The Gulf of Mexico:
Understanding America's Sea

Coast and Geodetic Survey personnel developed the first realistic bathymetric map of any oceanic basin (above) from 3,000 soundings taken on the Survey Steamer *Blake* between 1873 and 1875 in the Gulf of Mexico

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celebrating200years.noaa.gov

The Gulf of Mexico is a semi-enclosed basin of the ocean. With the Caribbean Sea it constitutes America's Inland Sea.

The Gulf is bordered by five states in the United States (Florida, Alabama, Mississippi, Louisiana and Texas), six in Mexico (Tamaulipas, Veracruz, Tabasco, Campeche, Yucatan and Quintana Roo), and Cuba.

Of the semi-enclosed seas (like the Mediterranean), the Gulf of Mexico is the most intensely investigated and perhaps the best understood.

http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/pd/020/04-04/gulf.html

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Surface area:
1,500,000 sq km (580,000 sq mi)

West to East extent:
1,600 km (994 mi)

North to South extent:
900 km (559 mi)

worldatlas.com/aatlas/infopage/gulfofmexico.htm

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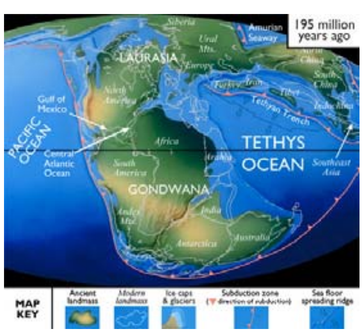
20 major fresh-water river systems drain into the Gulf, and near 65% of all river volume (*and pollution*) flows into this massive body of water through the Mississippi River Delta.

In many ways the Gulf of Mexico is like every other part of the ocean. But there are also differences. This presentation discusses the origins of the Gulf of Mexico and makes some comparisons to other parts of the world ocean in the context of the four traditional disciplines of oceanography: Geology, Physics, Chemistry, and Biology.

http://www.golfo-de-mexico.org

The Gulf began to form in the Triassic Period when North America began separating from Africa as a result of a rift forming between the plates currently known as North and South American continents.

By the mid-Jurassic, the Gulf was receiving sediment from the proto-Mississippi River.



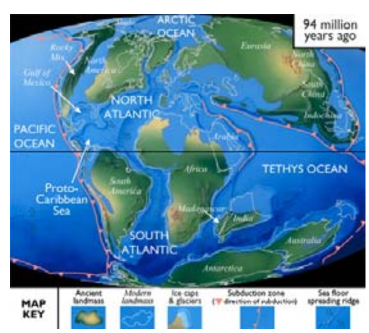
GEOLOGY

http://www.paleoportal.org/index.php?globalnav=time_space&sectionnav=period&period_id=9

Sedimentation continues today and has resulted in vastly thick deposits of clastics (particles of sand, silt, and clay carried by flowing water) and carbonates (biogenic precipitation of calcium carbonate mediated by organisms that use $CaCO_3$ for their shells) around the edges of the Gulf.

Thickness of Deposits:
Interior of US Gulf Coast states: >2 km
Coast of US Gulf Coast states
West of the Mississippi River: 10 km
East of the Mississippi River: 5 km
Offshore of Louisiana: 16 km

The thick deposits sometimes slump causing normal faults angling from the horizontal toward the Gulf. These faults have produced earthquakes, but typically have low seismicity and experience slip along the fault plane of of <0.2mm/yr.



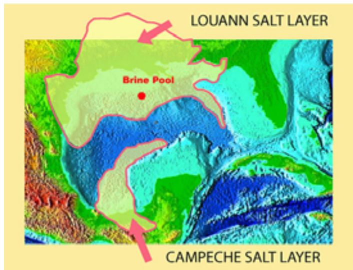
GEOLOGY

http://www.paleoportal.org/index.php?globalnav=time_space&sectionnav=period&period_id=9

The rifting of continents in the mid-Mesozoic split a large salt deposit and introduced new ocean crust between them.

The Louann Salt is more than 200 million years old, formed by evaporation of an ancient shallow sea on North American continent.

It is located below later deposits along the Gulf of Mexico's shoreline. In some places this salt has moved (deformed) because of the weight of the rocks above. Several scientists compare the movement to toothpaste squeezing out of the tube. The 'tube' consists of increasingly heavy deposits originating on land that smush the salt, or 'toothpaste' out below them toward the deeper waters of the Gulf.



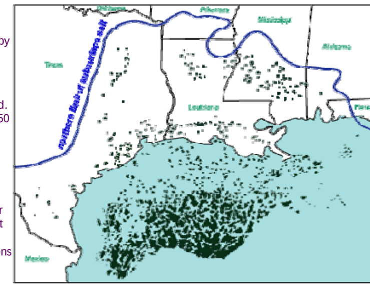
GEOLOGY

http://oceanexplorer.noaa.gov/explorations/02mexico/background/brinepool/gulf_salt_220.jpg

The blue line shows the northward extent of the Louann Salt. Dark green dots show where the deposit is deformed to make obvious structures by its underground movement.

On top of this salt rests sandstone (clastic) deposited in an arid environment during the Jurassic period. It contains wind blown dunes up to ~250 meters high and ~13 km long, 4,575 meters below the surface. Above this formation are a limestone (carbonate) and sandstone.

Why do we care?
1 - It certainly is neat to know how our part of the world looked before we got here.
2 – The clastic and carbonate formations described above are productive oil reservoirs from Texas and Arkansas to Alabama. The deformation caused by salt pushing through these layers makes traps to which the oil migrates where it can be recovered by drilling.



GEOLOGY

http://www.priweb.org/ed/pgws/backyard/sections/southcentral/southcentral2.html

The vertical cross-section of a salt dome, shows how previously horizontal layers of rock are folded as the salt pushes upward. Shading in each layer shows places where geologists and engineers would look for oil – essentially oil migrates to the highest point in any porous and permeable rock. Faults and bedding planes with impermeable rocks cut off the migration allowing the oil to collect.

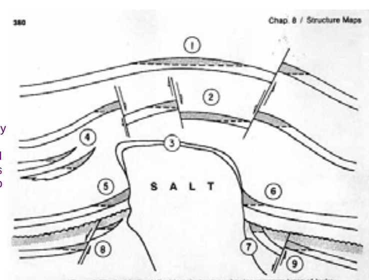
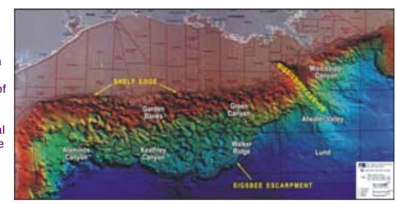


Figure 8-68 An idealized diapiric salt structure showing common types of hydrocarbon traps. (From *Salt Domes*, by Michel T. Halbouty. Copyright 1979 by Gulf Publishing Company, Houston, Texas. Used with permission. All rights reserved.)

GEOLOGY

http://www.geo.wvu.edu/~jtoro/Petroleum/Review%202.html

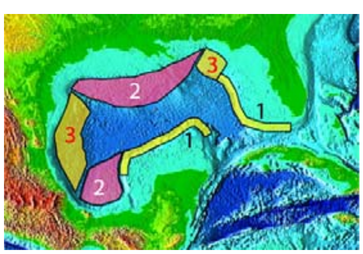
This multibeam bathymetry map of the northwestern and northern Gulf of Mexico continental shelf and slope shows the topography of the area affected by Louann salt layer and subsequent river deposition, as well as an ancestral outlet of the Mississippi River (the MR Canyon). *Figure provided to NOAA Ocean Explorer courtesy of Harry H. Roberts.*



GEOLOGY

http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/media/gulf_600.html

The topography developed by salt and river deposition (labeled '2' in the figure) is not typical for continental margins such as the Atlantic Coast. Areas marked '1' are carbonate platforms. They are edged by a steep cliff (escarpment). Only the areas marked '3' illustrate the relatively shallow continental slope and rise typically seen at the margin between continental and oceanic crust.



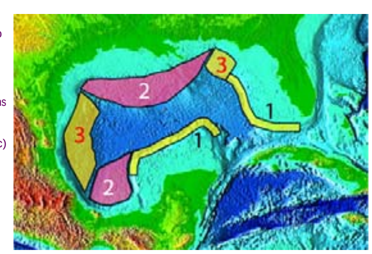
GEOLOGY

http://oceanexplorer_noaa_gov-explorations-02mexico-background-brinepool-gulf_salt_220.htm

The two carbonate platforms are geologically similar and are thought to have been deposited together in the early-late Jurassic after the salt layer was deposited.

Both the Florida and Yucatan Platforms were initially exposed and only subsided below sea level during late Jurassic (Fla) and mid Cretaceous (Yuc) times. The subsidence is assumed to be related to cooling of the tectonic plates after rifting occurred.

Since the platforms submerged, they have been experiencing deposition of carbonates (in shallow marine reef environments) and evaporites (in arid environments).



GEOLOGY

http://www.gulfbase.org/facts.php

Shoreline Length
~5,700 km, Florida to Yucatan
~380 km, Cuba
>27,000 km, Shoreline including US bays

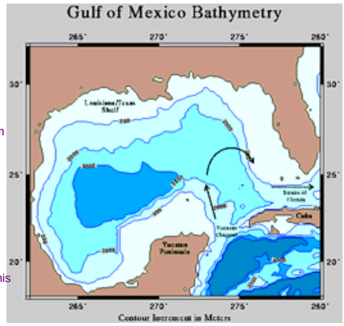
Basin Topography
38% Shallow, intertidal <20 m
22% Continental Shelf, 20-180 m
20% Continental Rise, 180-3000 m
20% Abyss, >3000 m

Sigsbee Deep: ~4000 m

Mean Depth: 1615 m

Volume: 2,400,000 km³

Notice that the deepest part of the Gulf – the Sigsbee Deep (Darkest blue on the figure) is between the two portions of the salt layer. This is where oceanic crust extruded to separate them.



GEOLOGY

http://www.gulfbase.org/facts.php
http://www.intecmar.usb.ve/CoMLCaribbean/Summaries/summary_BoGoM.htm
http://ocean.colorado.edu/~kantha/Altimetry/gulf_of_mexico.html

A primary factor in the chemistry of the Gulf of Mexico is salinity. More than 150 rivers contribute freshwater to the Gulf. The Mississippi River makes the greatest contribution (64% of the total flow), and the total of all US drainage to the Gulf is 84% of the flow. Rivers in Mexico and Cuba contribute the rest. Freshwater vents on the southwest shelf of Florida also contribute freshwater.

Because of these freshwater sources, salinity in the Gulf averages 28-32 ppt, as compared to 35 ppt in the rest of the ocean.

Some parts of the Gulf have slightly higher average salinity than the world ocean. This may be attributed to the existence of brine seeps on the seafloor, which contribute water of ~200 ppt to the mix. These form where subsurface salt migrates to the surface and dissolves.

CHEMISTRY

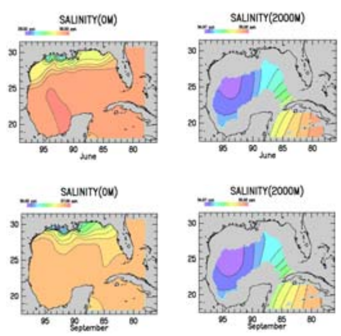
http://www.golfo-de-mexico.org
http://www.coast-nopp.org/resource_guide/elem_mid_school/physical_param_acts/saline.html

Gulf of Mexico salinity varies seasonally, with depth, and laterally.

The figures use a color scheme that changes on each figure to maximize the resolution of visible change. Keep in mind that the highest and lowest values are not the same on all plots. Check the rainbow legend to find the max and min.

September highs and June lows illustrated in the surface water figures have to do with the balance of freshwater runoff of US rivers (maximum in spring) and evaporation (maximum in summer).

There is less seasonal and lateral variation in deep waters, and these waters are more reflective of the 35 ppt average of the world ocean.



CHEMISTRY

http://www.dynalysis.com/Projects/projects.html

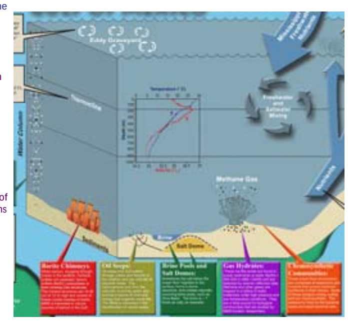
Get a copy of this excellent poster by contacting the MMS http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html

Brine Pools, barite chimneys, and oil seeps are features of the Gulf seafloor that influence it's chemistry. All are closely related to the deposition of salt and subsequent rocks discussed earlier.

Brine pools form by dissolution of salt that has migrated to the surface. Barite chimneys (~20cm high) occur when barium (frequently found in the salt layer) meets sulfate in the in the sea water. Oil seeps are caused by the migration of oil from reservoir rock to the surface (frequently near salt domes).

Gas hydrates (methane seeps) are another feature of the Gulf floor. These are formed where ice contains hydrocarbon like methane in its crystalline lattice. They occur at low temperature and high pressure (~300-500 m).

All of these features are associated with unusual communities.
Chemosynthetic communities (in which bacterial oxidize sulfide for an energy source and therefore provide organic matter for tubeworms and mussels to eat) are found near gas hydrates and oil seeps.



CHEMISTRY

http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html

No discussion of Gulf chemistry would be complete without considering the input of nutrients from the rivers that drain the Gulf watershed. These nutrients include nitrogen, phosphorus and silicon which phytoplankton use to photosynthesize in the presence of sunlight.

The microscopic algae use N and P to make their organic parts, while they use the Si to precipitate biogenic silica as tests (small shells) for protection.

The large freshwater inflow contributes to a large phytoplankton population and encourages productive food webs and healthy commercial fisheries throughout the Gulf of Mexico.

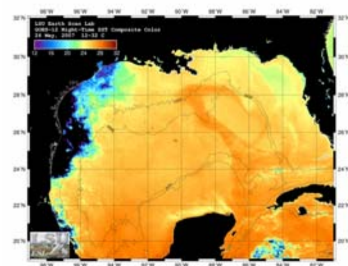
Falling particles from dead phytoplankton, zooplankton and fecal pellets deliver the organic material to the bottom of the Gulf where decomposition of the organic material releases the nutrients to the deep water

CHEMISTRY

http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html

Circulation in the Gulf of Mexico is part of the large-scale ocean circulation that connects different basins and moves water while balancing heat exchange between polar and equatorial oceans. Surface circulation is most easily observed using sea surface temperature images obtained from satellites.

This thermal figure is built by collecting and coding similarly pixels around the "warmest pixel" in a group from a sequence of night time imagery (obtained every 30 minutes) spanning about 10 hours. The pixel size is ~ 4km in size.

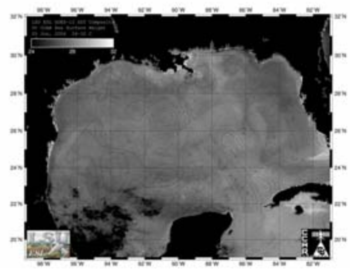


PHYSICS

http://www.esl.lsu.edu/research/CMI-GOES/s

Sea surface height is related to sea surface temperature in part by the relationship between temperature and density. Hotter water will have greater height because it is less dense.

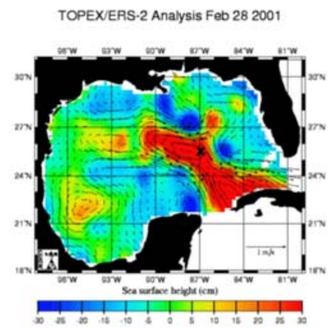
This figure shows a hill of higher water coming into the Gulf from the Caribbean via the Yucatan Strait.



PHYSICS

http://www.esl.lsu.edu/research/CMI-GOES/s

Another factor that contributes to sea-surface height is flow velocity. Clockwise (anticyclonic) flow coincides with high central pressure and pushes water up to make a small hill in the middle of circulating gyres. Arrows show direction and relative speed of water.



PHYSICS

http://www.csi.lsu.edu/physi.ocean.asp

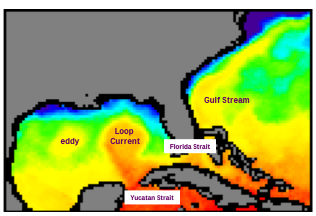
The Loop Current connects waters of the Gulf to the Caribbean and the Atlantic Ocean, where they join with the Gulf Stream to become one of the strongest currents in the world's ocean.

Warm water flows north through the Yucatan Strait, runs clockwise (anticyclonic) and exits through the Straits of Florida.

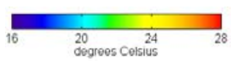
The Loop Current extends farther north in summer, and not as far in winter.

Sometimes the loop becomes unstable and an eddy (usually also clockwise) separates from the flow and drifts to the west. The figure shows an eddy as a roughly circular warm feature to the west of the warmer Loop Current.

Watch the Loop Current evolve and the eddy dissipate over a period of 6 weeks in 1998.

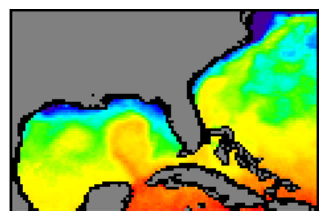


week ending 1/17/98



PHYSICS

http://www.ssmi.com/rss_research/viewing_ocean_currents_with_sst.html



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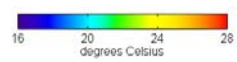

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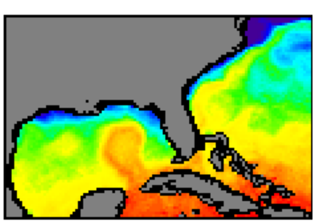

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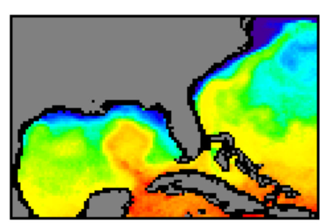
http://www.ssmi.com/rss_research/viewing_ocean_currents_with_sst.html



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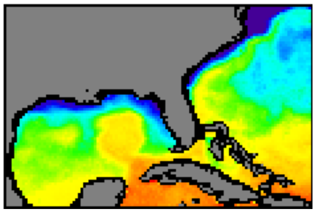

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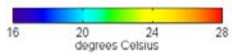
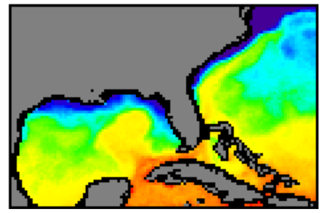


PHYSICS

http://www.ssmi.com/rss_research/viewing_ocean_currents_with_sst.html



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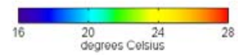


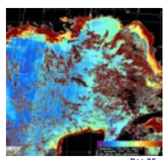
PHYSICS

http://www.ssmi.com/rss_research/viewing_ocean_currents_with_sst.html

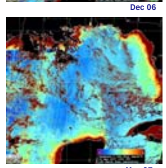
Chlorophyll *a* is produced by the phytoplankton that thrive in the nutrient rich coastal waters of the Gulf. The images show variation in the amounts of chlrophyll *a* – and thus phytoplankton production – in the eastern Gulf of Mexico for specific dates. The rainbow legend has two small white numbers – in all cases the number on the left is 0 and the number on the right is 4 (mg/cm3). But the color of 4 is darker in the May figure. So what does this say about production in May versus December this year?

The figures were produced using the Ocean Color Monitor (OCM), a satellite image used to estimate chlorophyll *a* concentrations as well as to quantify suspended sediments. This imagery has relatively high resolution, with pixels = 360m, while other types have 1km pixels.

Keep in mind that these measurements can be affected by many factors including, suspended sediment. So, realize the limits of the technique while interpreting the patterns.



Dec 06



May 07

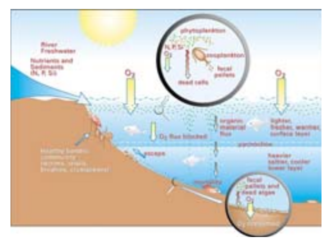
BIOLOGY

http://www.esl.lsu.edu/imagery/ocm/web/ocm_archive.php?day=2&month=1&year=2007&jpegtype=gom

The Gulf coast receives large volumes of river water from the Mississippi and Atchafalaya Rivers. The rivers flood from spring into summer, producing a stratified (layered) water column of dense, cooler seawater, overlain by lighter, warmer freshwater.

The nutrient rich water above fuels large phytoplankton blooms on the shelf. Phytoplankton incorporates oxygen into the upper layer of water.

The stratification is associated with a pycnocline (rapid vertical change in density) across which oxygen from the surface layer cannot pass. But dead organic matter does fall through and consumes oxygen through decomposition. This is a natural process.

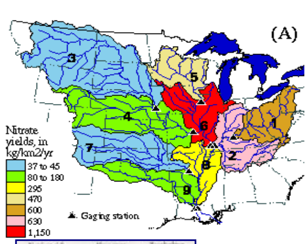


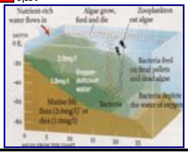
BIOLOGY

In recent decades, greater quantities of nutrients being delivered by the Mississippi and Atchafalaya Rivers has caused blooms of plankton that contribute large amounts of OM to bottom waters, resulting in a large area of oxygen depletion off of the Louisiana and sometimes Texas Coast.

This is known as the 'dead zone.' The process of hypoxia formation is similar to that which occurs in many estuaries along highly populated parts of the Gulf coast.

It results from the use of artificial fertilizers that runoff into the rivers, as well as discharges of municipal sewage or livestock manure.





(Goolsby et al., 1999)

BIOLOGY

The issue of hypoxia illustrates an extremely important ecological fact.

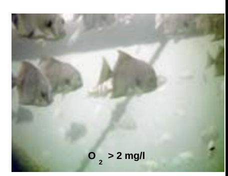
Biology in the Gulf of Mexico is highly related to abiotic factors: chemical (nutrient), physical (stratification), and geological (river) factors.

On the other hand, biology, by the presence of specific organisms, may change the way that the abiotic processes manifest.

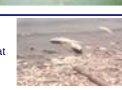
Example:
As a result of hypoxia, we are likely to see deposition of highly organic clastic sediments or different types of biogenic sediment (because of different types of phytoplankton population changes).

Changes in the food web might result in different ratios of nutrients present in the water column at any given time.

The same principles apply throughout the Gulf. The types of organisms that can be observed are highly related to the abiotic environment (including climate, which was not discussed here).



- Direct mortality
- Altered migration
- Reduction in suitable habitat
- Increased susceptibility to predation
- Changes in food resources
- Susceptibility of early life stages



BIOLOGY

Courtesy of N. Rabalais

Therefore, in the Gulf we see many types of animals that are observed in the world ocean, but their distribution is determined by abiotic features and processes that have been described in this presentation.

Water depth contributes to occurrence of mammals: dolphins on the continental shelf, sperm whales on the continental slope and deeper, no blue whales.

BIOLOGY

http://www.gomr.mms.gov/images_opt/graphics/lagniapp/whalebig.jpg

Sediment composition and texture controls shoreline infauna with specific types of organisms associated with fine grained silt and clay versus sandy beaches.

The amount of sediment carried in the water is also important, so Louisiana shores with high suspended sediment concentrations are less likely to see horsehoe crabs that any of the other US Gulf coastal beaches.

Florida has sandy beaches, but the sand is made of calcium carbonate, which comes with its own specific faunal assemblage.

BIOLOGY

www.mexico-with-heart.com ; www.bertaut.com/realfish25.html
www.dauphinislandtimes.com/photos
www.napleshamptoninn.com/apg_1163882466.php

A whole suite of abiotic factors controls the types of organisms observed anywhere in the Gulf. And the Gulf is considered one of the most productive parts of the world ocean (http://www.gulfbase.org/facts.php).

Nutrients delivered by land create many commercially viable fisheries.

Amberjack, Greater
Seriola dumerili

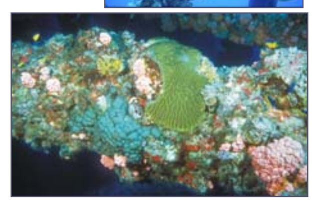
Tuna, Blackfin
Thunnus atlanticus

BIOLOGY

http://www.rodnreel.com/gulffish/gulffish.asp?cmd=view&FishID=1

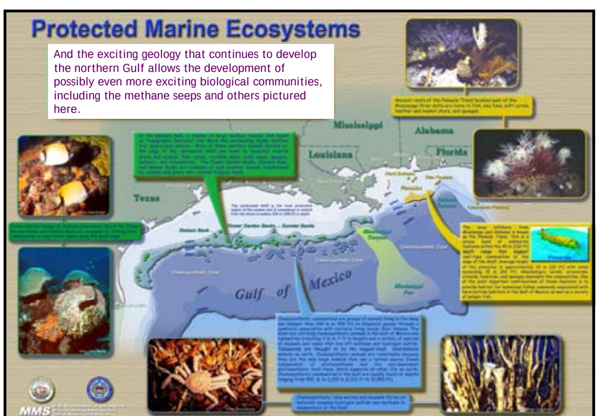
Shallow Florida and Yucatan platforms allow growth of coral reef and associated diverse fauna.

Coral are also found far from the suspended sediment that would suffocate them on the Louisiana-Texas coast in deep offshore waters, made accessible to the necessary sunlight by salt domes (Flower Garden Banks) and oil rigs (as shown in figure).



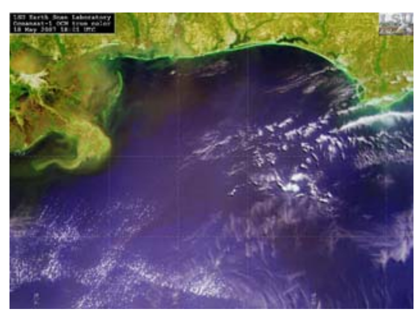
BIOLOGY

Photos courtesy of P. Sammarco



And the exciting geology that continues to develop the northern Gulf allows the development of possibly even more exciting biological communities, including the methane seeps and others pictured here.

http://www.gomr.mms.gov/images_opt/graphics/lagniapp/2006-003P.jpg



... thus ends a brief natural history of the Gulf of Mexico ...

The topics were diverse and not covered exhaustively. Please contact me if you have any questions or want to discuss anything in greater detail.

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