Complex Feed Back Loops Controlling Heterozoan Reef Development on Salt Diapirs, La Popa Basin, Mexico*

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Search and Discovery Article #50260 (2010)
Posted May 31, 2010

*Adapted from 2007-2008 AAPG Distinguished Lecture. Please refer to companion article, by the author; it is entitled "Tracking the Migration of Salt Diapirs Using Halokinetic Sequence Stratigraphy" and is Search and Discovery Article #40534 (2010).

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Abstract

In the distal part of the Hidalgoan foreland basin in NE Mexico three, isolated carbonate platforms nucleated on seafloor topography created by vertically rising passive diapirs. The platforms developed in both the Late Cretaceous (Maastrichtian) and early Paleocene and are composed of heterozoan fauna dominated by coralline red algae, benthic foraminifera, sponges, and bivalves.

Carbonate facies type and architecture of each platform was distinctly influenced by the complex interplay of both short-term local conditions surrounding individual diapirs and by long-term regional conditions that affected the entire shelf. Local conditions included windward-leeward platform geomorphology, possible cold seeps at the salt-sediment interface, and halokinesis. Regional conditions included eustatic sea-level fluctuations, foreland basin tectonism, and siliciclastic sediment supply to the outer shelf via hyperpycnal flows. No single factor dominates the system, but each plays a recognizable role in the final outcome of facies type, geometry, and initiation and demise of the platform.

Platform facies are distributed asymmetrically across individual diapirs, reflecting windward versus leeward margin paleogeographic setting and differential minibasin subsidence related to salt withdrawal. Carbonate facies form the base of angular unconformity-bounded carbonate/siliciclastic cycles called "halokinetic sequences." The cycles reflect local variations in net diapiric-rise rates versus local sediment accumulation rates and vary in number and character between the different diapirs and between the windward and leeward margins of each diapir.

The presence of heterozoan faunal assemblages forming the platforms may be in response to high nutrient levels from local methane seeps forming at the salt-sediment interface and from continental runoff. The platforms form in the upper parts of parasequence sets developed within the transgressive systems tract (TST) of 3rd-order distal-deltaic siliciclastic depositional sequences. Hidalgoan shortening of La Popa

basin formed large wavelength salt-cored detachment folds. Diapirs that lie in the hinges of folds were shortened or “squeezed” significantly more than diapirs that lie on the limbs of folds. Squeezed diapirs generated much higher and broader topographic relief and are dominated by extensive, thick, shallow water (<15m deep) sponge, red algal reef and grainstone bank facies, whereas limb diapirs contain thin, deeper water (>30m deep) silty, red algal packstone facies reflecting lower carbonate production rates in a deeper water setting.

References

Bates, C. C., 1953, Rational theory of delta formation: AAPG Bulletin, v. 37, p. 2119-2162.

Betzler, C., Brachert, T.C., Braga, J.C., and Martin, J.M., 1997, Nearshore, temperate, carbonate depositional systems (lower Tortonian, Agua Amarga Basin, southern Spain): implications for carbonate sequence stratigraphy: Sedimentary Geology, v. 113, p. 27–53.

Carannante, G., Esteban, M, Milliman, J.D., and Simone, L., 1988. Carbonate lithofacies as palaeolatitude indicators: problems and limitations. Sedimentary Geology, v. 60, p. 333-346.

Goldhammer, R.K., 1999, Mesozoic sequence stratigraphy and paleogeographic evolution of northeastern Mexico, in Mesozoic sedimentary and tectonic history of north-central Mexico: Geological Society of America Special Paper No. 340, p. 1-59.

Harris, P.M., 1994, Part 2: Satellite images and description of study areas - Great Barrier Reef, Australia, *in* Harris, P.M., and W.S. Kowalik, eds., Satellite Images of Carbonate Depositional Settings: AAPG Methods of Exploration no. 11, p. 105-113.

James, N.P., 1997, The cool-water carbonate depositional realm, *in* James, N.P., and Clarke, A.D., eds., Cool-Water Carbonates: SEPM Special Publication 56, p. 1–20.

Klosterman, S.L., M.R. Sandy, F.J. Vega, K.A. Giles, K. Graf, D. Shelley, and J. Sole, 2007, New Paleocene Rhynchonellide brachiopods from the Potrerillos Formation, Northeast Mexico: Journal of Paleontology; May 2007; v. 81; no. 3; p. 483-489;

Kneller, B.C., and McCaffrey, D.W., 1995, Modeling the effects of salt-induced topography on deposition from turbidity currents, in Salt, Sediment and Hydrocarbon: GCS-SEPM Foundation 16th Annual Research Conference, p. 137–145.

Lees, A., 1975, Possible influence of salinity and temperature on modern shelf carbonate sedimentation: Marine Geology, v. 19, p. 159-198.

Lees, A. and A.T. Buller, 1972, Modern temperate-water and warm water shelf carbonate sediments contrasted: Marine Geology, v. 13, p. M67-M73.

Nelson, C.S., 1988, An introductory perspective on non-tropical shelf carbonates: Sedimentary Geology, v. 60, p. 3–12.

Schlanger, S.O., 1981, Shallow-water limestones in oceana basins as tectonic and pale oceanographic indicators: SEPM Special Publication no. 32, p. 209-226.

Websites

French Research Institute for Exploitation of the Sea, http://www.ifremer.fr (http://www.ifremer.fr/serpentine/fiches/fiche4-img1-web.jpg) accessed May 9, 2010.

Resource Database for Gulf of Mexico Research, www.gulfbase.org, accessed May 9, 2010.

Controls on Heterozoan Reefs Developed on Salt Diapirs, La Popa Basin, Mexico

By:
Katherine Giles
AAPG Distinguished Lecturer 2007-2008

Sponsored by:
Institute of Tectonic Studies
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Acknowledgments

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- **Brenda Buck (UNLV)**

- paleosol morphology and isotopic character, sedimentology

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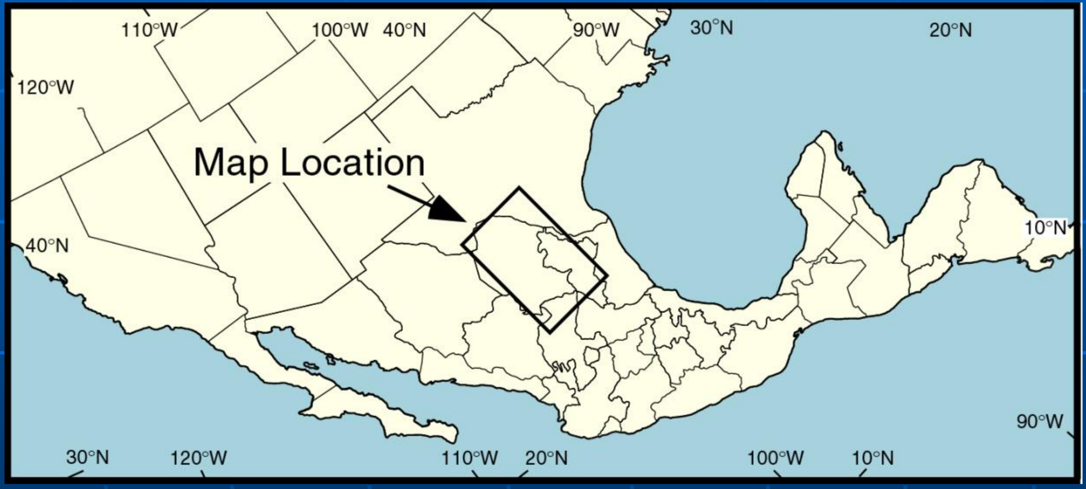
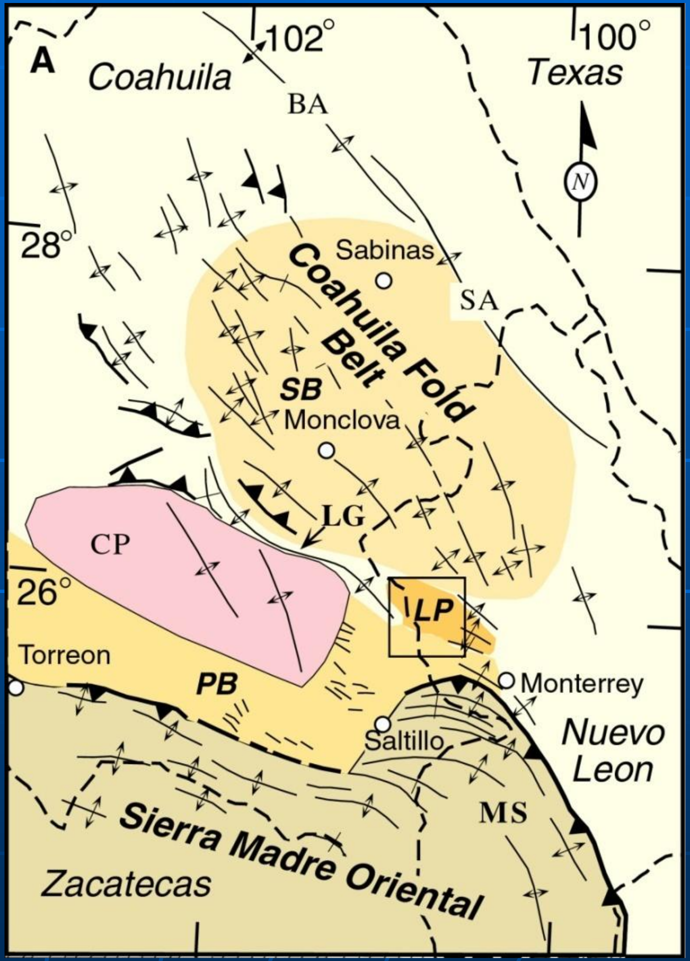
Regional Location of La Popa Basin



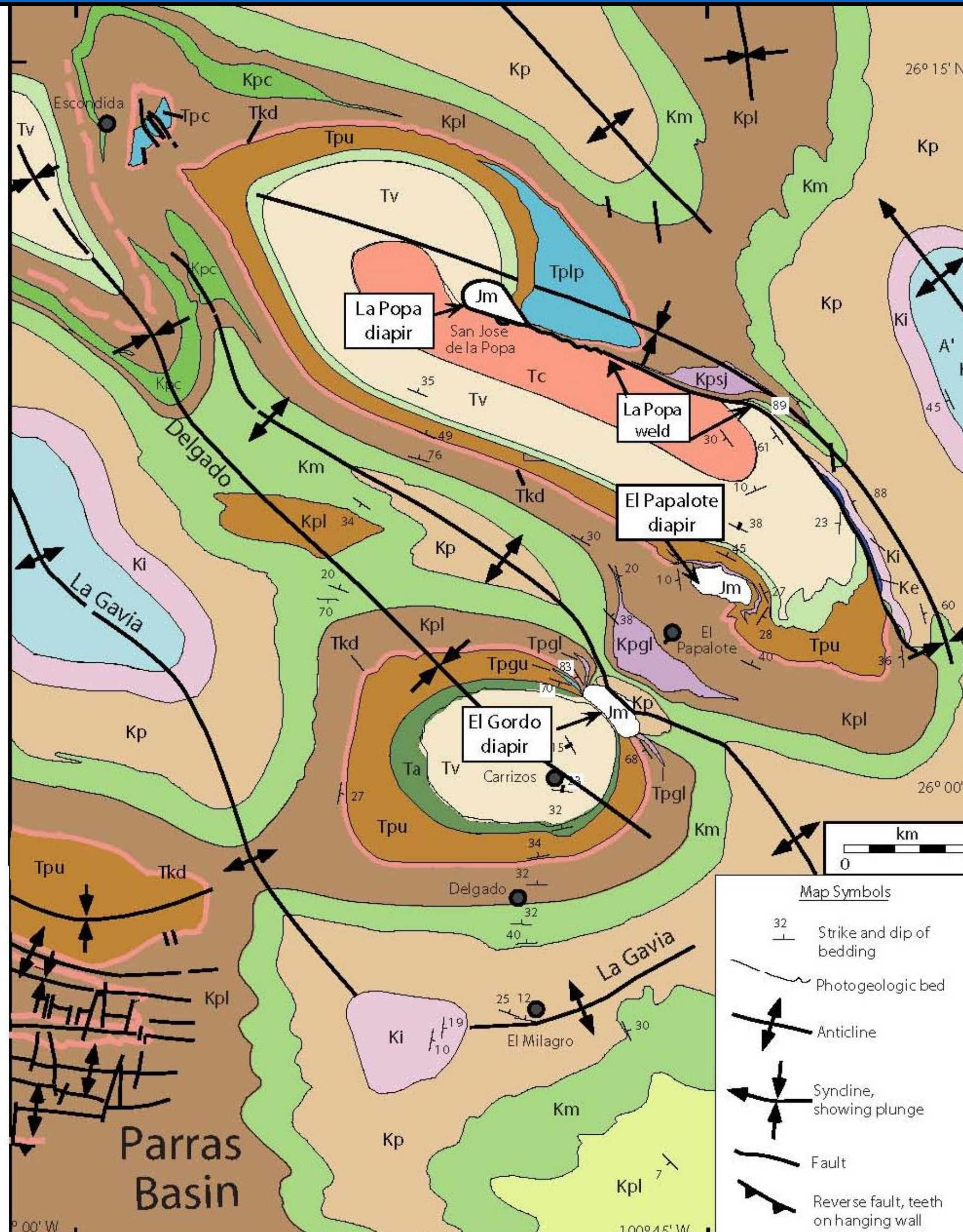


Satellite Image of La Popa Basin

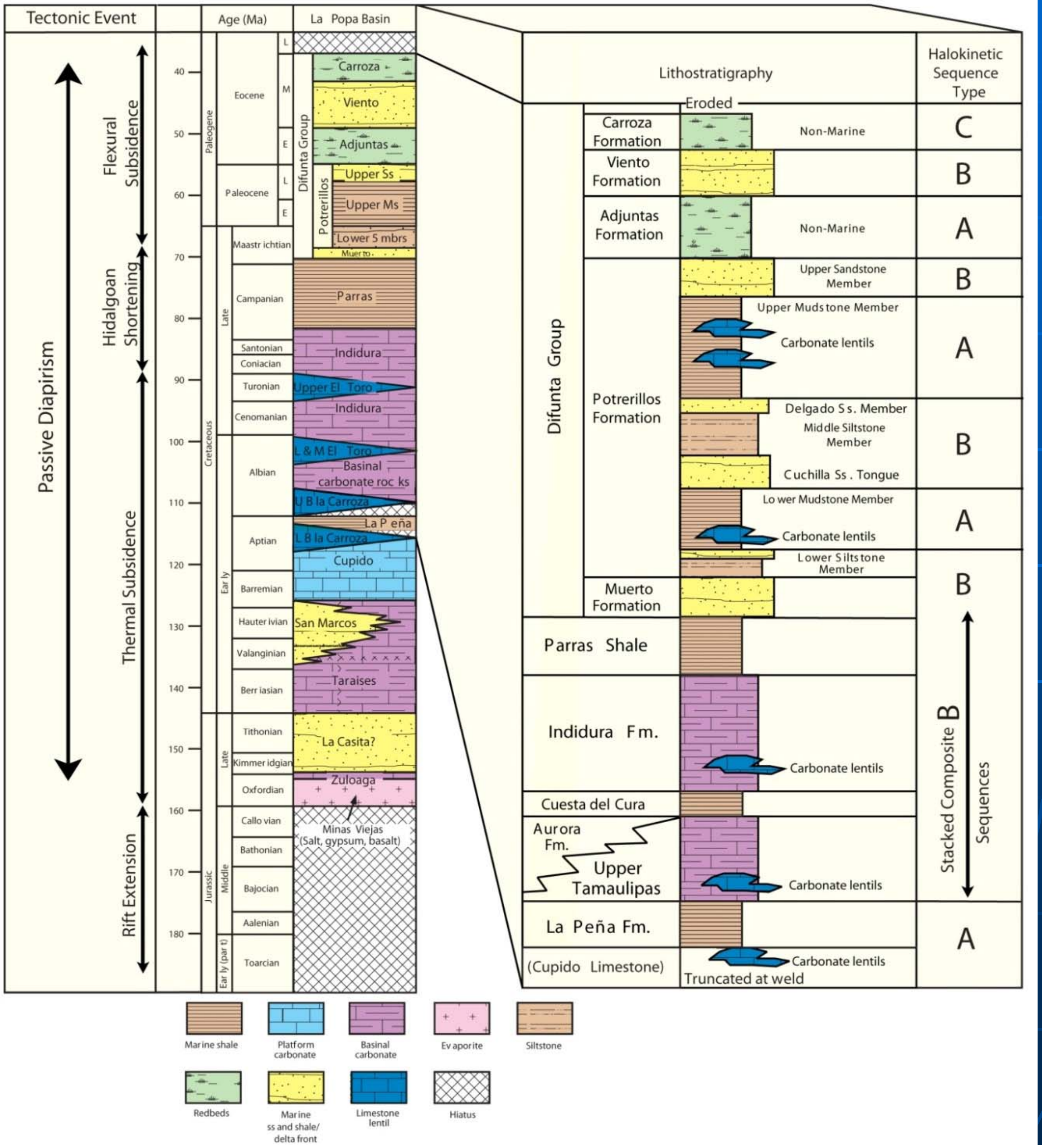
Geologic Map of La Popa basin

Explanation

- Tc — Carroza Formation
- Tv — Viento Formation
- Ta — Adjuntas Formation
- Tpu — Upper Potrerillos Formation
  - Tplp — La Popa lentil
  - Tpgu — Upper Gordo lentil
  - Tpc — North Chivos lentil
- Tkd — Delgado Sandstone Member
- Kpl — Lower Potrerillos Formation
  - Kpsj — San Jose lentil
  - Kpgl — Lower Gordo lentil
  - Kpc — Cuchilla Sandstone Tongue
- Km — Muerto Formation
- Kp — Parras Shale
- Ki — Indidura Formation
- Ke — Lower Cretaceous lentils
- Kl — Lower Cretaceous limestone
- Jm — Jurassic evaporite

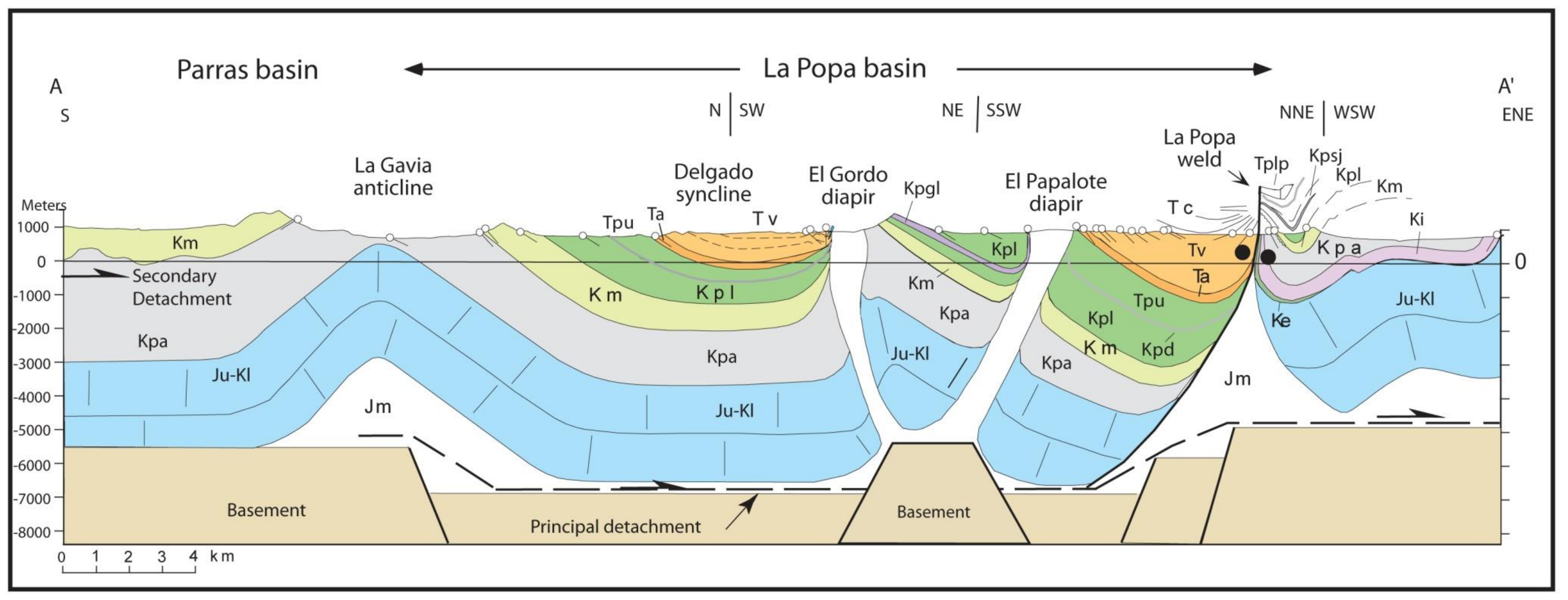


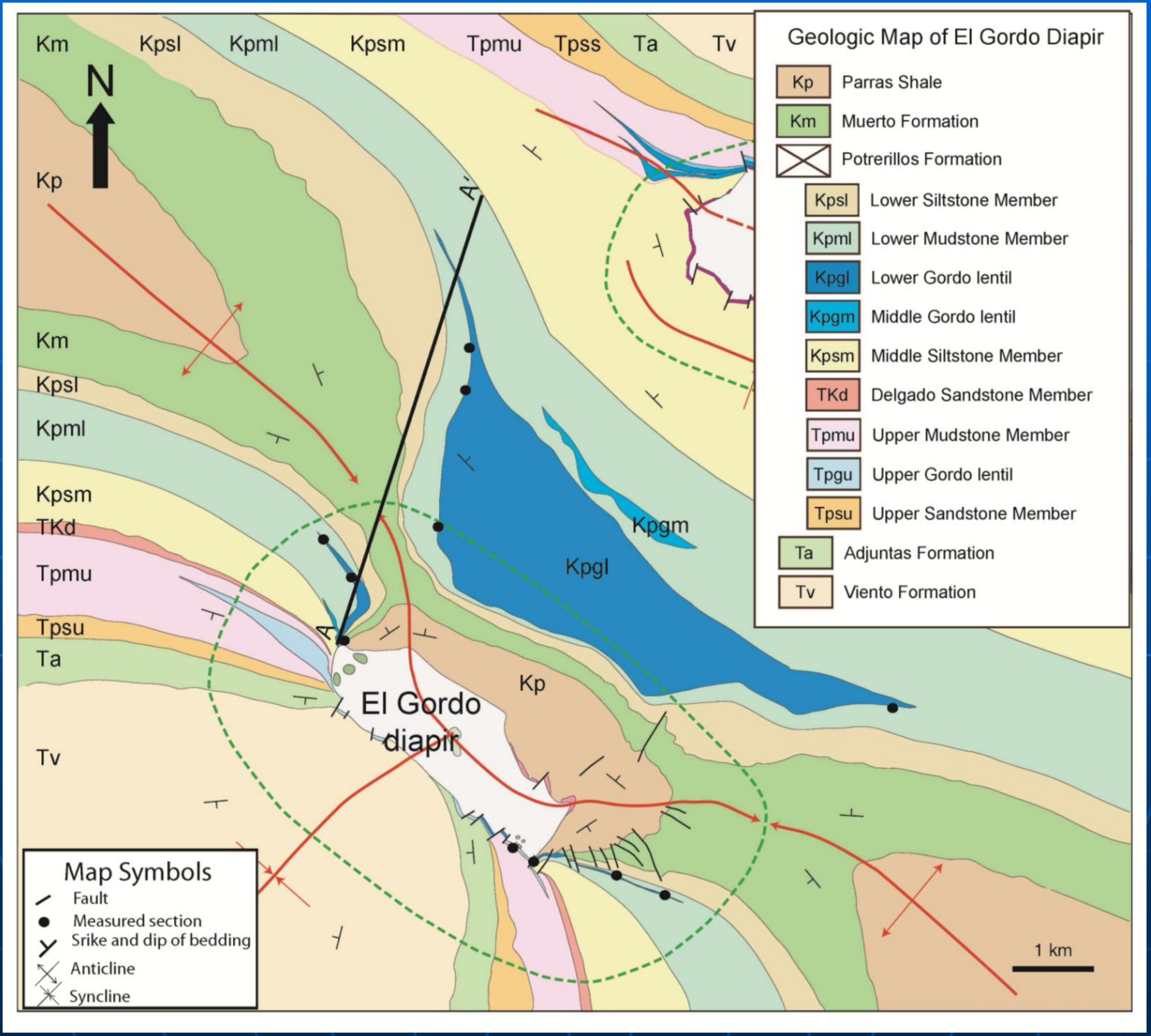
Tectonostratigraphic Column



KT Boundary

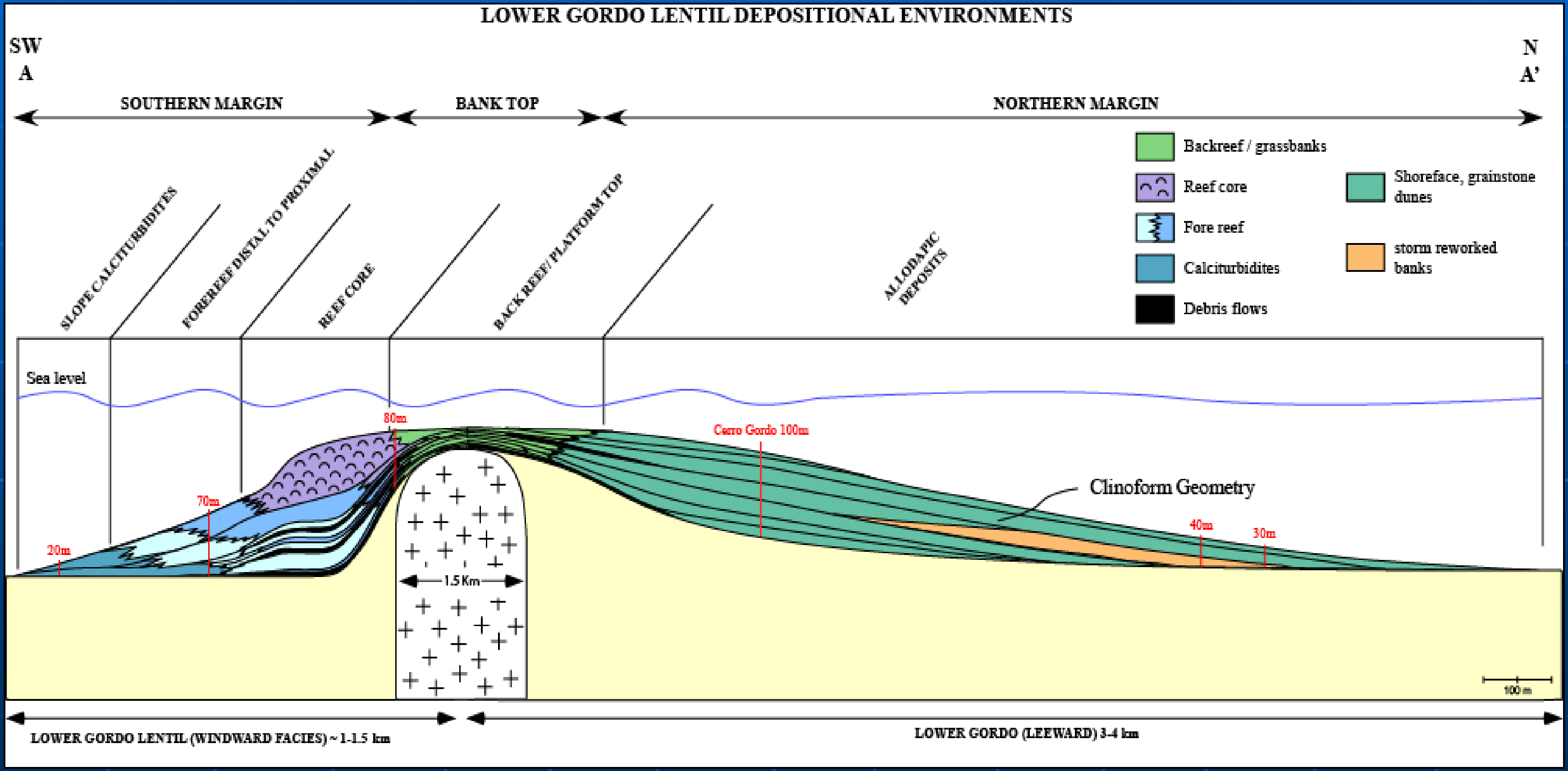
Cross Section Across La Popa Basin



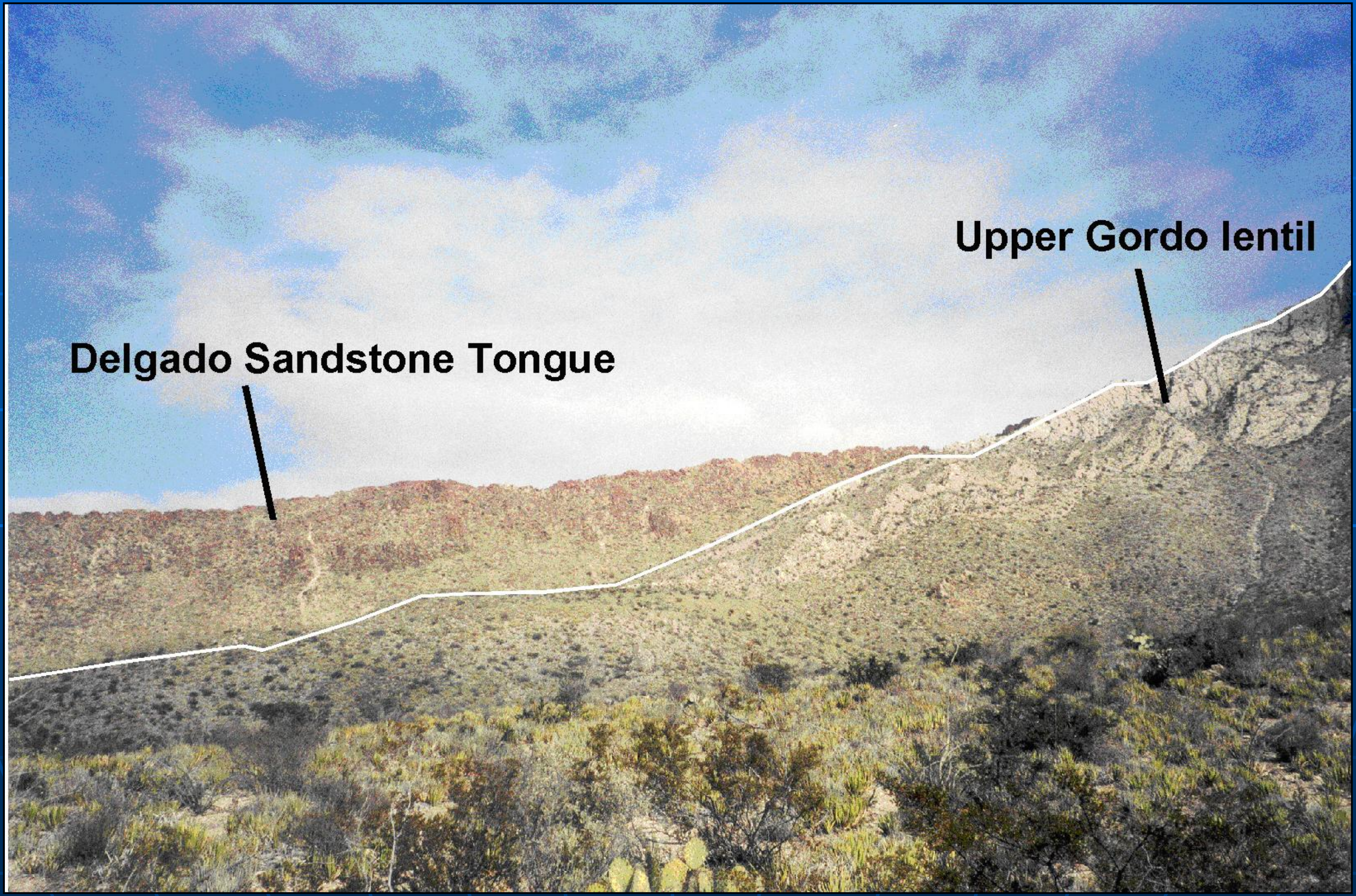

Geologic Map of El Gordo Diapir
Kp Parras Shale
Km Muerto Formation
Potrerillos Formation
Kpsl Lower Siltstone Member
Kpml Lower Mudstone Member
Kpgl Lower Gordo lentil
Kpgm Middle Gordo lentil
Kpsm Middle Siltstone Member
TKd Delgado Sandstone Member
Tpmu Upper Mudstone Member
Tpgu Upper Gordo lentil
Tpsu Upper Sandstone Member
Ta Adjuntas Formation
Tv Viento Formation
Map Symbols
Fault
Measured section
Srike and dip of bedding
Anticline
Syncline
El Gordo diapir
N
A
A'
1 km
Km
Kpsl
Kpml
Kpsm
Tpmu
Tpss
Ta
Tv
Kp
TKd
Tpsu
Kpgm
Kpgl

Outcrop of El Gordo Diapir

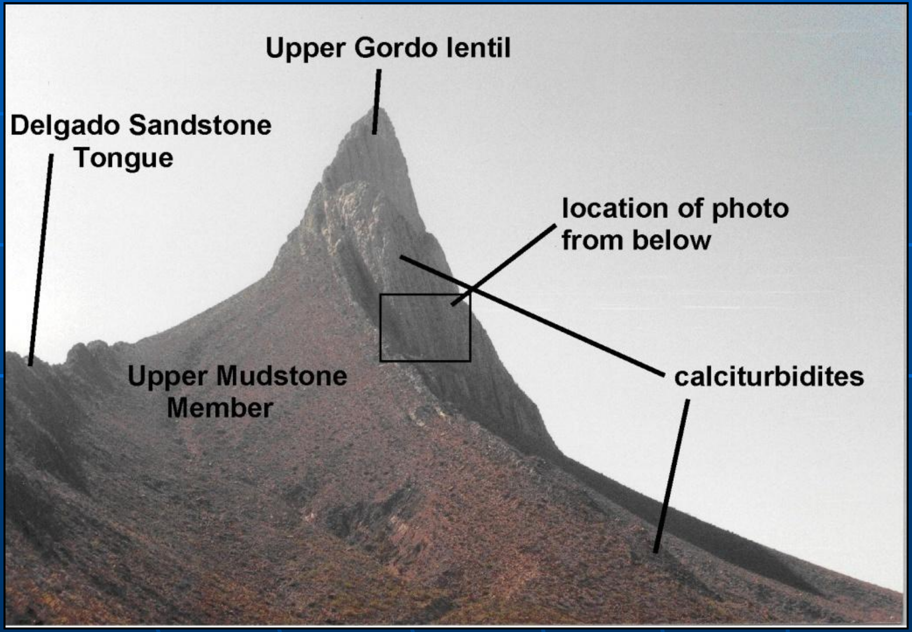
Local Controls:
Windward-Leeward Facies
El Gordo Depofacies Cross Section



Windward Facies
Outcrop of massive reef

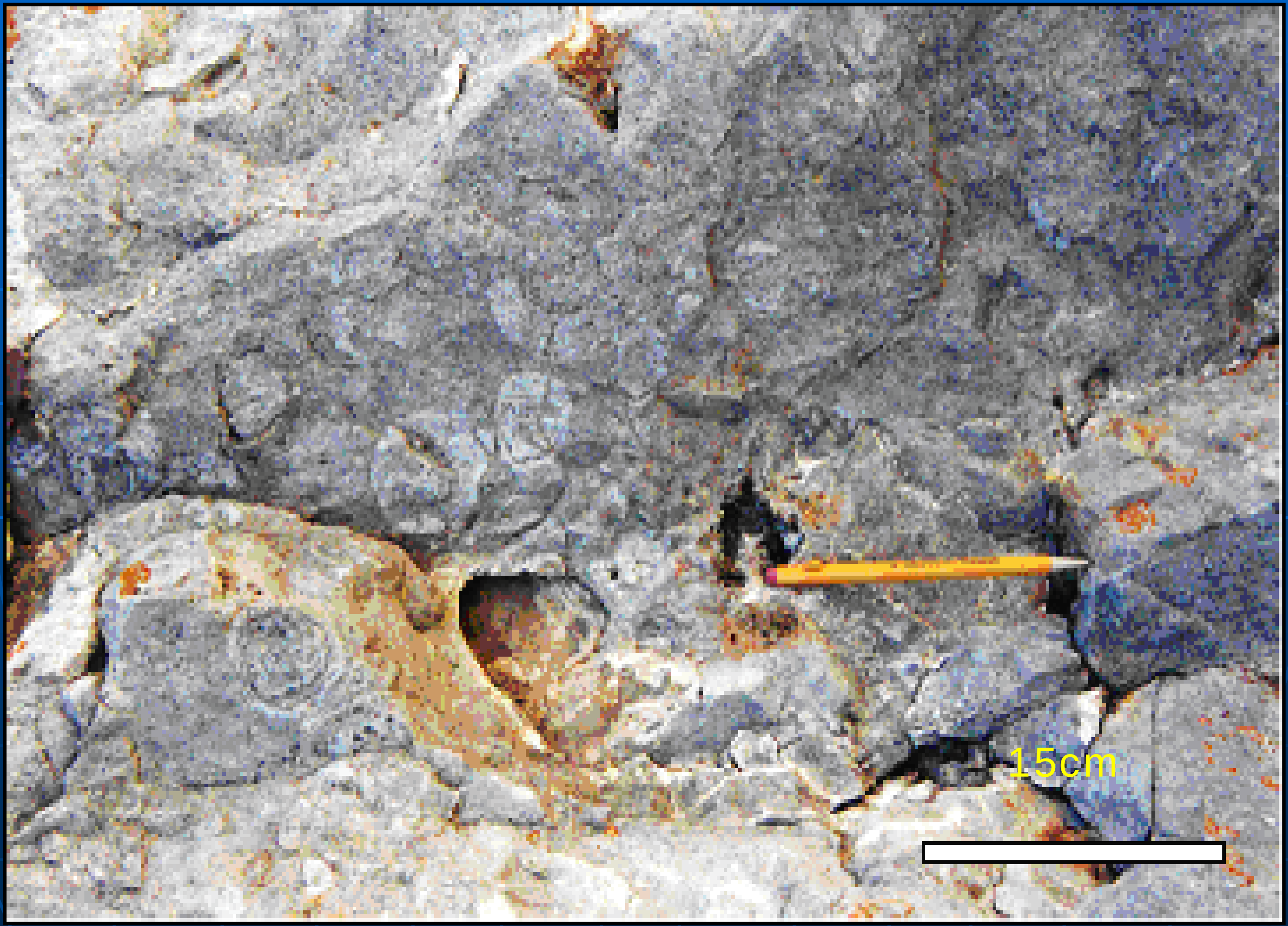


Windward Facies
Forereef Calciturbidities



Windward Facies Heterozoan Fauna: Red Algal & Sponge Reef

Windward Facies
Heterozoan Fauna: Rhodoliths



Leeward Facies
Outcrop of Grainstone Clinoforms in Paleocene La Popa Lentil

Photo by Bob Goldhammer

Leeward Facies
Heterozoan Fauna: Benthic foram, echinoderm, red algal grainstone

Great Barrier Reef Satellite Image Windward-Leeward Facies

(Harris and Kowalik, AAPG Methods of Exploration. No 11 1994.)

Heterozoan Fauna vs. Photozoan Fauna

Heterozoan Fauna:

- Red algae
- Sponges
- Echinoderms
- Bivalves
- Bryozoans
- Brachiopods
- Benthic forams

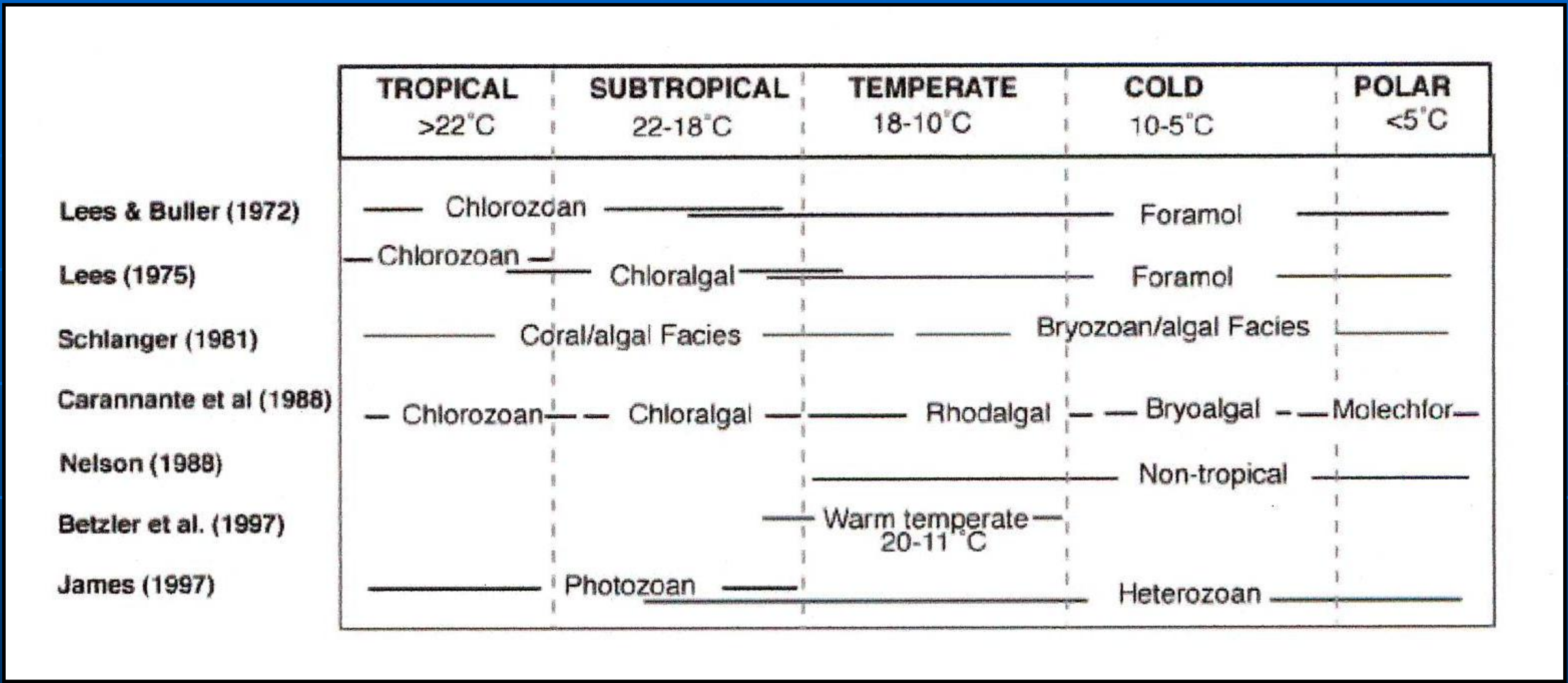
Photozoan Fauna:

- Hermatypic coral
- Green algae
- Rudistid clams

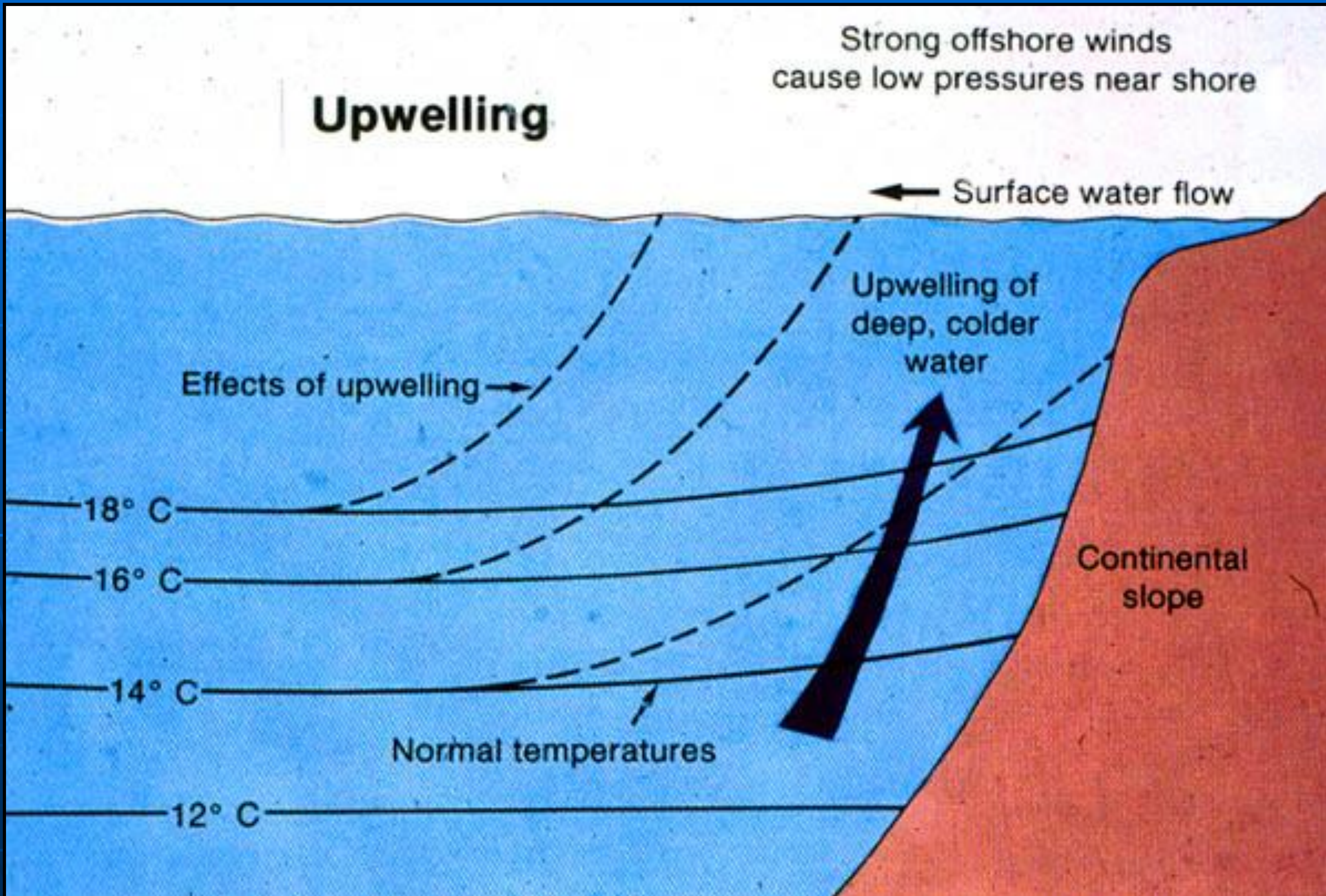
Controls on Heterozoan Faunal Distribution

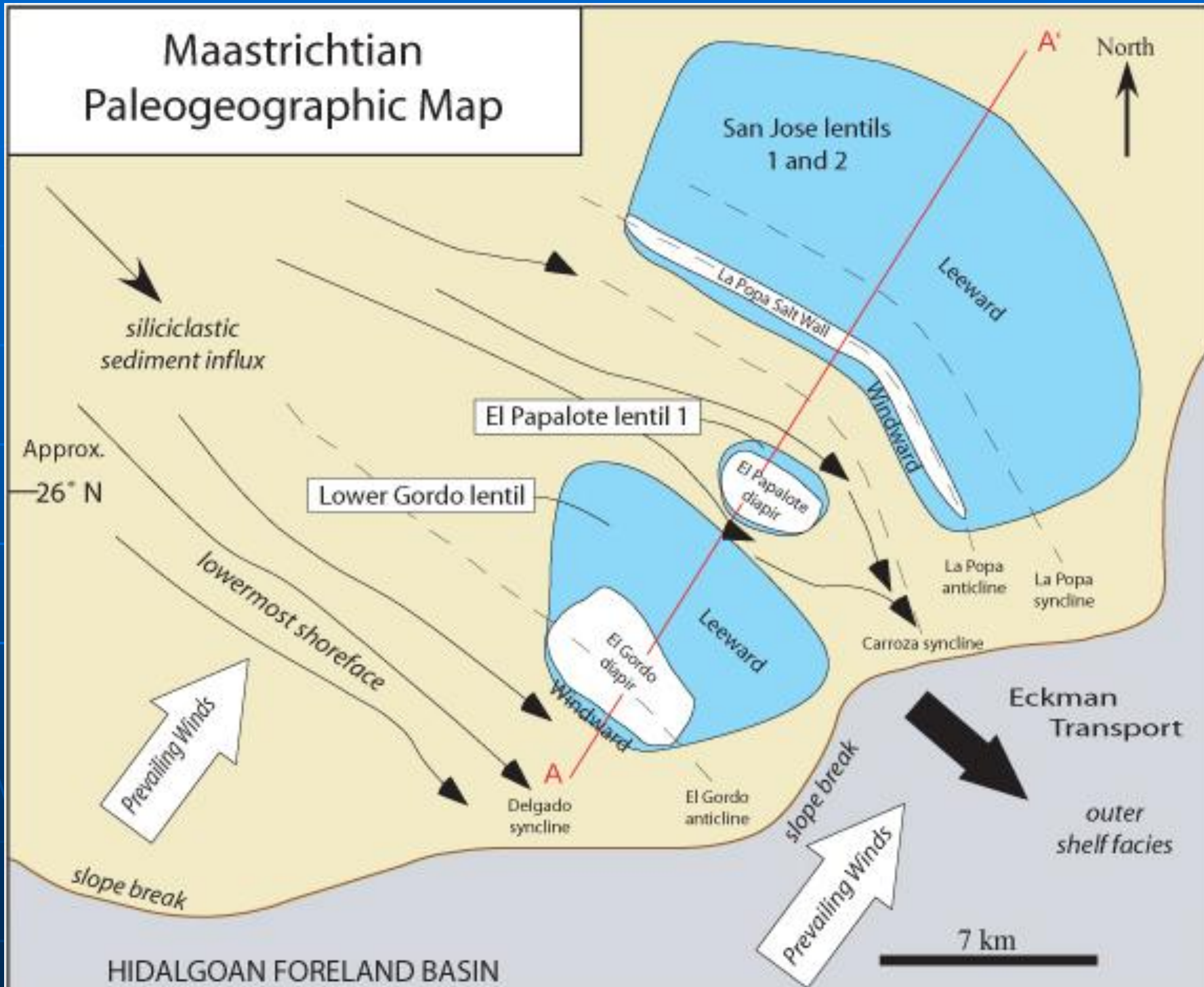
1. Cool water temperatures
   - Latitude
   - Upwelling
2. High nutrient levels
   - Upwelling
   - Continental runoff
   - Methane/cold seeps

Cold Water Controls: Latitudinal Belts

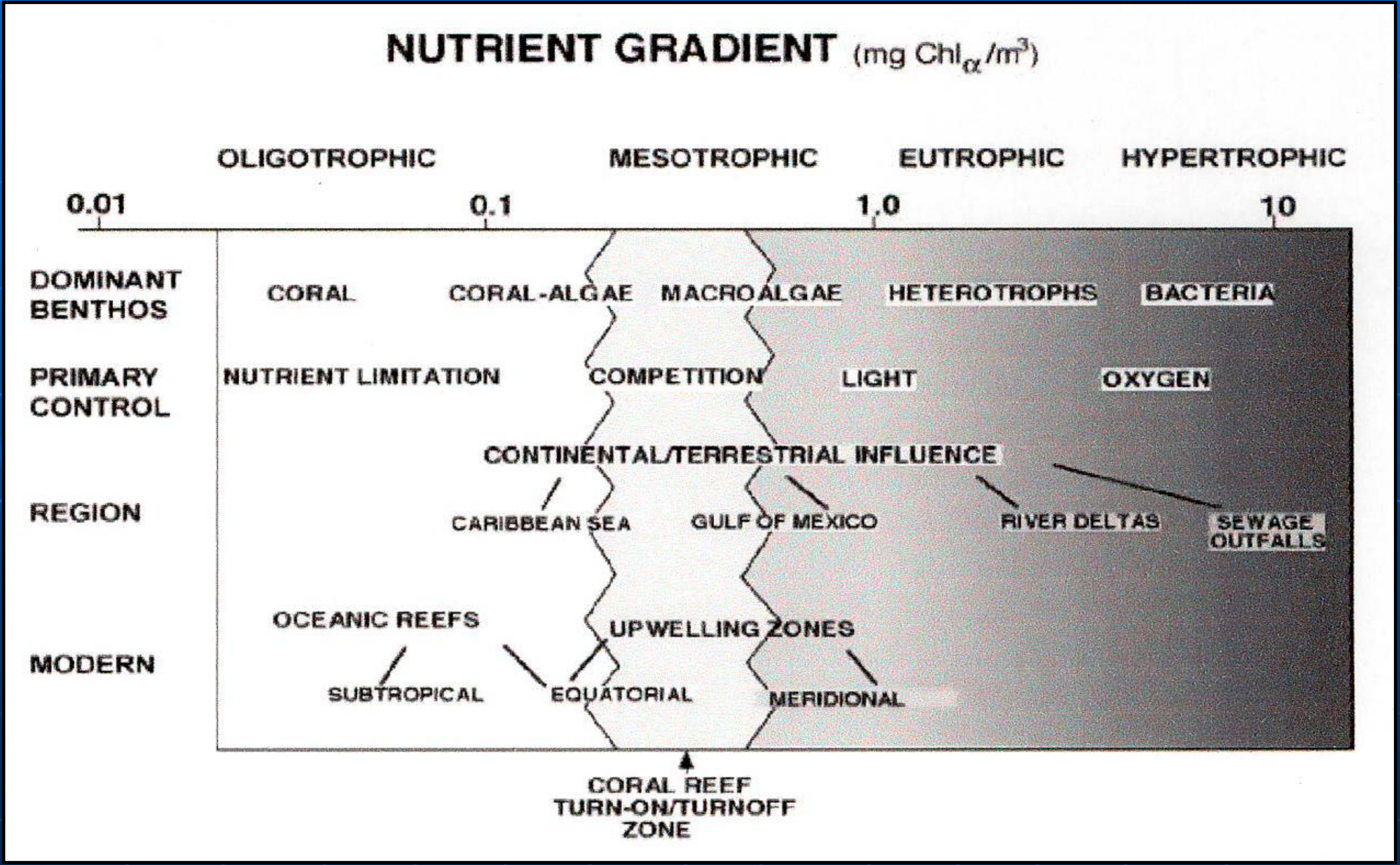


Cold Water Controls: Upwelling




Maastrichtian
Paleogeographic Map
North
A'
San Jose lentils
1 and 2
La Popa Salt Wall
Leeward
Windward
siliciclastic
sediment influx
El Papalote lentil 1
El Papalote diapir
Lower Gordo lentil
Approx.
26° N
La Popa anticline
La Popa syncline
Carroza syncline
El Gordo diapir
Leeward
Windward
lowermost shoreface
Prevailing Winds
A
Delgado syncline
El Gordo anticline
slope break
Eckman
Transport
outer
shelf facies
slope break
Prevailing Winds
7 km
HIDALGOAN FORELAND BASIN

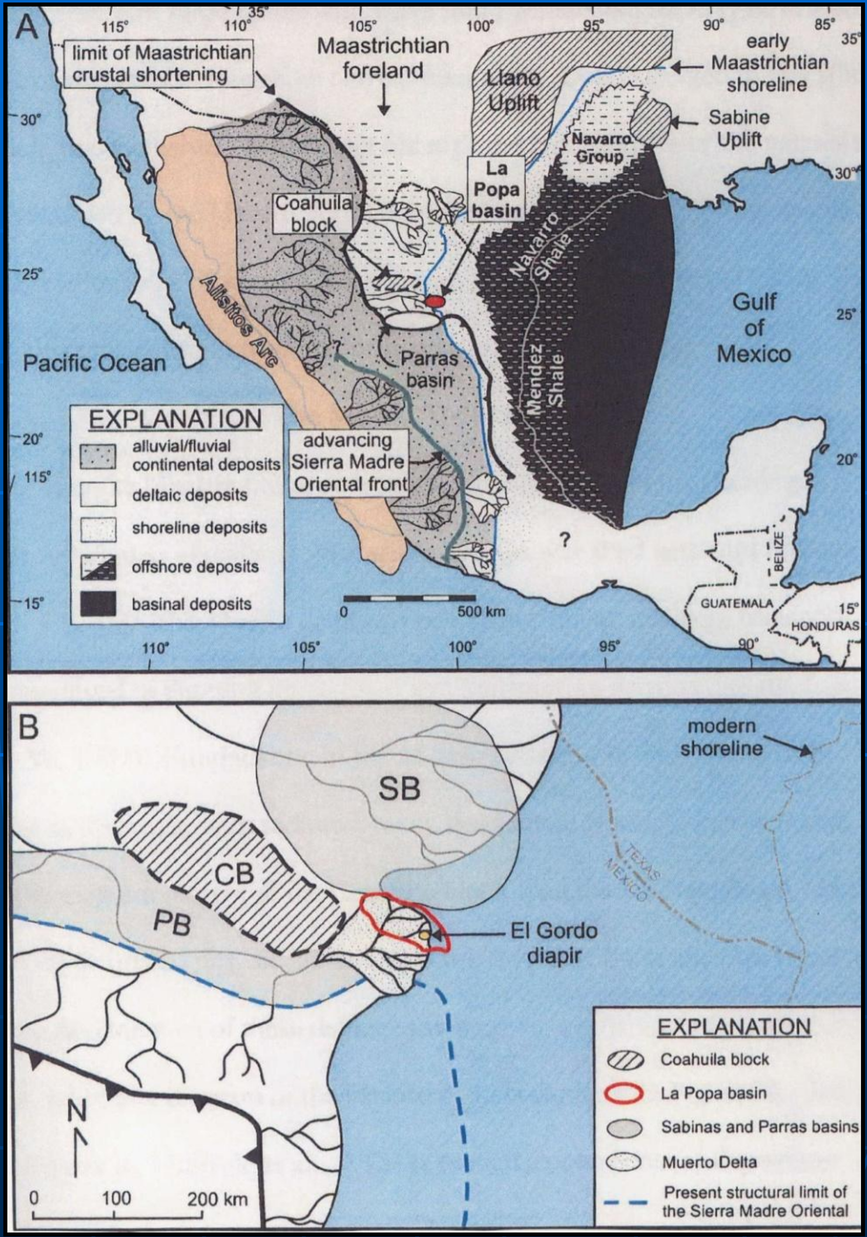
High Nutrient Control



Ways to Increase Nutrient Levels

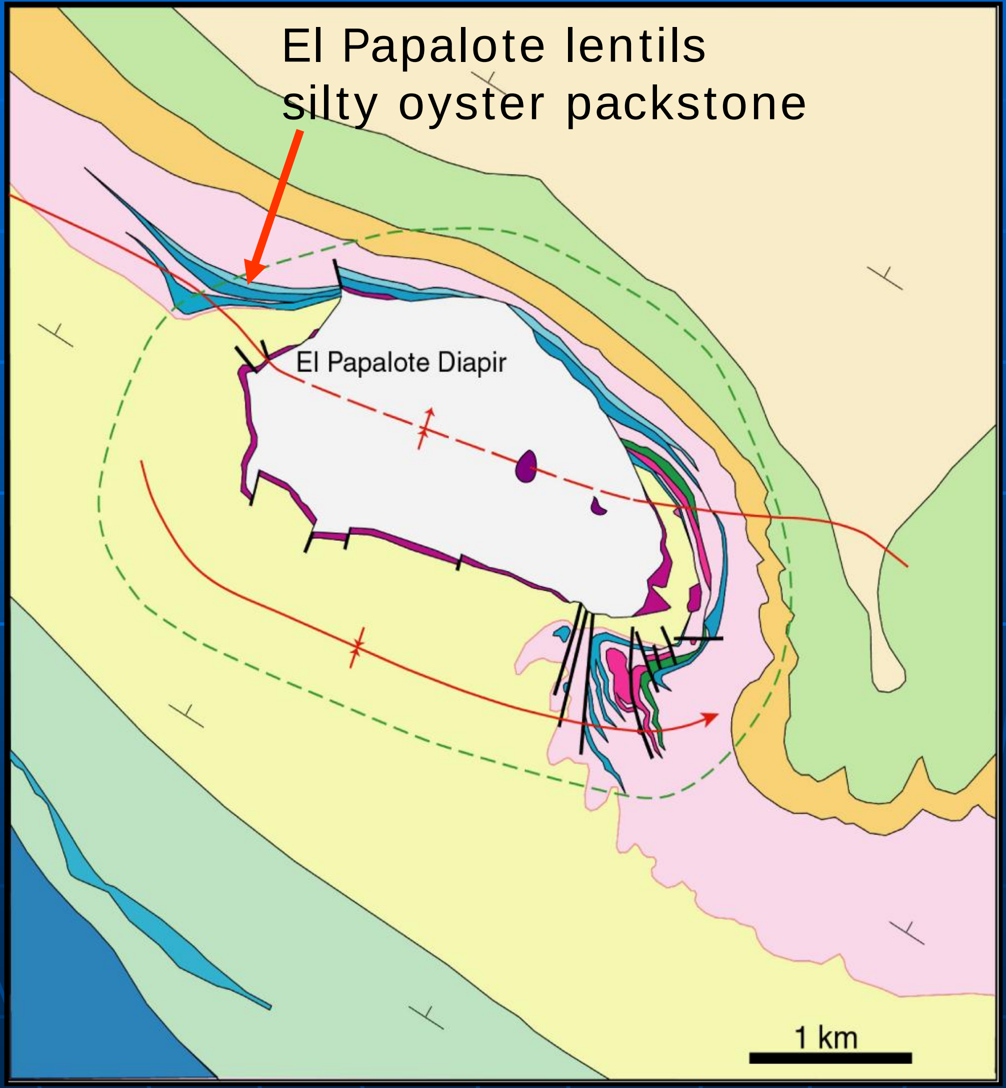
1. Upwelling
2. Continental runoff
3. Methane/cold seeps

Increased Nutrient Levels: Continental Runoff



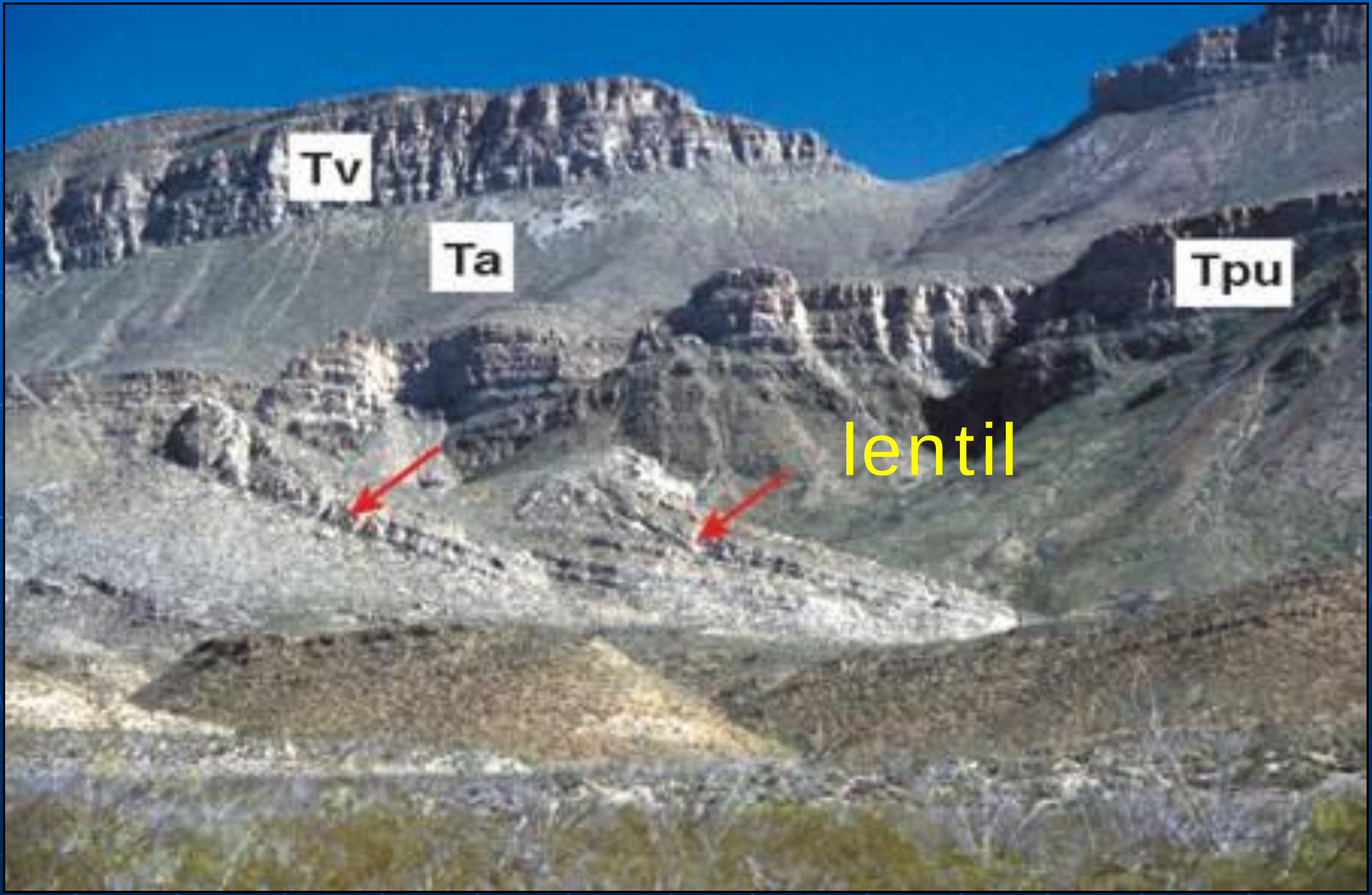
Modified from Goldhammer (1999)

Geologic Map of El Papalote Diapir

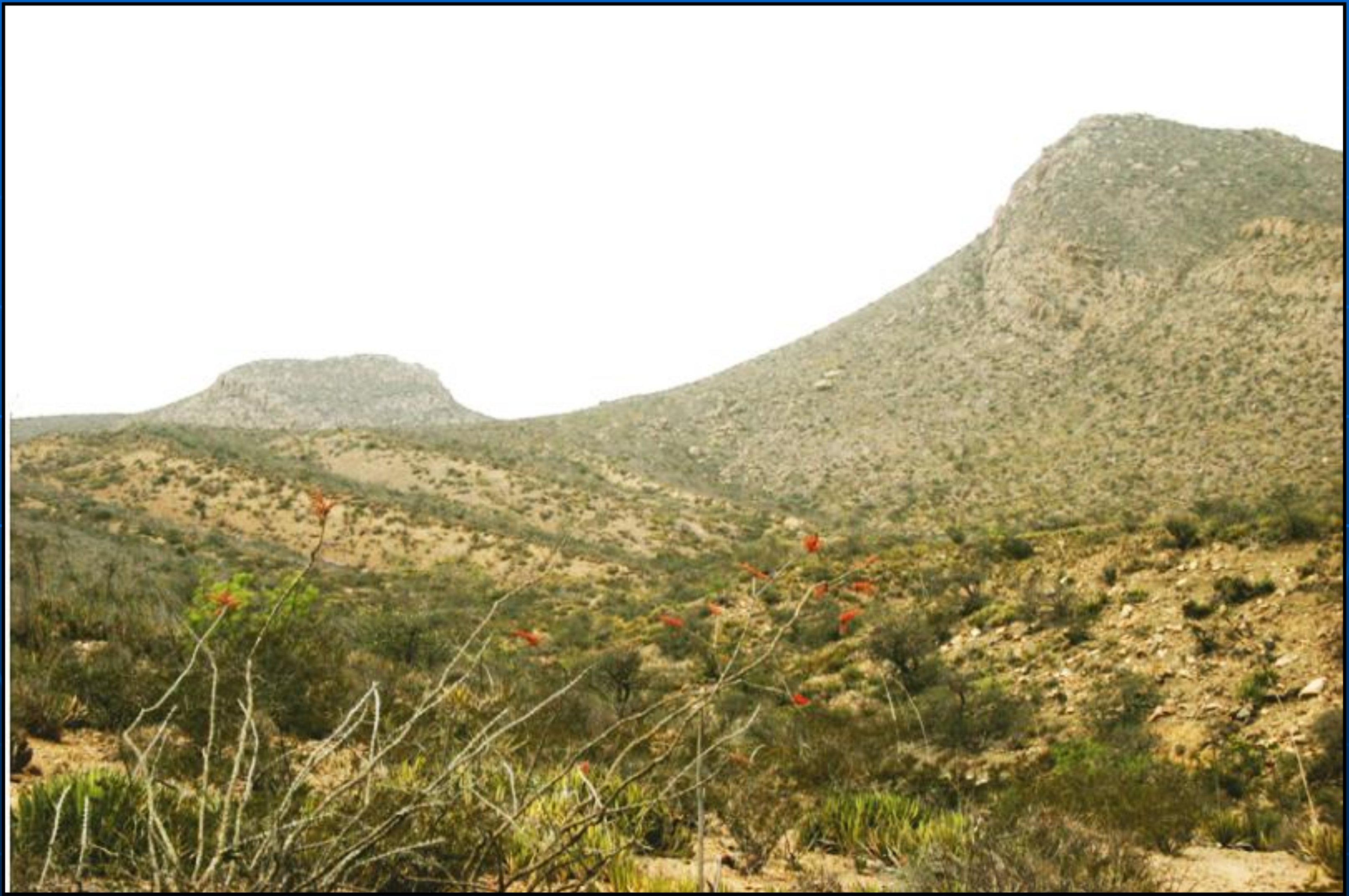


El Papalote Lentil Facies Silty Oyster Bank

Outcrop of Lentil Geometry

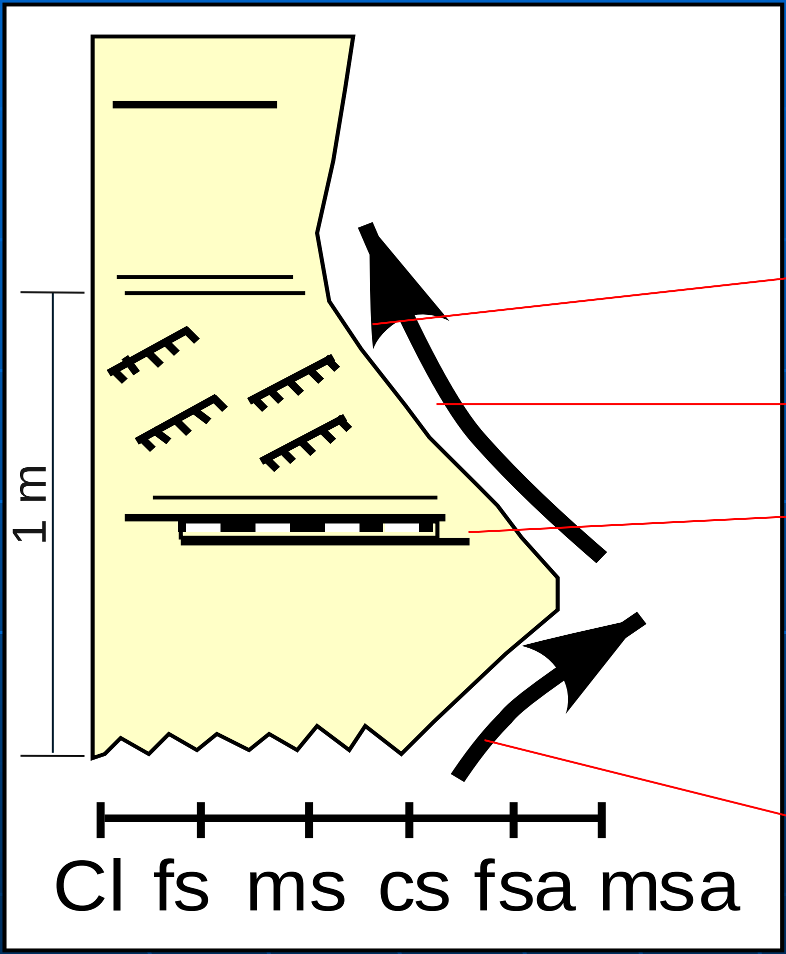


Lentils and Hyperpycnal Flows/Deposits



Basinal Black Shales and Hyperpycnal Flows/Deposits

Outcrop of Hyperpycnal Flow Deposits



Hyperpycnal Flows Indicate Increased Continental Runoff

‘Density outflows from a river mouth with a density greater than the ambient fluid into which they flow’ (Bates, 1953)

- Form bottom-riding density flows resulting from extreme river flooding events.

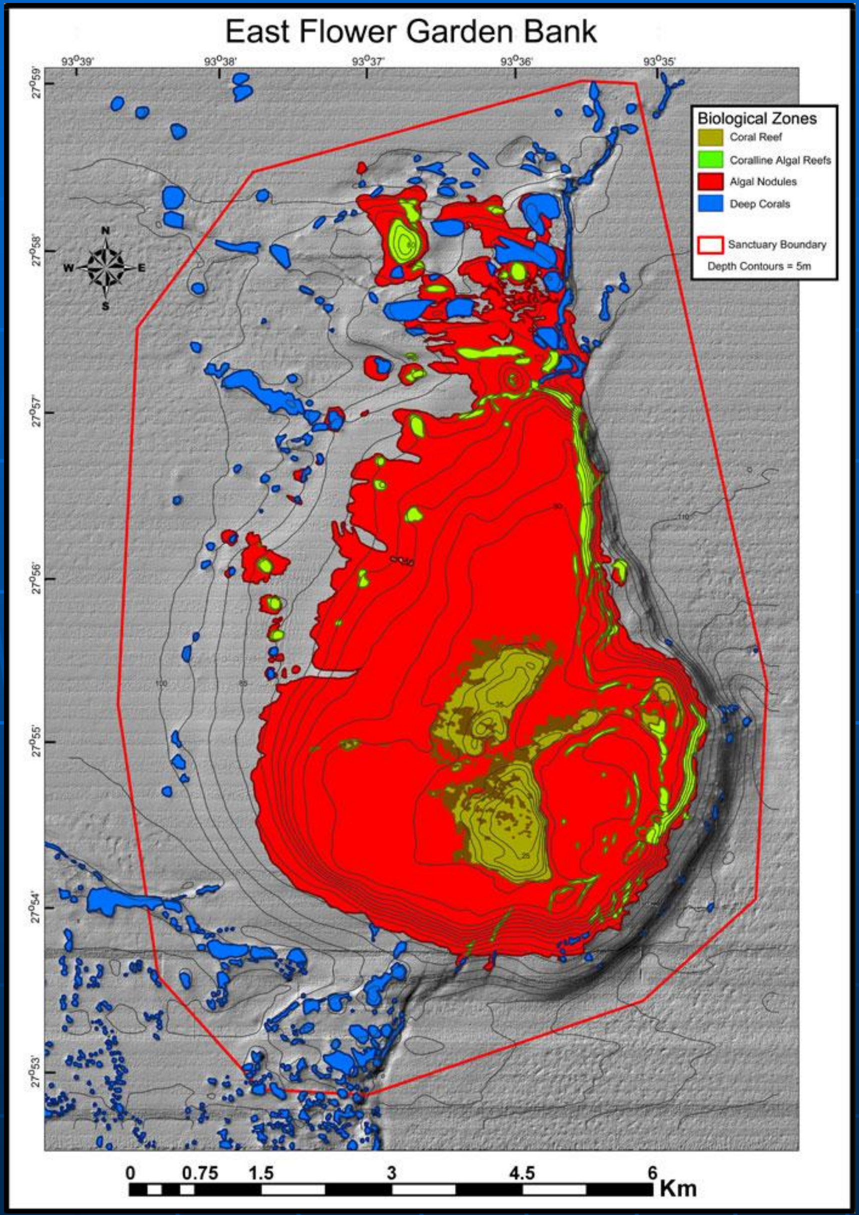
Increased Nutrient Levels: Methane Cold Seeps

http://www.ifremer.fr/serpentine/fiches/fiche4-img1-web.jpg

Gulf of Mexico Chemosynthetic Communities on Salt Diapirs

www.gulfbase.org

East Flower Garden Banks as Modern Analog



Water temperature:

20℃-30℃ tropical

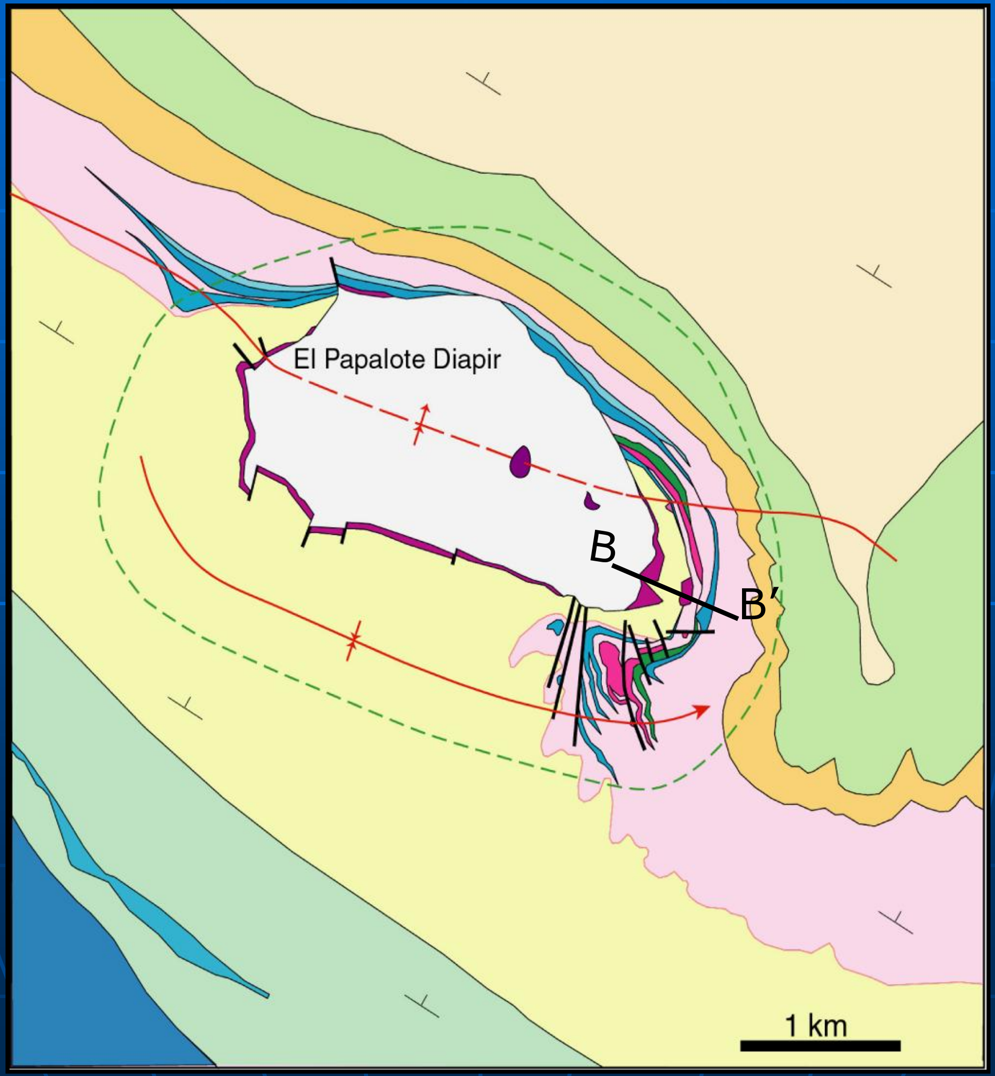
Water depth ranges:

20m-136m

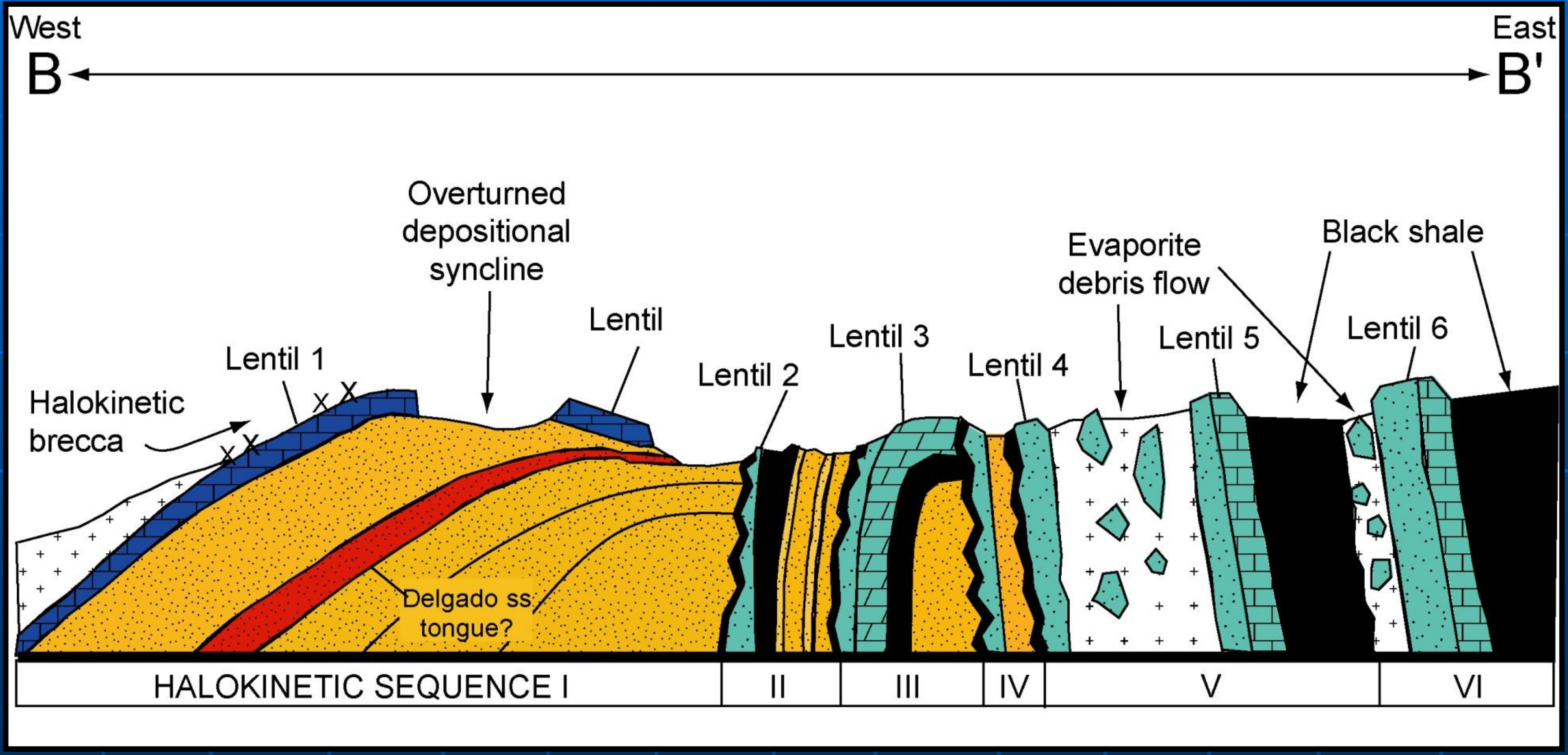
www.gulfbase.org

Local Diapiric Controls
Outcrop of El Papalote Diapir

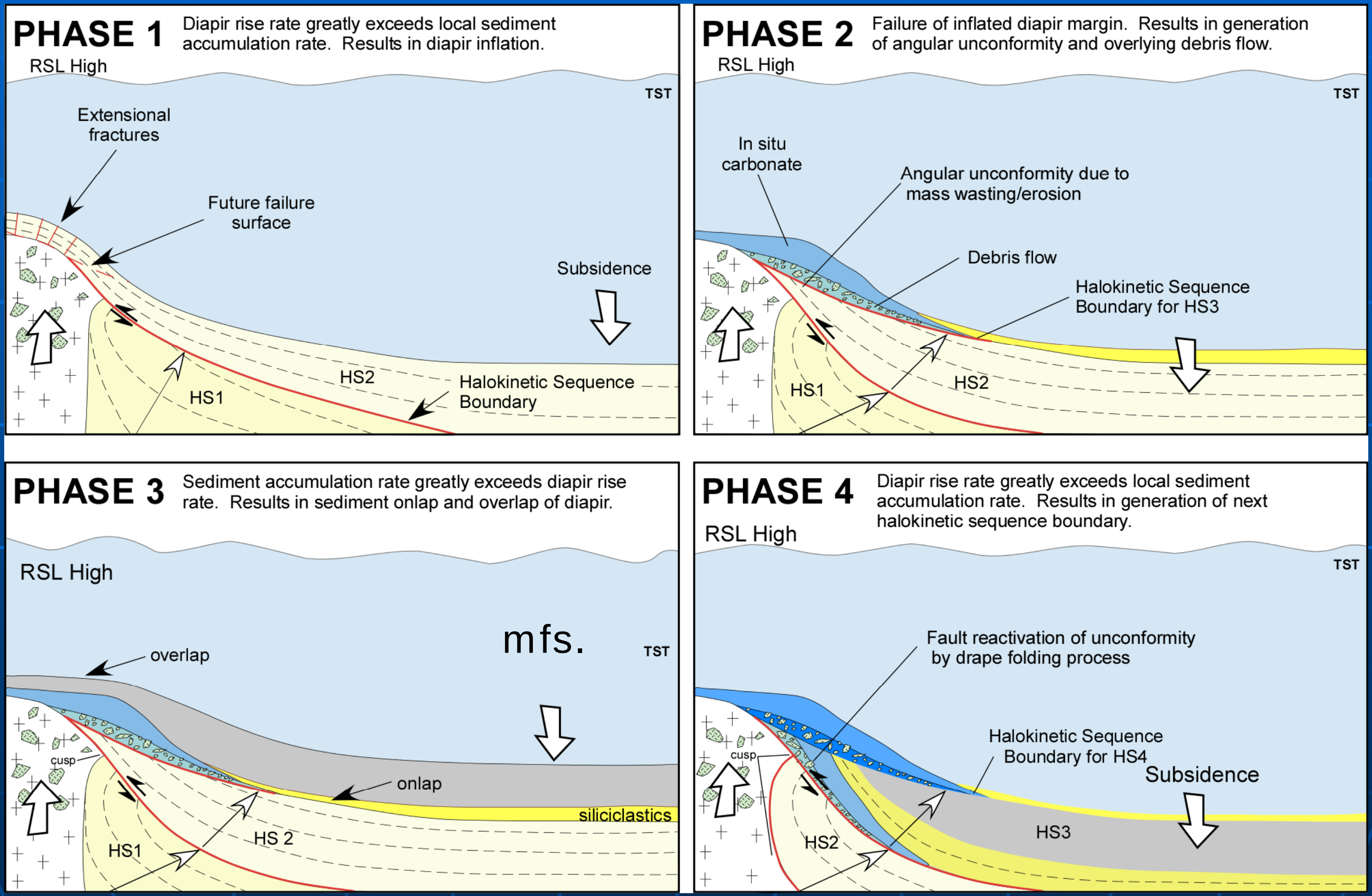
Geologic Map of El Papalote Diapir



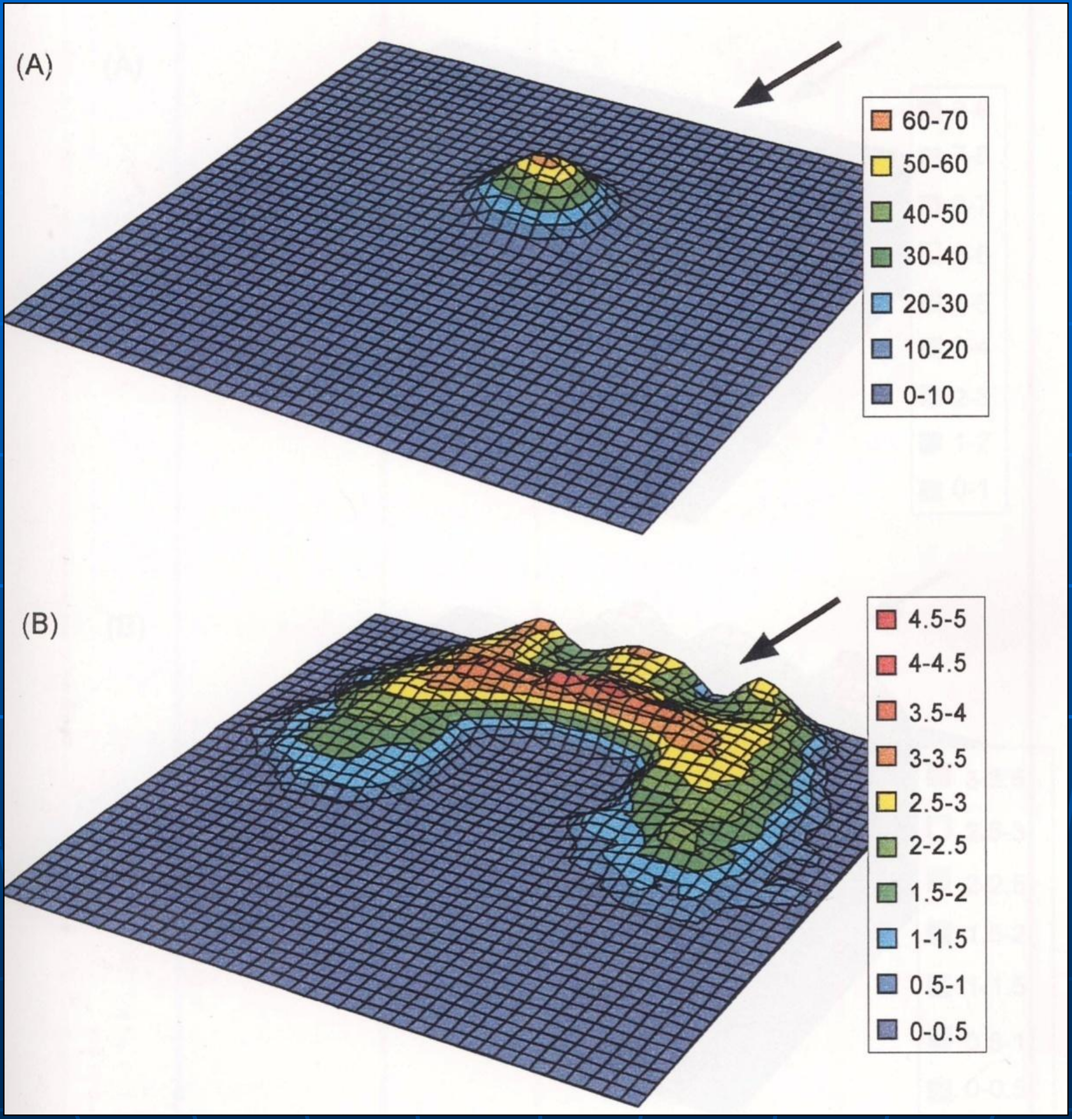
Cross Section of El Papalote Diapir



Model of Type A Halokinetic Sequences

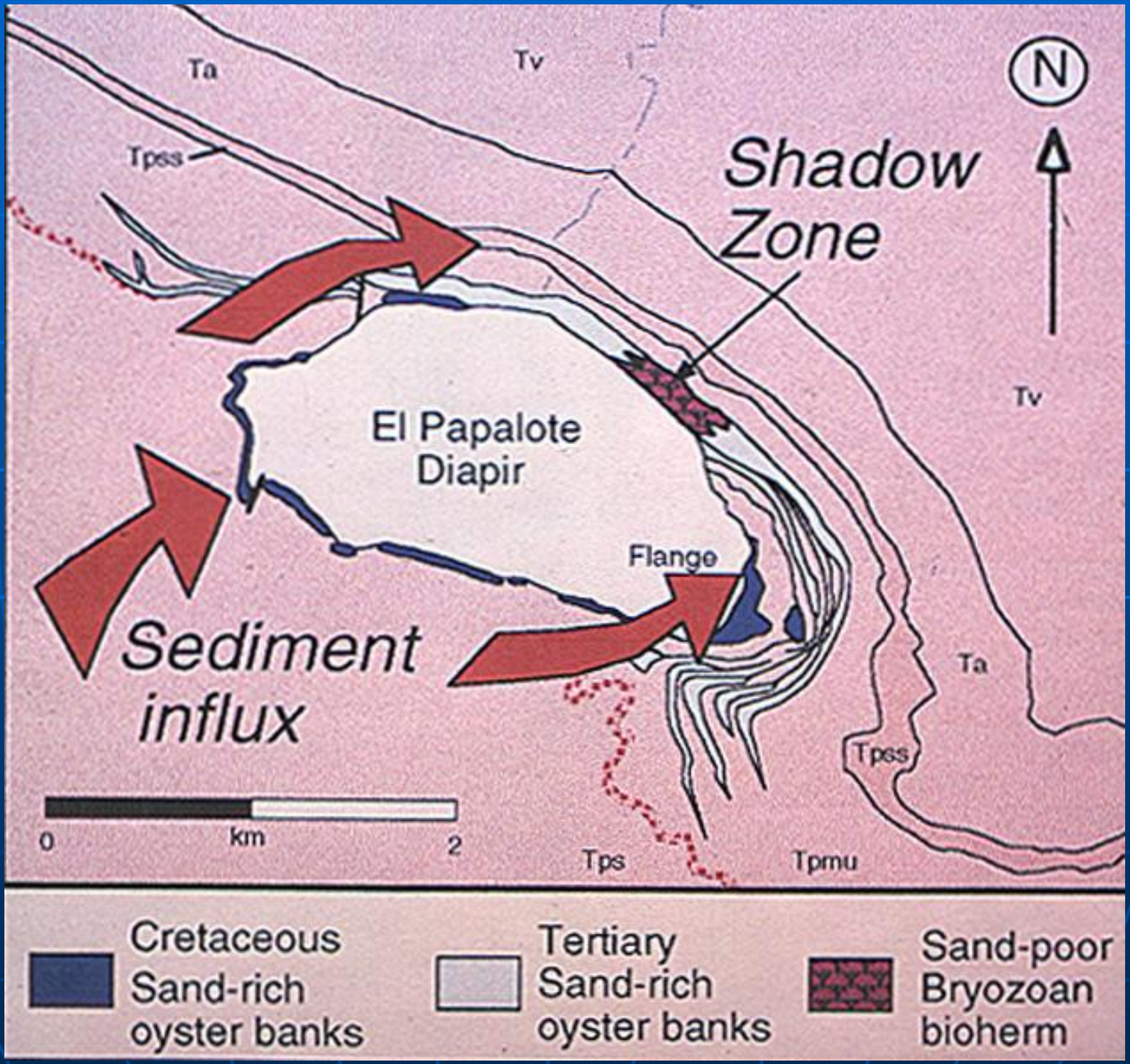


Local Control- Shadow Zone



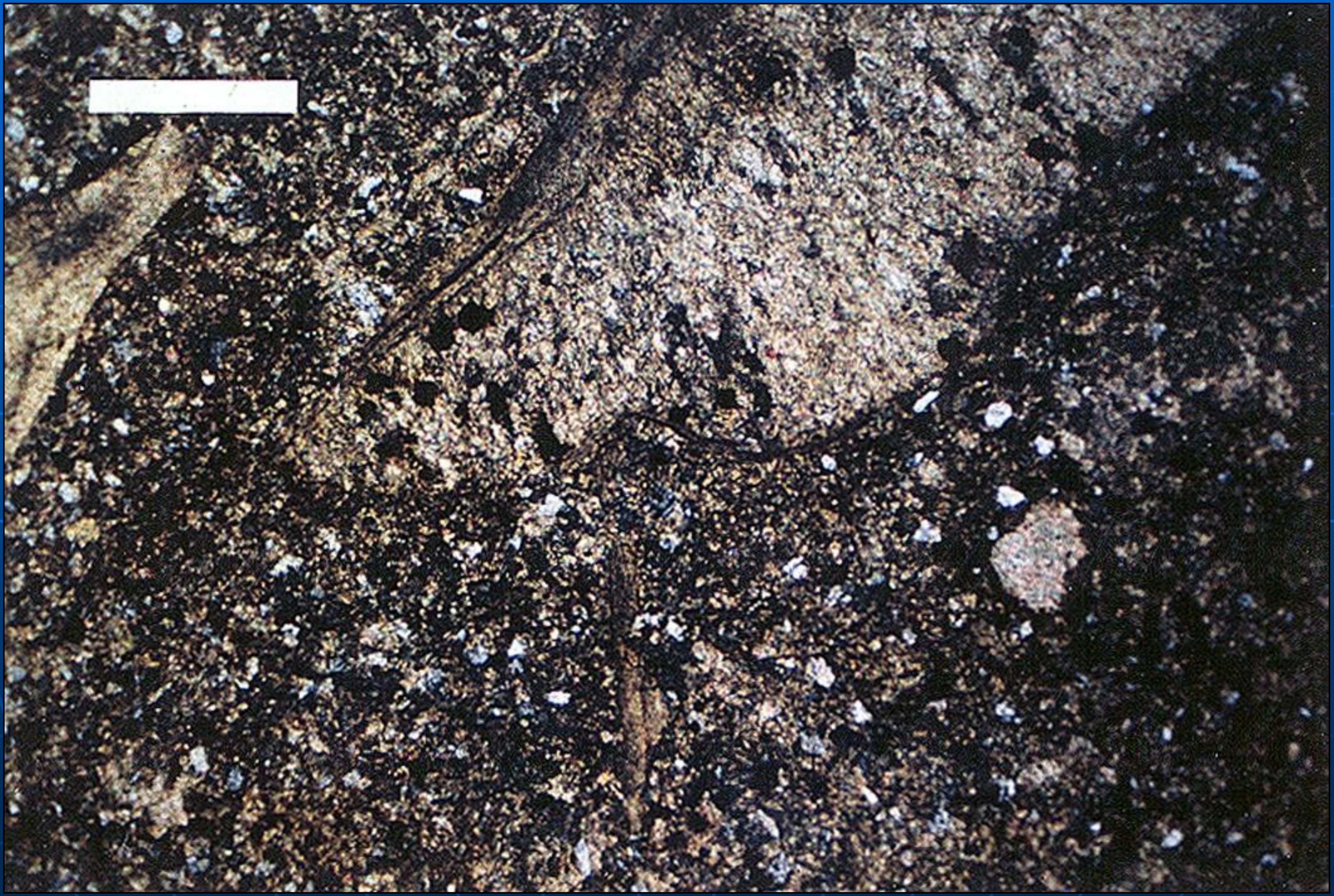
From Kneller and McCaffrey (GCSSEPM, 1995)

Type A Shadow Zone

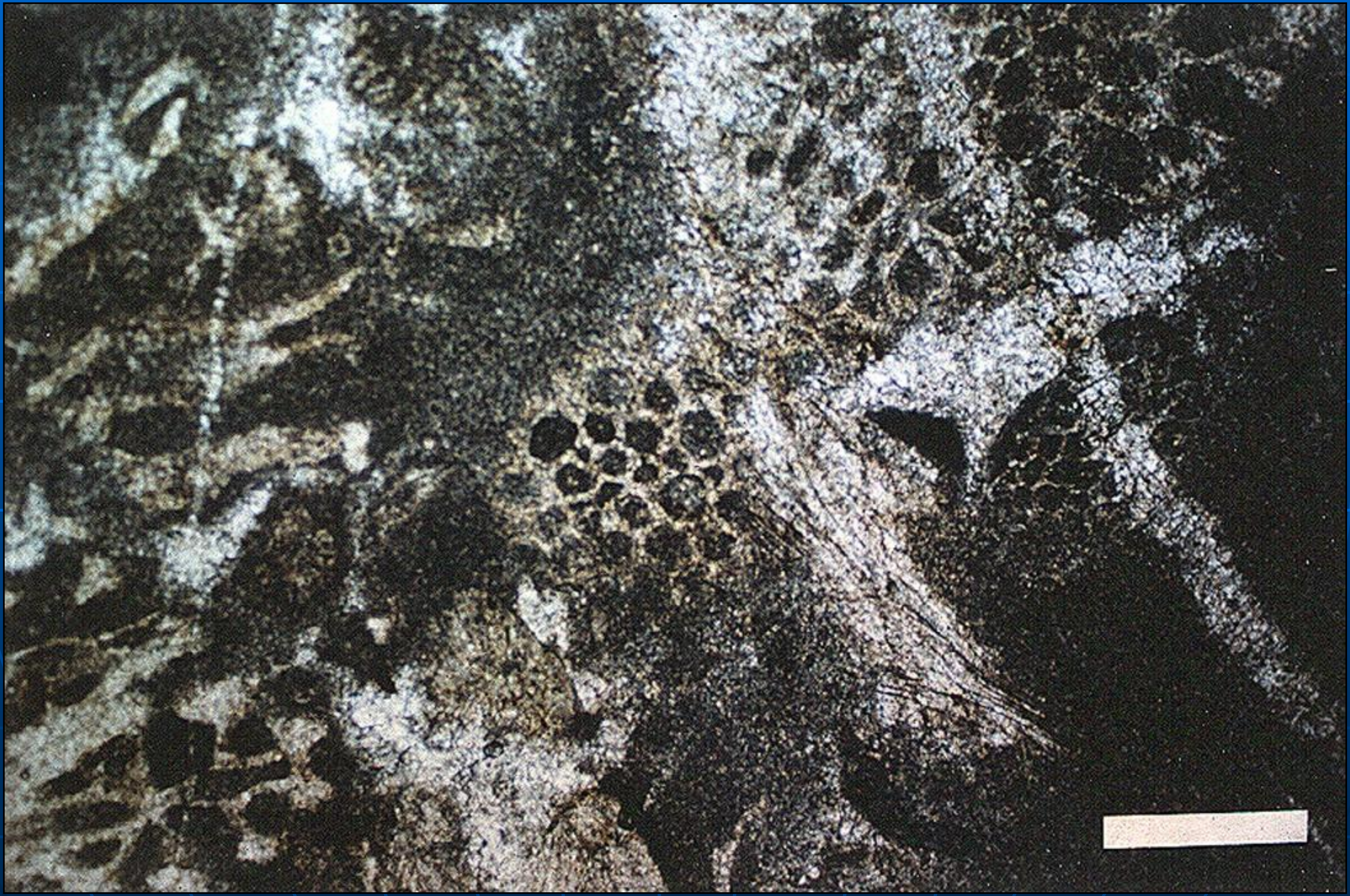


Normal Lentil Facies

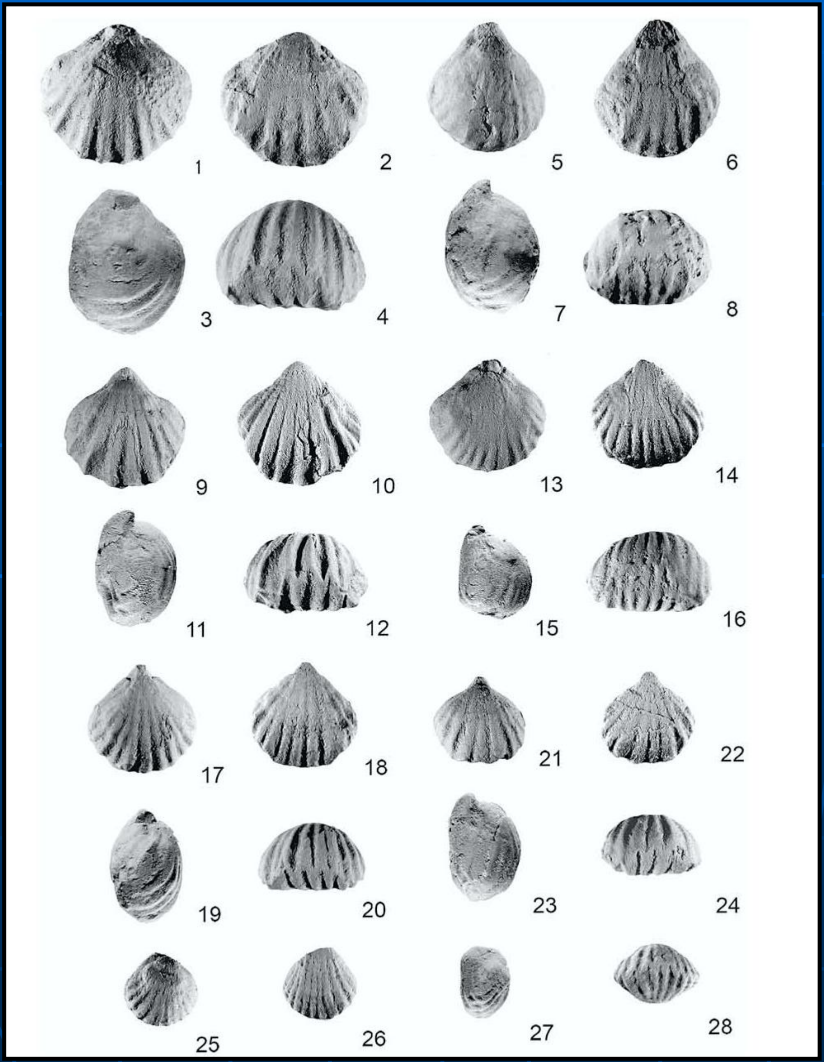
Silty Mollusc Packstone



Shadow Zone Lentil Facies
Sponge, Bryozoan, Brachiopod

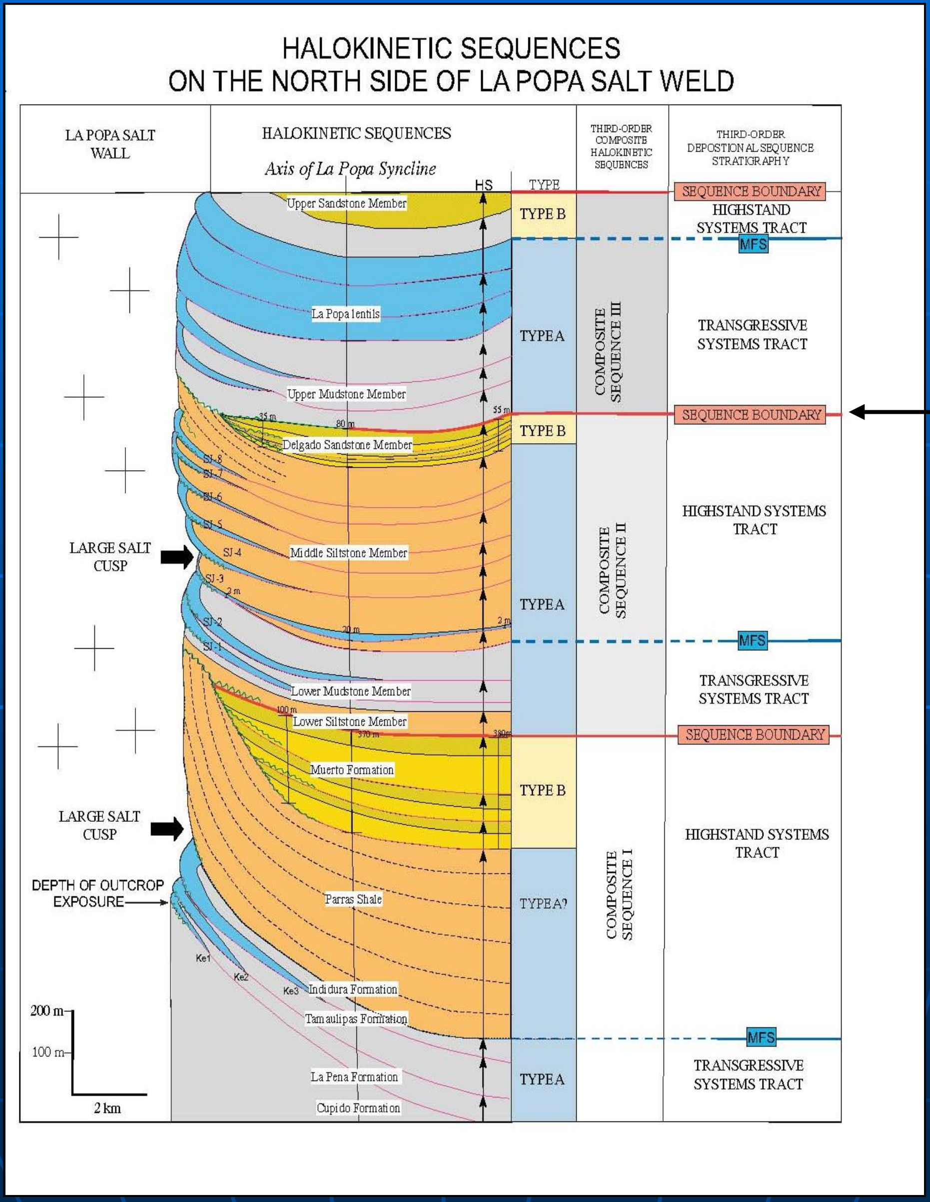


Shadow Zone Lentil Facies: Brachiopod Bioherm

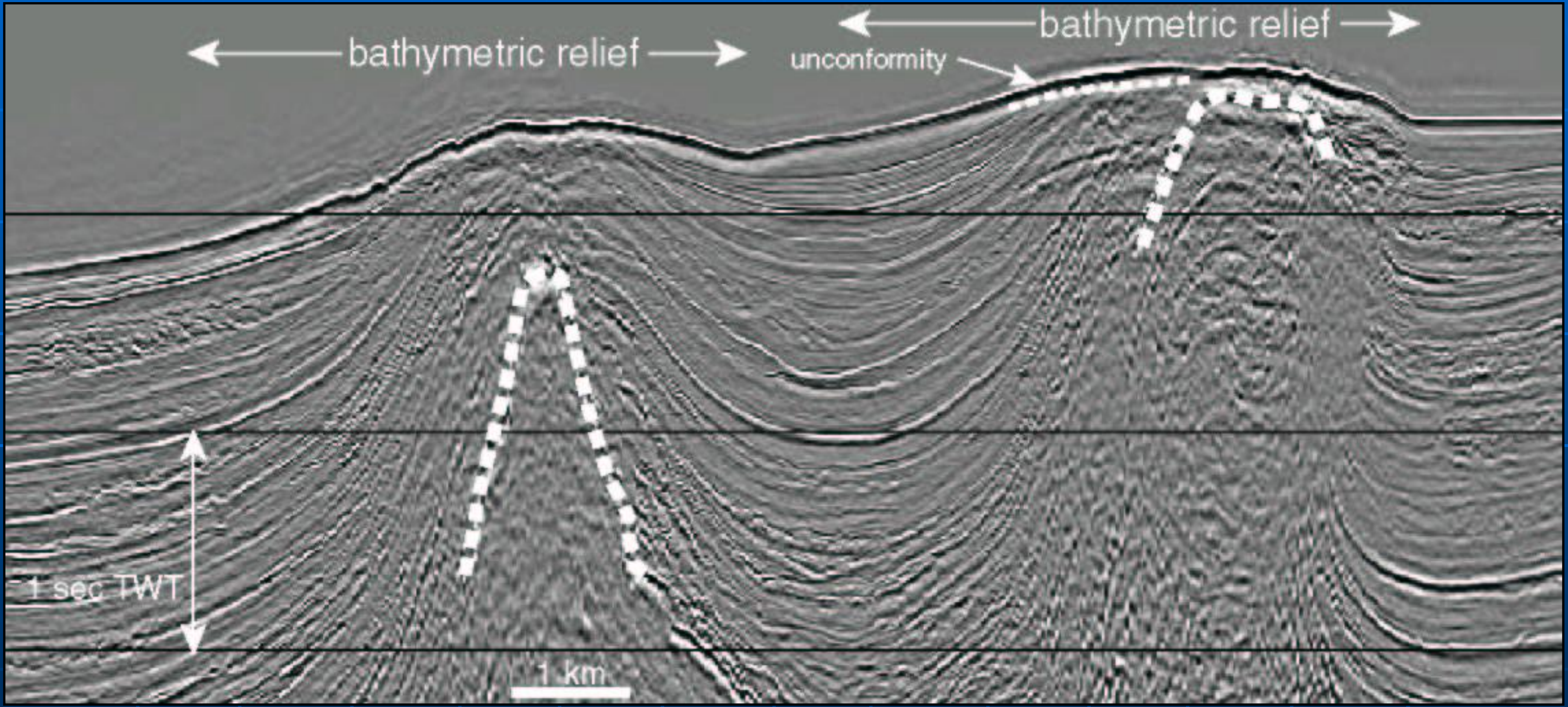


Klosterman et.al, 2007, J. Paleont

Regional Control Relative Sea Level

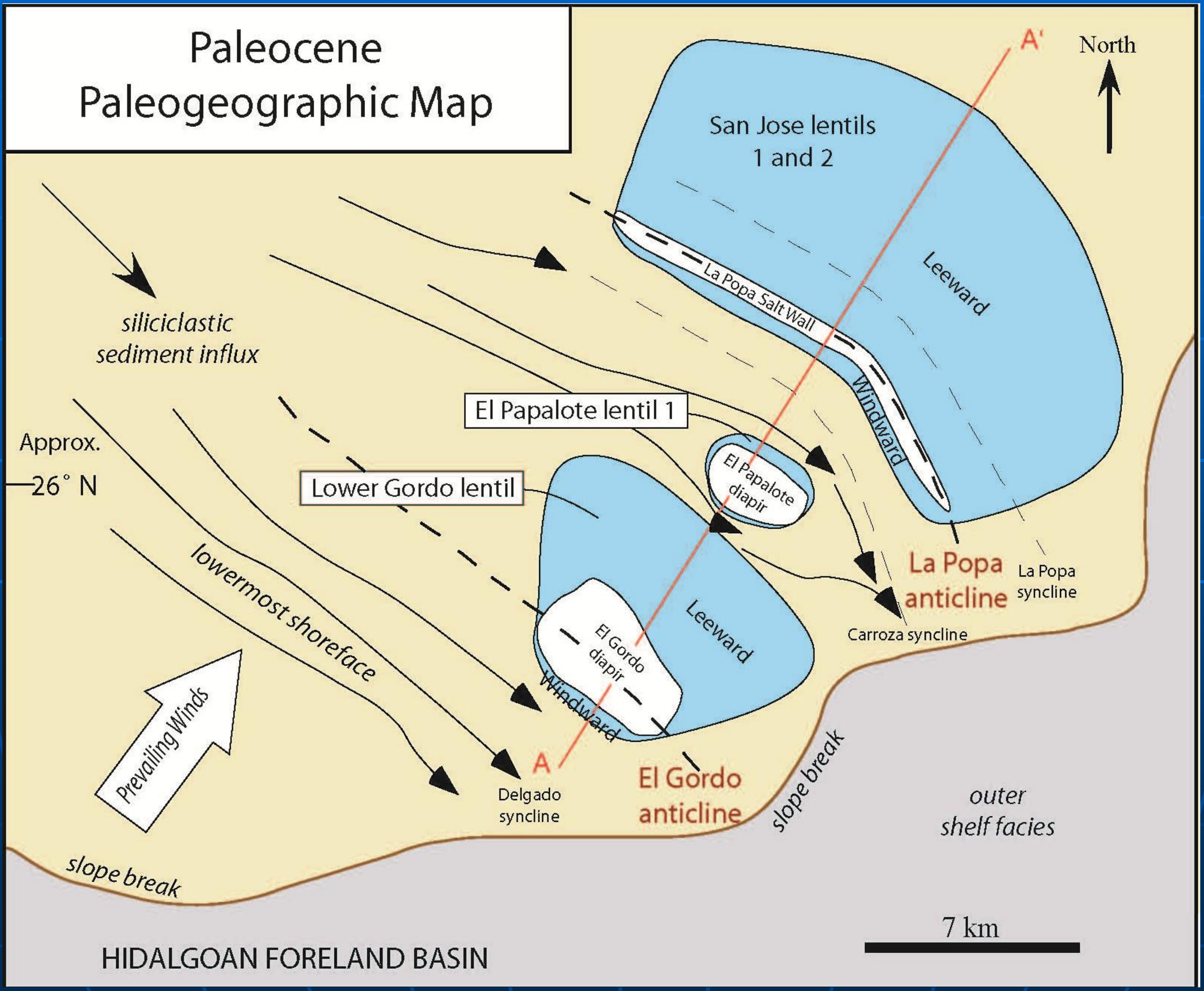


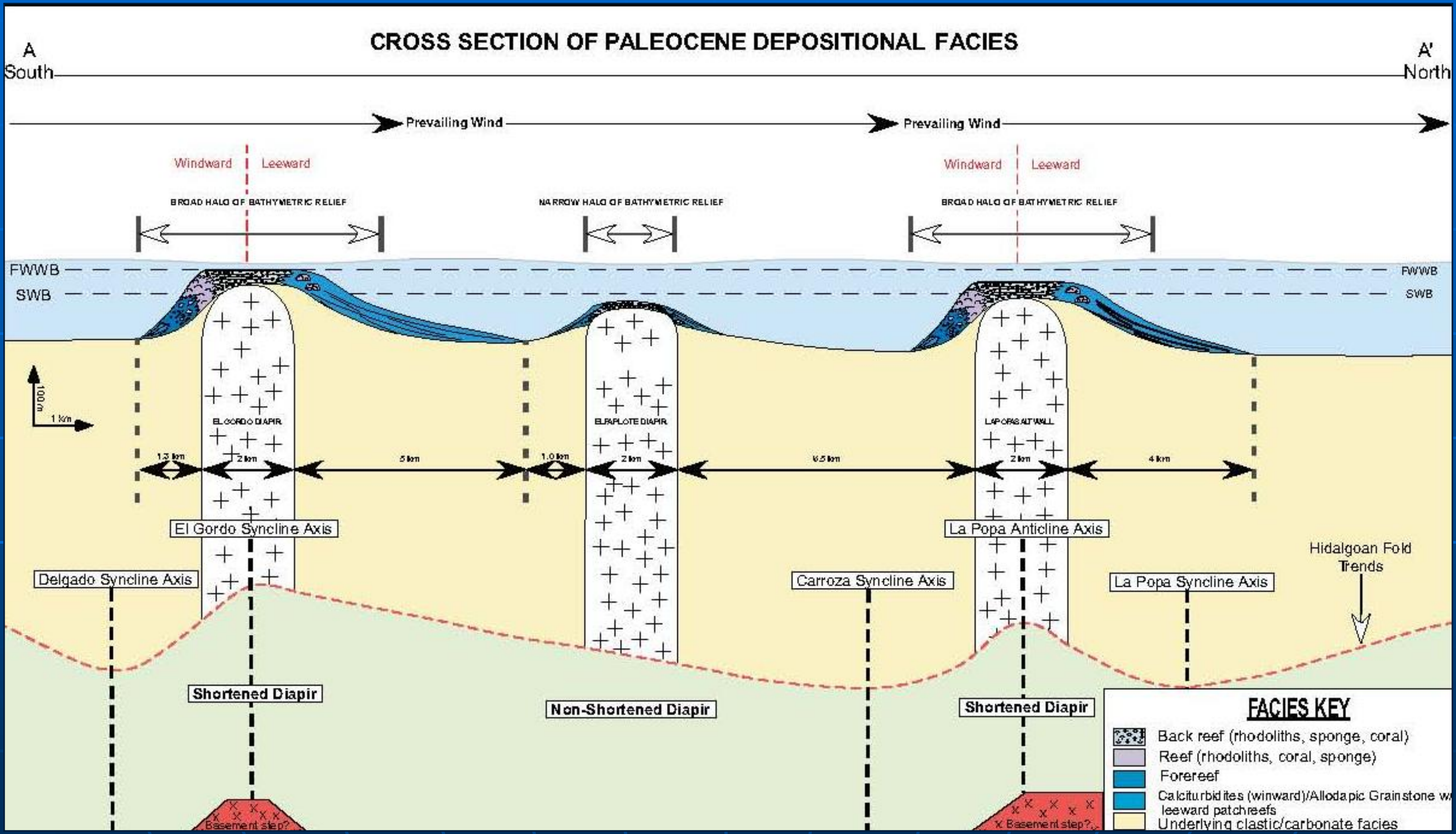
Regional Structural Control
Seismic of "Squeezed" Diapir



Data courtesy of WesternGeco and Shell

Regional Structural Control





CROSS SECTION OF PALEOCENE DEPOSITIONAL FACIES
A
South
A'
North
Prevailing Wind
Prevailing Wind
Windward
Leeward
Windward
Leeward
BROAD HALO OF BATHYMETRIC RELIEF
NARROW HALO OF BATHYMETRIC RELIEF
BROAD HALO OF BATHYMETRIC RELIEF
FWWB
SWB
FWWB
SWB
100 m
1 Km
1.3 km
2 km
5 km
1.0 km
2 km
6.5 km
2 km
4 km
El Gordo Syncline Axis
La Popa Anticline Axis
Hidalgoan Fold Trends
Delgado Syncline Axis
Carroza Syncline Axis
La Popa Syncline Axis
Shortened Diapir
Non-Shortened Diapir
Shortened Diapir
Basement step?
Basement step?
FACIES KEY
Back reef (rhodoliths, sponge, coral)
Reef (rhodoliths, coral, sponge)
Forereef
Calciturbidites (winward)/Allodapic Grainstone w/ leeward patchreefs
Underlying clastic/carbonate facies

Controls on Maastrictian and Paleogene Carbonate Platforms

1. Passive salt diapirs created bathymetric highs for platform development
2. Windward –leeward asymmetric facies distribution on platform
3. Heterozoan fauna due to raised nutrient levels from detrital influx and cold seeps?
4. Brachiopod reefs in shadow zone of diapir
5. Platforms confined to TST of 3rd-order depositional sequences
6. Thickest, most widespread, shallow water platforms on shortened diapirs