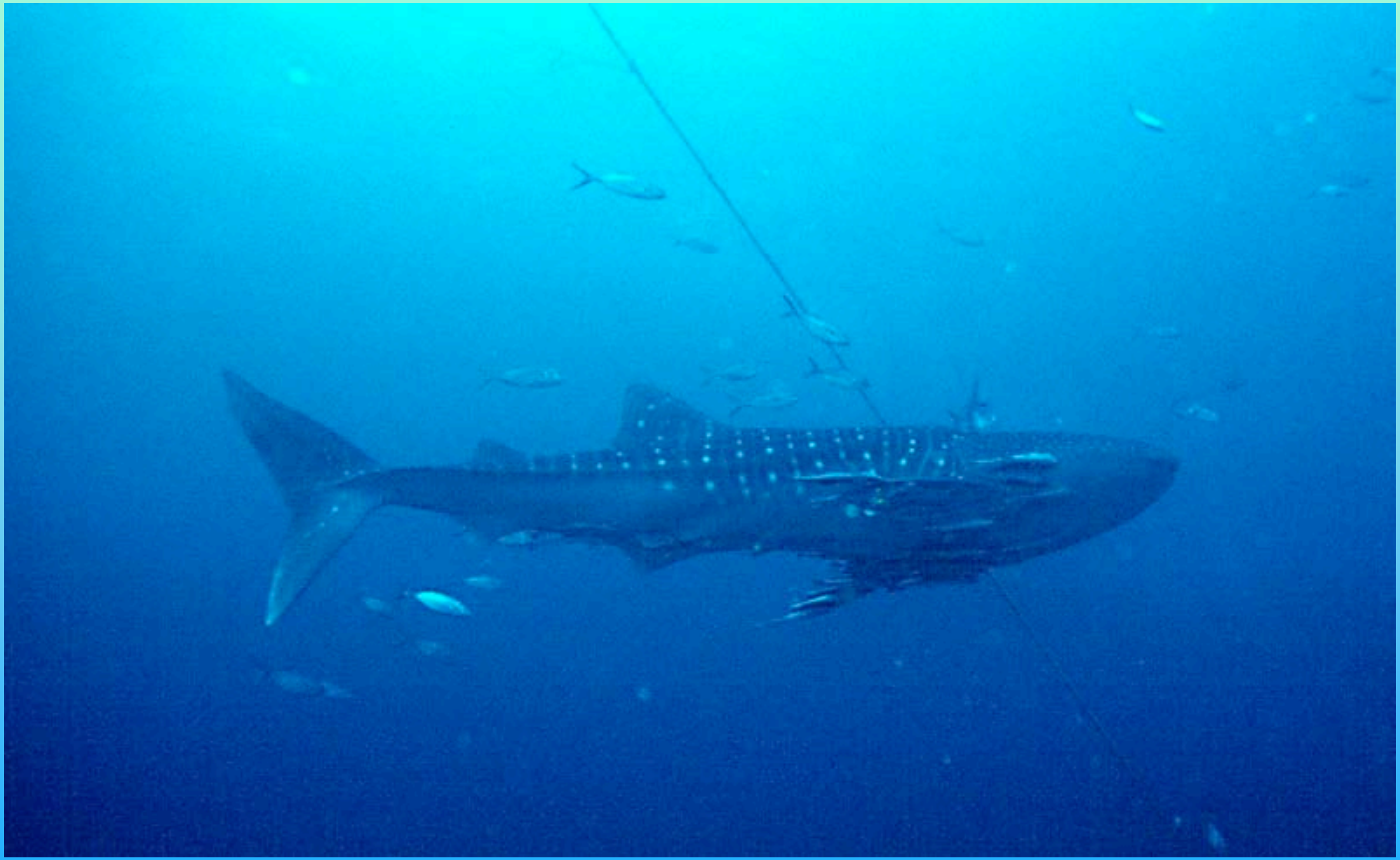
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Whale shark at Stetson Bank mooring line

Mark Betts, 2004

Whale shark at Stetson Bank with Sanctuary Director – G. P. Schmahl

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Feeding Manta Ray at Stetson Bank

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Manta Ray over Stetson Bank

Mark Betts, 2005

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Manta Ray and food at Stetson Bank

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Pencil slate sea urchin

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Four eye butterfly fish

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Scrawled file fish

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Queen angel fish

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Juvenile queen angel fish

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Sharp nose puffer fish

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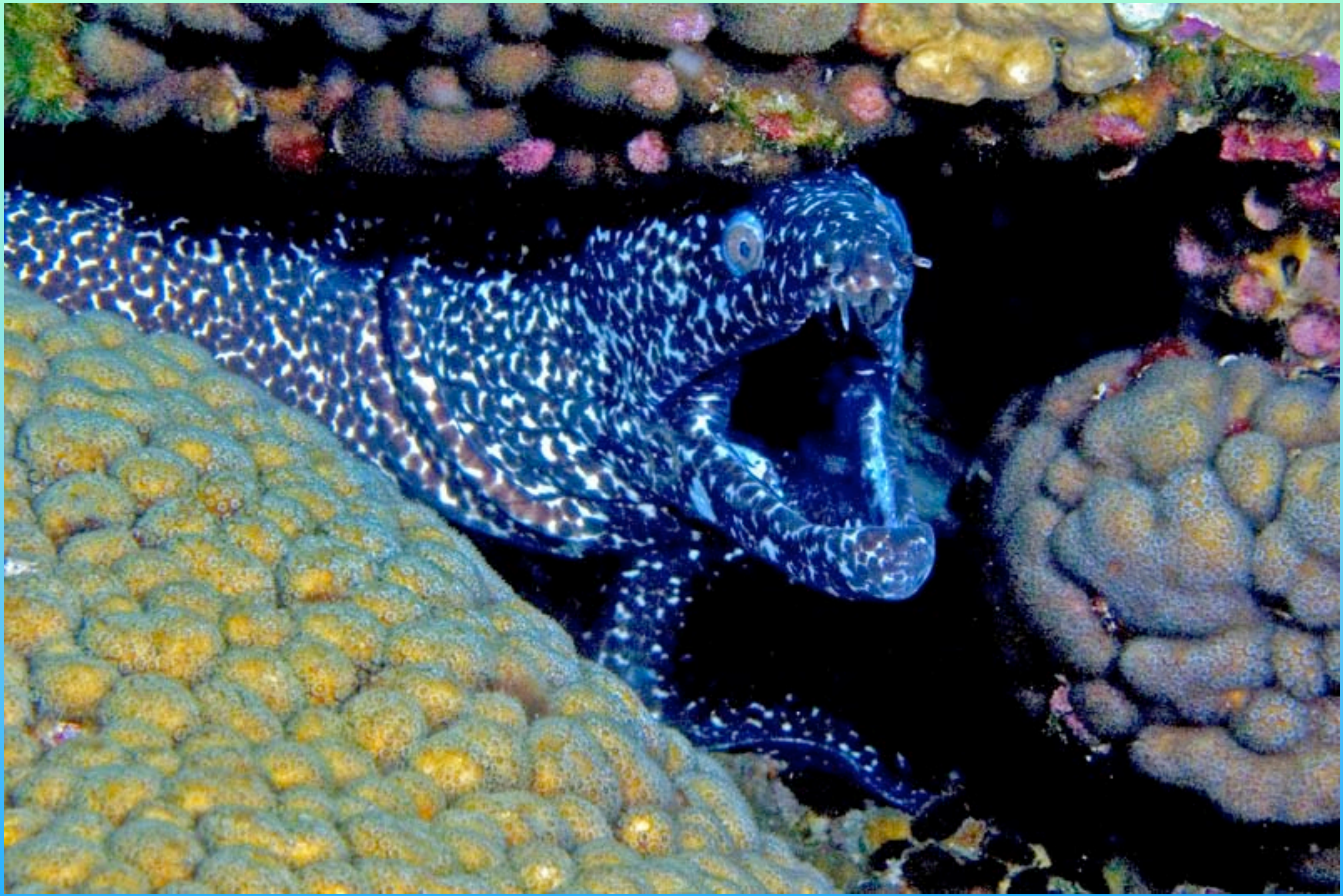
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Spotted moray eel

Mark Betts, 2005

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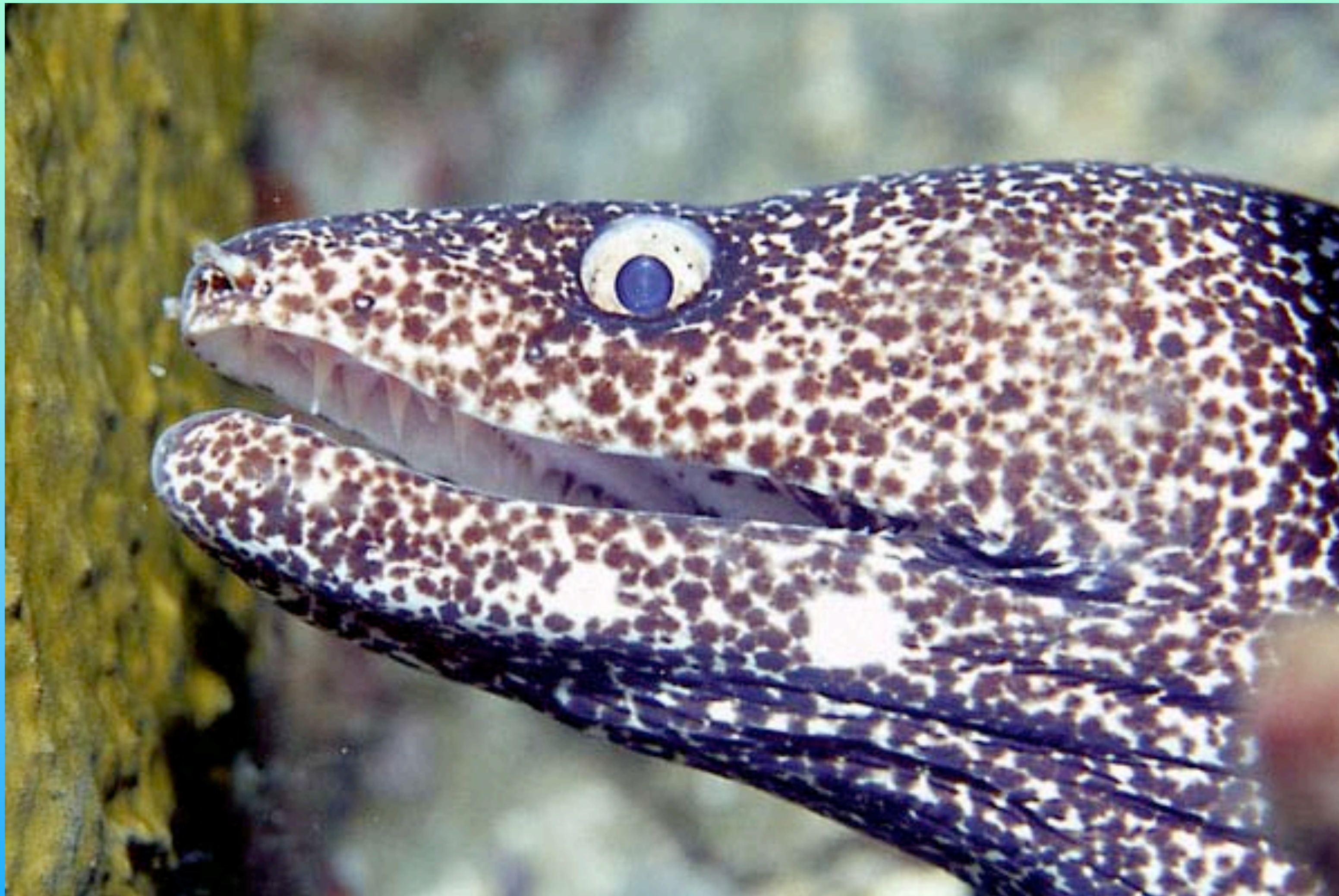

Spotted moray eel

Mark Betts, 2005

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

G. P. Schmahl and D. Haas installing new mooring buoy anchor

Bathymetry and subsurface analysis of Alderdice Bank, Gulf of Mexico

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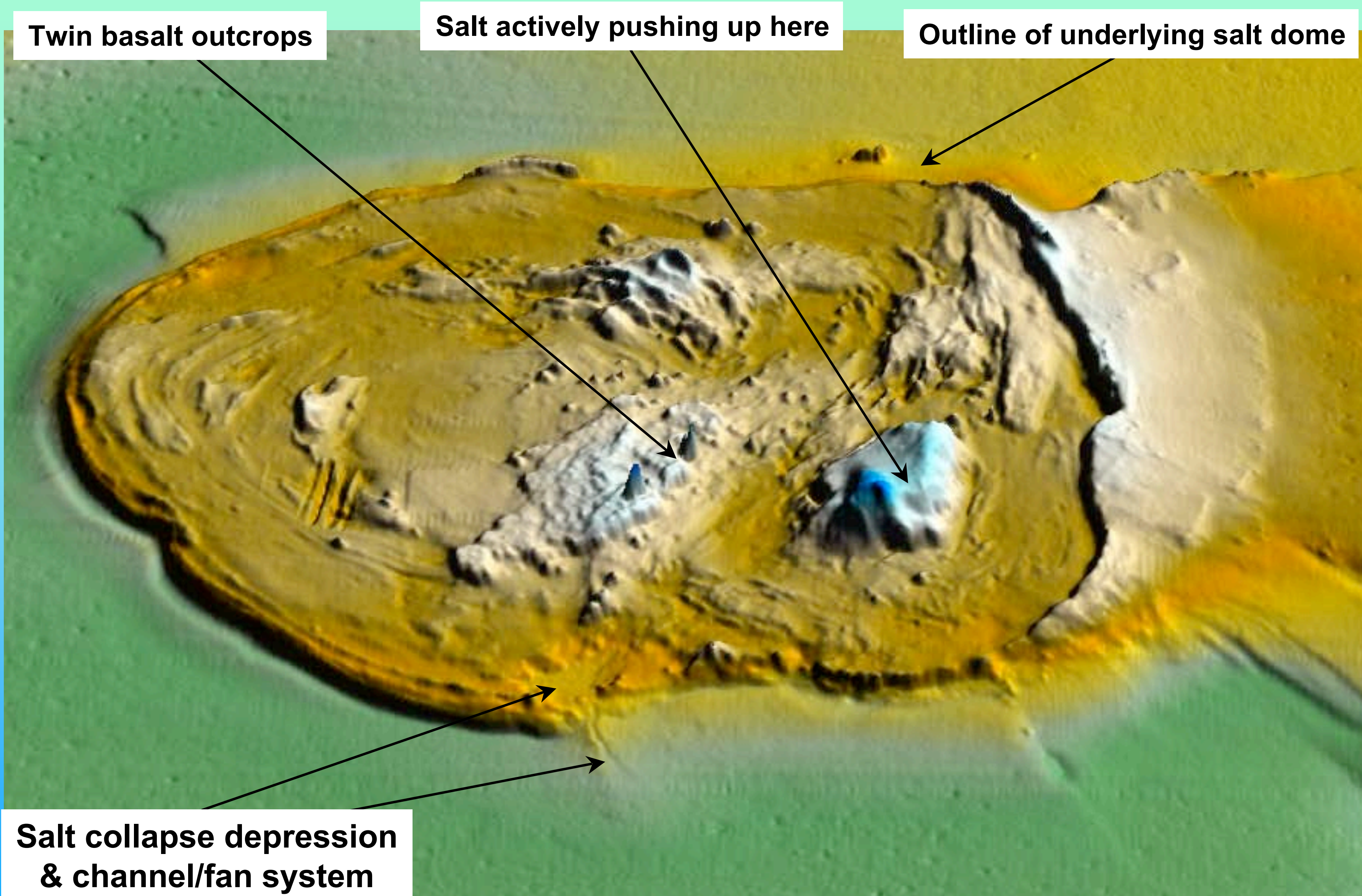
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Alderdice Bank seen from the South

Data from Gardner et al, 2002, USGS report
Visualized by M. Betts

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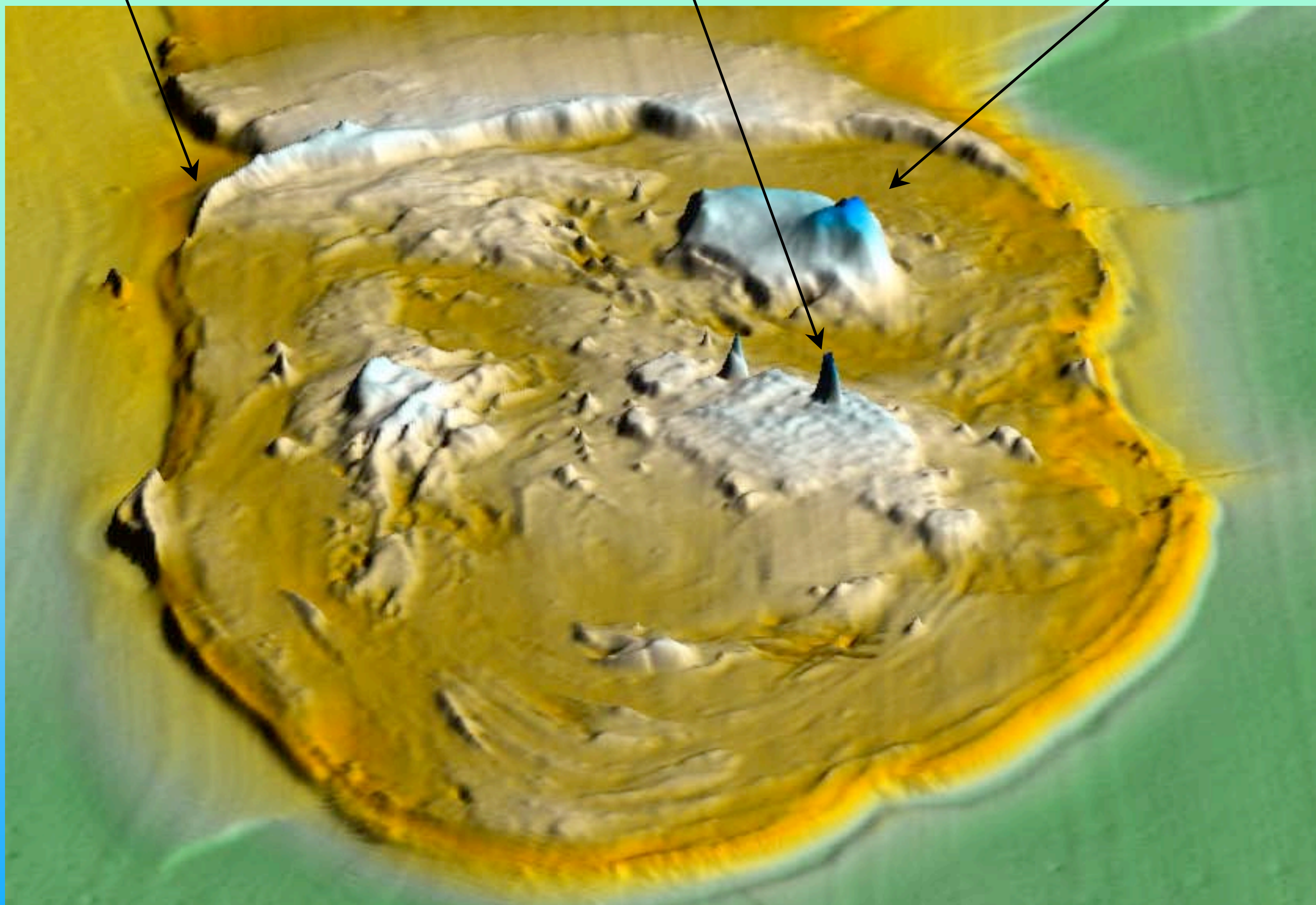
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Outline of underlying salt dome

Twin basalt outcrops

Salt actively pushing up here



Alderdice Bank seen from the West

Data from Gardner et al, 2002, USGS report
Visualized by M. Betts

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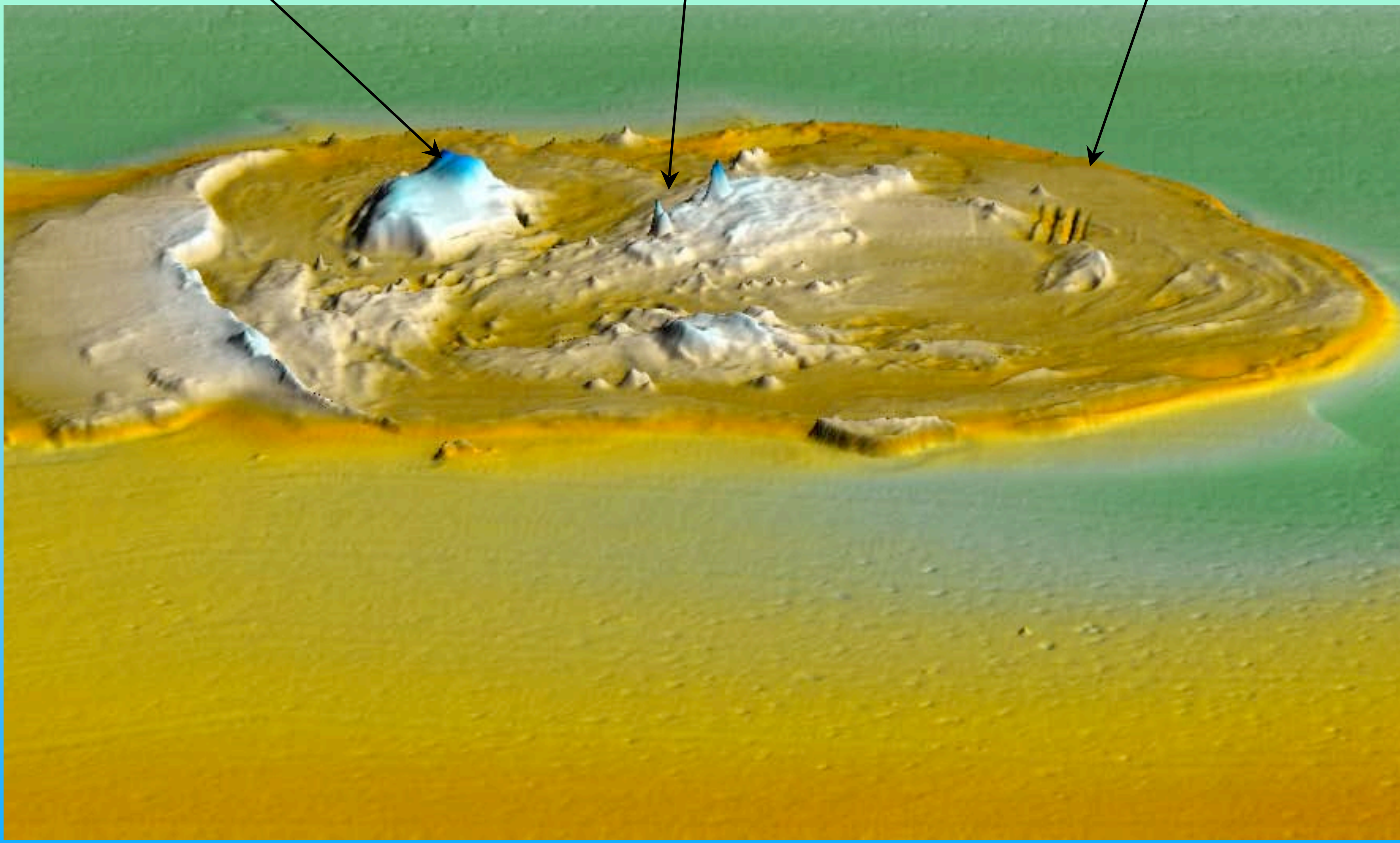
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Alderdice Bank seen from the North

Data from Gardner et al, 2002, USGS report
Visualized by M. Betts

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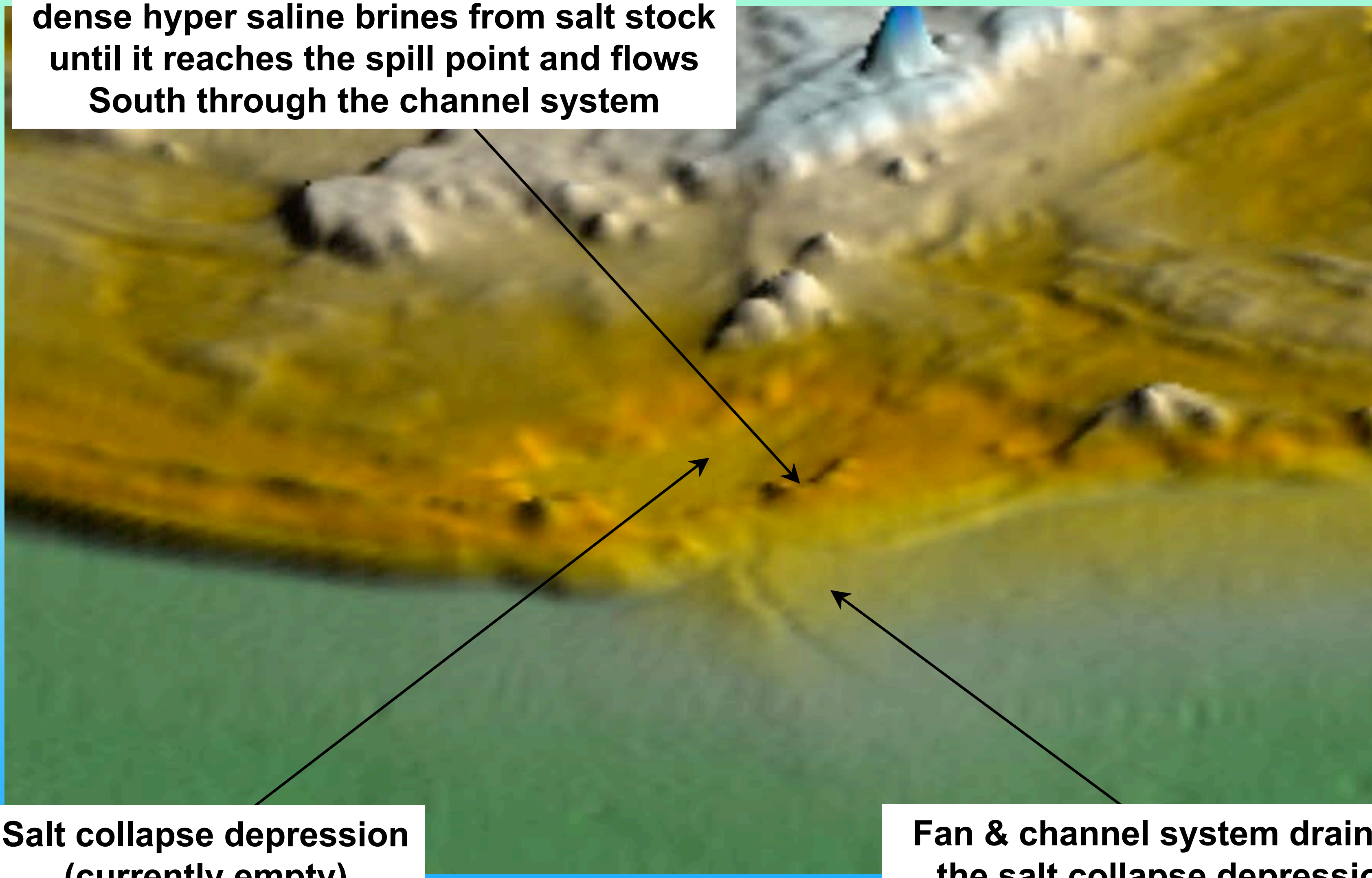
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Basalt spire on Alderdice Bank

Photo courtesy of NOAA

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Zoomed image of Alderdice Bank seen from the South

Data from Gardner et al, 2002, USGS report
Visualized by M. Betts

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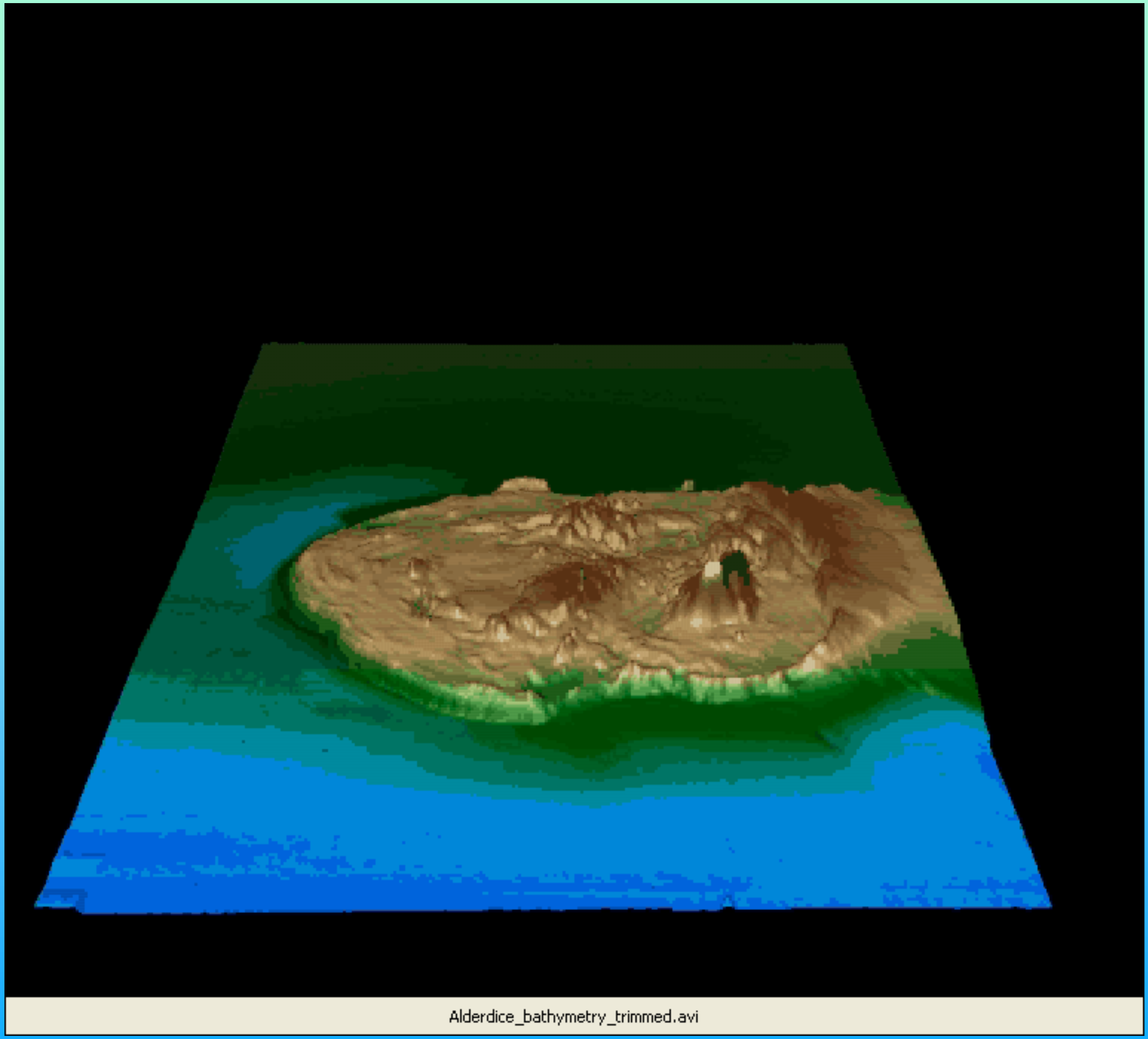
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



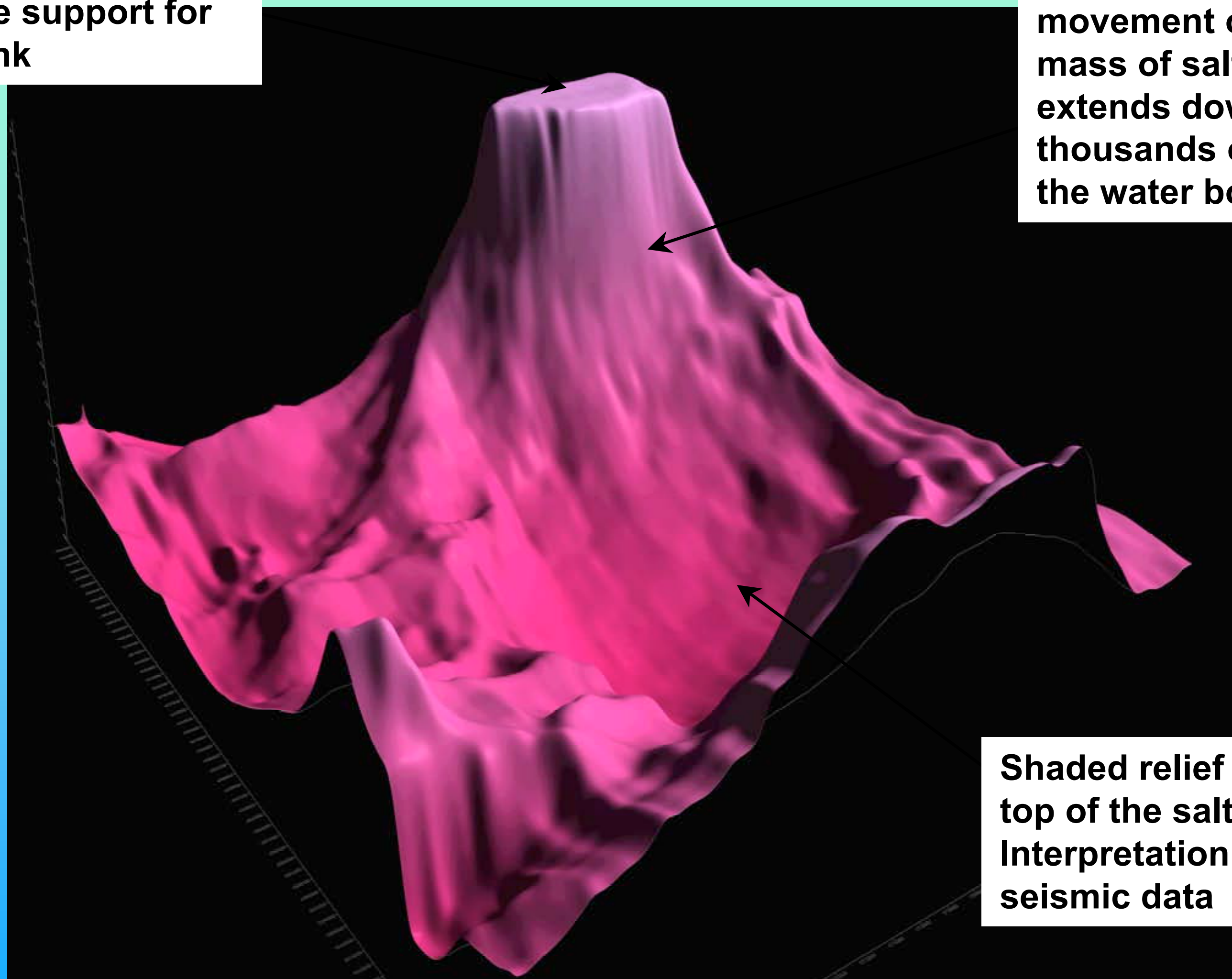
Alderdice Bank bathymetry animation

Click on picture to start animation

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

This part of the salt stock nearly reaches the surface and forms the support for Alderdice bank

Alderdice bank is formed by the up-ward movement of a large mass of salt that extends down thousands of feet below the water bottom



Shaded relief map on the top of the salt mass. Interpretation from 3D seismic data

Alderdice Bank underlying salt stock

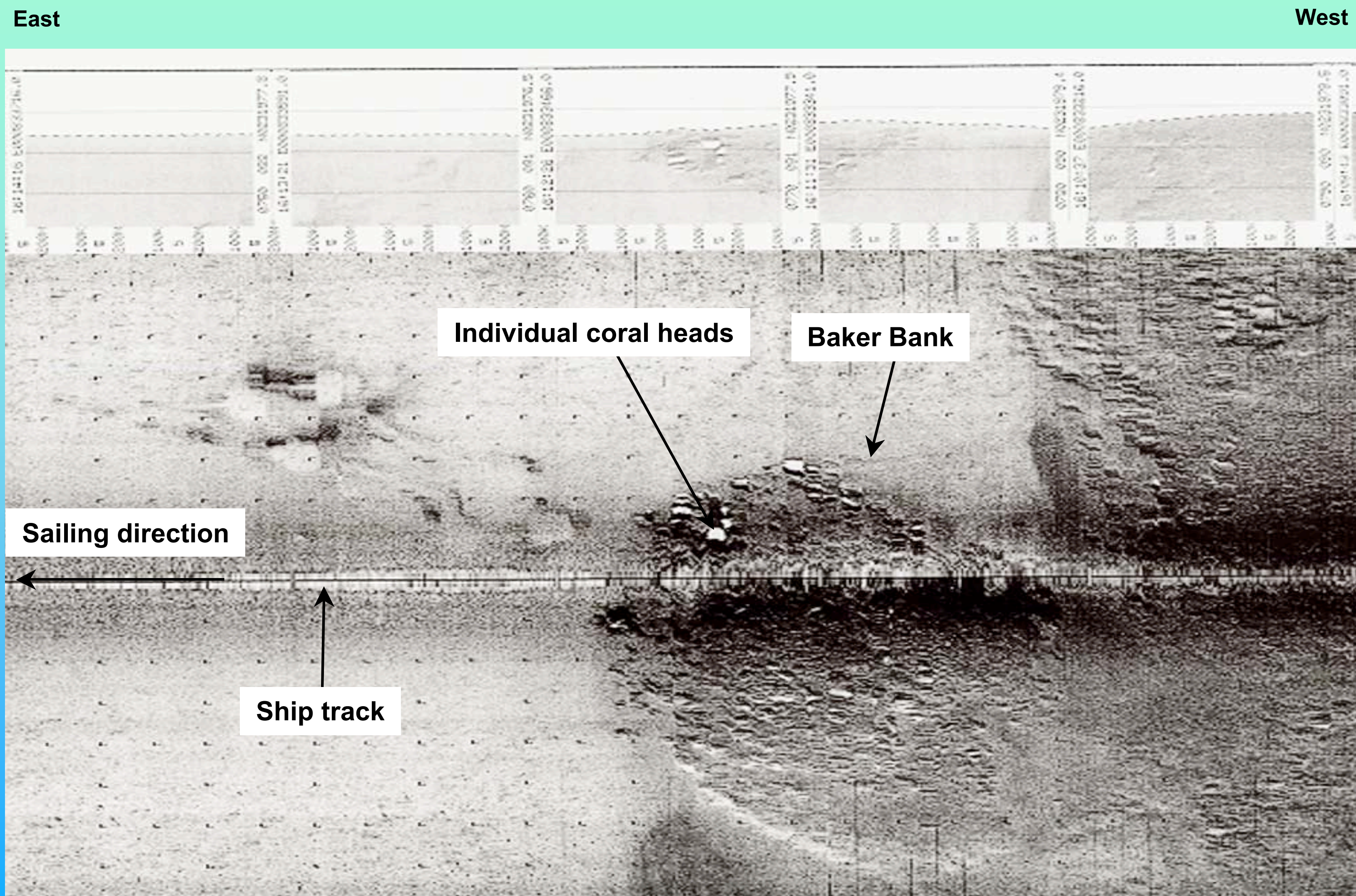
Data courtesy of WesternGeco
Interpreted by M. Betts

Hardground banks
Northwest Gulf of Mexico

The hardground supported Gulf of Mexico banks are markedly different from the salt supported banks. The hardground banks were formed in a dissimilar manner. They are usually found in areas were the ocean bottom is sandier with a lower percentage of soft clays. This is indicative of areas with stronger currents and not as much suspended load sediments (clays). The lower percentage of clays in the ocean bottom sediments and the water column results in thinner nephloid layers that inhibit reef colonization. These hardgrounds are often found on slight topographic highs such as fault scarps where the slight bathymetric difference results in additional winnowing of the clay and fine silt fraction by currents. Reef colonization can occur in these conditions when the right combination of depth, suitable substrate, temperature, and turbidity occur. These conditions have often been present in the offshore Texas area and several banks have formed there. These include:

- Baker Bank
- South Baker Bank
- Hospital Bank

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Side scan sonar image of Baker Bank

Data courtesy Devon Energy
Interpreted by M. Betts

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

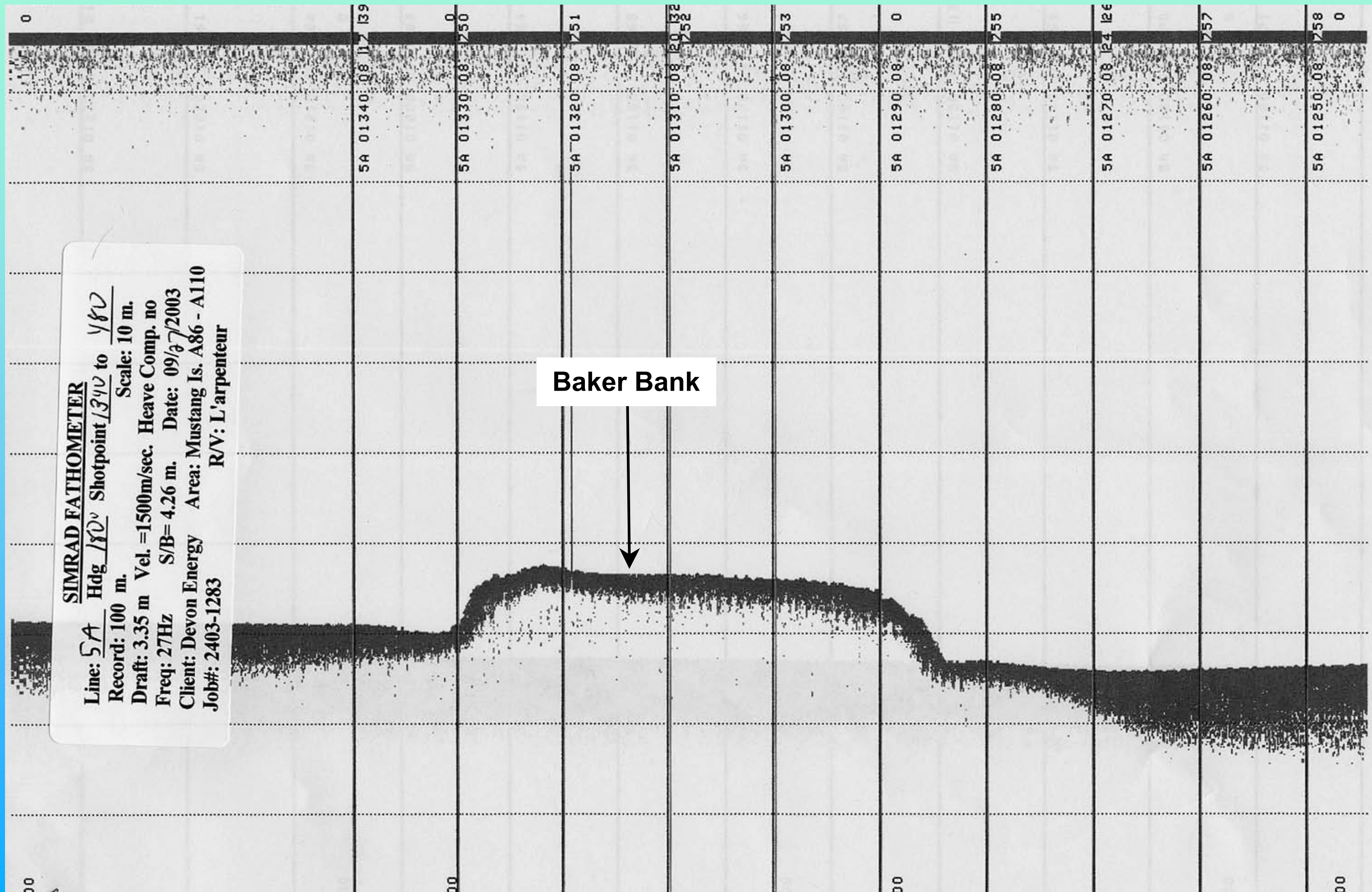
One of the major differences of the hardground supported banks is their sole reliance on the up-building by the reef organisms to keep up with the rising sea level. In salt supported banks, the salt can be pushed up hundreds of feet in response to the rapid addition of weight on top of the shelf from the increasing mass of sea water as sea level rises. The rising salt has the effect of keeping the reef within the active photic zone.

The hardground banks, on the other hand, have had little uplift other than the bathymetric changes resulting from reef growth. This growth was not vigorous enough to keep up with the rising sea level. The reefs have undergone a gradual transition from shallow water environment to deeper water environment.

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

North

South



Data courtesy Devon Energy
Interpreted by M. Betts

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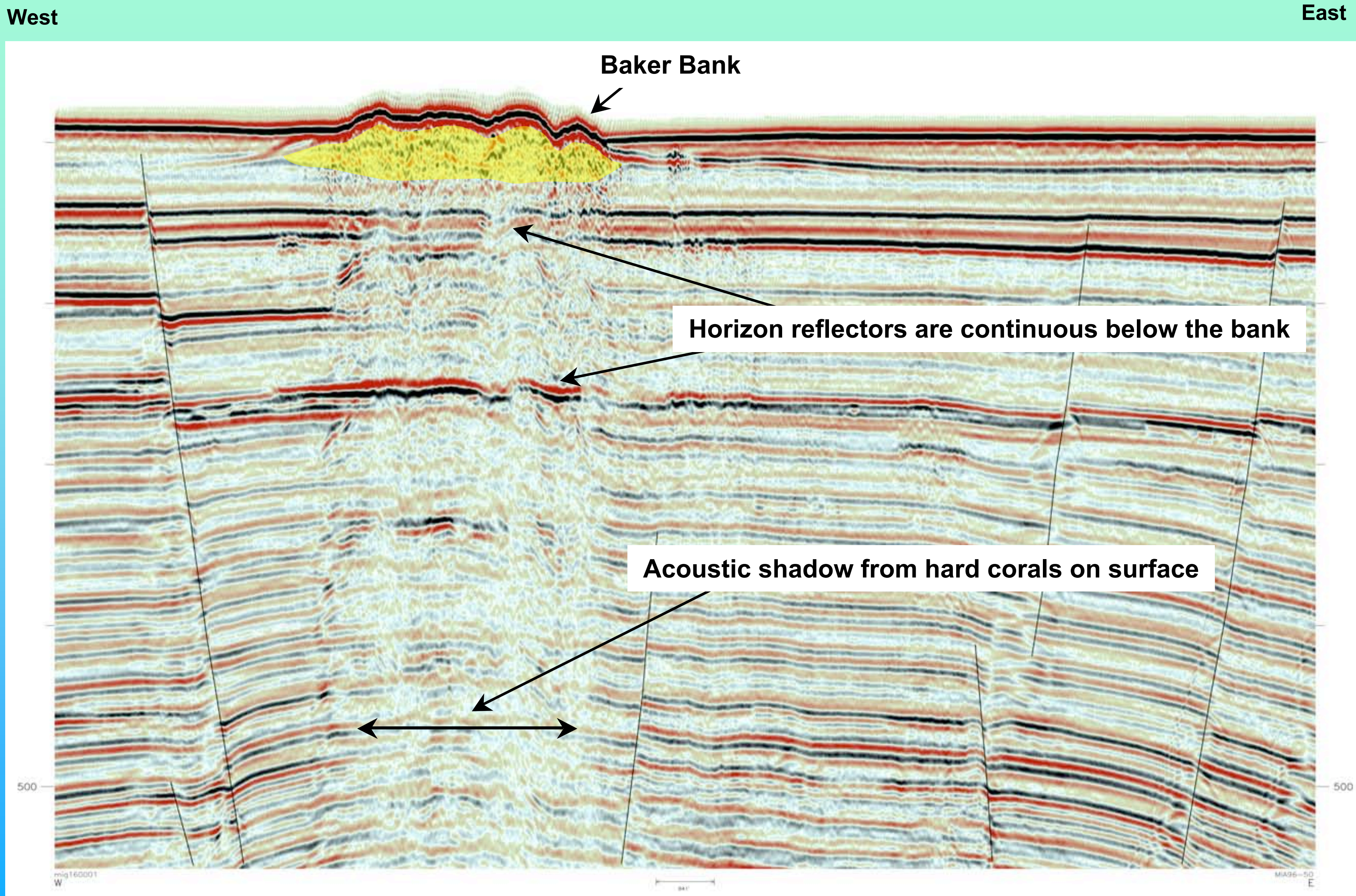
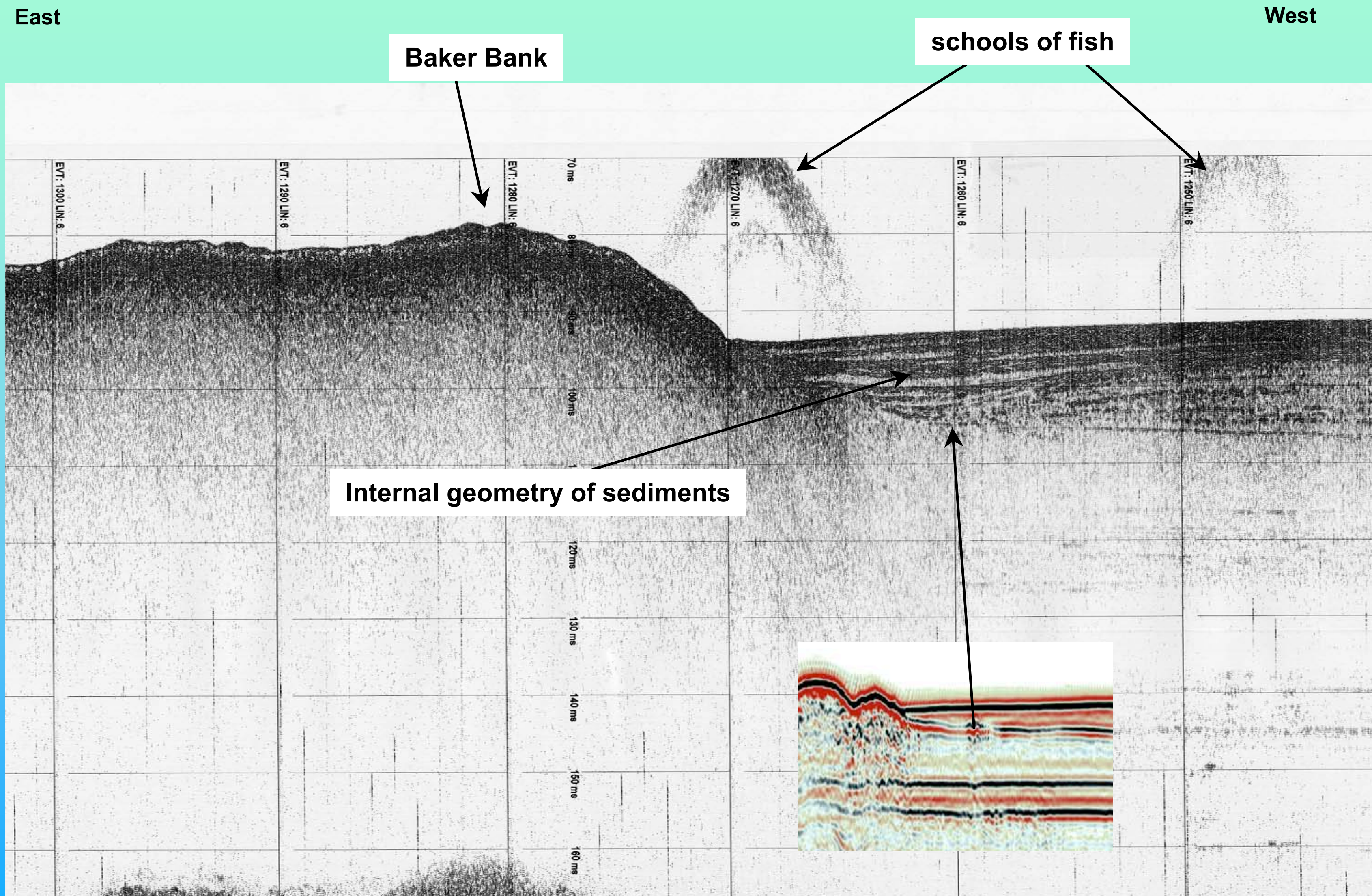
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



High frequency seismic data over Baker Bank

Data courtesy Devon Energy
Interpreted by M. Betts

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

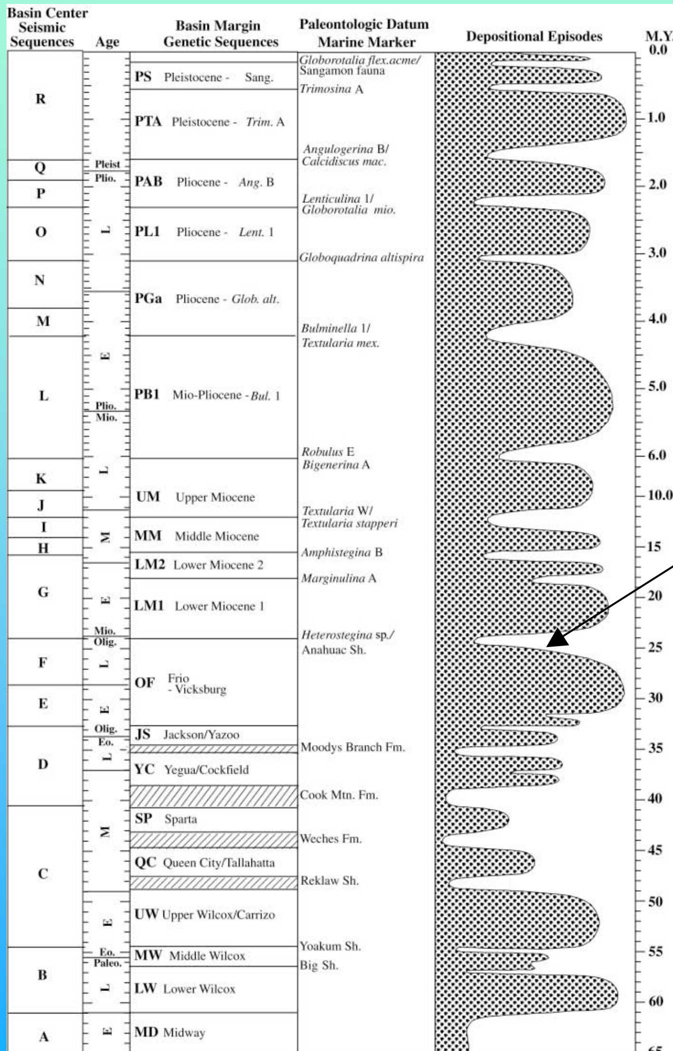


High resolution sub-sea profiler

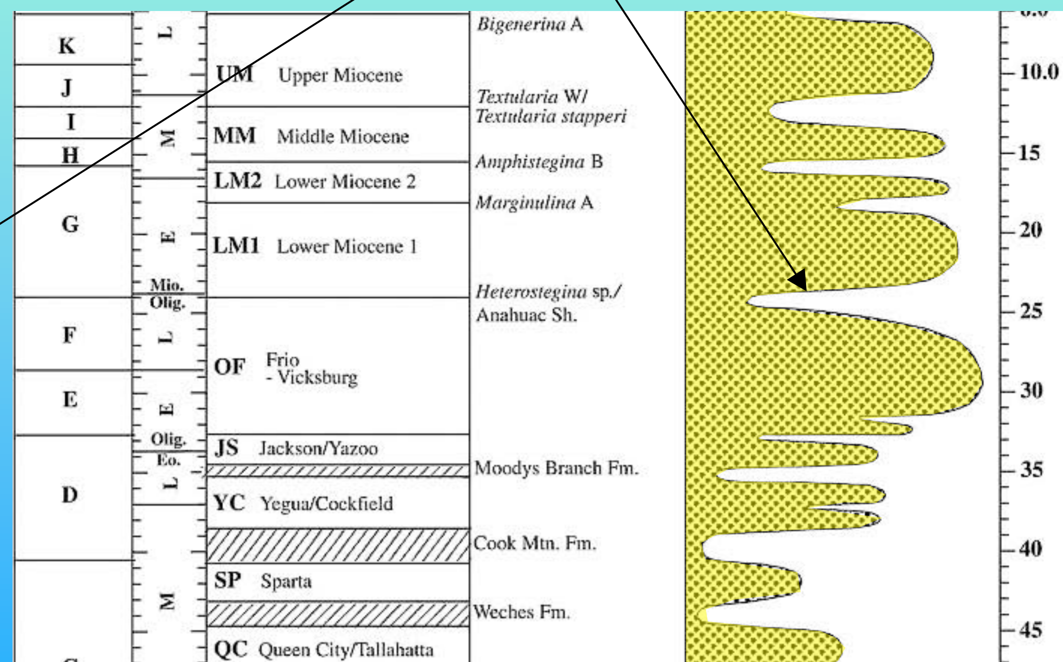
Data courtesy Devon Energy
Interpreted by M. Betts

Comparison of modern reefs to late Oligocene *Heterostegina* reefs

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

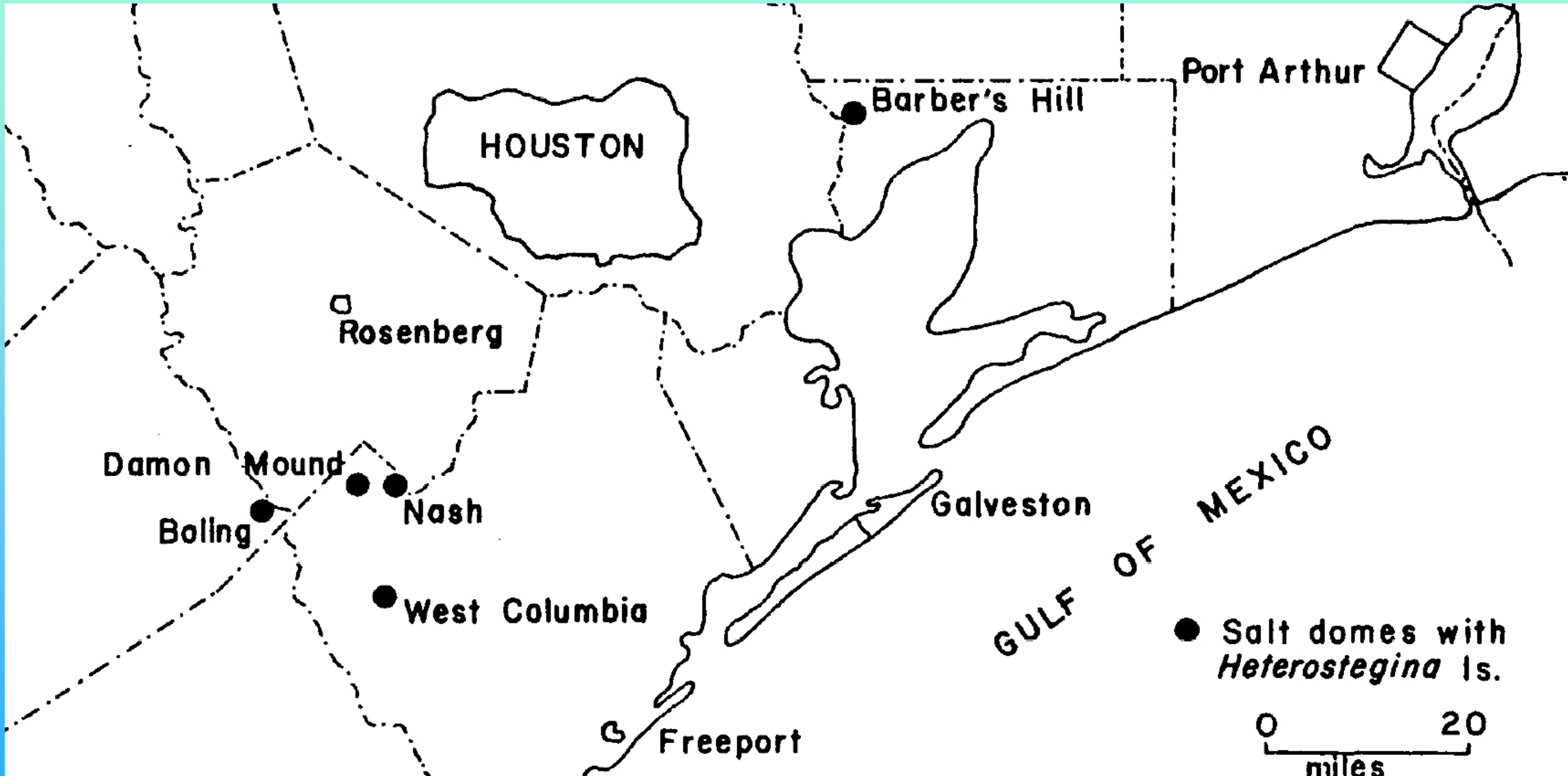


Anahuac calcareous shale *Het.* Lime 25 mya



Stratigraphic setting of late Oligocene reefs

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Salt domes with late Oligocene *Het.* reefs

Frost & Schafersman 1978 GCAGS

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Damon Mound salt dome on NE Texas coast
25' of relief

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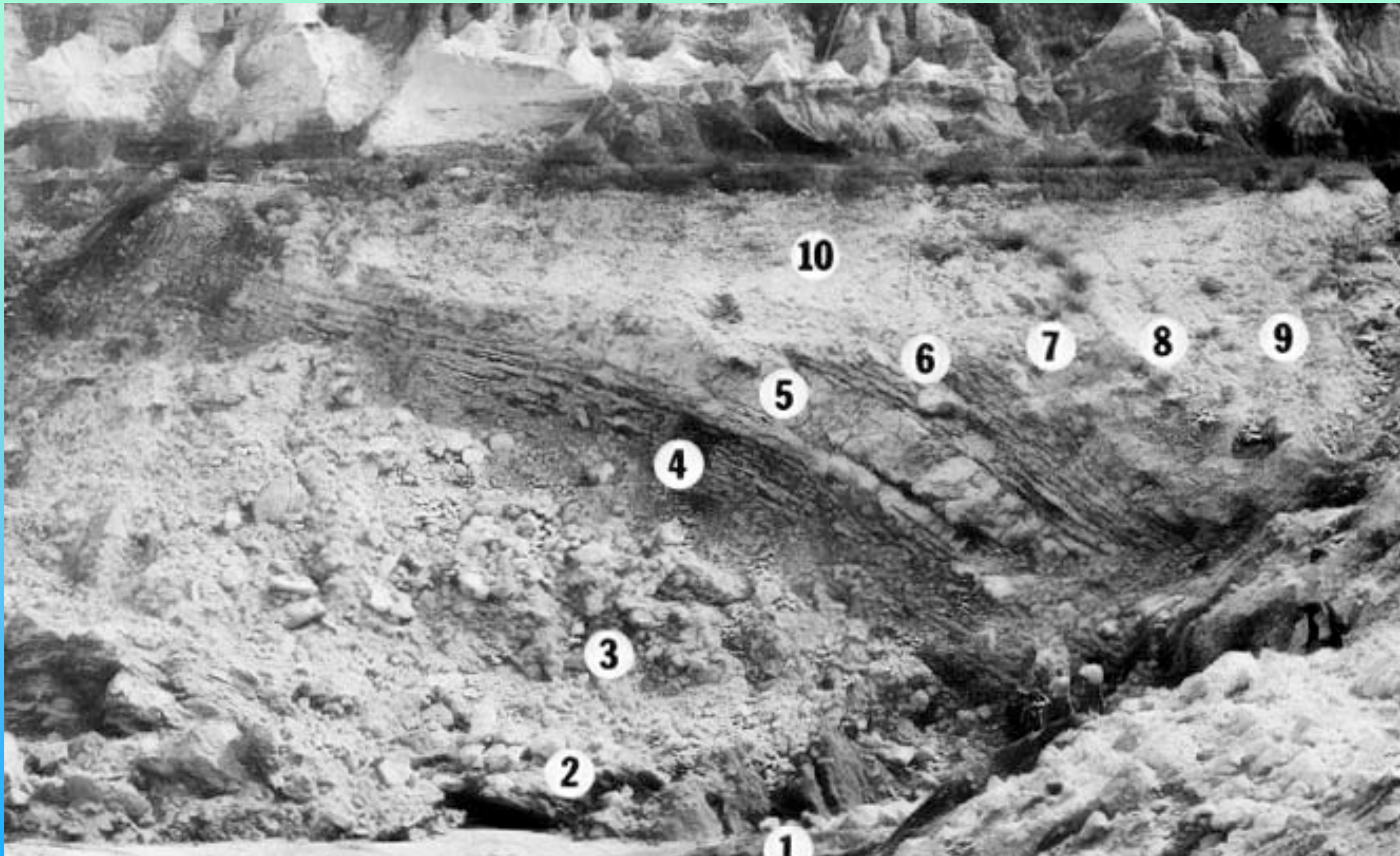
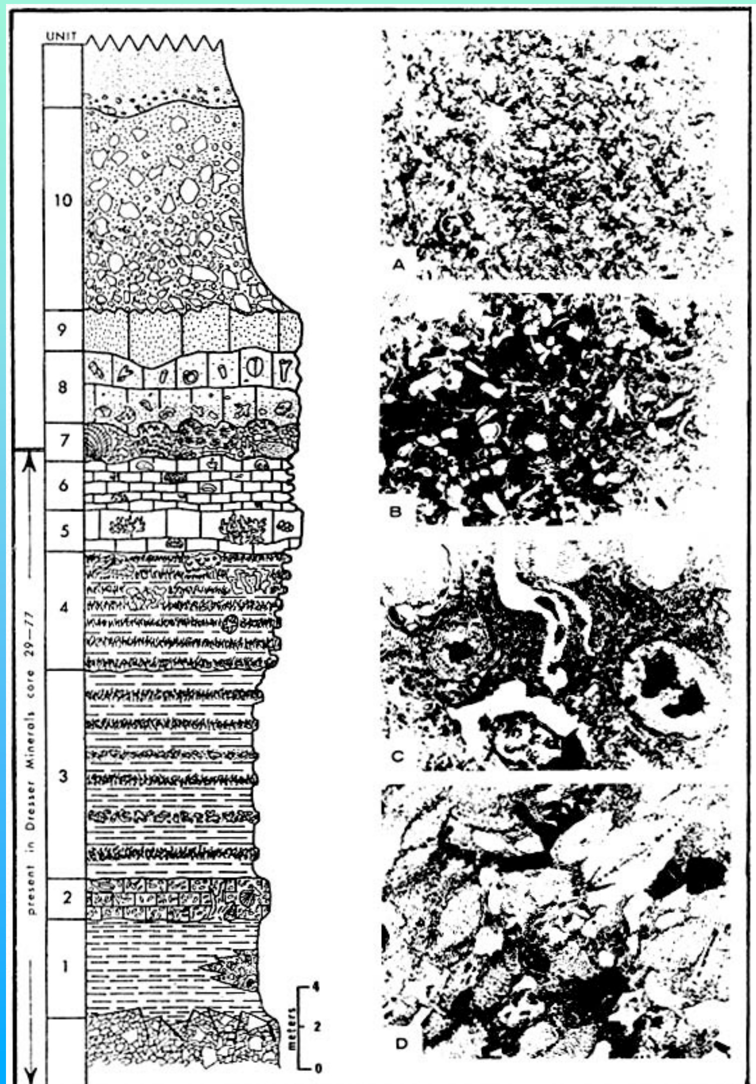
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

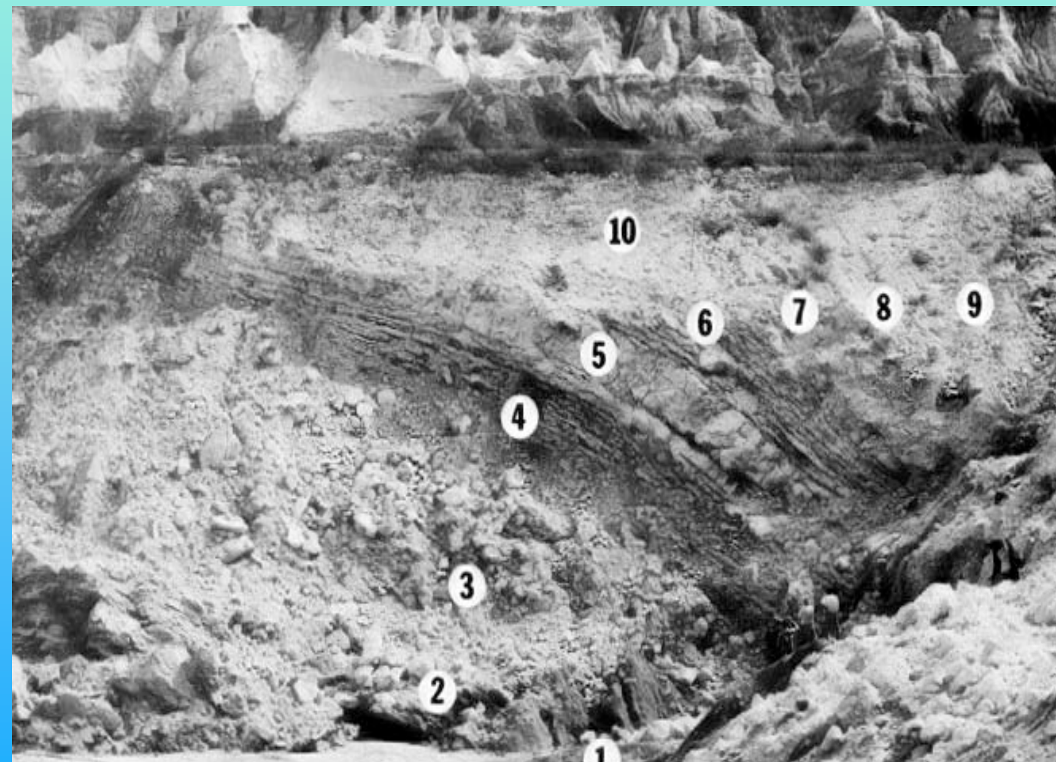


Damon Mound late Oligocene reef exposed in quarry wall

Frost & Schafersman 1978 GCAGS

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico





Frost & Schafersman 1978 GCAGS

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Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico

Thin section of Unit 2 - larger foraminiferal grainstone

Frost & Schafersman 1978 GCAGS

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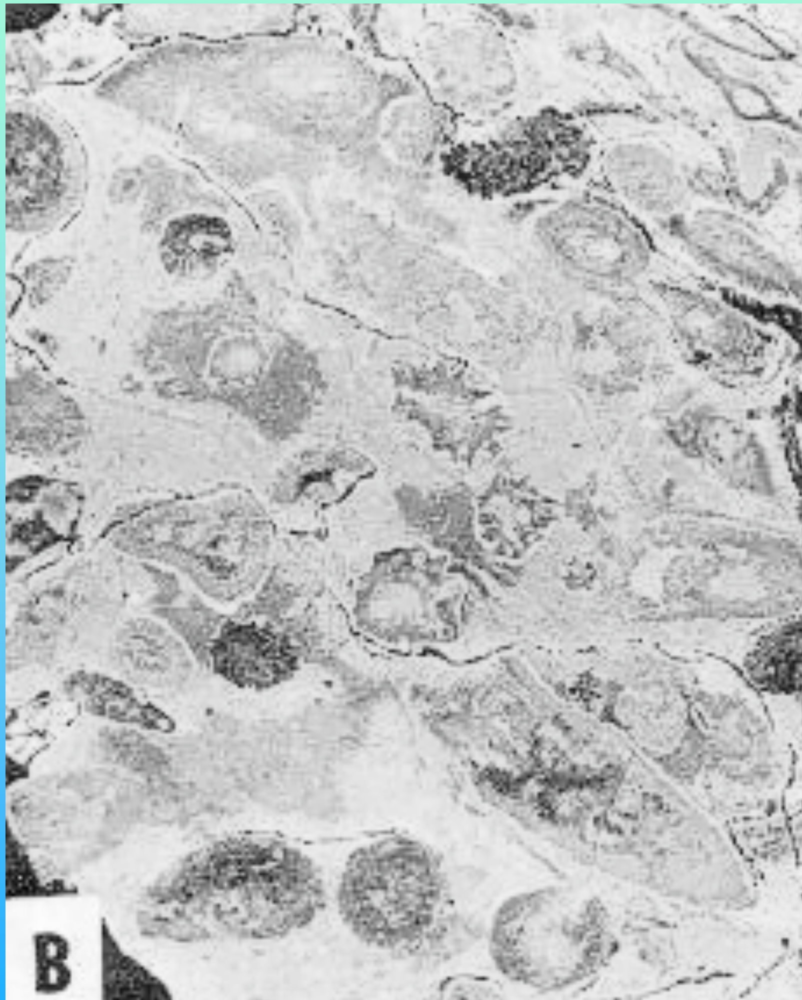
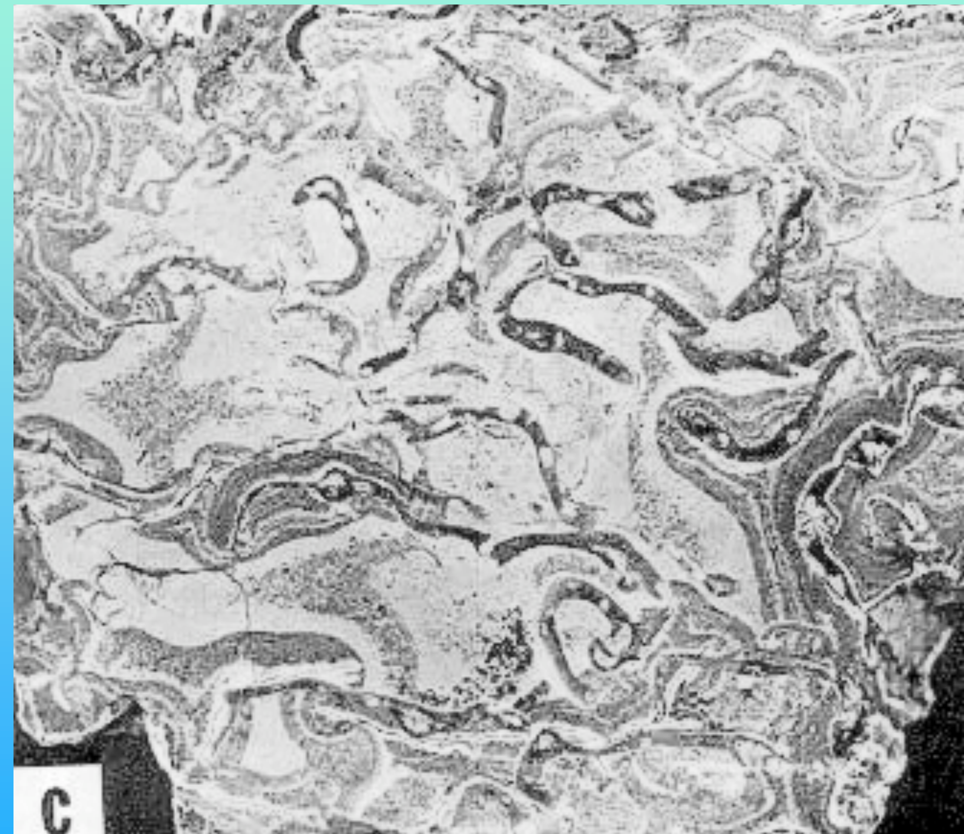
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



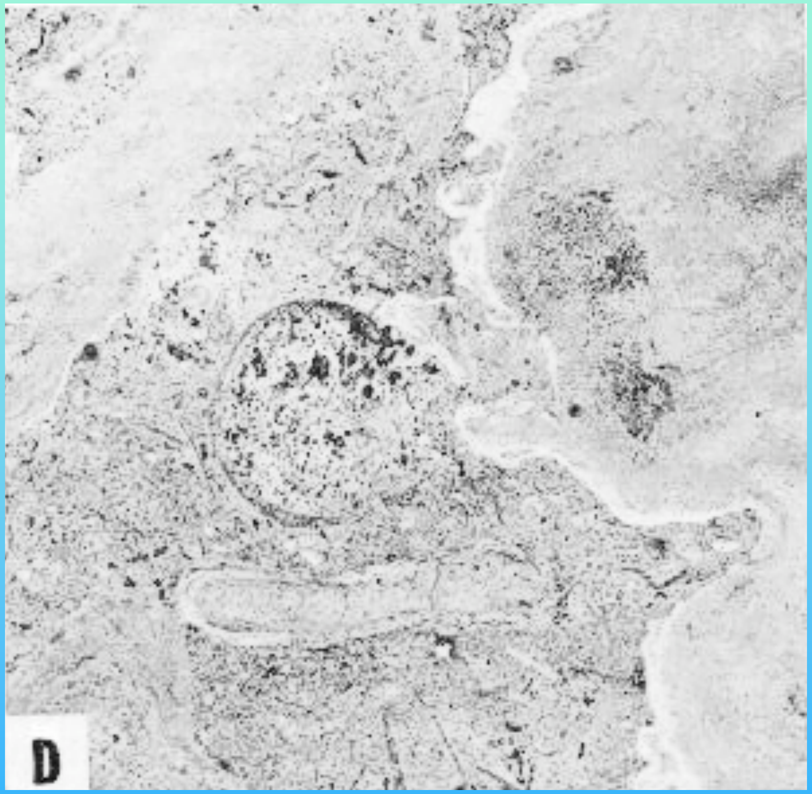
Polished slab through unit 3
***Porites Douvillei* thicket wackestone**



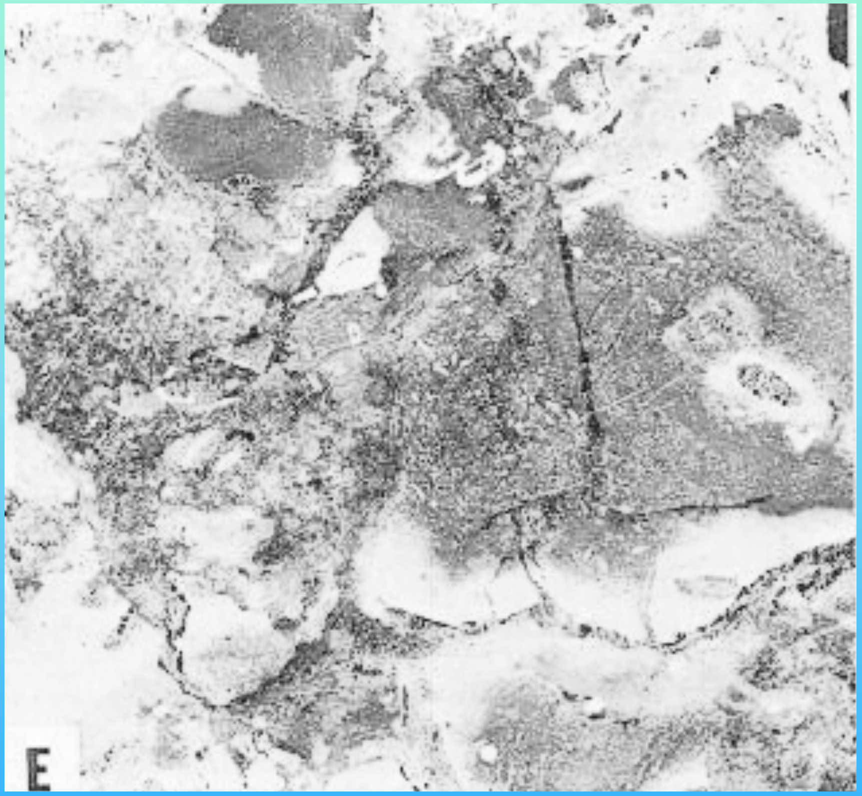
Polished slab through unit 4
***Leptoseris* packestone**

Frost & Schafersman 1978 GCAGS

Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Polished slab through unit 7
Porites panamensis **boundstone**



Polished slab through unit 7
reef core boundstone with cavity fill

Frost & Schafersman 1978 GCAGS

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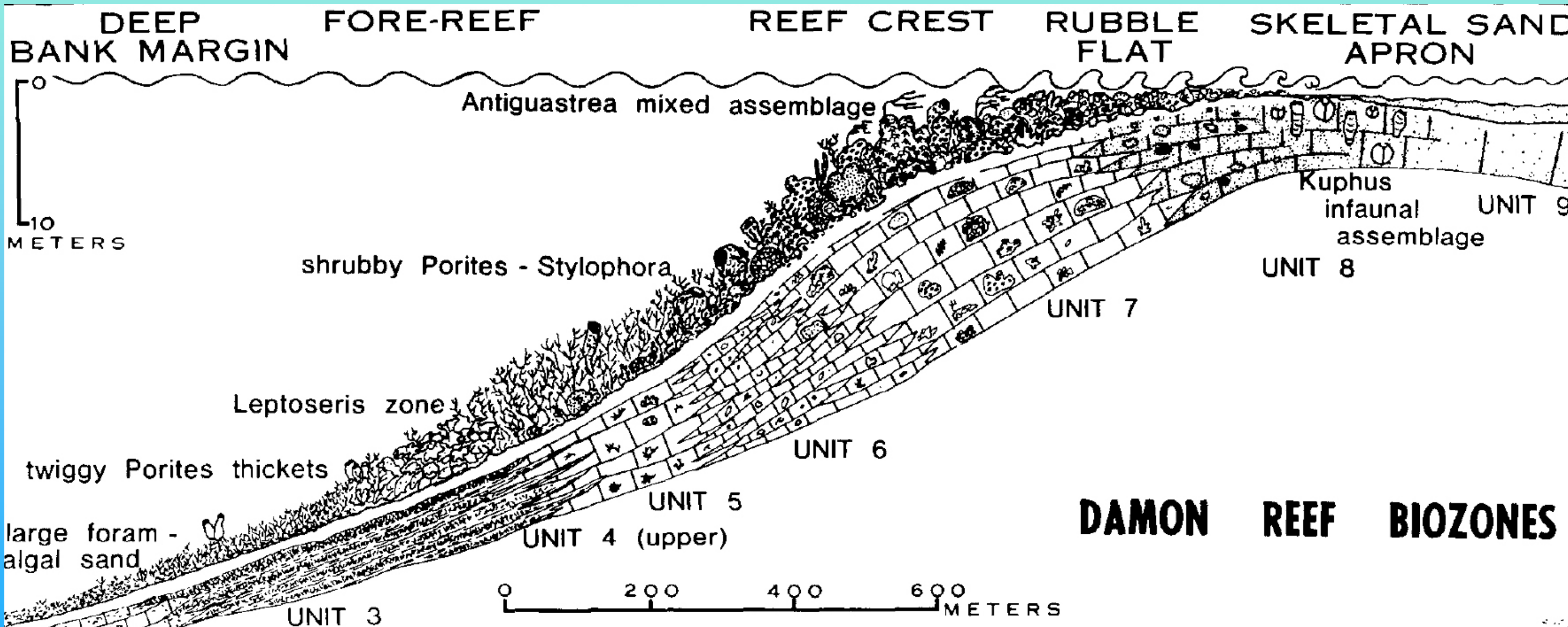
Quaternary evolution of shelf edge reef systems, Northwest Gulf of Mexico



Late Oligocene reef model

Frost & Schafersman 1978 GCAGS

Conclusions

- **Two types of banks: salt supported and hard ground**
  - **Salt supported banks**
    - **very recent – post low-stand**
    - **very active and continue to evolve**
    - **Salt can be deep or at surface**
  - **Hard ground supported banks**
    - **Banks evolved differently from salt supported banks**
    - **Not able to keep up with rise in sea level**
    - **More stable**
    - **Not as well studied**
- **Salt supported banks are similar to late Oligocene *Het.* reefs**
    - **Modern reefs lack *Porites douvillei* thicket facies**