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[PS]Holocene Cyanobacterial Mats and Lime Muds: Links to Middle East Carbonate Source Rock Potential*

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Abstract

Carbonate reservoirs ranging in age from Permian to Tertiary contain most of the 675 Bbbl of Arabian Gulf hydrocarbon reserves. Two major Holocene organic sources serve as probable models: whitings that turn part of the Arabian Gulf milky white; and cyanobacteria forming mats on intertidal areas. The mud and cyanobacteria is quickly sequestered into the sedimentary section in the axial trough of the Gulf and extensive tidal flats that rim it. Short-lived isotopes in the Bahama banks support the instantaneous character of whiting precipitation. Source rock analysis of the Gulf carbonate mud/cyanobacterial deposits demonstrates that these sediments are future source beds for hydrocarbons. Twenty-five percent of the 1.3 million metric tons precipitated and suspended each year in the Bahamas is organic matter, dropping to 1.8% of the surface sediment. The Bahamian Bank whitings and associated organic matter covering more limited areas is swept off the bank into deep water. Cores through Neogene western platform slope sediments preserve 1% TOC up to 4%. Cyanobacteria may contribute more hydrocarbons than previously thought. Organic matter associated with whiting blooms is believed to be dispersed in the lime muds of the ancient Arabian Gulf section and may have generated large volumes of its oil. Cyanobacterial membranes liquefy at low threshold temperatures. A short time interval burst of oil generation could produce transient overpressures liberating oil by micro fracturing and in some cases long-range migration. Rapid accumulation of large volumes of oil in a short time-span would provide the collective buoyancy necessary to drive large-scale migration. We propose that whitings of the modern Arabian Gulf are the key to the origin of the vast petroleum reserves of this region.

Holocene Cyanobacterial Mats & Lime Muds Links to Middle East Carbonate Source Rock Potential

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ABSTRACT

Carbonate reservoirs ranging in age from Permian to Tertiary contain most of the 675 Bbbl of Arabian Gulf hydrocarbon reserves. Two major Holocene organic sources serve as probable models: whitings that turn part of the Arabian Gulf milky white; and cyanobacteria forming mats on intertidal areas. The mud and cyanobacteria are quickly sequestered into the sedimentary section in the axial trough of the Gulf and extensive tidal flats that rim it. Short-lived isotopes in the Bahama Banks support the instantaneous character of whiting precipitation. Source rock analysis of the Gulf carbonate mud/cyanobacterial deposits demonstrates that these sediments are future source beds for hydrocarbons. 25% of the 1.3 million metric tons precipitated and suspended each year in the Bahamas is organic matter, dropping to 1.8% of the surface sediment. The Bahamian Bank whitings and associated organic matter covering more limited areas are swept off the bank into deep water. Cores through Neogene western platform slope sediments preserve 1% TOC up to 4%. Cyanobacteria may contribute more hydrocarbons than previously thought. Organic matter associated with whiting blooms is believed to be dispersed in the lime muds of the ancient Arabian Gulf section and may have generated large volumes of its oil. Cyanobacterial membranes liquefy at low threshold temperatures. A short time interval burst of oil generation could produce transient overpressures liberating oil by micro fracturing and in some cases long-range migration. Rapid accumulation of large volumes of oil in a short time-span would provide the collective buoyancy necessary to drive largescale migration. We propose that whitings of the modern Arabian Gulf are the key to the origin of the vast petroleum reserves of this region.

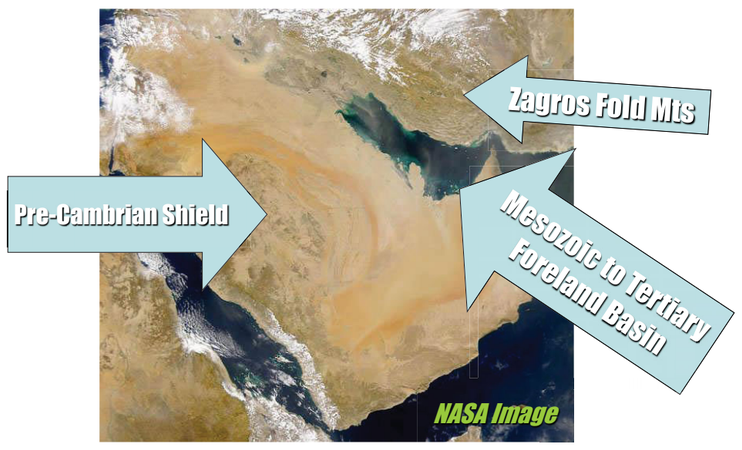
Hypothesis

- There are significant Holocene accumulations of cyanobacteria & lime mud in the Arabian Gulf axis & tidal zones
- These sediments have source rocks potential
- Similar sediments have accumulated since Triassic
- These ancient carbonate muds are source of the significant petroleum reserves of Arabian Gulf region
- The present is the key to the past!

CURRENT MIDDLE EASTERN RESERVES

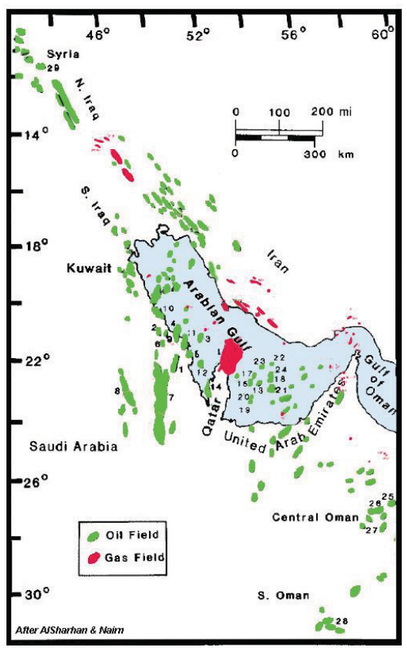
	Crude Oil (BB) -	Natural Gas (TCF)
Saudi Arabia	264.3 bbls	204.5 Tcf
Iran	132.5 bbls	945.0 Tcf
Iraq	115.0 bbls	110.0 Tcf
Kuwait	101.5 bbls	55.0 Tcf
UAE	97.8 bbls	212.0 Tcf
Qatar	15.2 bbls	910.0 Tcf
Oman	5.3 bbls	29.4 Tcf
Yemen	4.0 bbls	16.9 Tcf
Syria	2.5 bbls	8.5 Tcf
Bahrain	0.1 bbls	3.9 Tcf

Structural Province's - Arabian Gulf



The Mesozoic to Tertiary Foreland Basin has sequestered in excess of 2,500 meters of sediment that form the reservoirs and source rocks of the worlds largest oil fields.

MIDDLE EAST FIELDS



LOW % OF DISPERSED ORGANIC MATTER SOURCES MAJOR FIELDS?

Hydrocarbon Source

- Collister, Ehrlich, Mango, and Johnson (AAPG, 2004) show alkanes & isoprenoids dispersed in rocks are result of direct conversion of primary organic materials to oil.
- Source rocks with low TOC or considered undermature can generate significant oil when source carries enough of special kerogen derived from biological membranes unchanged until the time of liquefaction.
- Observations & experiments, mostly in French labs, show resistant organic membranes in the form of biopolymers play this role.
- Stable over a large range of conditions, surviving both early secondary bacterial attack and a late-stage progressive breakdown under increasing thermal stress.

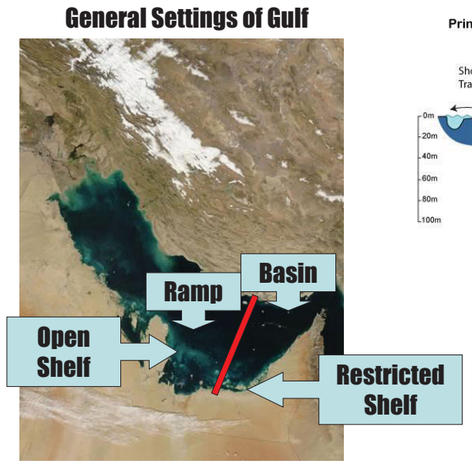
Analysis in Crude Oils of Alkanes & Isoprenoids

- The alkane/acyclic isoprenoid fraction is the main constituent of most crude oils.
- A large number of crude oils and rock extracts from Timan-Pechora basin (Russia) suggest this fraction is direct product of liquefaction of biological debris preserved essentially unaltered till oil generation.
- Result is the primary biological provenance of this fraction is preserved in the oil fraction.

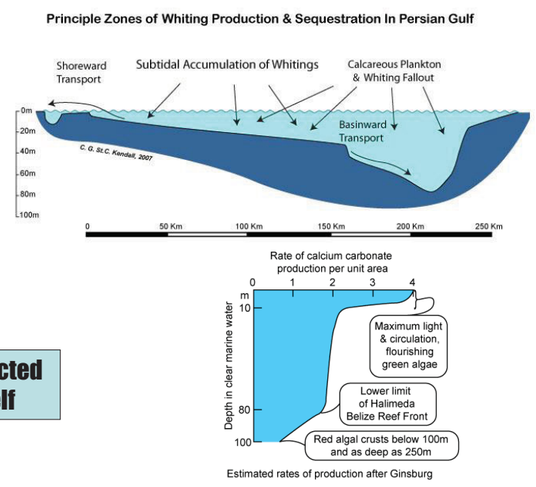
Gulf Whiting & Organic Matter Sequestration

Whiting mud-sized carbonate is sequestered in axial trough of Arabian Gulf and tidal flats of the coastal margins. Dispersed organic matter, though probably forming less than 1% of sediment signal since the Mesozoic, forms a formidable source for the hydrocarbons of the Gulf.

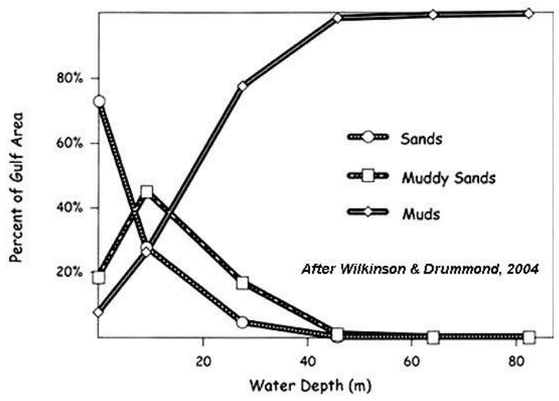
General Settings of Gulf



Principle Zones of Whiting Production & Sequestration In Persian Gulf



Persian Gulf Mud Distribution

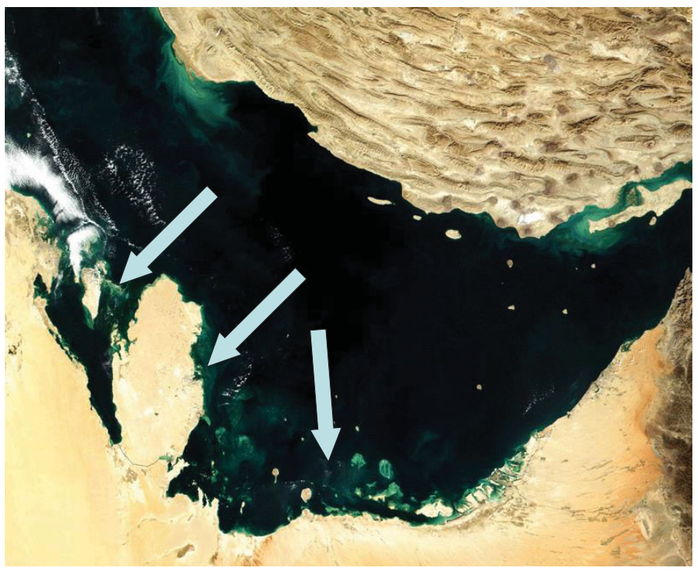


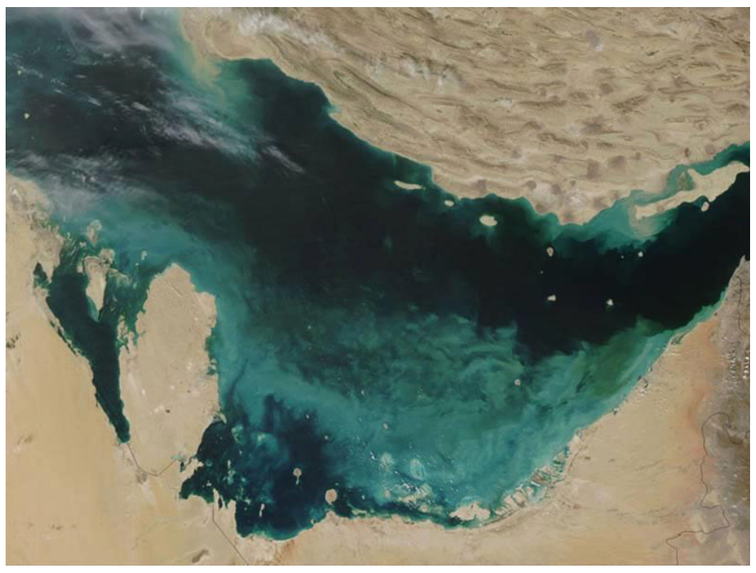
Gulf Whiting Precipitates

JACKSON SCHOOL OF GEOSCIENCES

Local Whitings

Arabian Gulf areas (NASA satellite scene) with very localized & diminished 'Whitings' (lime suspensions) off UAE on Pearl Bank, offshore East Qatar, north flank of Bahrain shoal, and offshore from Saudi/Kuwaiti border.

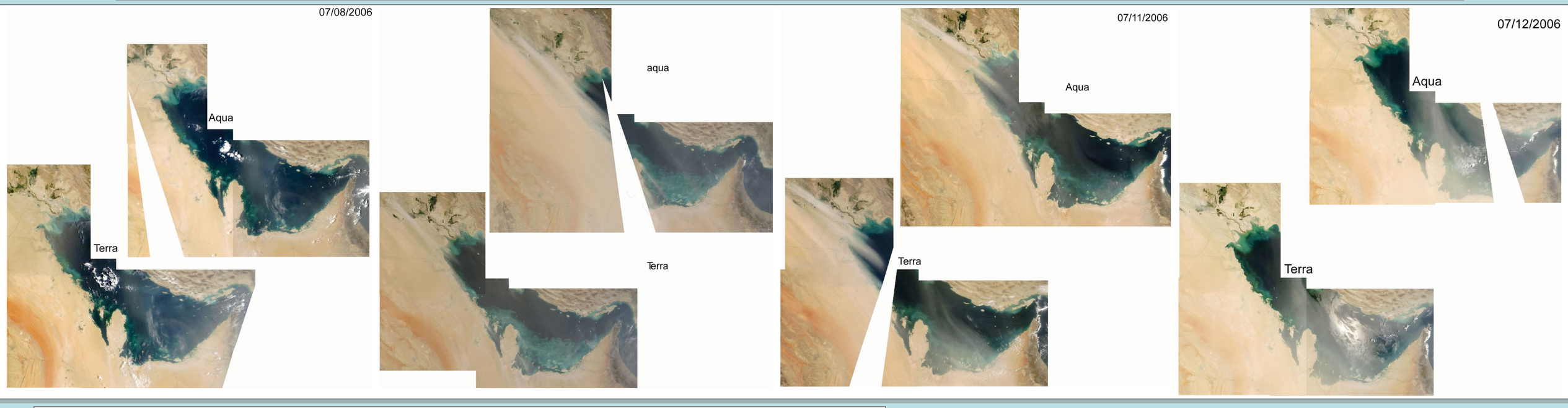




Regional Whiting

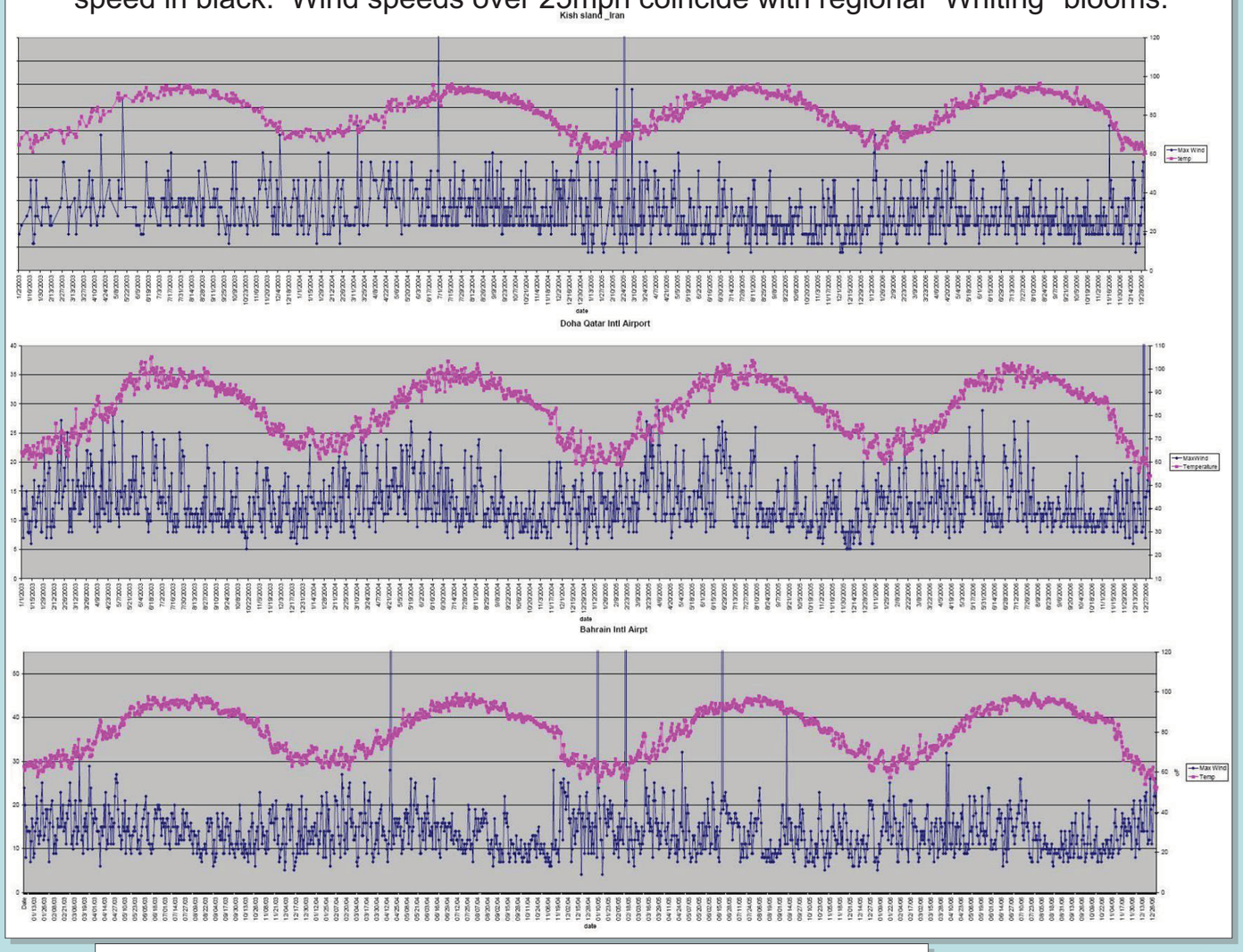
Arabian Gulf areas (NASA satellite scene) with extensive 'Whiting' (lime suspension) from Saudi to offshore the northern UAE over water often deeper than ten to twenty meters.

Satellite scenes SW, to West coast of Arabian Gulf captured 8 thru 12 July 2006, MODIS Rapid Response system site, NASA http://rapidfire.sci.gsfc.nasa.gov/.



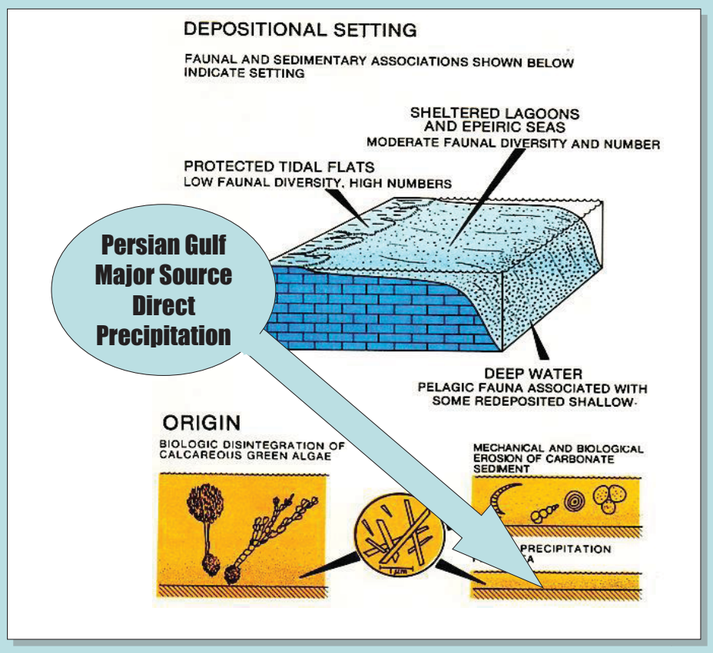
Weather station data

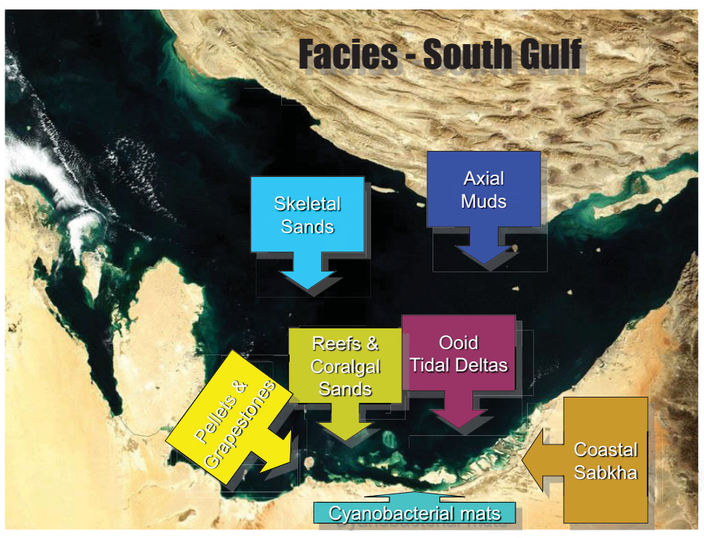
From Kish, Iran; Doha Airport; and Bahrain Airport with temperatures in pink & mph wind speed in black. Wind speeds over 25mph coincide with regional "Whiting" blooms.

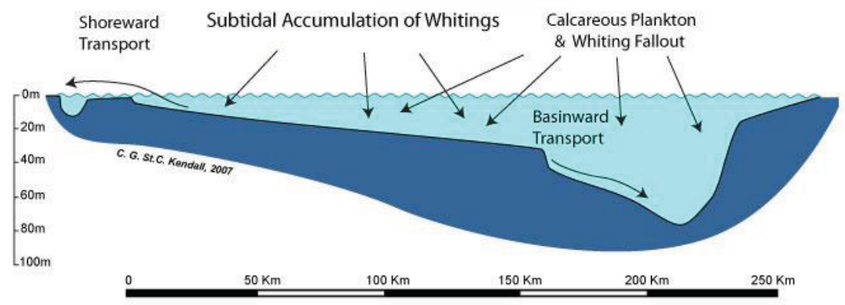


Wells and Illing (1964)

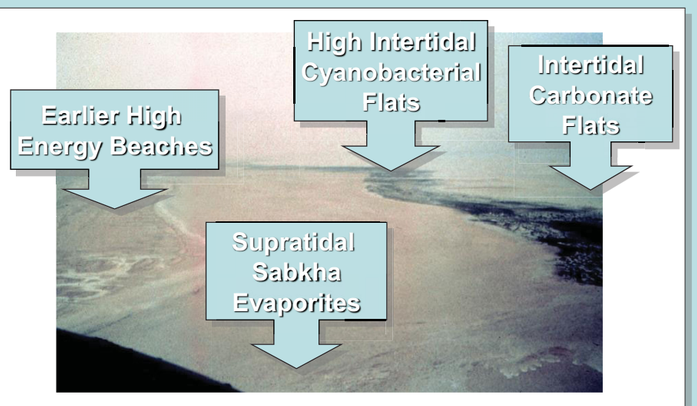
Among first to report whitings precipitated in Persian Gulf offshore Qatar, ascribing precipitation to photosynthetic removal of CO_2 by phytoplankton. Lab analysis by Groot (1964) established that suspended sediment from offshore was composed of 70% aragonite, 10% calcite, 15% mg calcite 5% quartz and 5% dolomite. He precipitated aragonite from Gulf waters over 2 to 3 weeks using $NaCO_3$ to remove CO_2 but rates did not match instantaneous formation of "whitings".

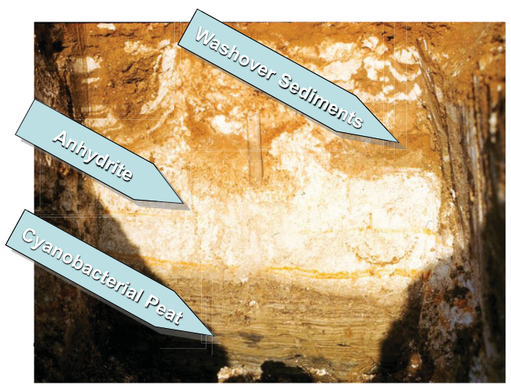






Lime muds & organics sequestered in axial trough & tidal flats

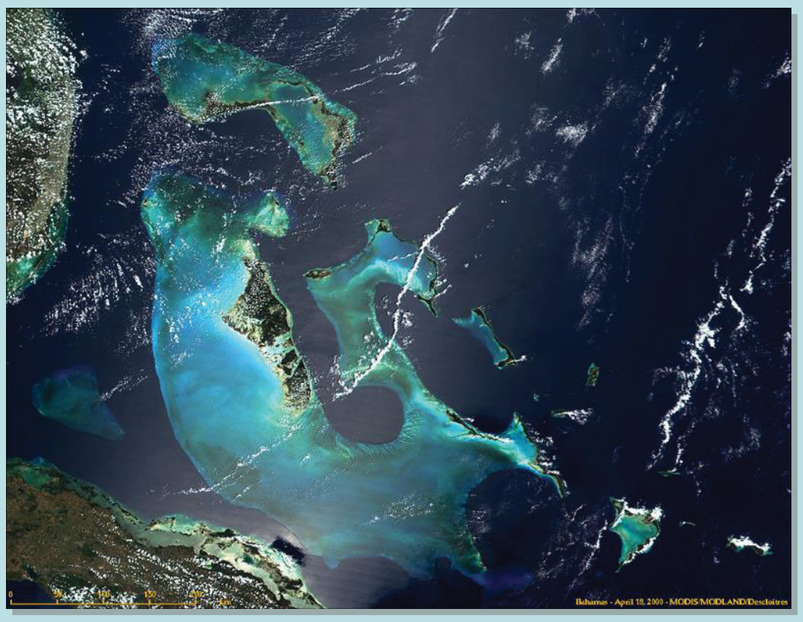


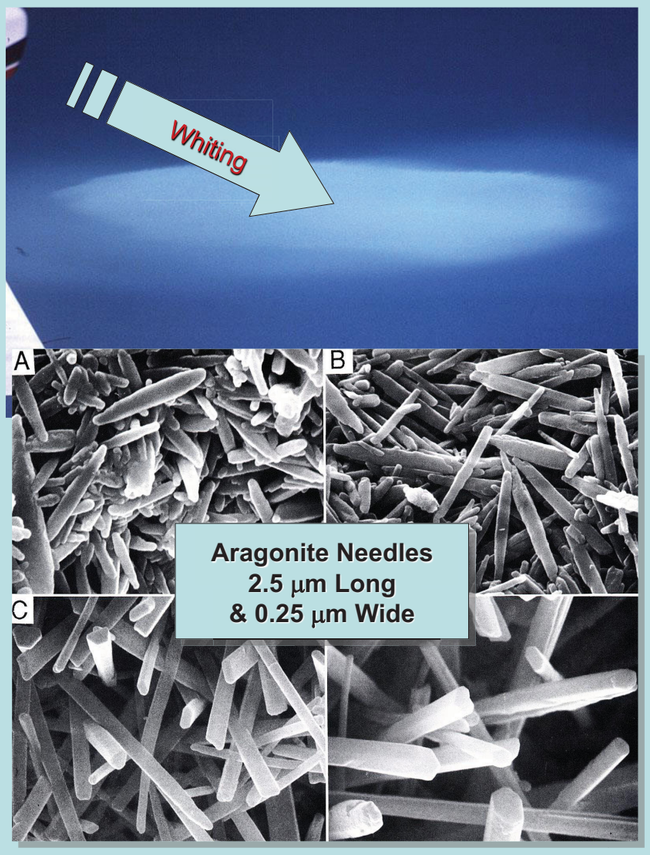


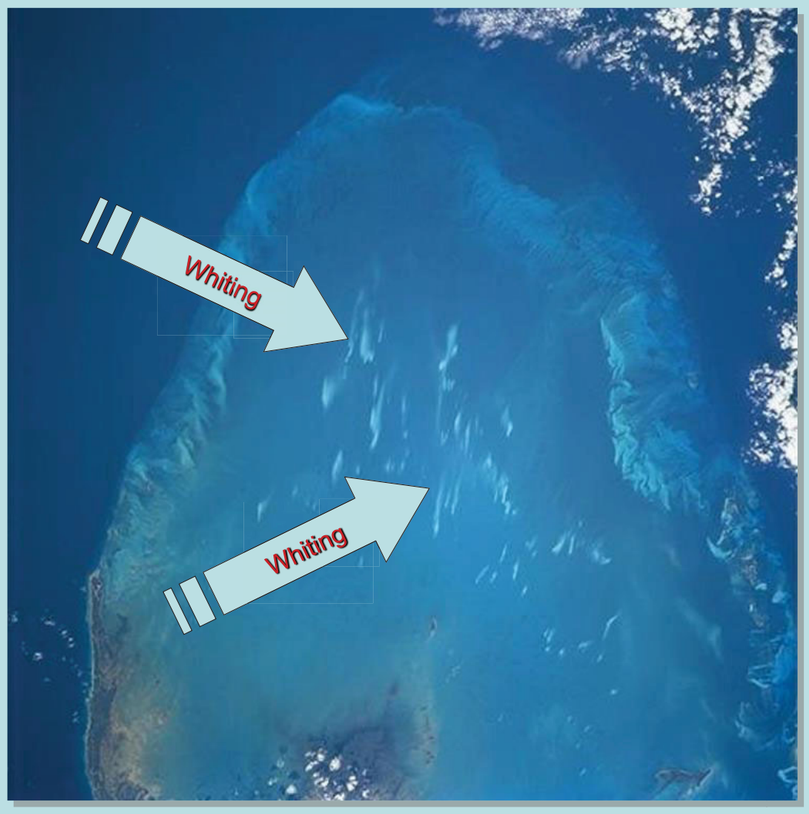
Lime mud sequestered in both basin axis and tidal flats

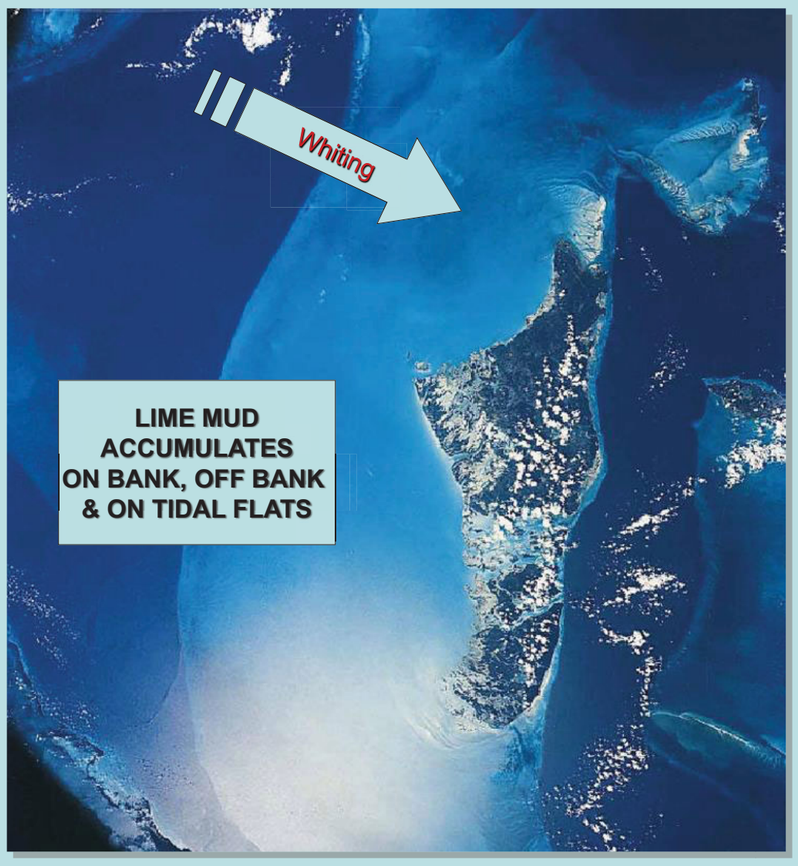
Holocene tidal flats are sequestering >1% of weight as organic matter!

Bahamian Whiting Precipitates



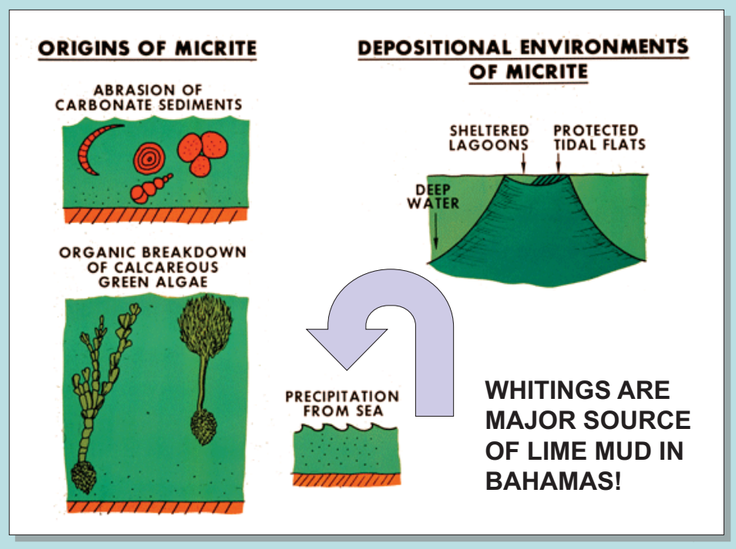






Instant Precipitates

Bahamian whitings represent instantaneous chemical or biochemical precipitation of aragonite (Shinn et al, 1989; Robbins and Blackwelder, 1992; and Robbins et al.,1997) with water outside whitings clear while whitings are a vivid white! Many whitings exist at one time drifting back and forth with the tides continually raining sediment to the bottom. No 'whiting' researcher has documented the dispersal or end of a whiting. Each wanes in intensity at slack tide only to strengthen when the tide rotates to the other direction. Cloud (1961) followed a single whiting for 48 hours and Shinn et al. (1989) followed whitings for 24 hrs. A group that persisted for 24 hrs over hard pellet sands where no mud could be stirred into suspension. Shinn et al. (1989) returned to the same whitings still drifting over pellet sand 2 days later and Robbins et al. (1997) documented their persistence from satellite images. In contrast artificial whitings, made by stirring the bottom with a large net, settled within 6 hours while nearby natural whitings persisted and did not dissipate (Shinn et al. 1989). Whiting water pumped into settling tanks aboard a boat settled in 6 hrs.



Rates of Accumulation

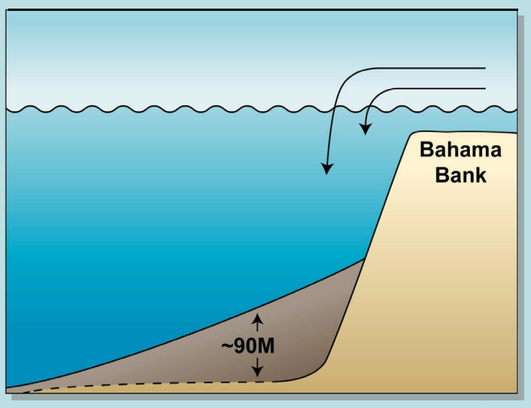
Short-lived isotopes determined rates of accumulation (Shinn et al., 2000). Bottom sediment, and filtered bottom sediment that had been suspended by a storm, were compared with sediment filtered from active whitings. Samples analyzed within 20 days of collection were examined using a high-resolution gamma ray spectrometer for short-lived isotopes Be-7 and Th-234. These have respective half lives of approx. 53 and 23 days. Active billowing whitings had Be-7 and Th-234 but the bottom sediment was depleted while none of the bottom sediment stirred up during a storm contained these short-lived isotopes. If these radiogenic elements were adsorbed on the sediment surface, or if epitaxial growth had occurred, these short-lived isotopes would be present.

Whiting Mud Sequestration

The passage of each hurricane exports lime mud spilled over the edge of the bank during winter storms in vast quantities. As a result in 1992, 7 weeks after passage of Hurricane Andrew, lime mud collected as layers up to 5 cm thick over shallow ooid sand areas near the bank edge (Shinn et al., 1993). These layers were interpreted to come from a slurry of lime mud exiting the bank en route to the Florida Straits and Tongue of the Ocean. This Holocene sediment collected as an up to 90-m-thick wedge at the base of the Bahama Bank slope (Wilber et al.,1990) representing 40 to 80% by volume of the mud presently sequestered for the entire bank. The vertical and lateral progradation rate for this wedge is 11-15 m/ka and 80-110 m/ka, respectively (Wilber et al., 1990). This measures the amount accumulated during the last 6-8 ka and does not consider whiting mud carried northward in the Gulf Stream to distant locations and/or to dissolution.

Ball et al. (1967) and Perkins and Enos (1968) report significant off-bank sediment transport in Florida following Hurricanes Donna and Betsy. Similar observations were made and photographed in Florida by Shinn following Hurricane Andrew in 1992. Lime mud-laden sediment continues to spill off the platform for weeks following a hurricane. The Bahamian Bank has been submerged for the past 6-8 ka and is affected by a hurricane every 6 to 10 years. Overproduction, possibly far greater than 280%, is necessary to account for what is presently on the bank.

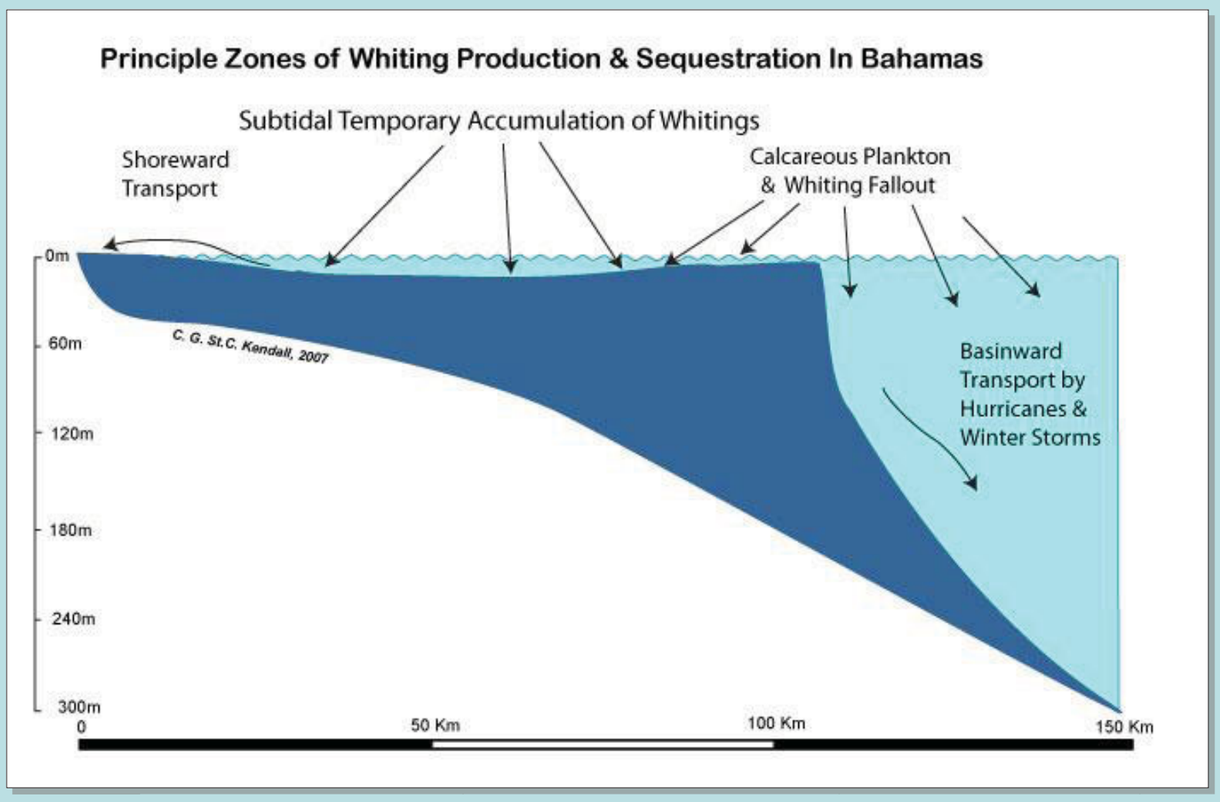
Sequestration in Downslope Wedge

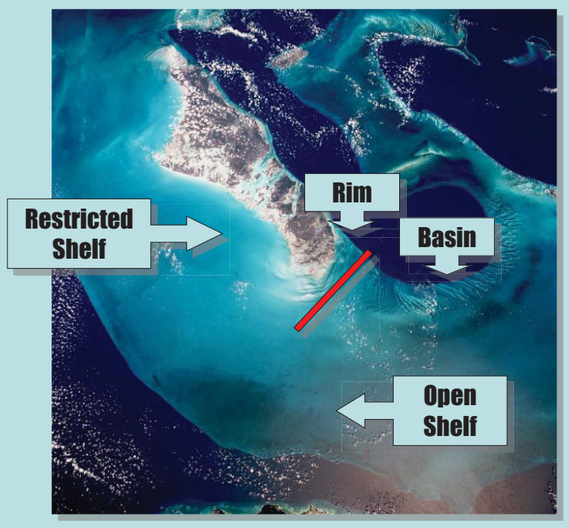


Sequestration on Tidal Flat

Little Bahama Bank 03
Be-7 (dpm/g)

Whiting #1	5.58	+/- 0.52
Dissolution 1/4	8.42	+/- 1.41
Dissolution 1/8	12.12	+/- 1.37
Bottom sed	0.44	+/- 0.17
Sail Cay whiting	2.56	+/- 0.57
Art whiting	Trace (1.6)	N/A
Art bottom sed	Trace (0.19)	N/A
M.A. air samp	1835.0	+/-65.21





Organic Matter

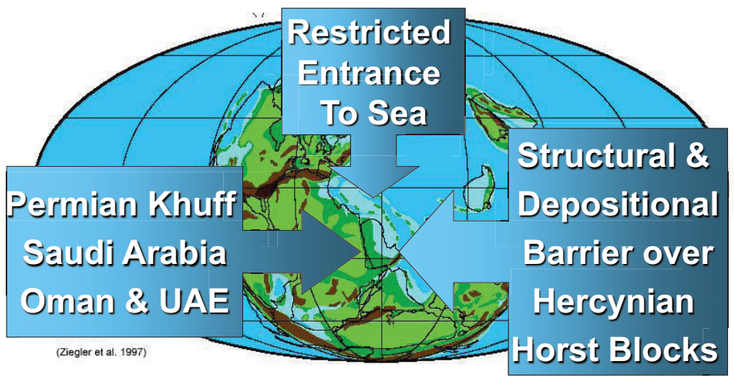
Phytoplankton nuclei cores to cells

Viable phytoplankton cyanobacterial cells documented in whitings by Robbins and Blackwelder (1992) have not been observed in bottom sediment because they deteriorate quickly after deposition. However viable cells are present in the center of aragonite needle clusters in active whitings. Sediment stirred from the bottom is days to months old and contains only deteriorated organic matter. Aragonite needles adhering to the surface of living planktonic cyanobacteria, as documented by Robbins and Blackwlder (1992) and in publications by Yates indicates rapid precipitation within the water column (Yates and Robbins, 1998; Yates and Robbins; 1999, Yates and Robbins, 2001). However 25% of the 1.3 million metric tons precipitated and suspended each year in the Bahamas is organic matter, dropping to 1.8% of the surface sediment.

The Bahamian Bank whitings and associated organic matter covering more limited areas are swept off the bank into deep water. Cores through Neogene western platform slope sediments preserve 1% TOC up to 4% (Kramer, Swart, DeCarlo & Schosvbo, 2005).

Geological setting of Arabian Gulf oil fields and their hydrocarbons are related to sequestered cyanobacterial remains in geologic section

Arid Tropics Air System

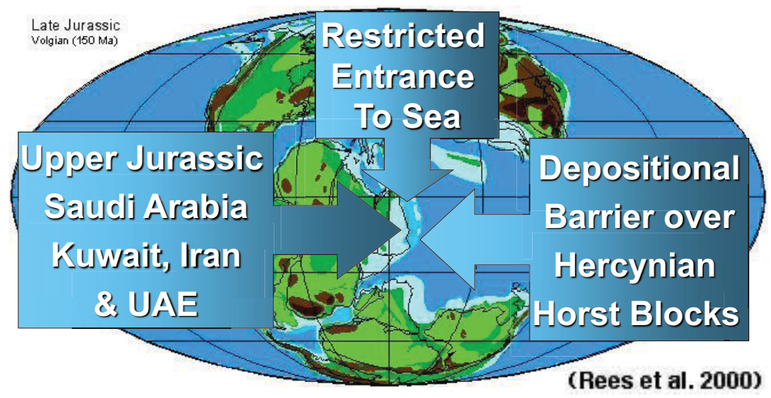


Wide Shadow from Adjacent Continents

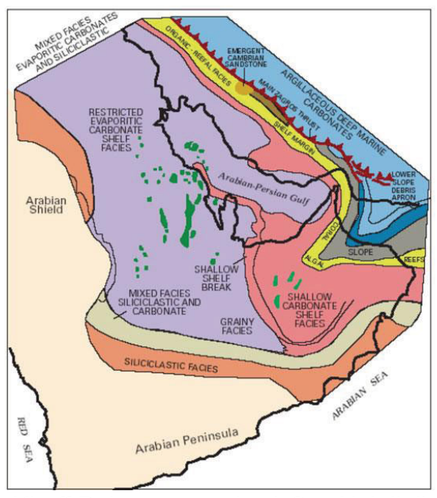
Khuff & Tuwaik Mt Grp Settings

Permian Khuff and Jurassic Tuwaik Mt Group accumulated in similar interior basin settings with high potential for generation of lime mud associated with organic matter with a high potential for preservation and generation of hydrocarbons, as evidenced by the current field development.

Tropical Air System !

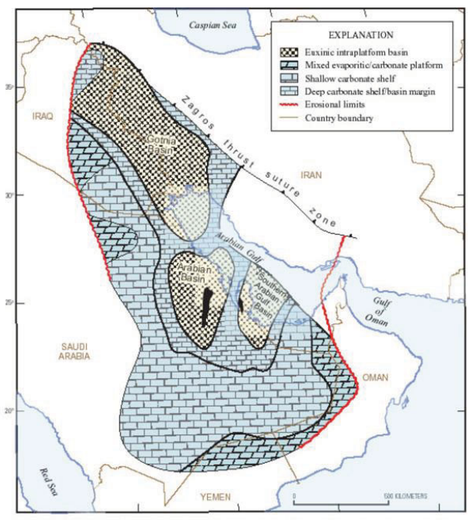


Wide Shadow from Adjacent Continents

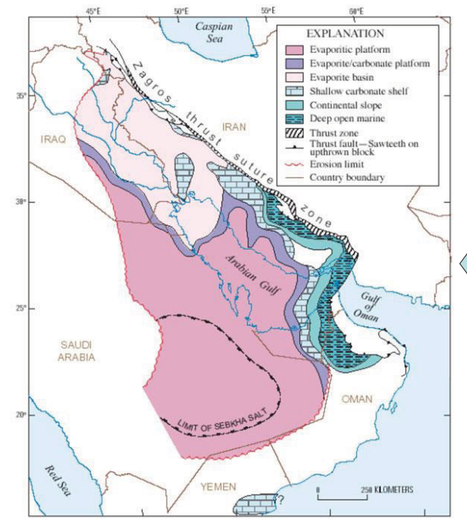


Khuff Paleogeography (after Al Jallal)

Lime Source



Lime Source



Lime Source

GOTNIAN DEPOSITIONAL SETTING (*Al-Sharhan & Kendall, 1986*)

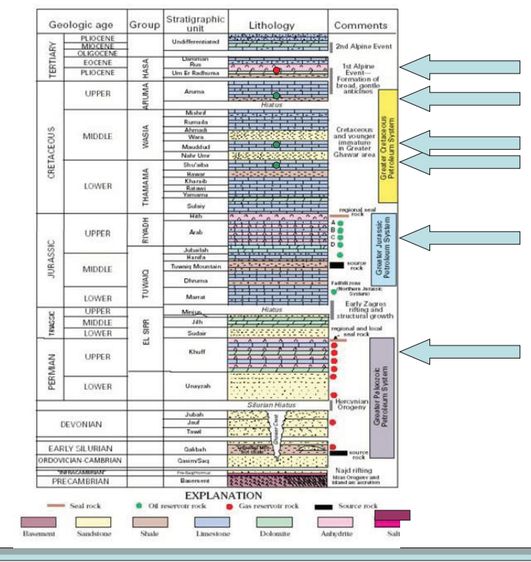
Hydrocarbon Production of Arabian plate Stratigraphic section

-

Section represents approx 2,438.5m in 200 My

-

Accumulation Rate 1.22 mm per 1 ky



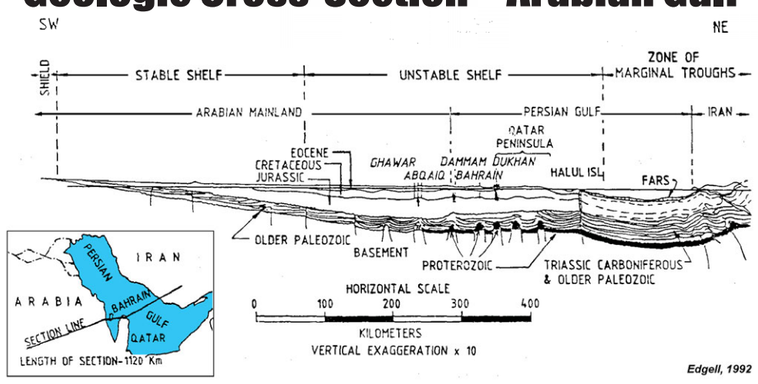
Arabian Gulf Basin

Traces complex history of tectonics, sedimentary fill & hydrocarbon production which is older to west [Paleozoic] & younger at Arabian Gulf Coast [Mesozoic] & youngest in east in Zagros Mts [Upper Tertiary]:

- **PreCambrian to Infra-Cambrian - *Salt Production in Continental Interior***
- **Silurian and Ordovician clastics - *Unaizah Production of Continental Interior***
- **Permian clastics & carbonates - *Khuff Production of Trailing margin***
- **Upper Jurassic carbonates - *Arab & Tuwaik Mt Grp Production Trailing margin***
- **Lower Cretaceous carbonates - *Shuaiba & Thammama of Production of Trailing margin***
- **Middle Cretaceous – *Mishrif Production of Compression & Zagros Mts starts***
- **Tertiary carbonates & clastics - *Asmari Production Compressional margin***

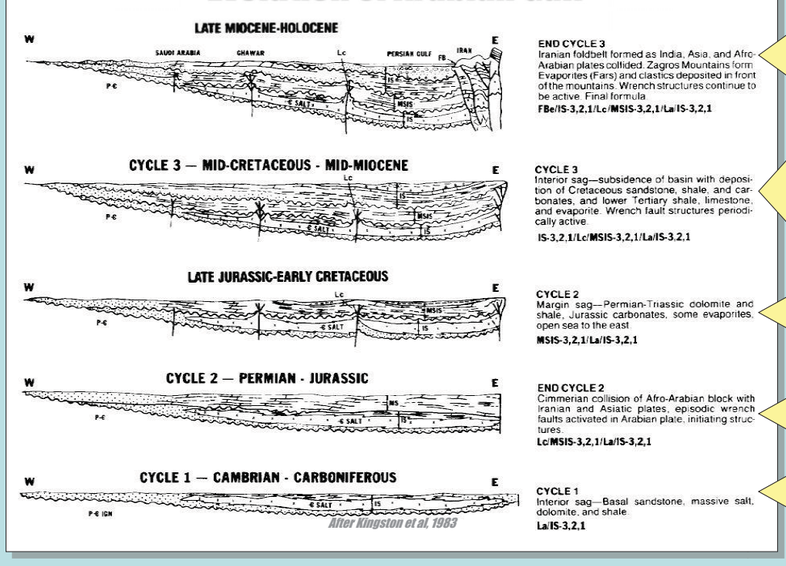
Mesozoic through Tertiary - Lime Mud Source

Geologic Cross-Section - Arabian Gulf



Edgell, 1992

Evolution of Arabian Gulf



Foreland Basin

Compression & Foreland Basin

Extensional margin

Extensional margin

Interior Sag

Classic Hydrocarbon Source, Seal, & Reservoir

Source Rocks

- ***Permian Khuff - Saudi Arabia***
- ***Lw Jurassic Tuwaiq Mt. Group - Saudi Arabia***
- ***Lw Cretaceous Maudud Fm. of UAE***

Seals

- ***Usually playa & sabkha evaporites***

Reservoirs

- ***Deep Ghawar***
- ***Berri, Ghawar***
- ***Zakum Field, UAE Thamama I, II, & III, Shaybah***
- ***Mishrif***
- ***Asmari***

ORGANIC MATTER HYPOTHESIS

- Since the Triassic, Arabian Gulf sink for organic matter probably in form of multiple organic blooms.
- Organic matter trapped in intertidal flat & basinal muds.
- Biological membranes form dispersed organic matter with simple chemical composition & structure, liquefying at threshold temperature, requiring no time & temperature history for maturation.
- Burst of oil generation produces transient overpressures with liberation of oil by microfracturing and long-range migration through these fractures.
- Ensures large volumes of oil generated over a short time.

CONCLUSIONS

- Cyanobacteria & mud form significant accumulations in Holocene axis & tidal zones of Arabian Gulf.
- These sediments have source rocks potential.
- Similar sediments accumulated since Triassic.
- These ancient carbonate muds are source of significant Arabian Gulf reserves.