Received Shelton Award for best paper presented in Search and Discovery 2010.

Tracking the Migration of Salt Diapirs Using Halokinetic Sequence Stratigraphy*

Katherine Giles[1]

Search and Discovery Article #40534 (2010)
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*Adapted from 2007-2008 AAPG Distinguished Lecture. Please refer to companion article by the author; it is entitled "Complex Feed Back Loops Controlling Heterozoan Reef Development on Salt Diapirs, La Popa Basin, Mexico" and is Search and Discovery Article #50260 (2010).

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Abstract

The progressive migration of diapiric salt bodies can be interpreted using stratal and structural relationships present in the sedimentary packages that surround them. Distinctive near-diapir growth stratal packages associated with vertically moving passive diapirs are referred to as "halokinetic sequences". Halokinetic sequences are angular unconformity bounded, growth-stratal packages that form due to temporal variations in relief over passively rising diapirs. These stratal packages document the dynamic interplay between salt movement and adjacent sedimentation.

Two end-member types of halokinetic sequences (Type A and Type B) have been recognized on outcrop in the shelfal strata of La Popa salt basin, Mexico. The types differ in depositional facies, maximum degree of internal folding, amount of fault reactivation on unconformities, overall sedimentation rate, and distance of halokinetic sequence termination from the salt/sediment interface. Type A sequences are associated with periods of overall very low sediment accumulation rates typical of marine transgression on the shelf. They contain basal, diapir-derived debris flows encased in outer shelf fine-grained sandstones deposited by hyperpycnal flows that are abruptly overlain by outer shelf black shales. These strata are locally tightly folded with truncation angles of up to 90° at sequence boundaries. Sequence boundaries show significant fault reactivation during later halokinesis and evidence of brittle shear.

Type A sequences terminate directly against the diapir. Type B sequences are associated with periods of moderately high sediment accumulation rates typical of marine regression on the shelf. They contain basal, lower shoreface sandstones that shallow upward to tidal and lagoonal sandstone. These strata display minimal folding with truncation angles that are <15°. There is little or no reactivation of the sequence boundaries during later halokinesis. Type B diapir-proximal sequence terminations are spatially separated from the diapir by an average of 250m.

Both styles of halokinetic sequences are seen on seismic lines and can be used to "fingerprint" the fluctuating conditions present near the

diapir during migration. The characteristics of the two types of sequences and their stratal arrangement into composite sequences have important implications for reservoir quality, geometry, continuity, and charge potential in diapir-related traps.

Reference

Giles, K.A. and T.F. Lawton, 2007, Halokinetic sequence stratigraphy adjacent to the El Papalote diapir, northeastern Mexico: AAPG Bulletin, v. 86, p. 823-840.

Tracking the Migration of Salt Diapirs using Halokinetic Sequence Stratigraphy

By:

Katherine Giles

AAPG Distinguished Lecturer 2007-2008

Sponsored by:

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Current Research Personal

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- **Timothy F. Lawton (NMSU)**

- sedimentology, stratigraphy, and tectonics

- **Mark Rowan (Rowan Consulting, Inc.)**

- structure and tectonics

- **Francisco Vega-Vera (Universidad Nacional Autonoma de Mexico)**

-biostratigraphy

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- structure and tectonics

- **Gene Perry (Northern Illinois University)**

- sedimentology, diagenesis and fluid flow

- **Brenda Buck (UNLV)**

- paleosol morphology and isotopic character, sedimentology

- **Andrew Hanson (UNLV)**

- sedimentology, diagenesis and fluid flow

- **Gary Gray (ExxonMobil Corp.)**

- structure and geochemistry

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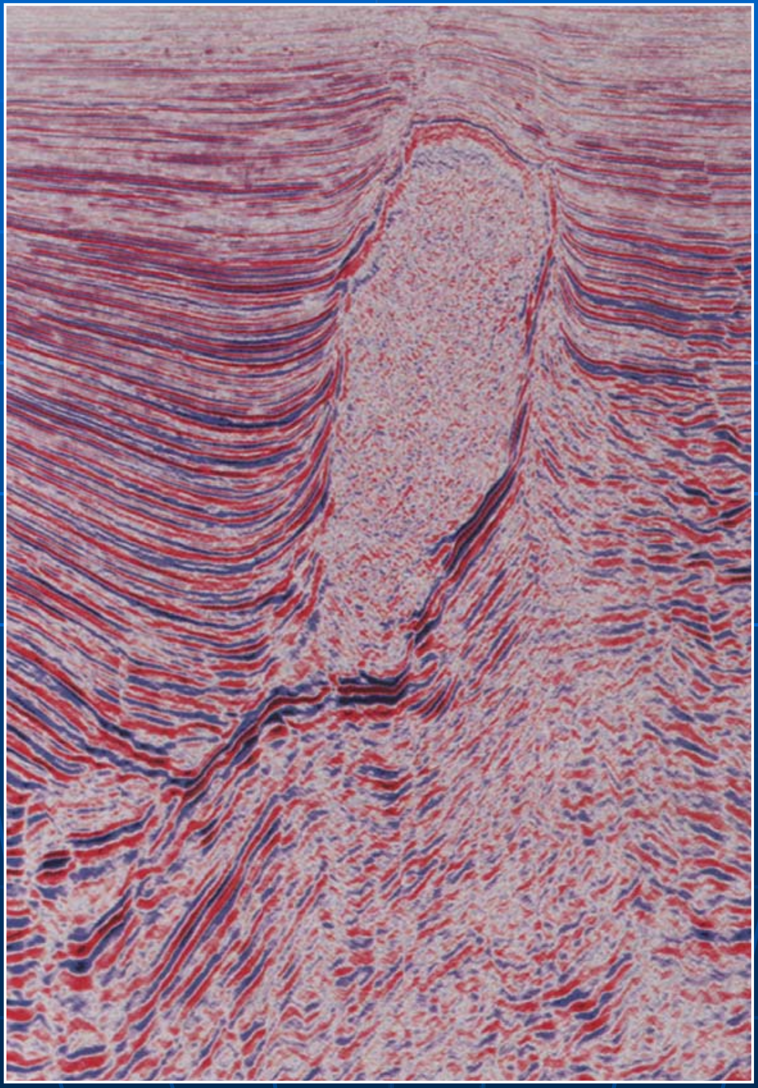
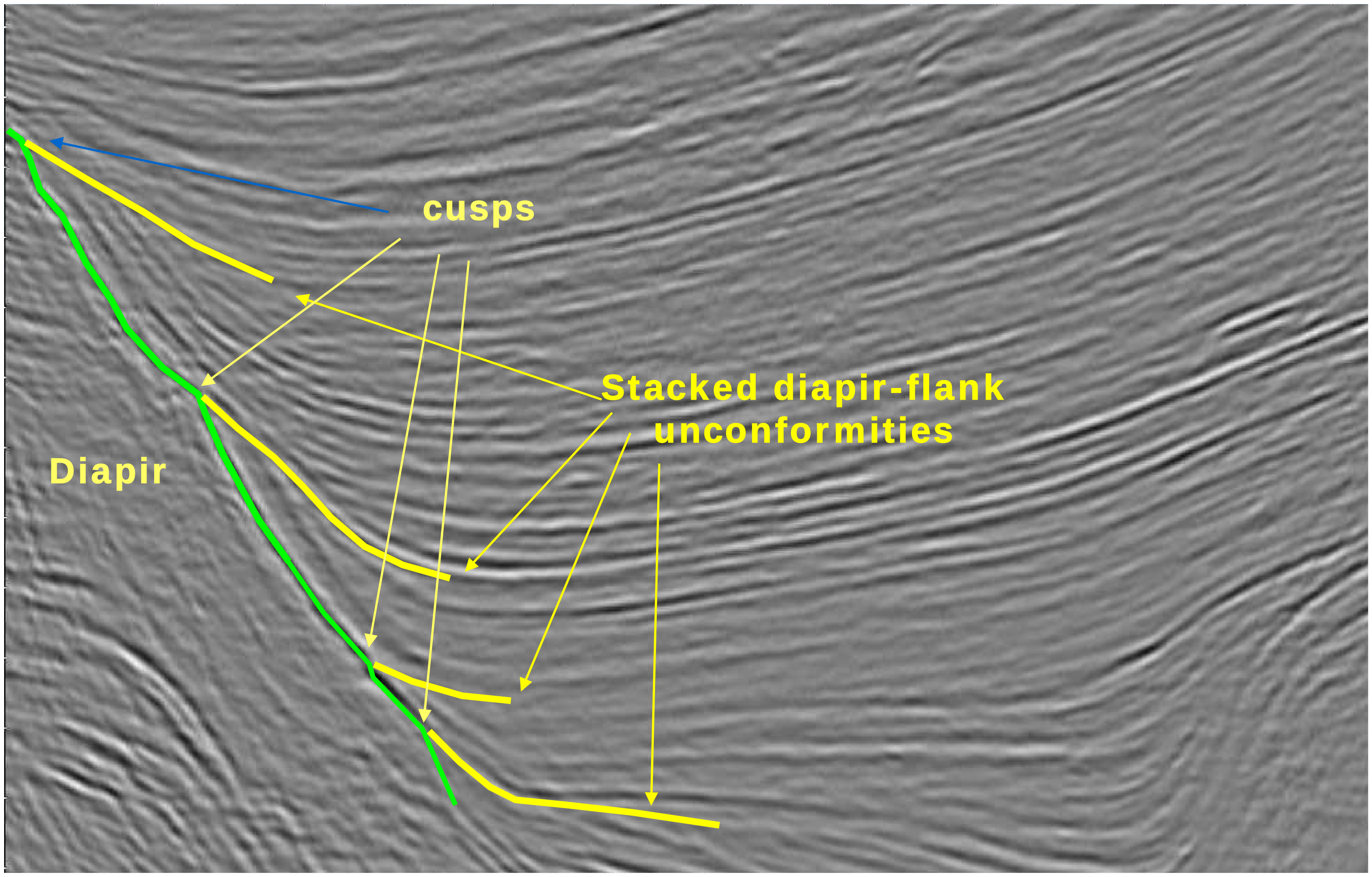
Seismic Line Across a Vertical Passive Diapir in the Gulf of Mexico



Seismic Line Across Passive Diapir With Angular Unconformities

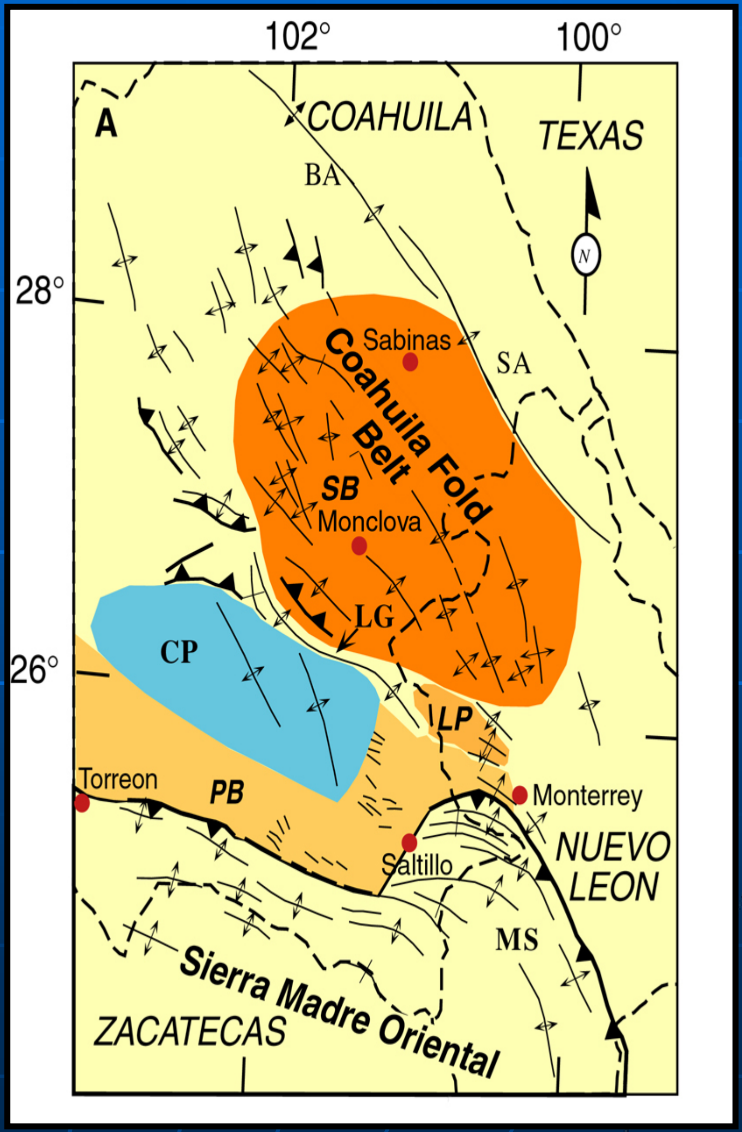


Halokinetic Sequences

Consist of relatively conformable successions of growth strata genetically influenced by near-surface extrusive salt movement and are locally bounded at the top and base by angular unconformities that become disconformable to conformable with increasing distance from the diapir.

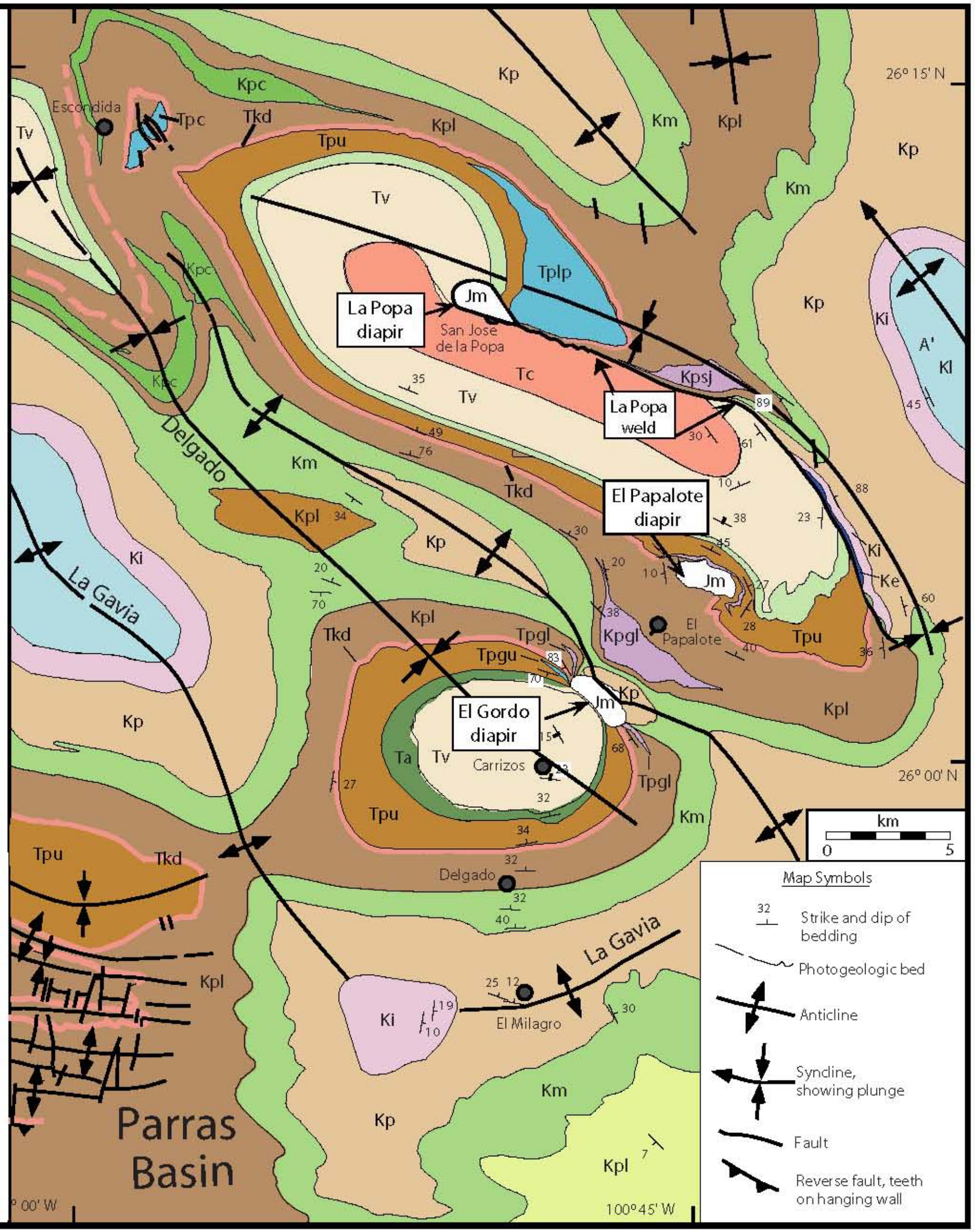
Giles and Lawton, 2002, AAPG Bulletin

Regional Tectonic Elements Map of La Popa Basin in Mexico



Satellite Image of La Popa Basin and the Sierra Madre Oriental

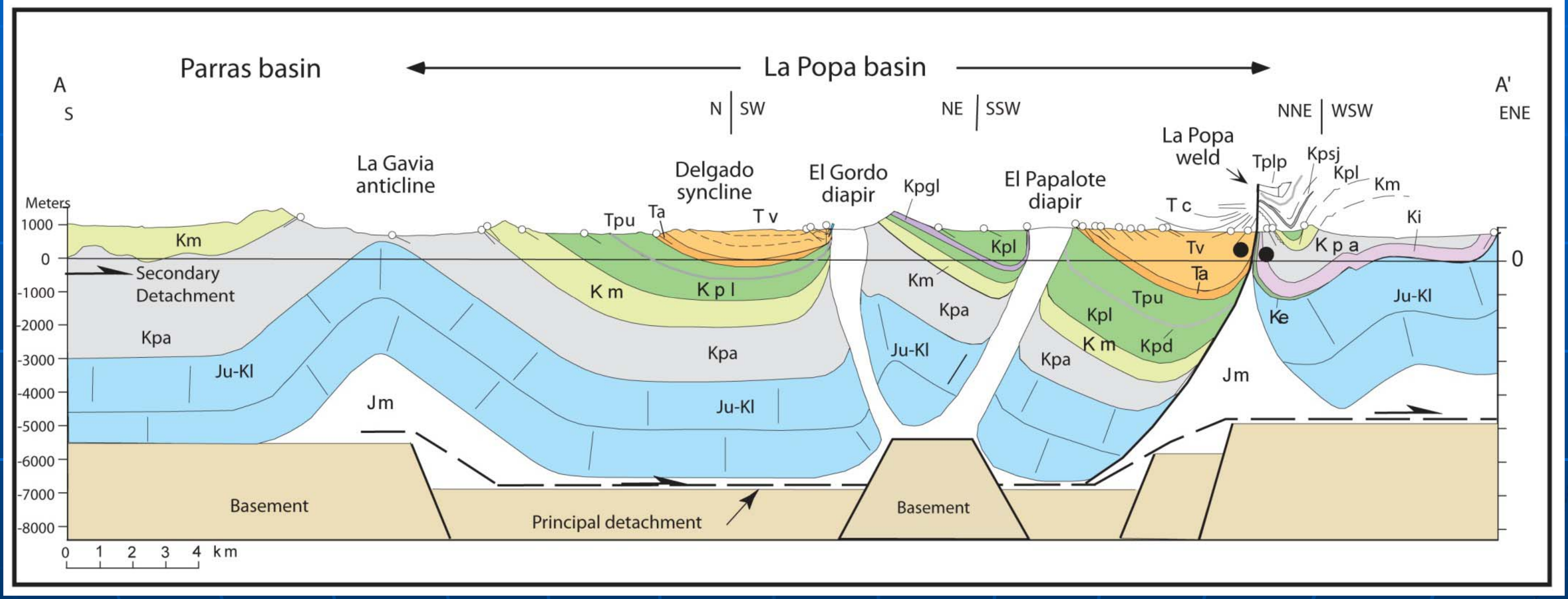
Geologic Map of La Popa basin



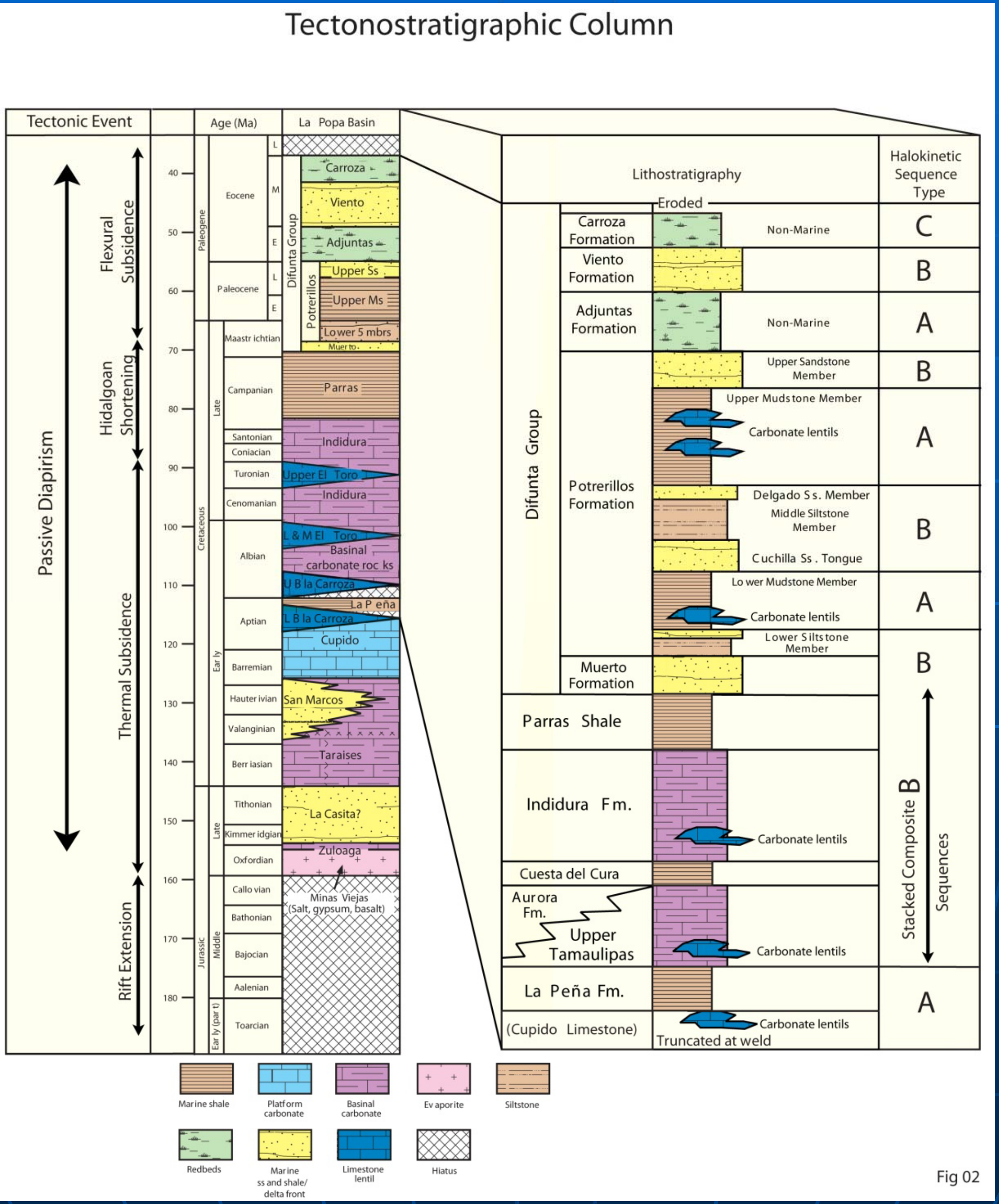
Explanation

- 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

Geologic Cross Section of La Popa Basin



Tectonostratigraphic History of the La Popa Basin



La Popa Basin Halokinetic Sequence Types

- Type A: "J" hook folded
- Type B: wedge folded
- Type C: non-folded

Aerial Photograph of El Papalote Diapir

Geologic Map of El Papalote Diapir

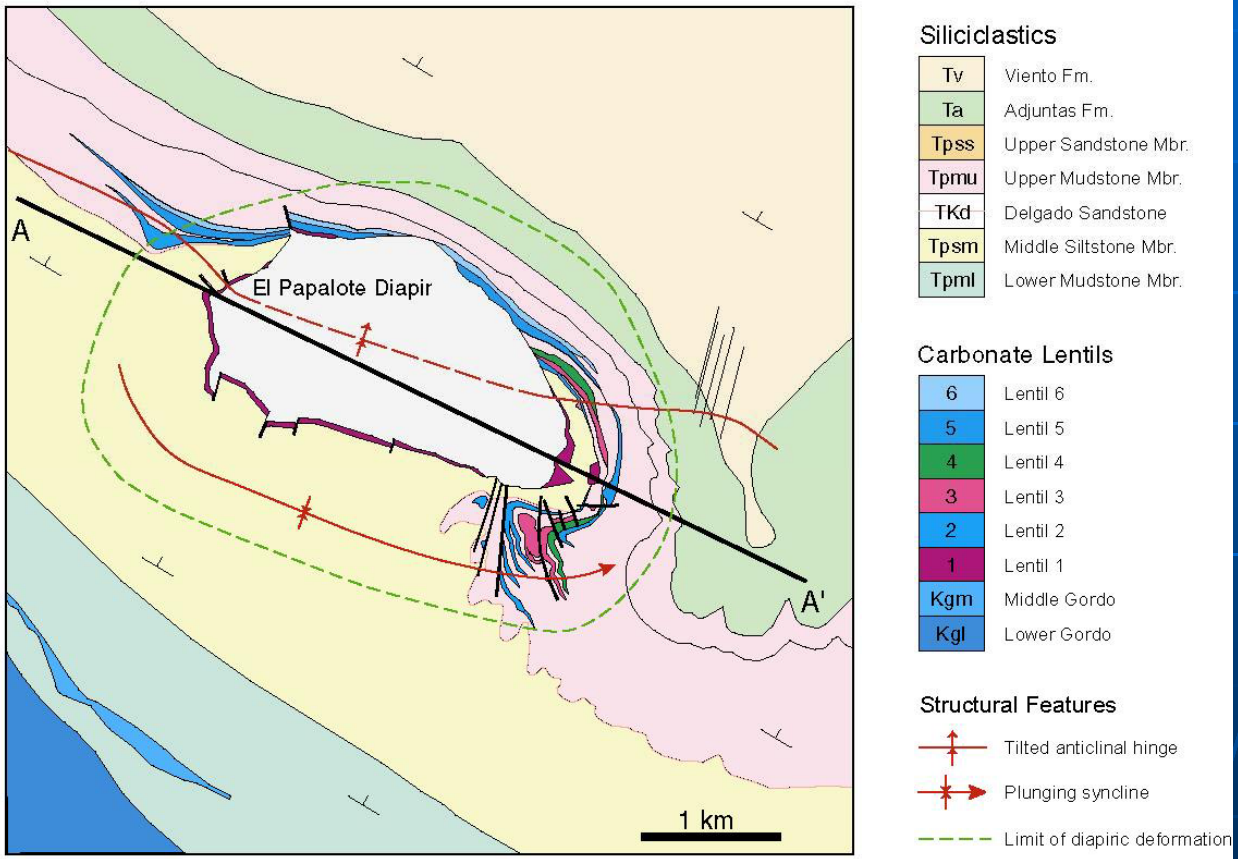
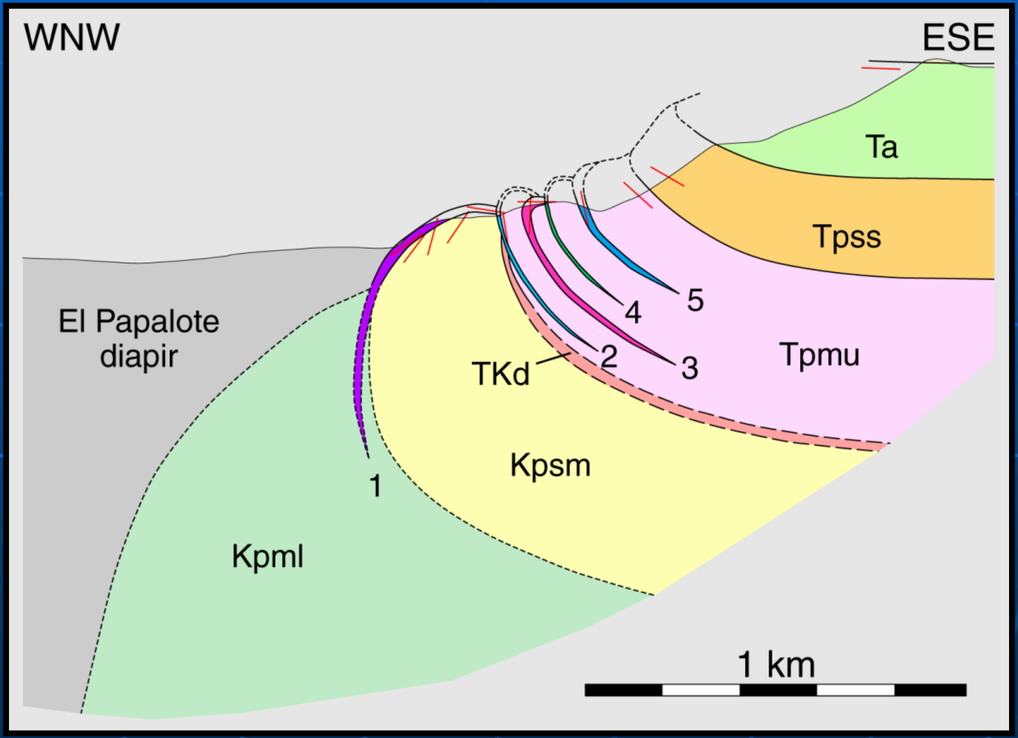
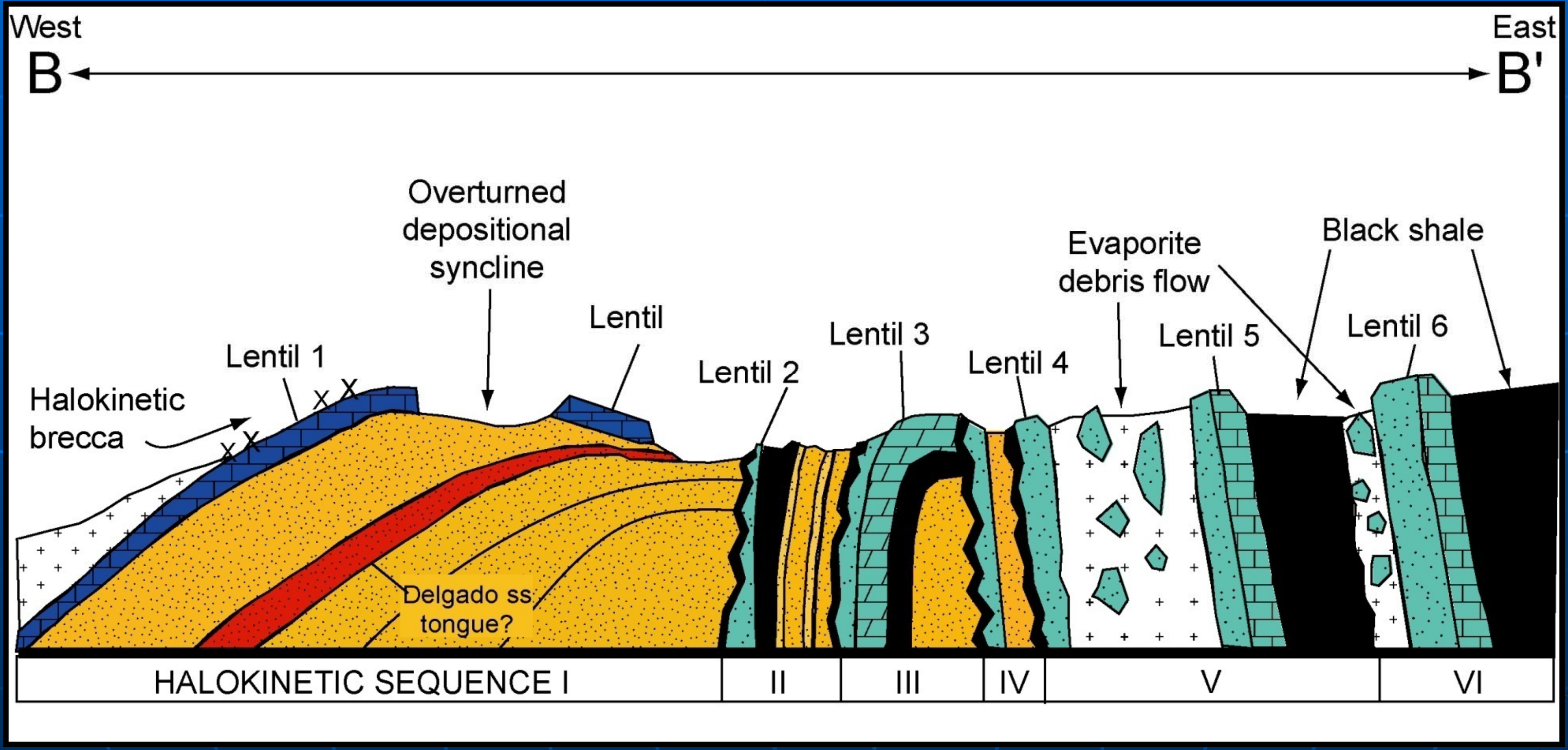


Figure 1.1 Geologic map of El Papalote diapir.

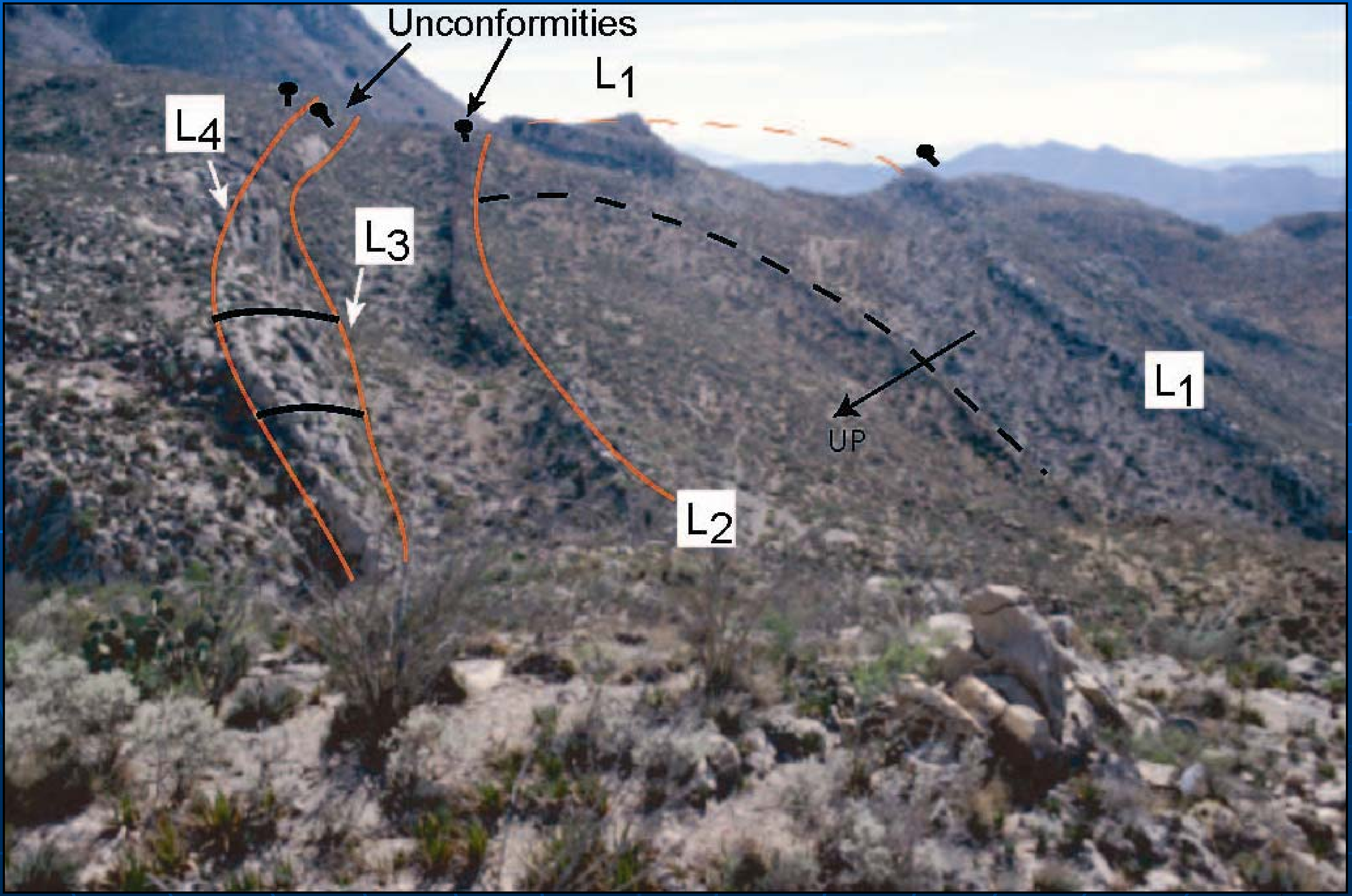
East overhang cross section of El Papalote Diapir



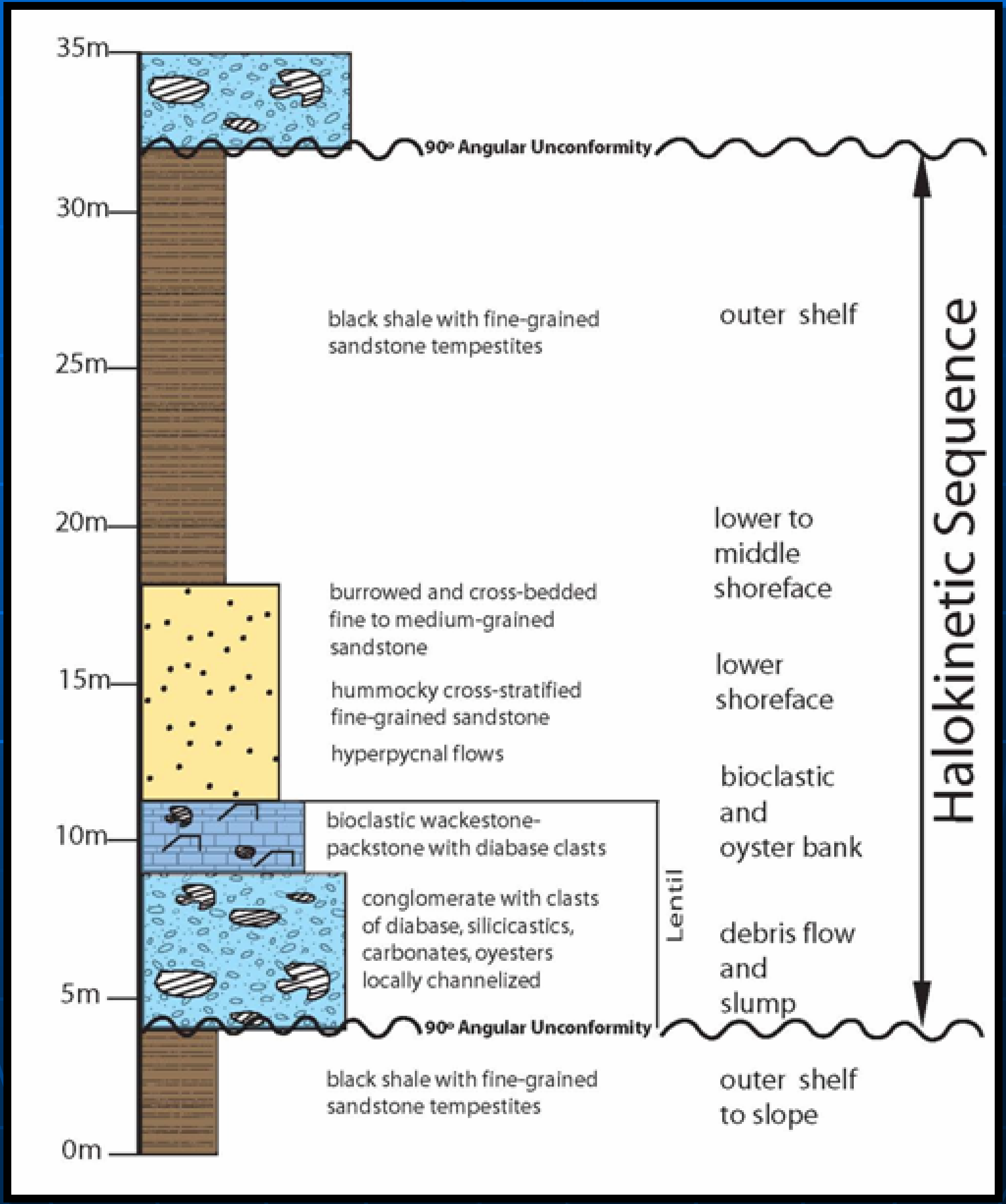
Detailed Cross Section at El Papalote Diapir of East Overhang Facies



El Papalote East Overhang Outcrop



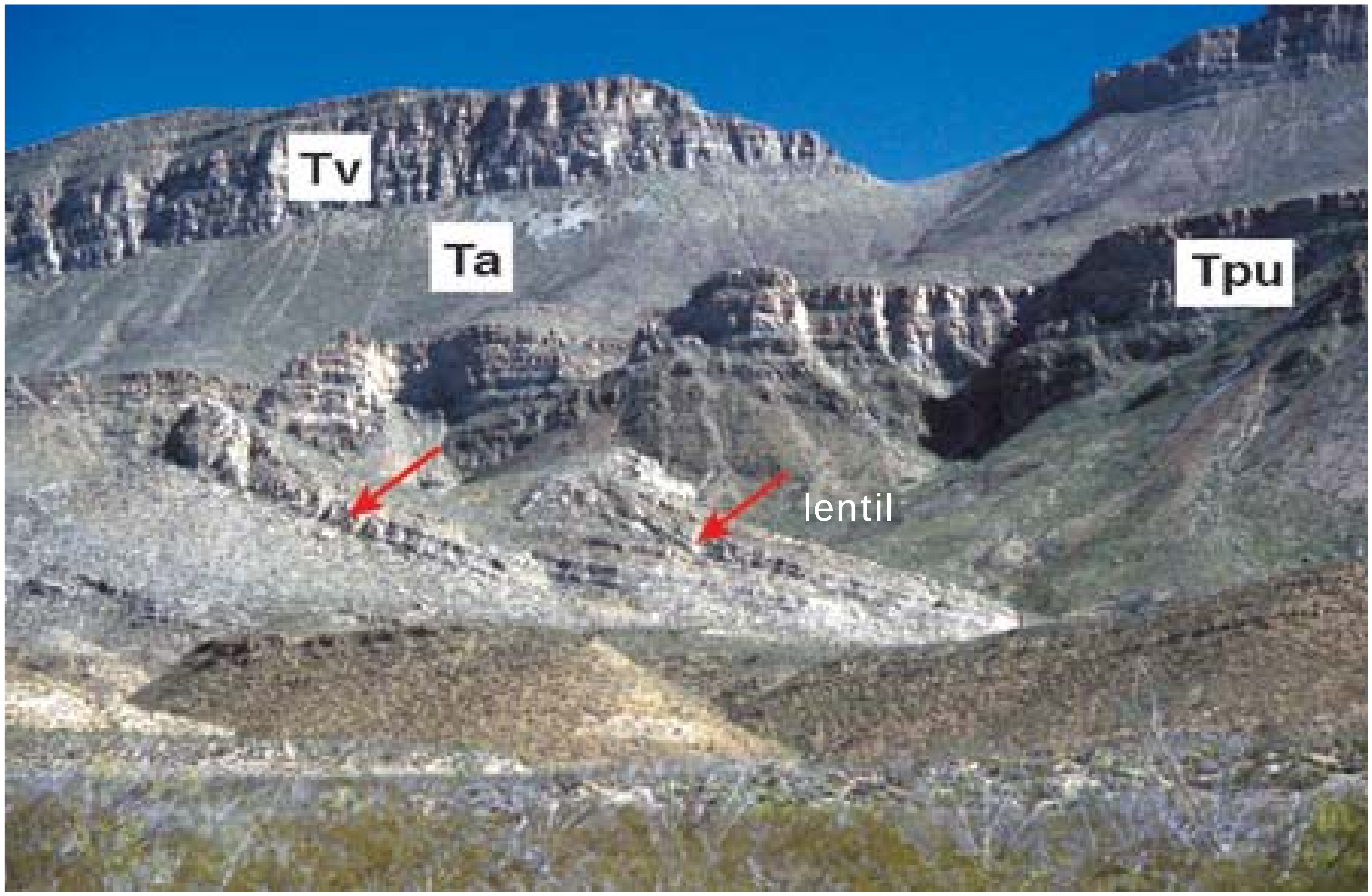
Idealized Type A Halokinetic Sequence



Type A Carbonate Lentil Facies: Metaigneous Clasts

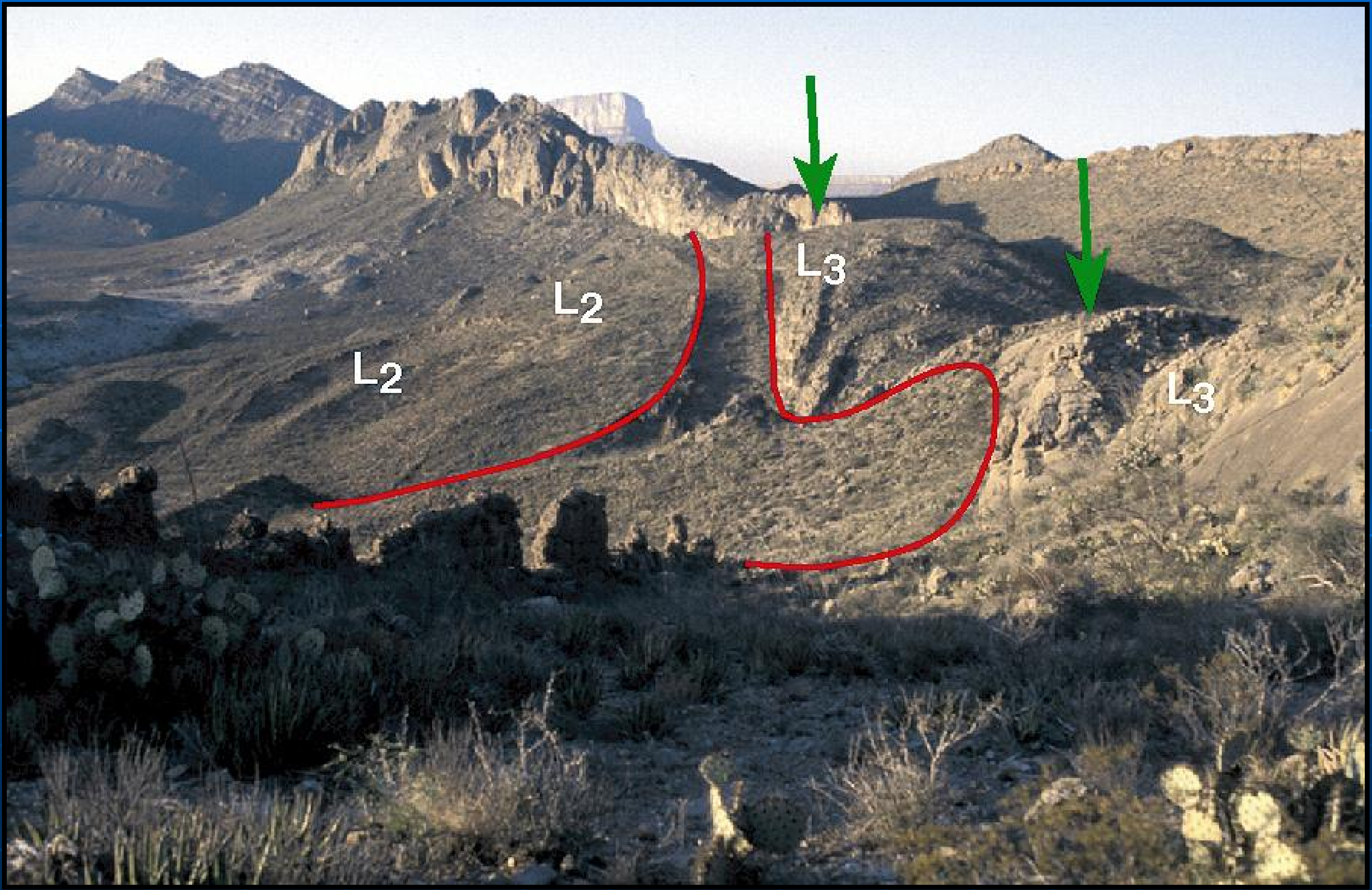
Type A Carbonate Lentil Facies: Oyster Bank

Carbonate Lentil Geometry



Type A Siliciclastic Facies

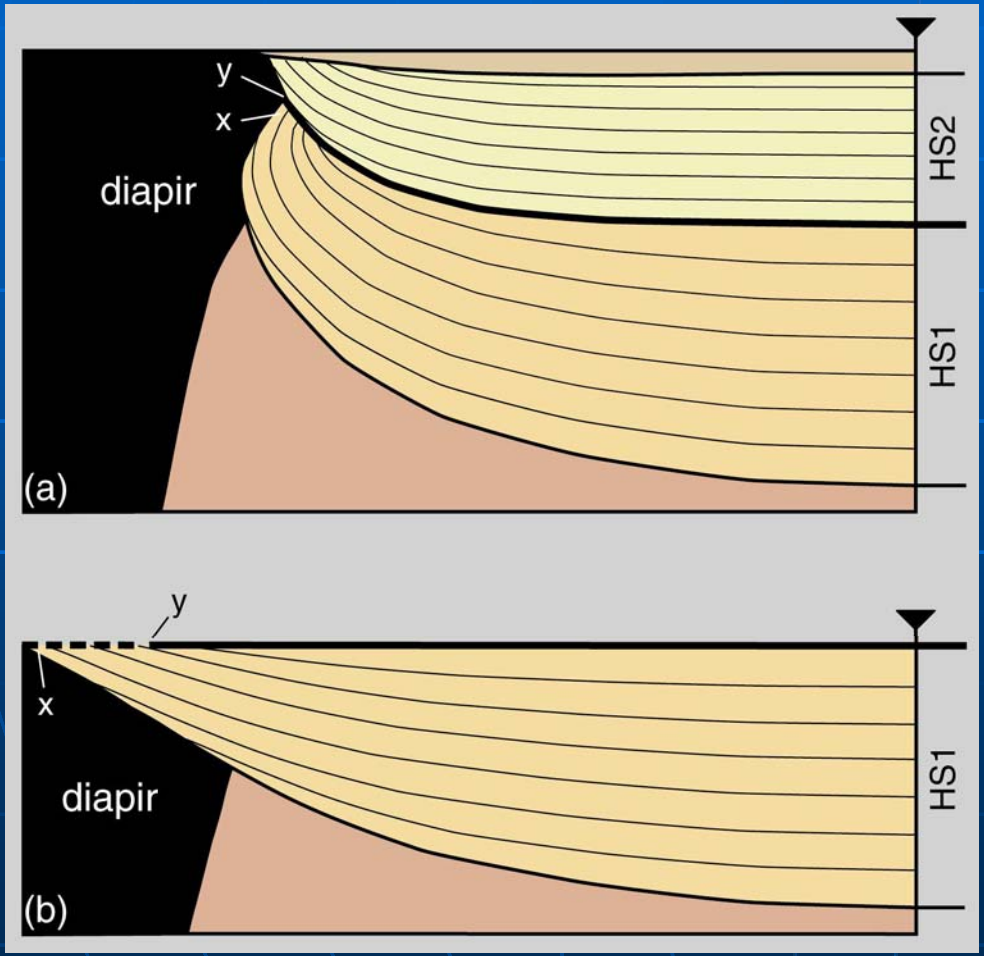
Outcrop of "J" Hook Folds



Evidence that Halokinetic Sequences Are Related to Passive Diapirism

- Clastics thin and onlap toward the diapir
- Carbonates thin and become more distal away from the diapir
- Local unconformities that become conformable within several hundred meters of diapir
- Debris flows adjacent to diapirs contain diapiric detritus
- Diapir was periodically exposed at the sea floor

Complex Flexural Slip Model



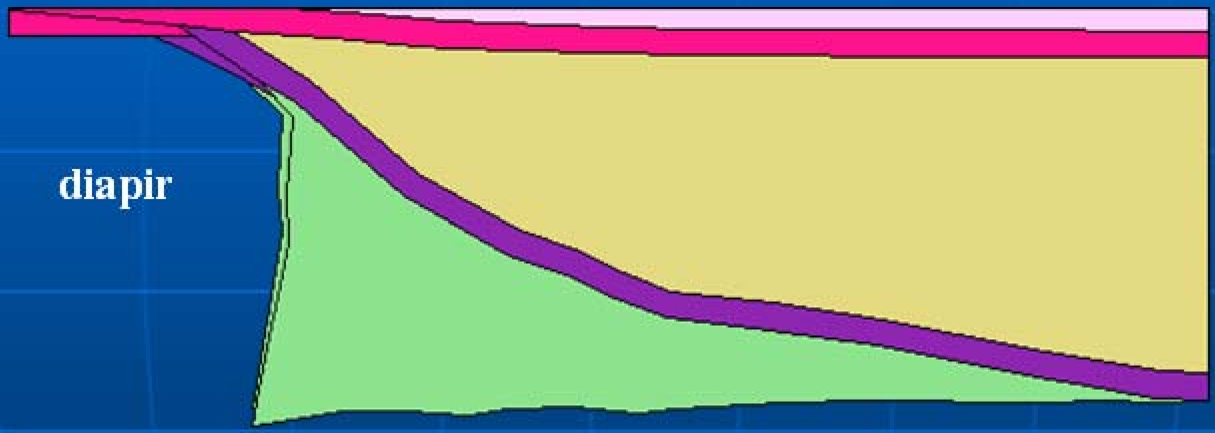
Kinematics

- Vertical pin in basin
- Flexural slip along non-parallel bedding
- Unconformities and onlap surfaces become zones of concentrated slip

Drape Fold Animation

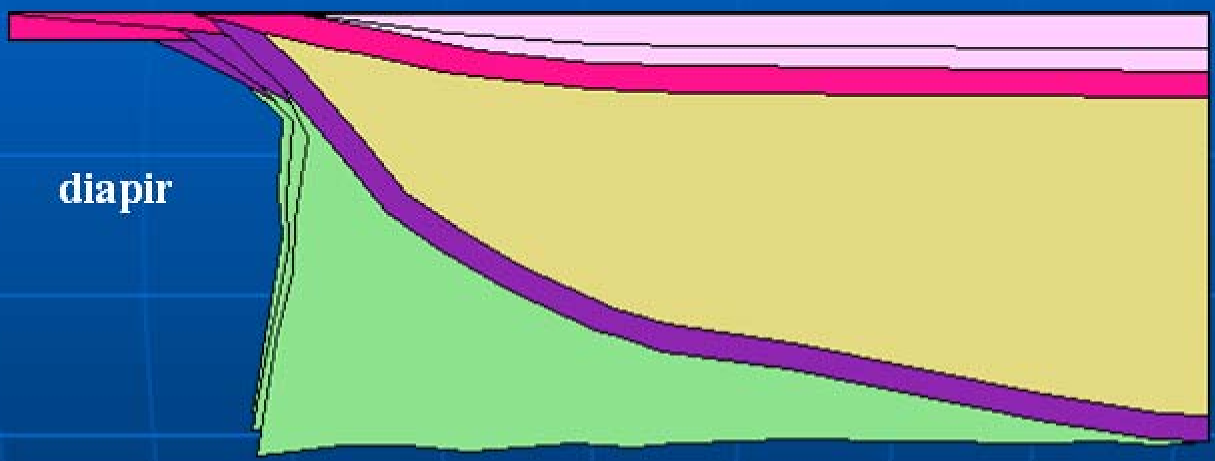
Modeled using LithoTect

Drape Fold Animation



Modeled using LithoTect

Drape Fold Animation



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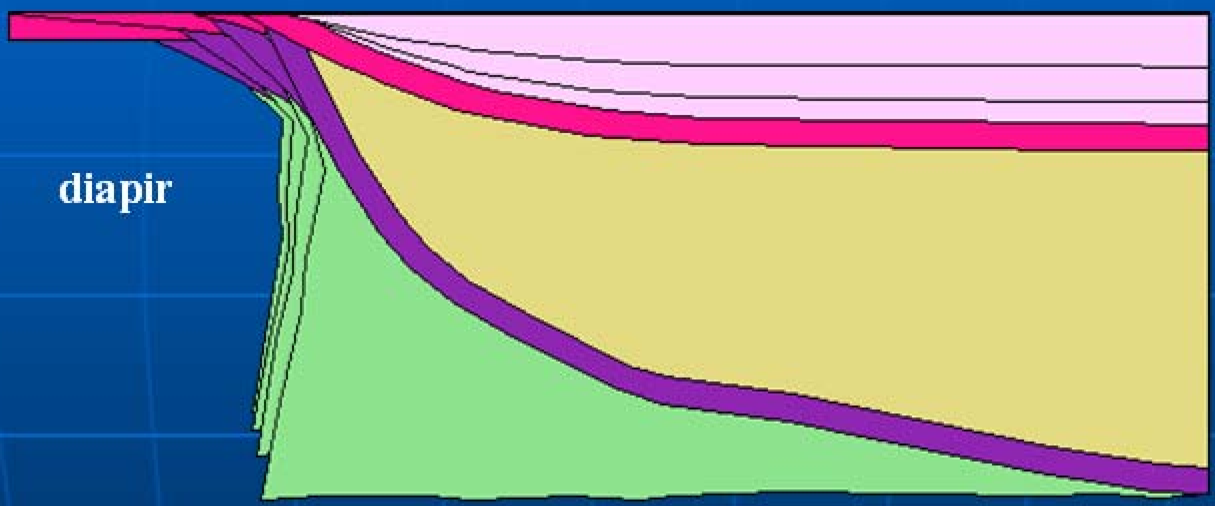

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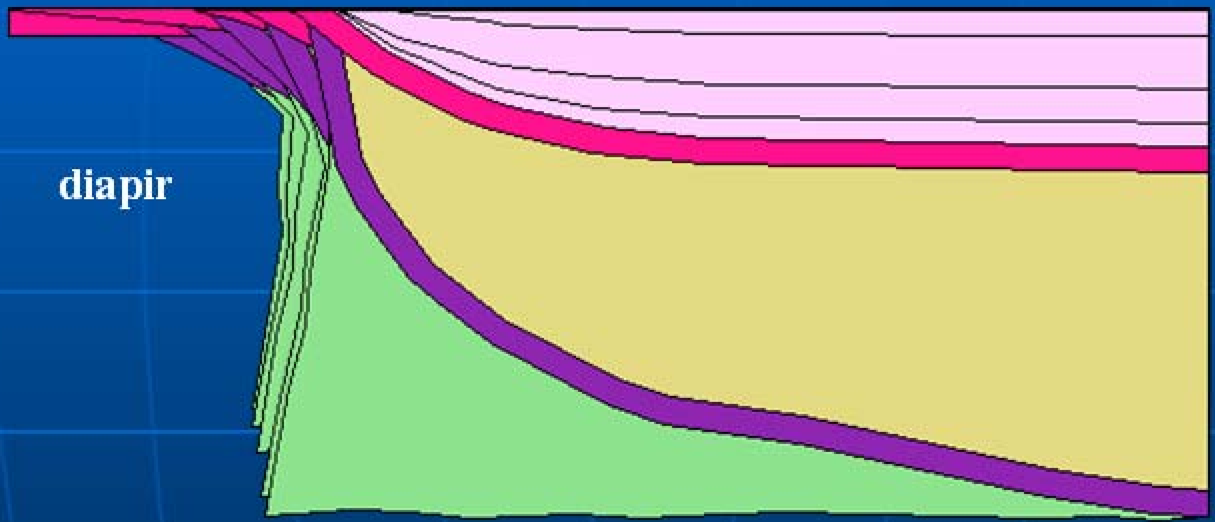

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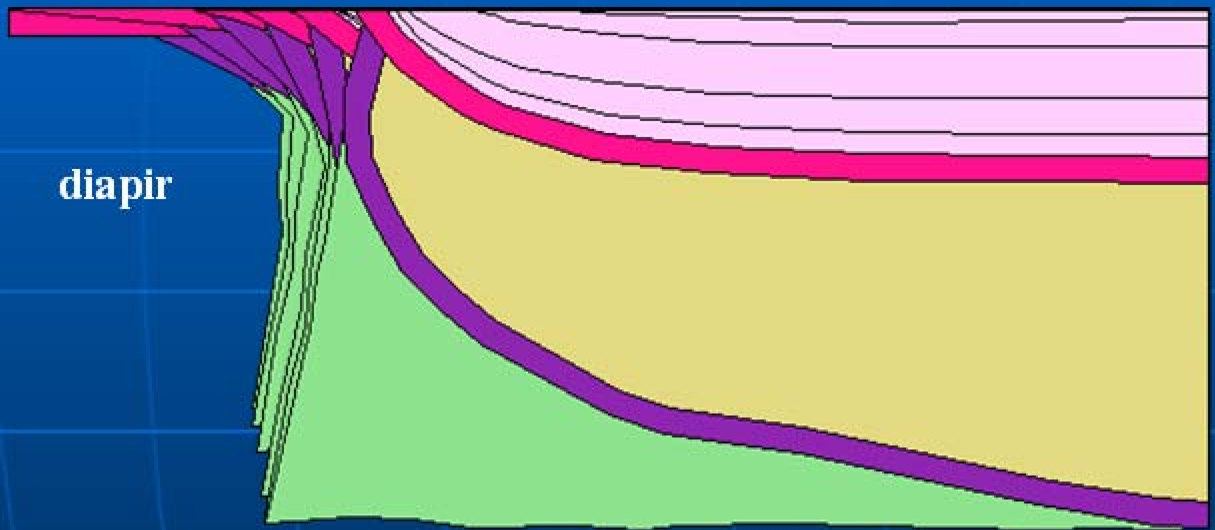

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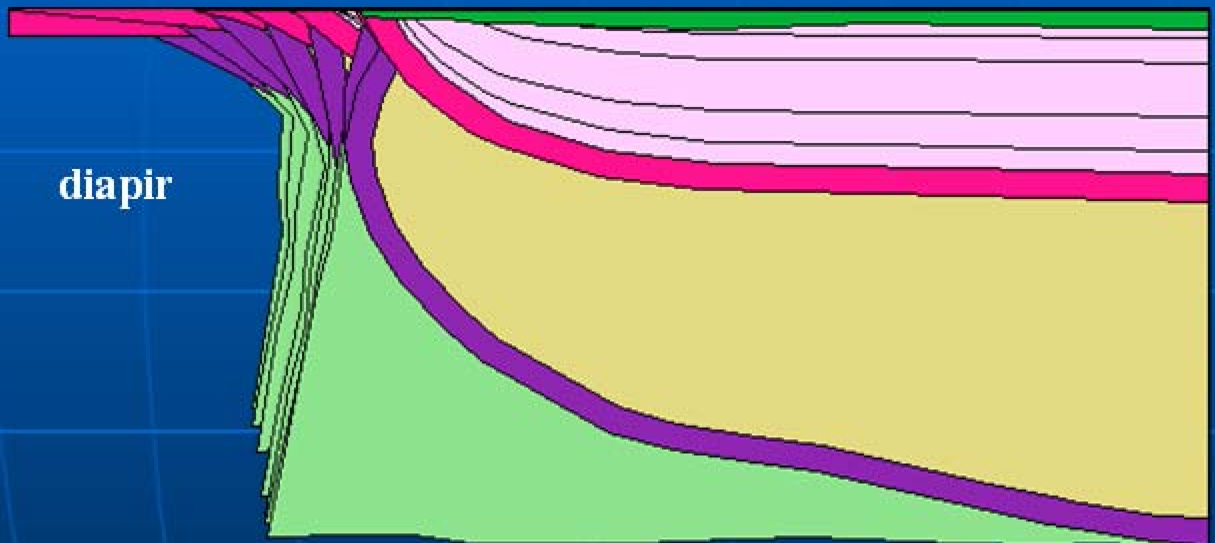

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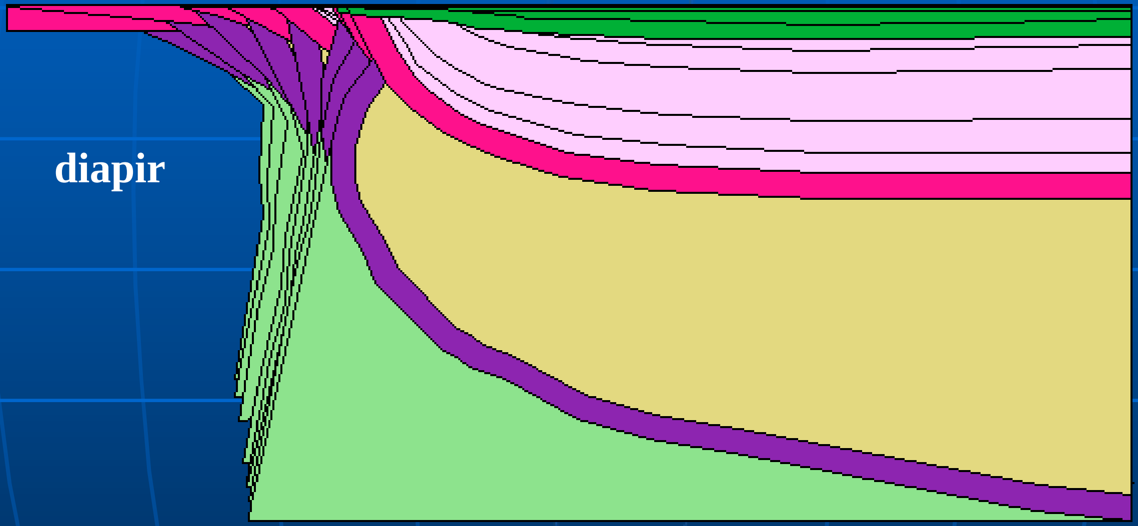
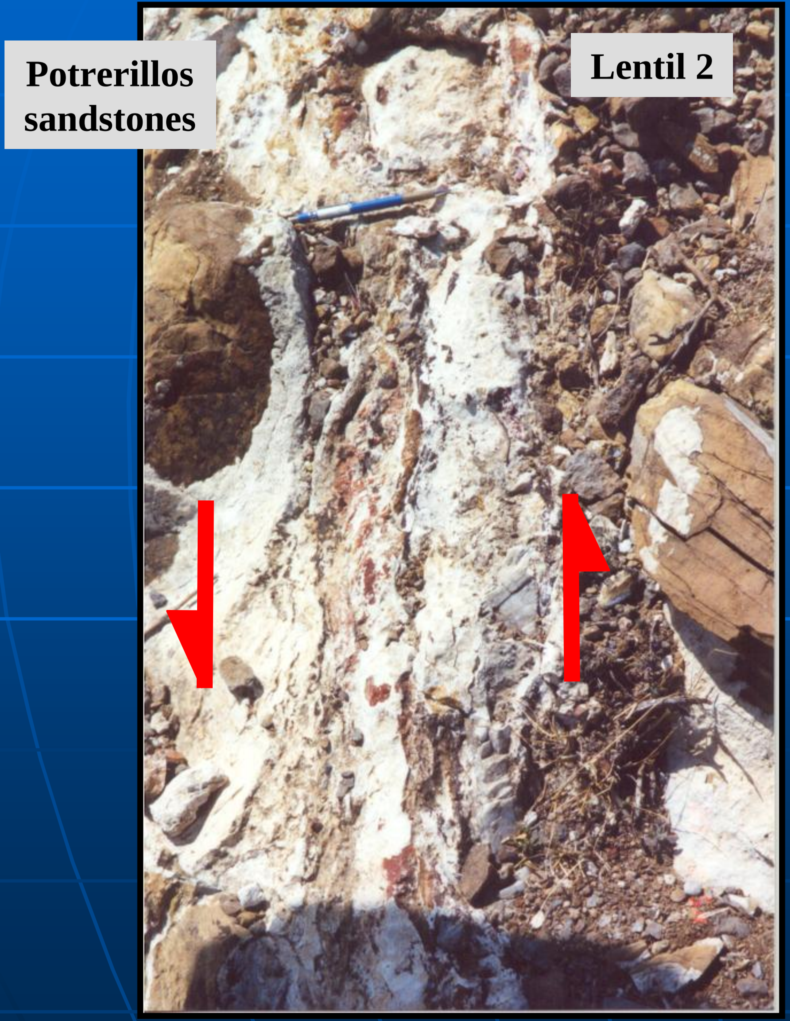
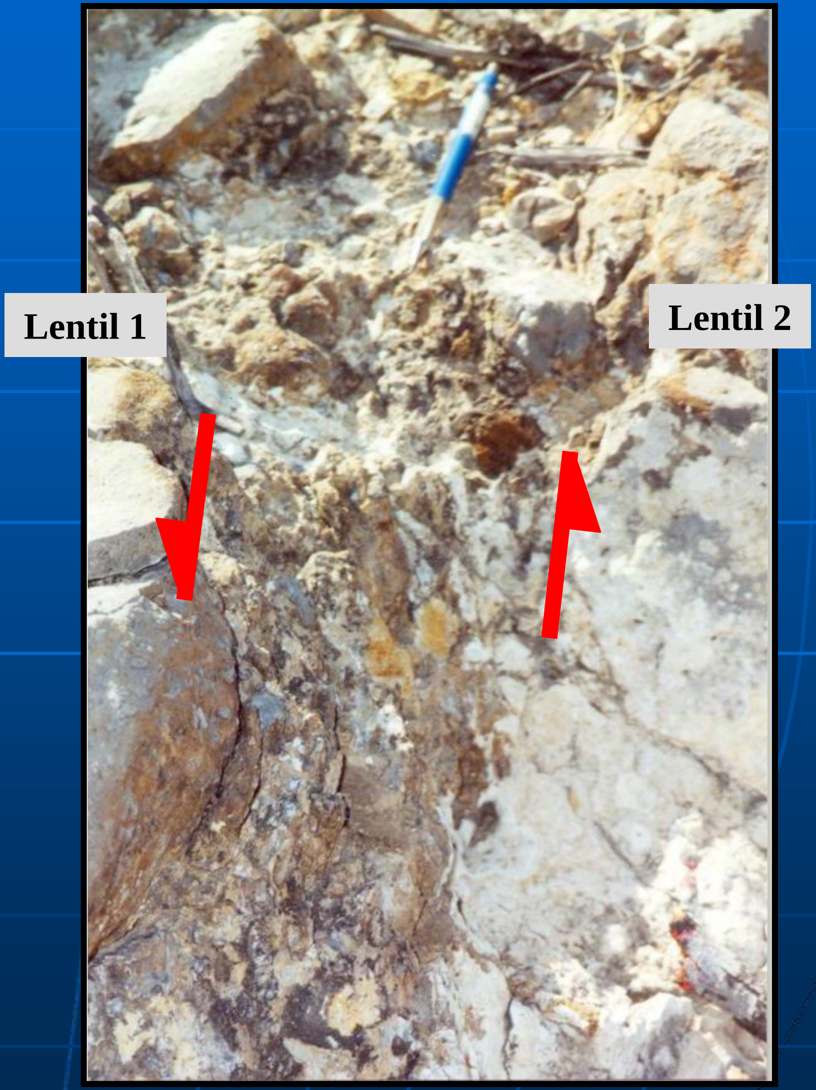


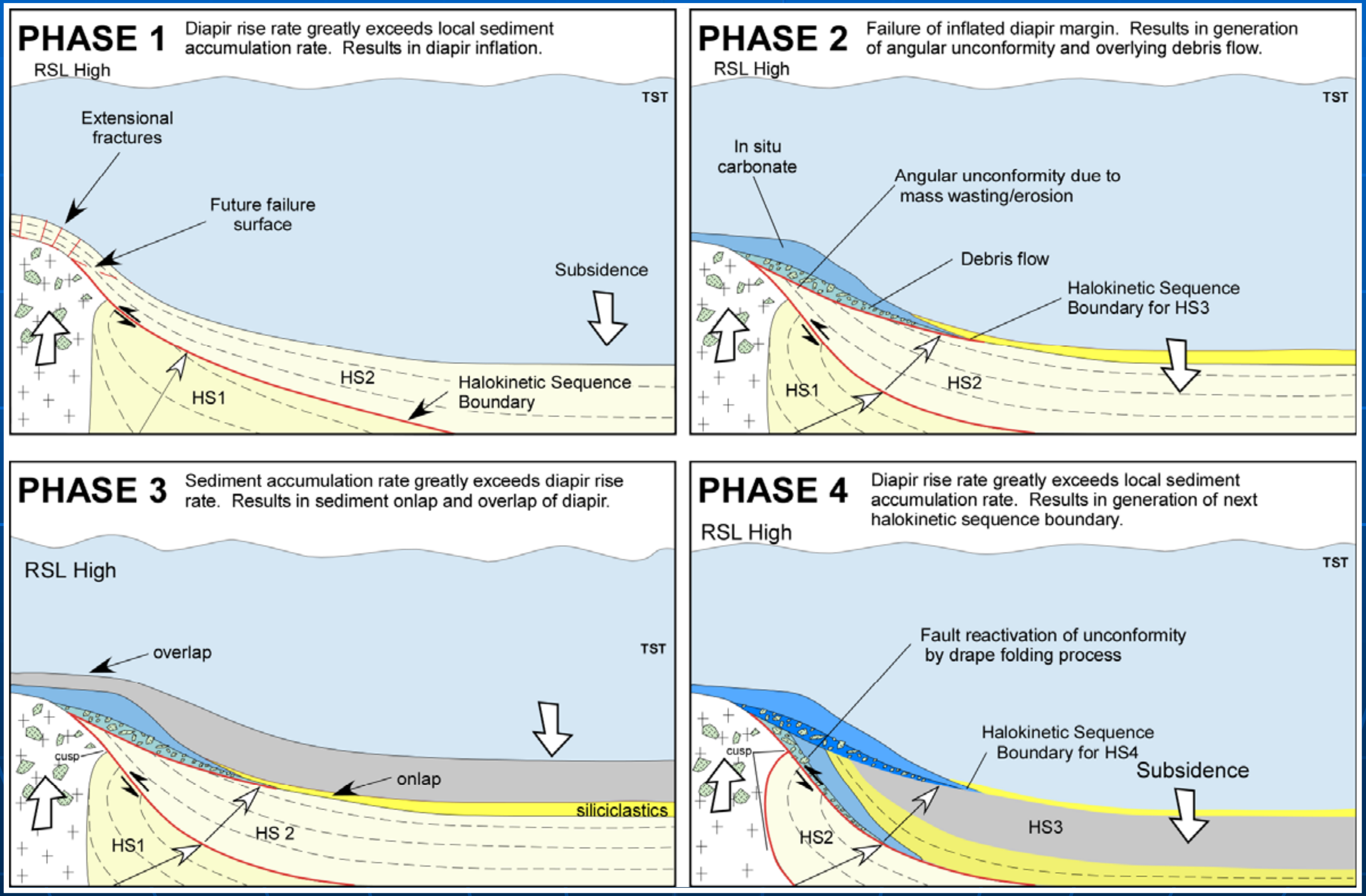
Modeled using LithoTect

Unconformity Exposures





Type A Halokinetic Sequence Model



Geologic Map of La Popa basin

Explanation

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- Tkd — Delgado Sandstone Member
- Kpl — Lower Potrerillos Formation
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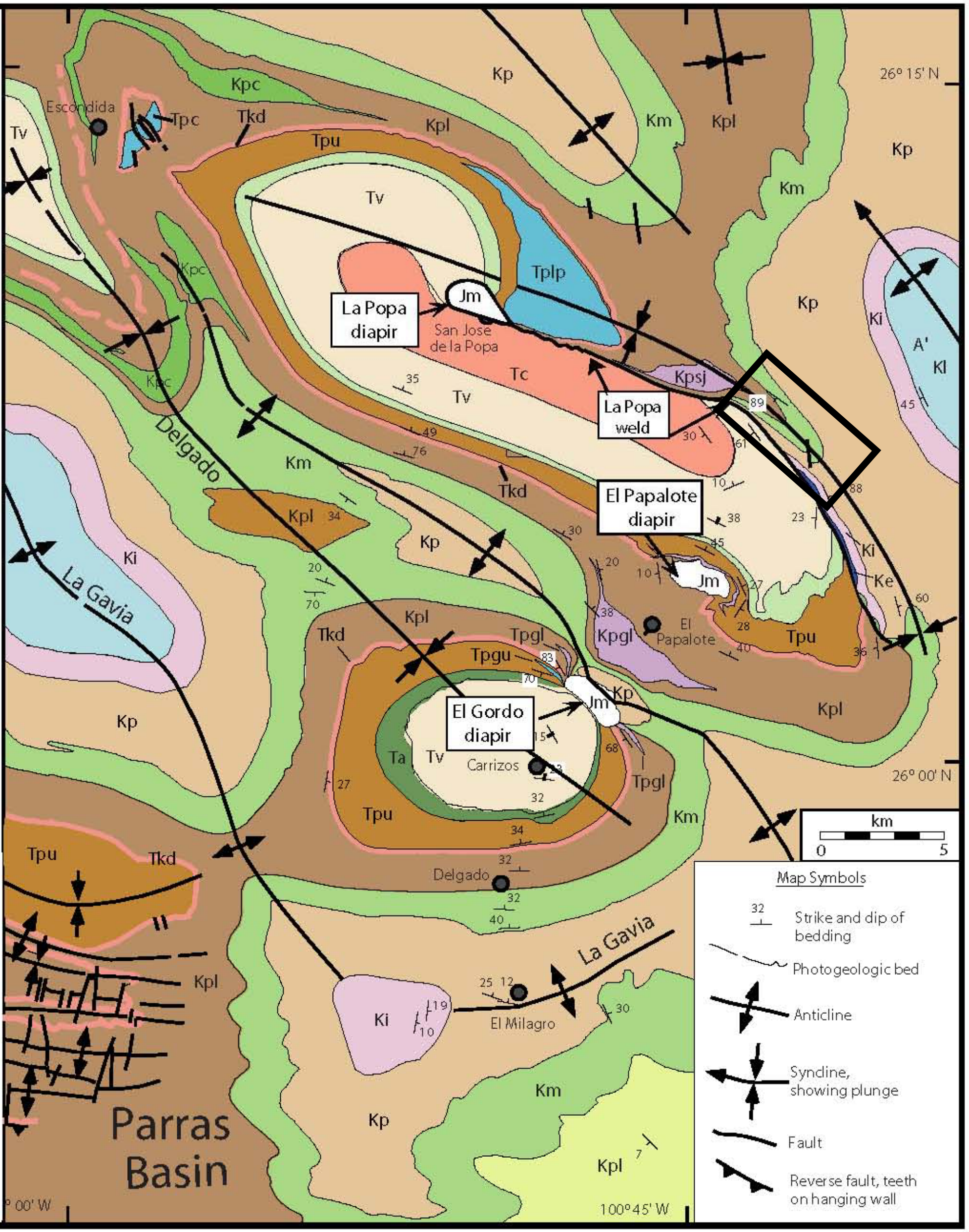
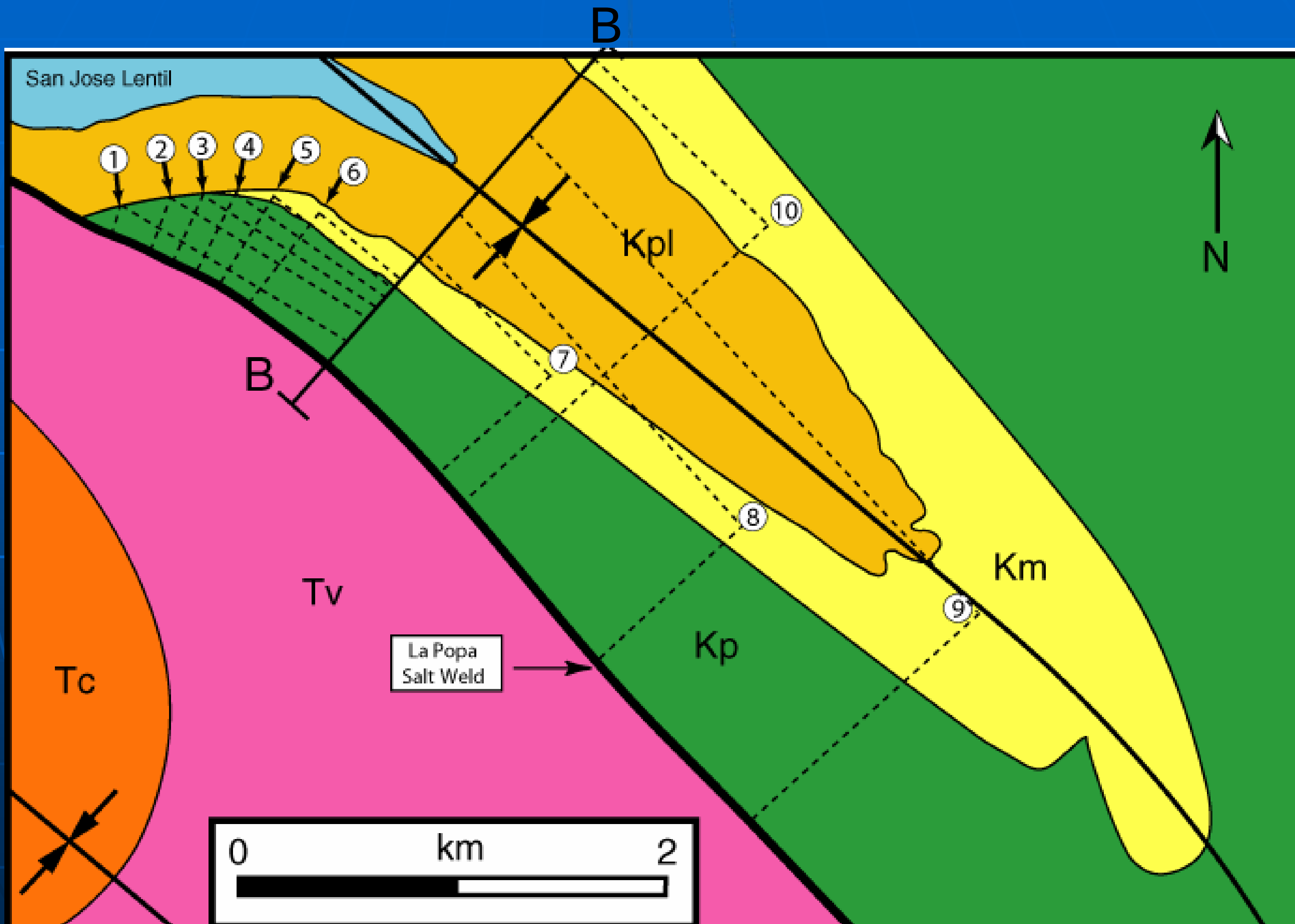
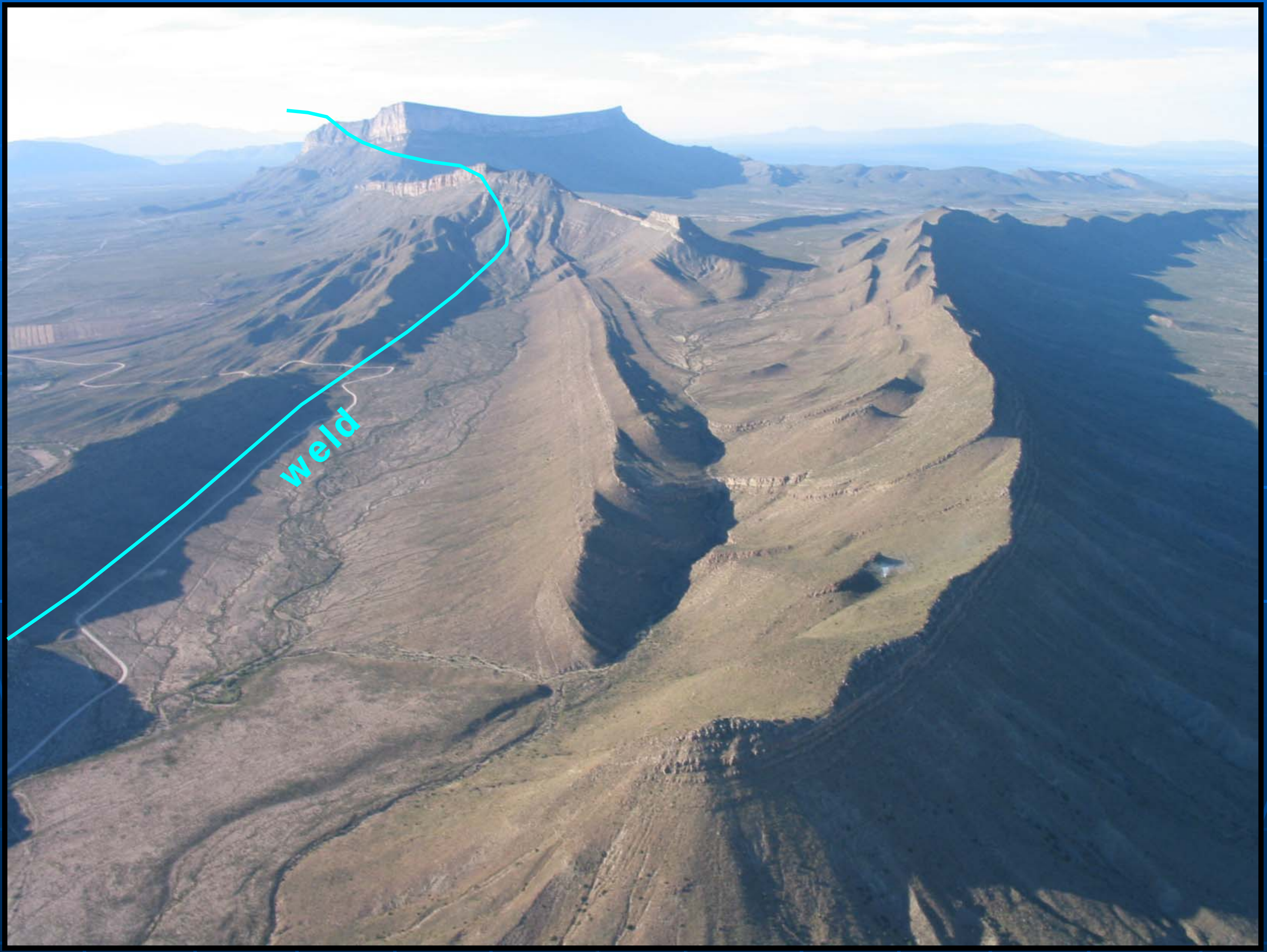
  - Kpgl — Lower Gordo lentil
  - Kpc — Cuchilla Sandstone Tongue
- Km — Muerto Formation
- Kp — Parras Shale
- Ki — Indidura Formation
- Ke — Lower Cretaceous lentils
- Kl — Lower Cretaceous limestone
- Jm — Jurassic evaporite



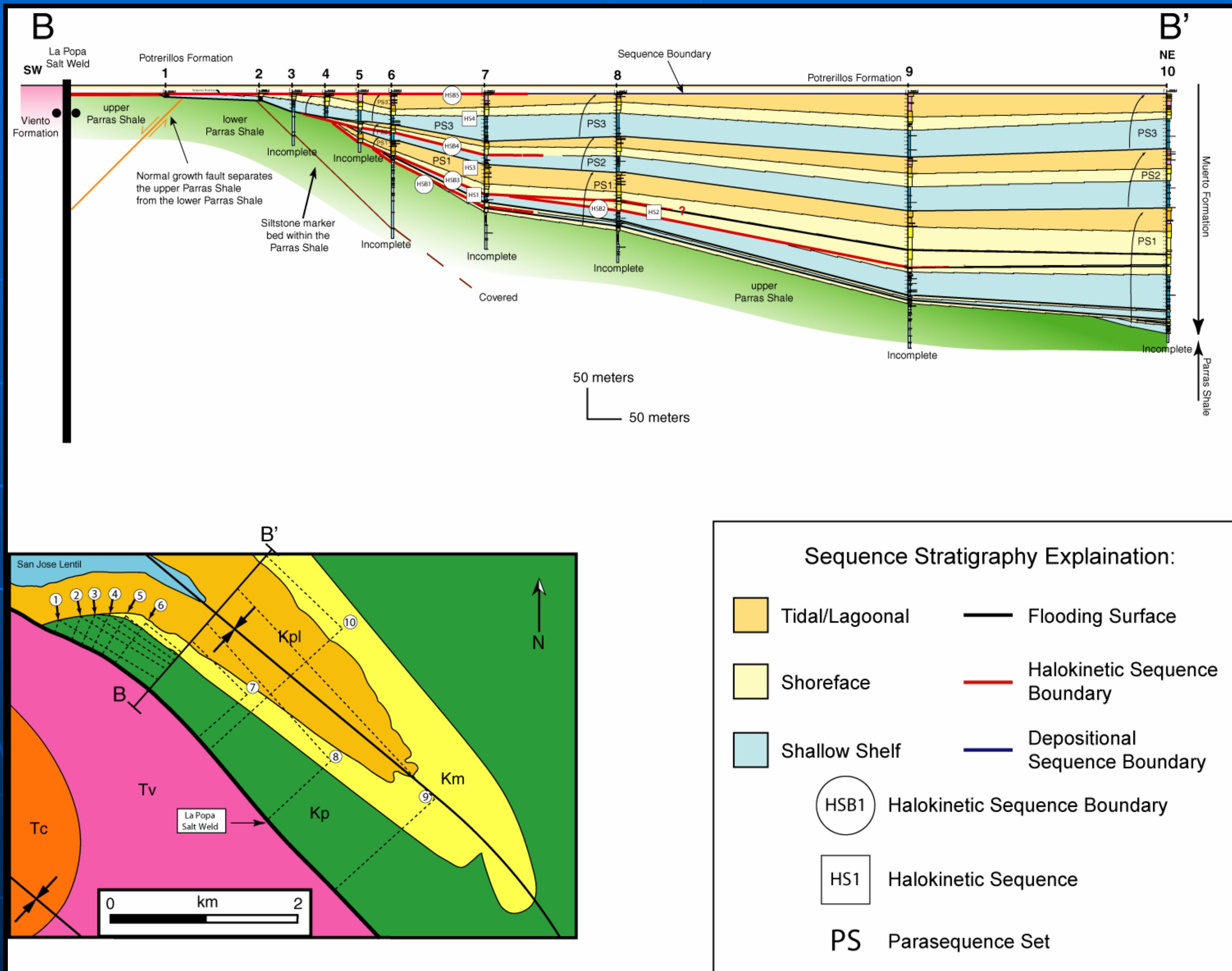
La Popa Salt Weld Map



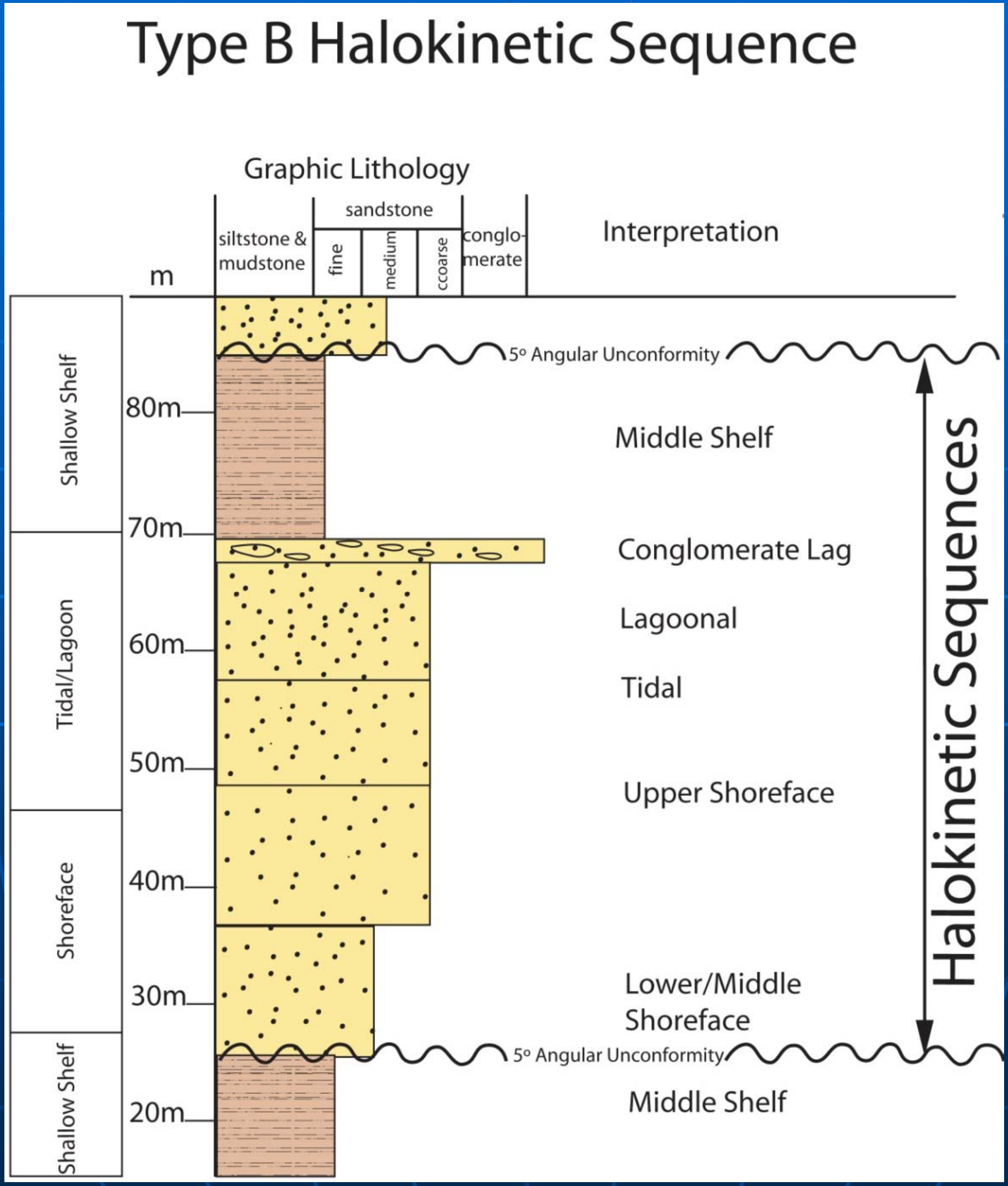
Outcrop Photo of Muerto Pinch Out



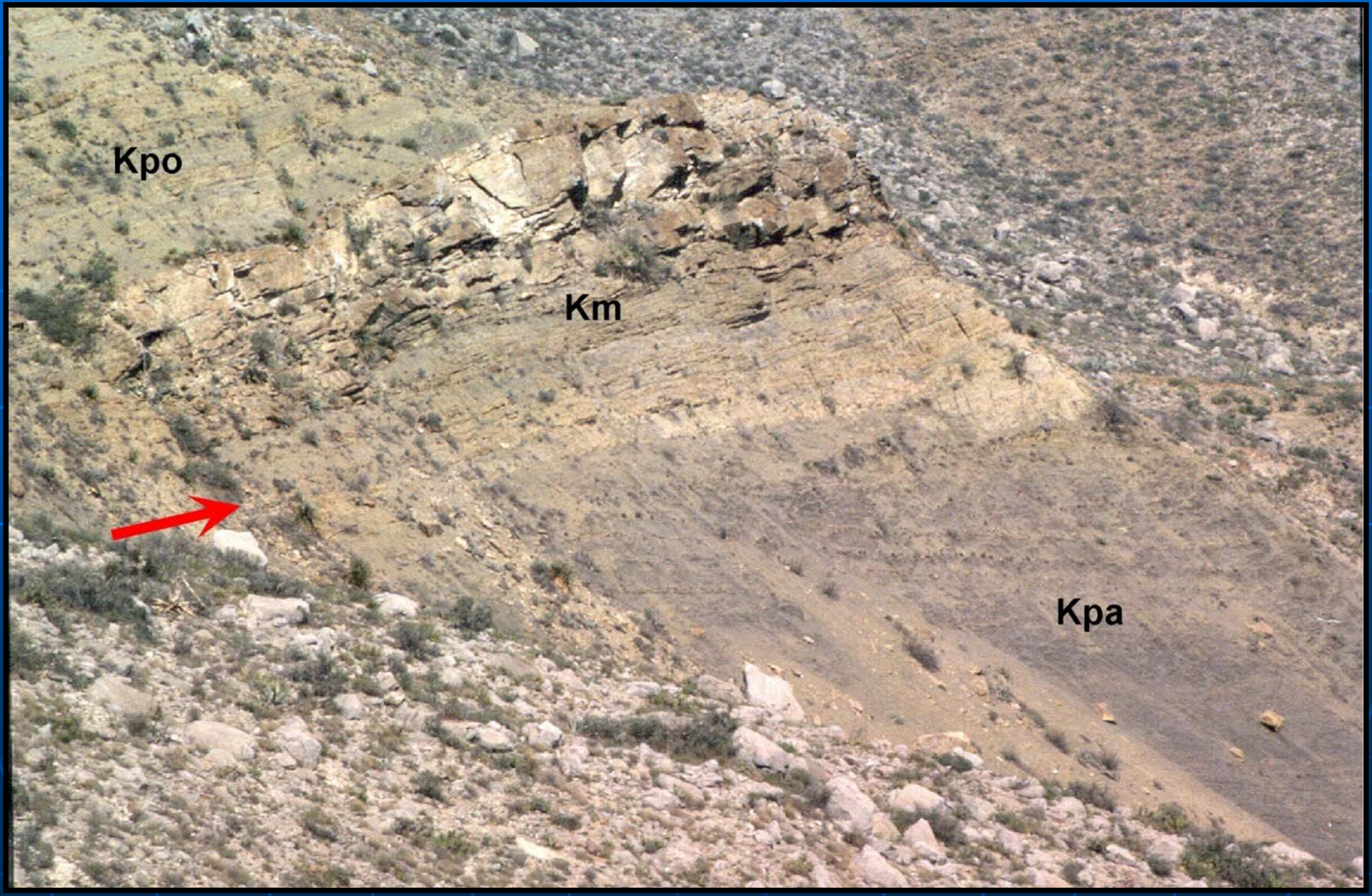
Cross Section of Muerto Formation



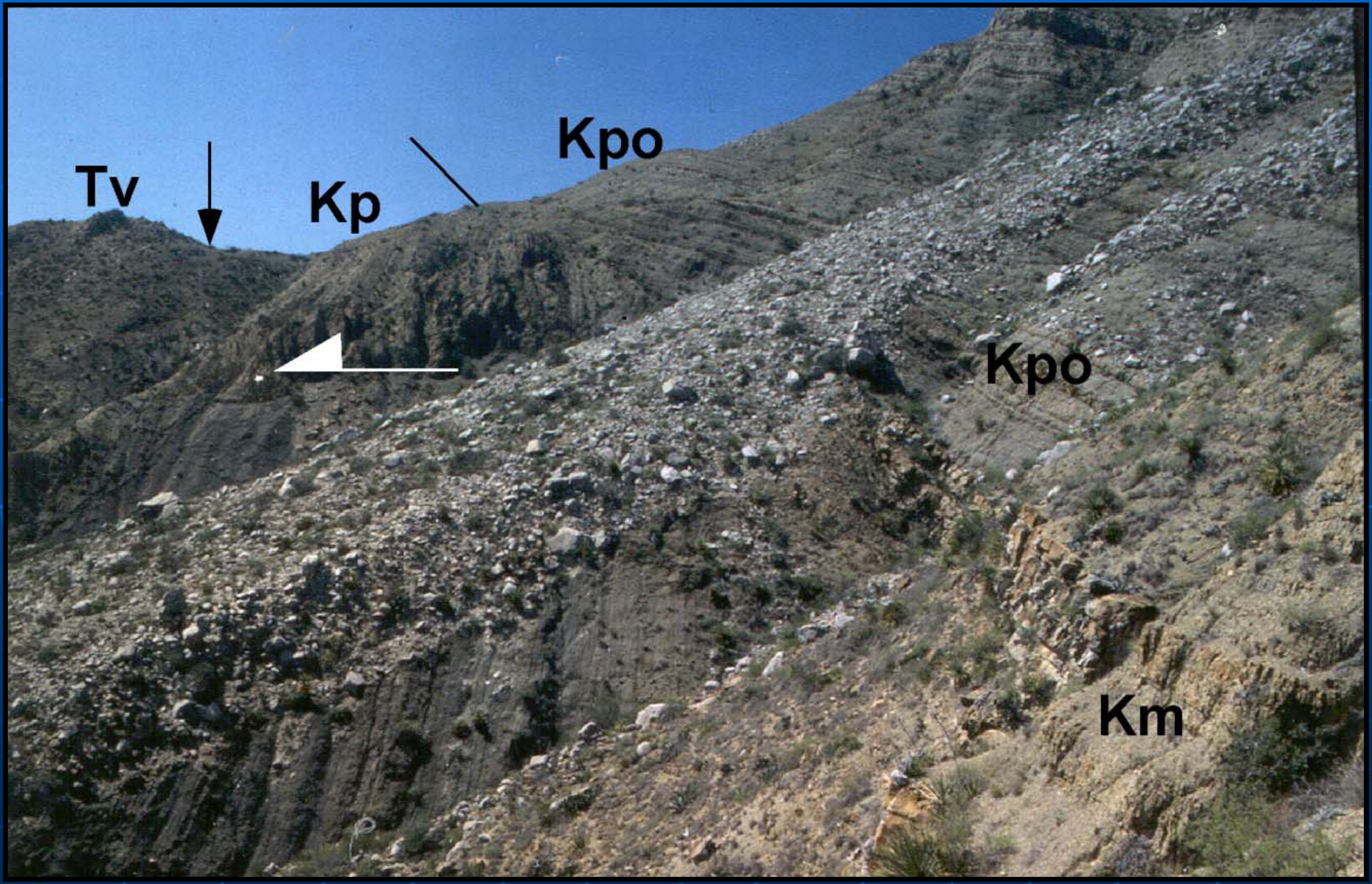
Idealized Type B Halokinetic Sequence



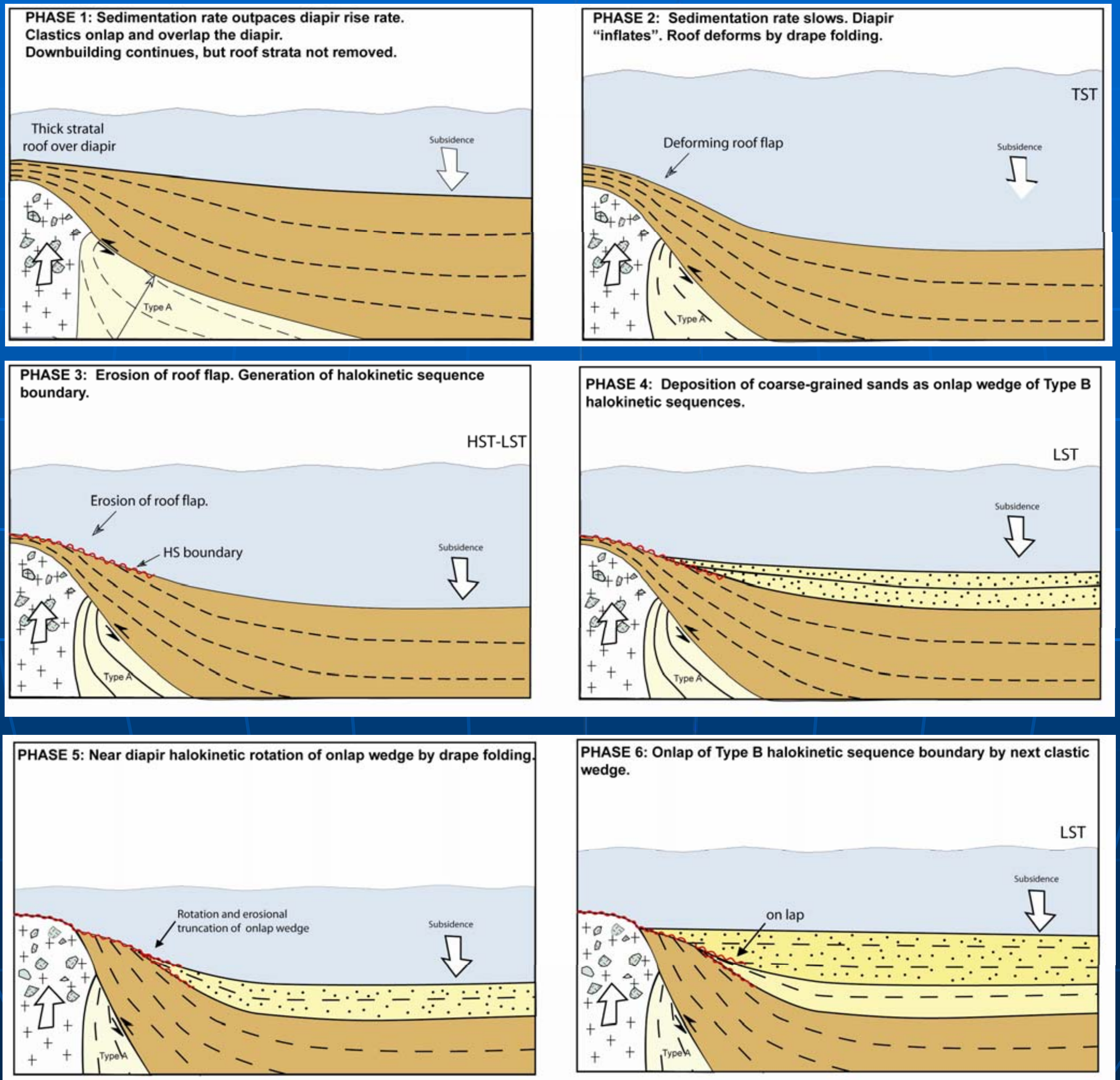
Type B Angular Unconformity



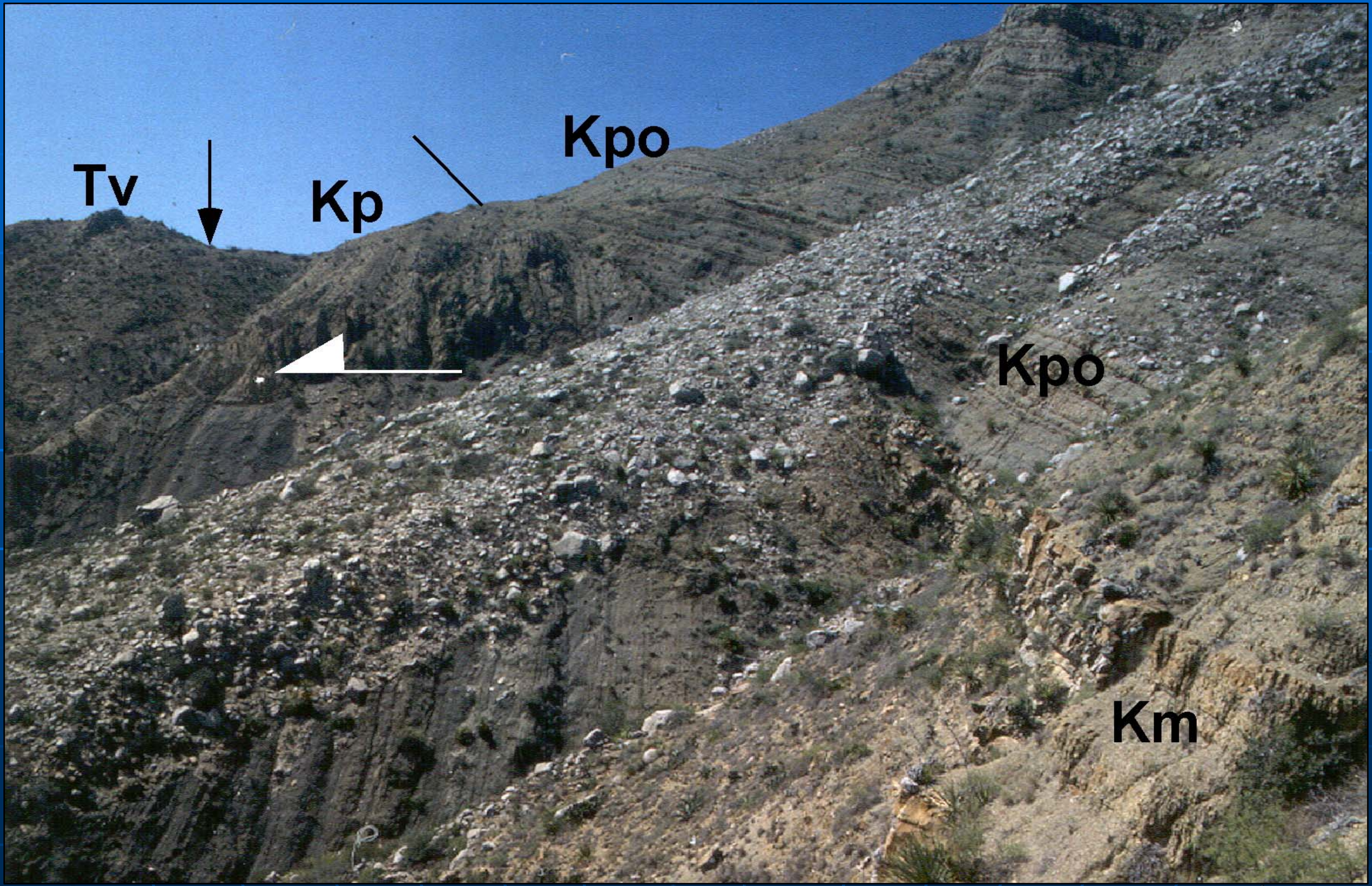
Type B Angular Unconformity



Type B Halokinetic Sequence Model

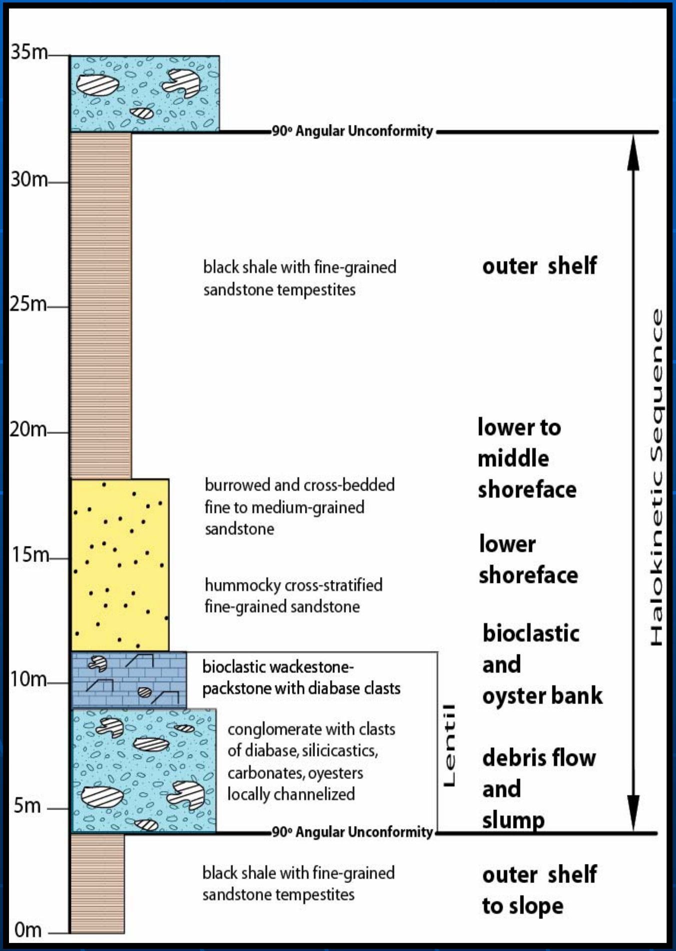


Growth Strata at Weld Bend

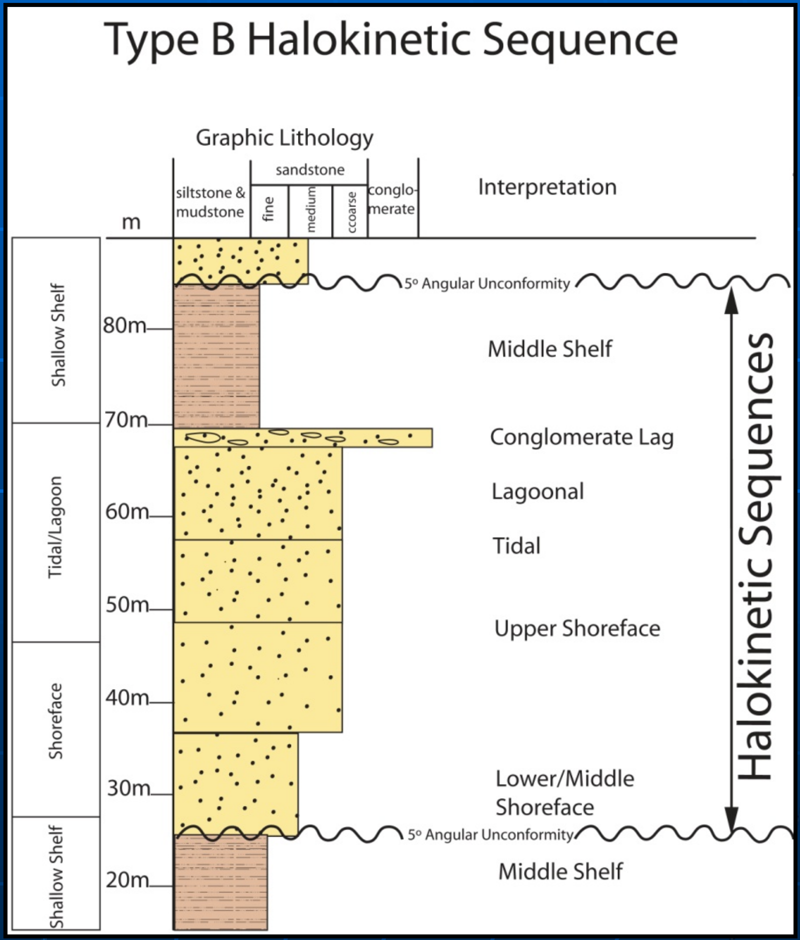


Comparison- Type A & Type B Facies

Type A

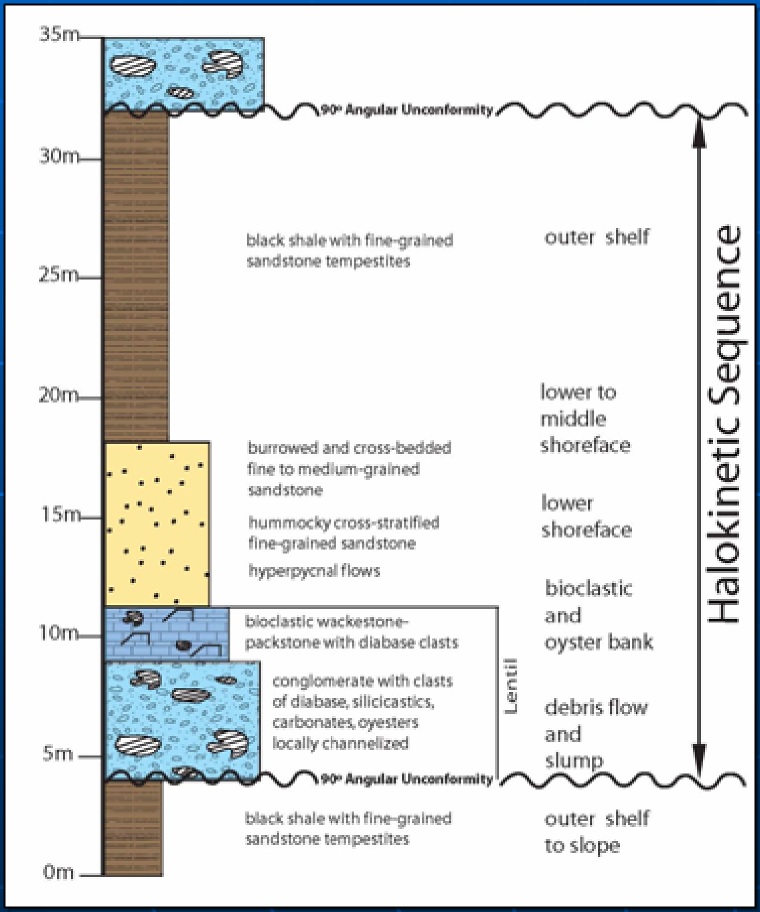


Type B

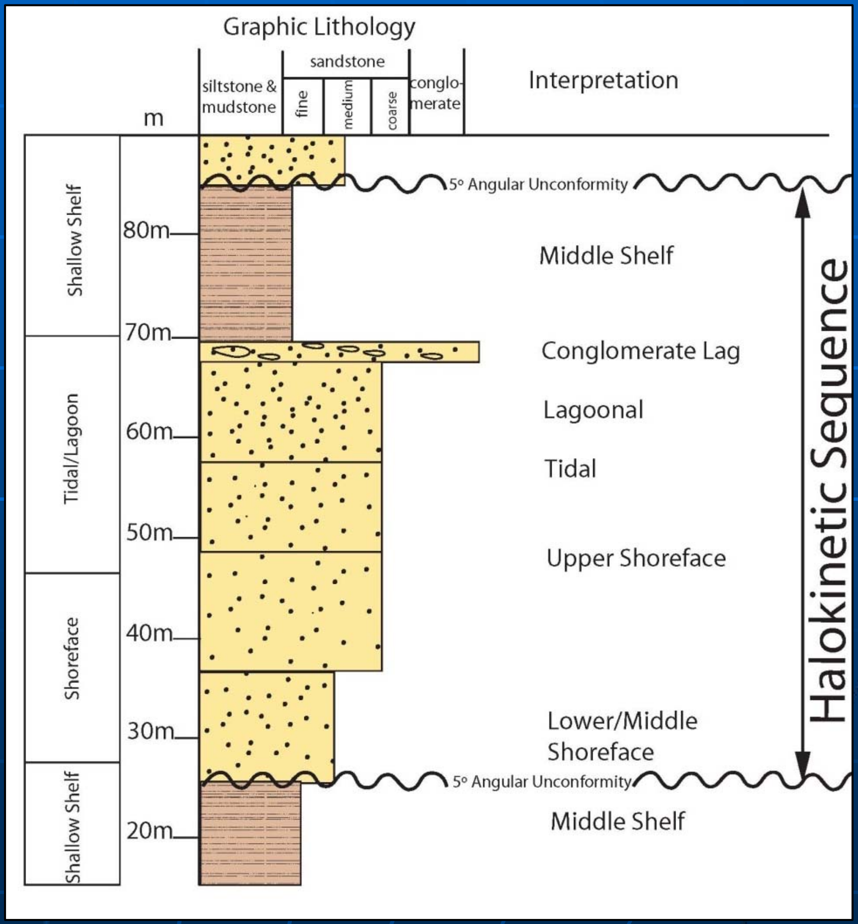


Idealized Type A and Type B Halokinetic Sequences

Type A

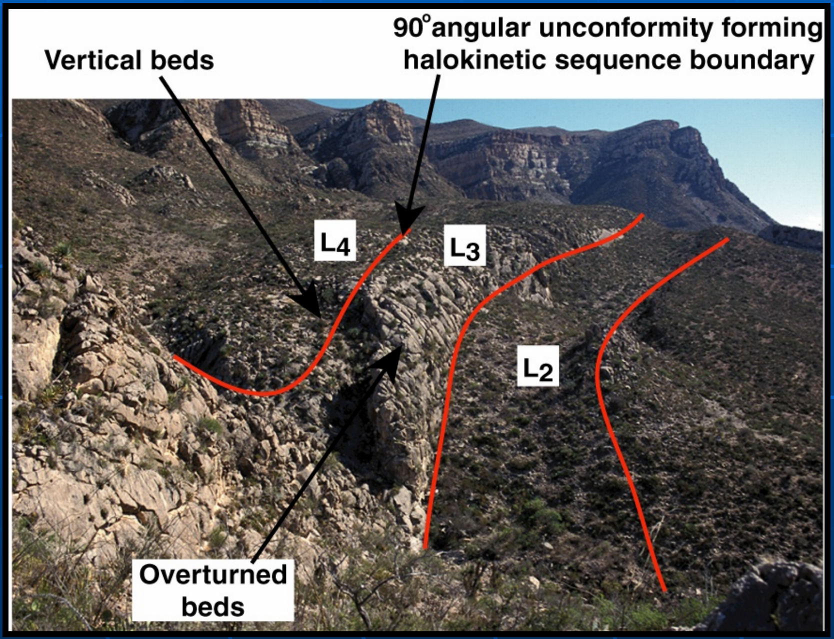


Type B

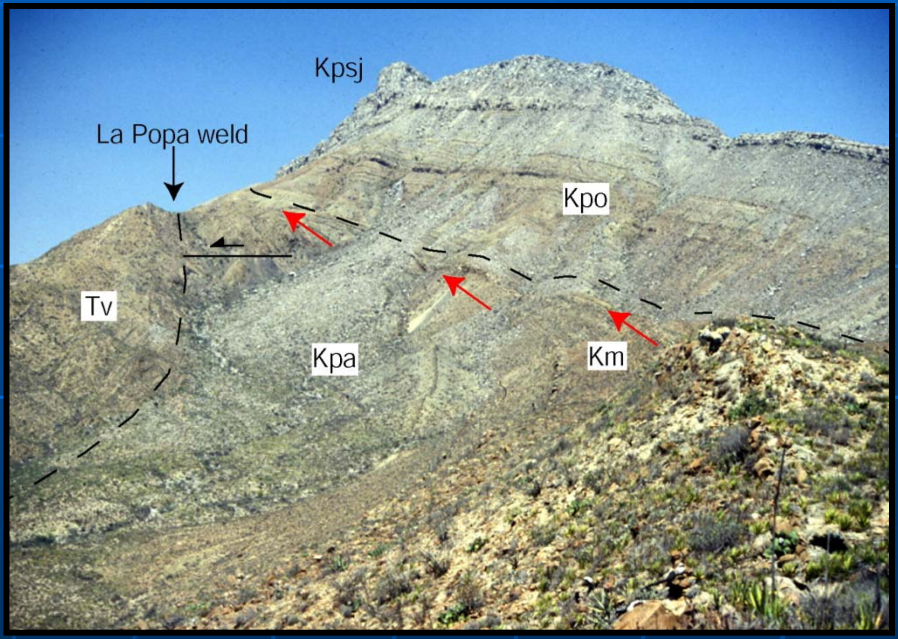


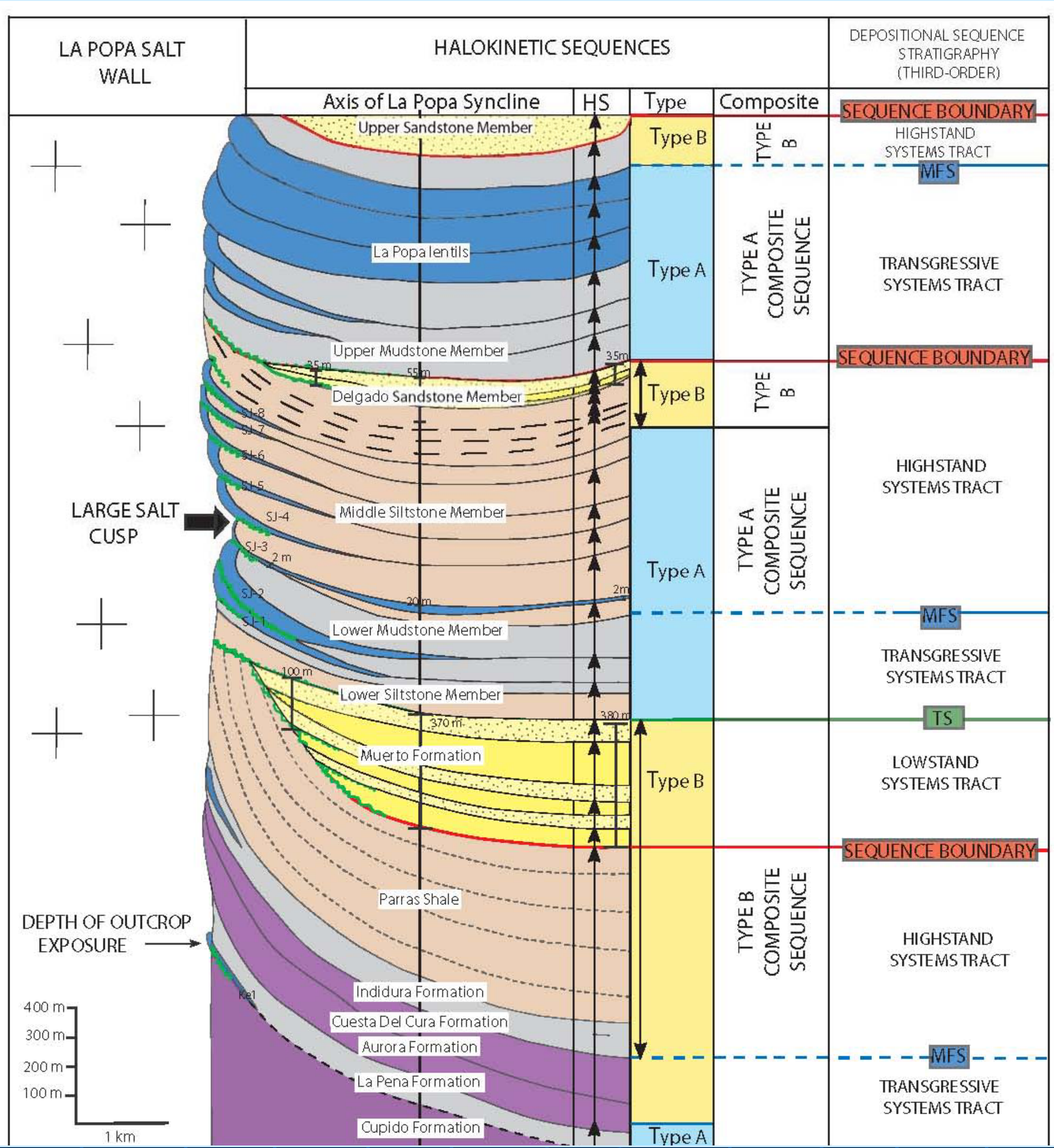
Comparison- Type A & Type B Folding

Type A



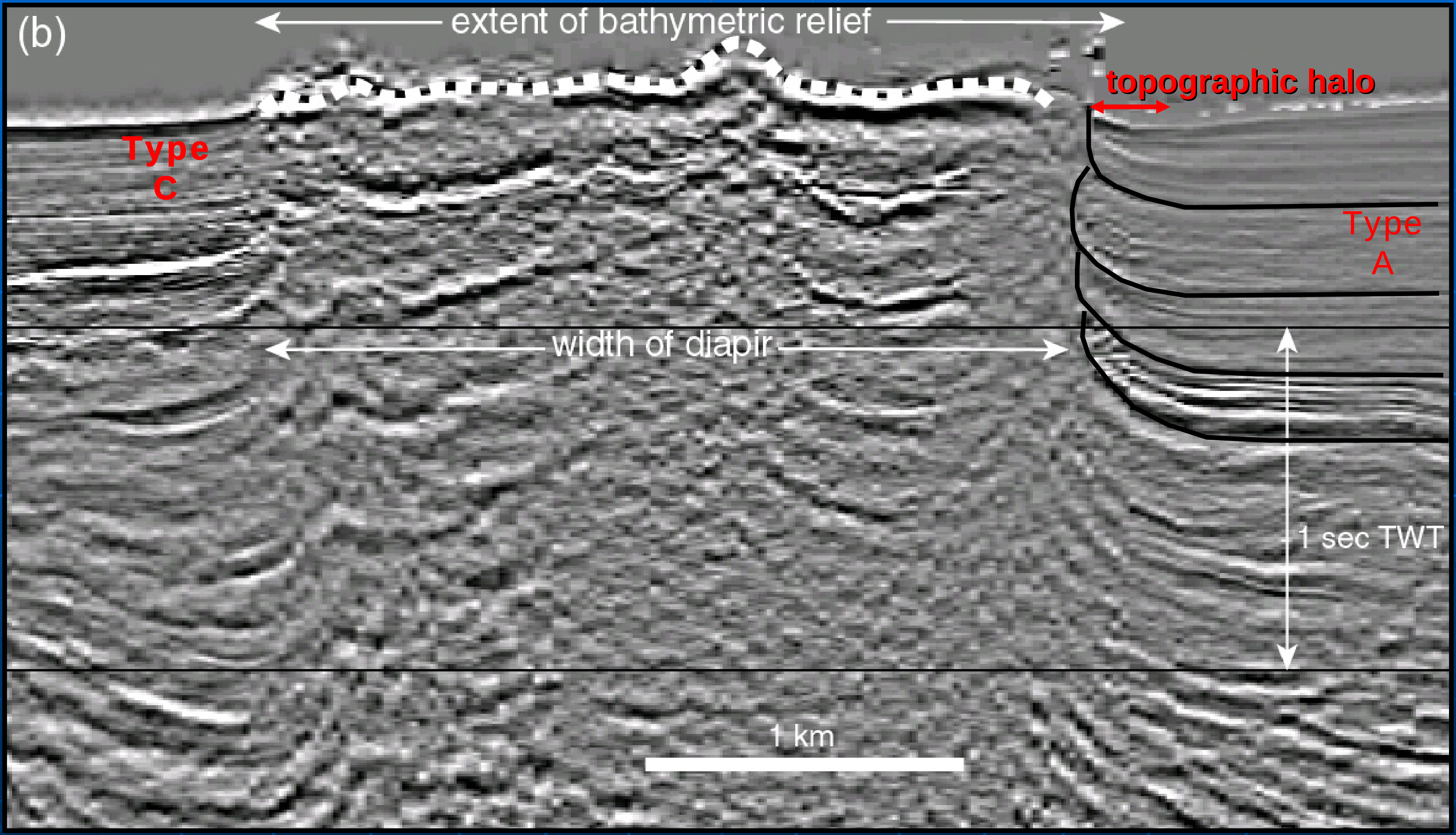
Type B



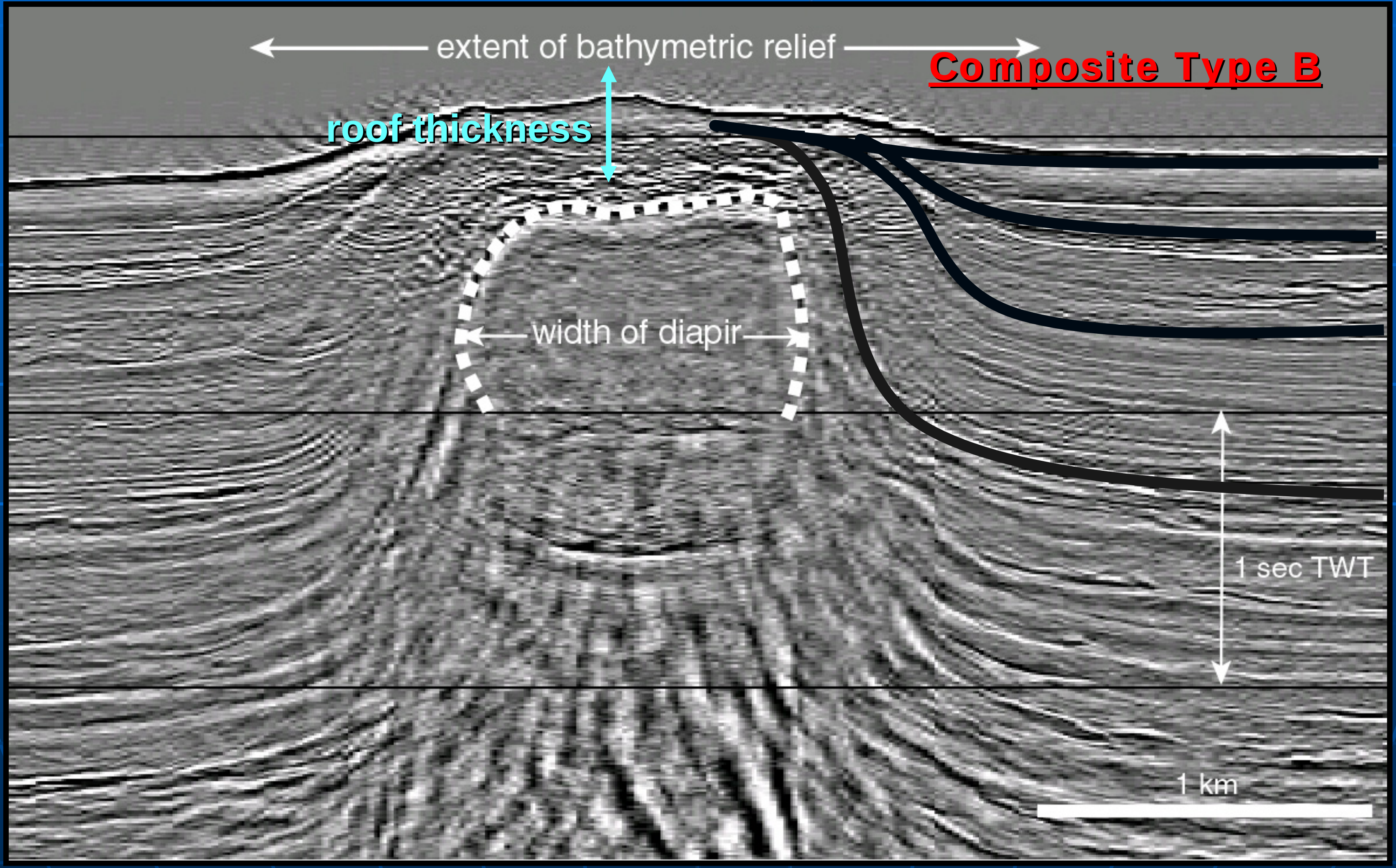


LA POPA SALT WALL
HALOKINETIC SEQUENCES
DEPOSITIONAL SEQUENCE STRATIGRAPHY (THIRD-ORDER)
Axis of La Popa Syncline
HS
Type
Composite
SEQUENCE BOUNDARY
Upper Sandstone Member
Type B
TYPE B
HIGHSTAND SYSTEMS TRACT
MFS
La Popa lentils
Type A
TYPE A COMPOSITE SEQUENCE
TRANSGRESSIVE SYSTEMS TRACT
Upper Mudstone Member
SEQUENCE BOUNDARY
Delgado Sandstone Member
Type B
TYPE B
SJ-8
SJ-7
SJ-6
SJ-5
LARGE SALT CUSP
SJ-4
Middle Siltstone Member
HIGHSTAND SYSTEMS TRACT
SJ-3
Type A
TYPE A COMPOSITE SEQUENCE
SJ-2
SJ-1
MFS
Lower Mudstone Member
TRANSGRESSIVE SYSTEMS TRACT
Lower Siltstone Member
TS
Muerto Formation
Type B
LOWSTAND SYSTEMS TRACT
SEQUENCE BOUNDARY
Parras Shale
DEPTH OF OUTCROP EXPOSURE
TYPE B COMPOSITE SEQUENCE
HIGHSTAND SYSTEMS TRACT
Indidura Formation
Cuesta Del Cura Formation
Aurora Formation
MFS
La Pena Formation
TRANSGRESSIVE SYSTEMS TRACT
Cupido Formation
Type A
400 m
300 m
200 m
100 m
1 km

Thin Roof Beam



Thick Roof Beam



Controls on Roof Beam Thickness

Diapir Rise Rate

- Overburden load on Autochthonous level
- Shortening

Sediment Accumulation Rate

- Flux of sediment to the site
  - sea level
  - tectonics
  - climate
- Subsidence rate

Long term diapir rise rate	<	Sed. accum. rate	= Thick beam
Long term diapir rise rate	>	Sed. accum. rate	= Thin beam

Controls on Roof Beam Thickness

Diapir Rise Rate

- Overburden Load on Autochthonous level
- Shortening

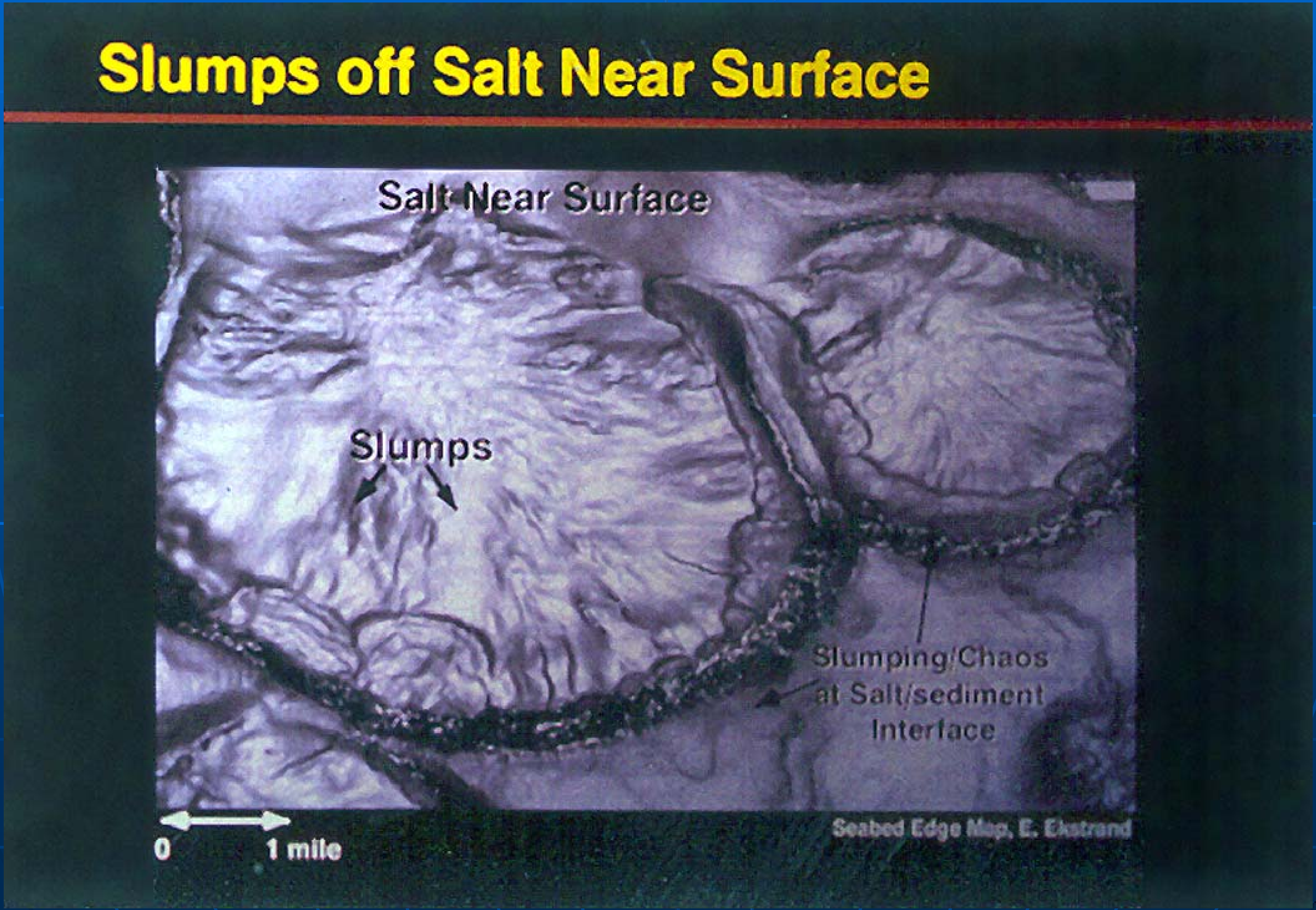
Sediment Accumulation Rate

- Flux of sediment to the site
  - sea level
  - tectonics
  - climate
- Subsidence rate

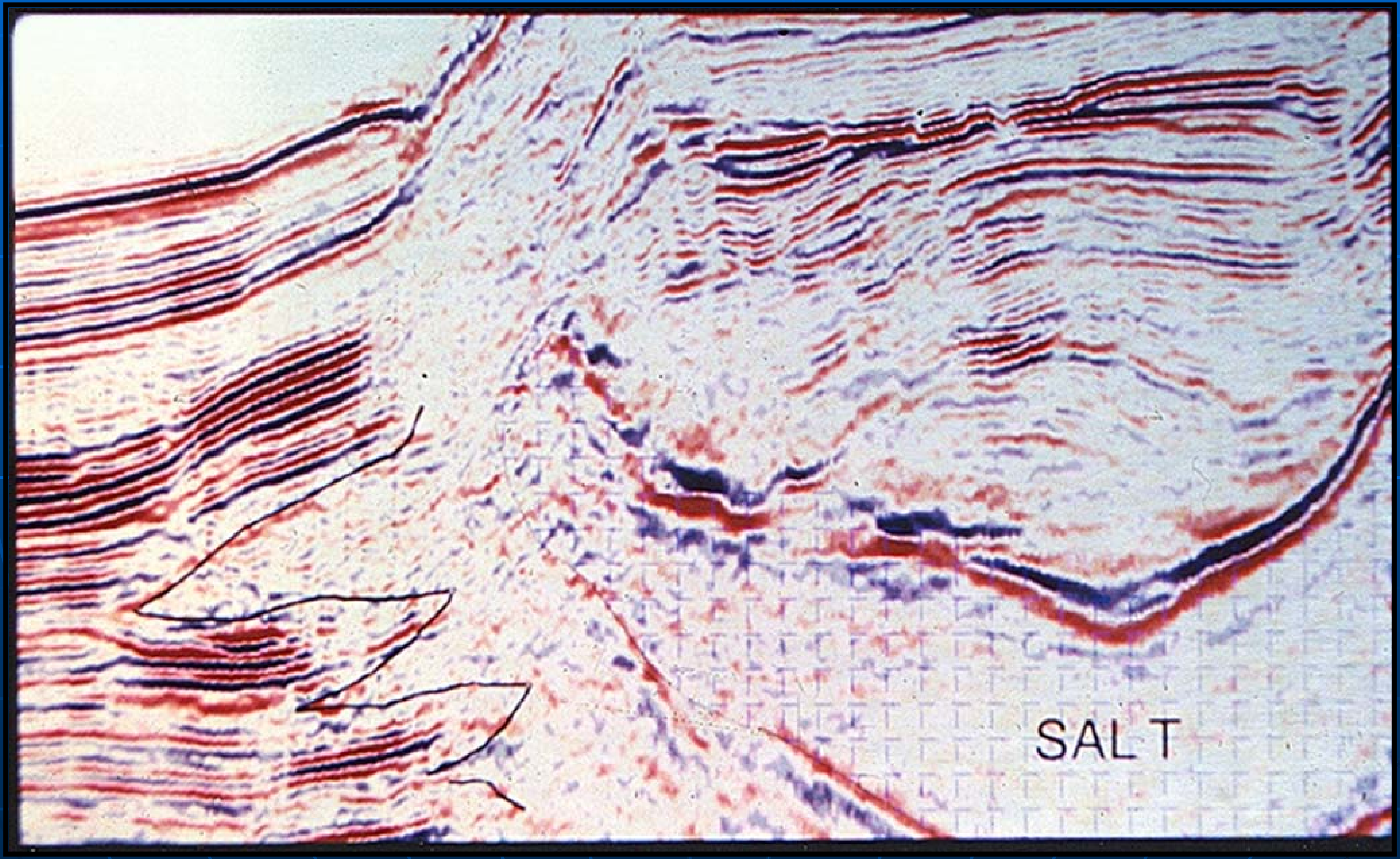
Type A Thin Beam = Long term Diapir rise rate > Sediment accumulation rate

Type B Thick Beam = Long term diapir rise rate < Sediment accumulation rate

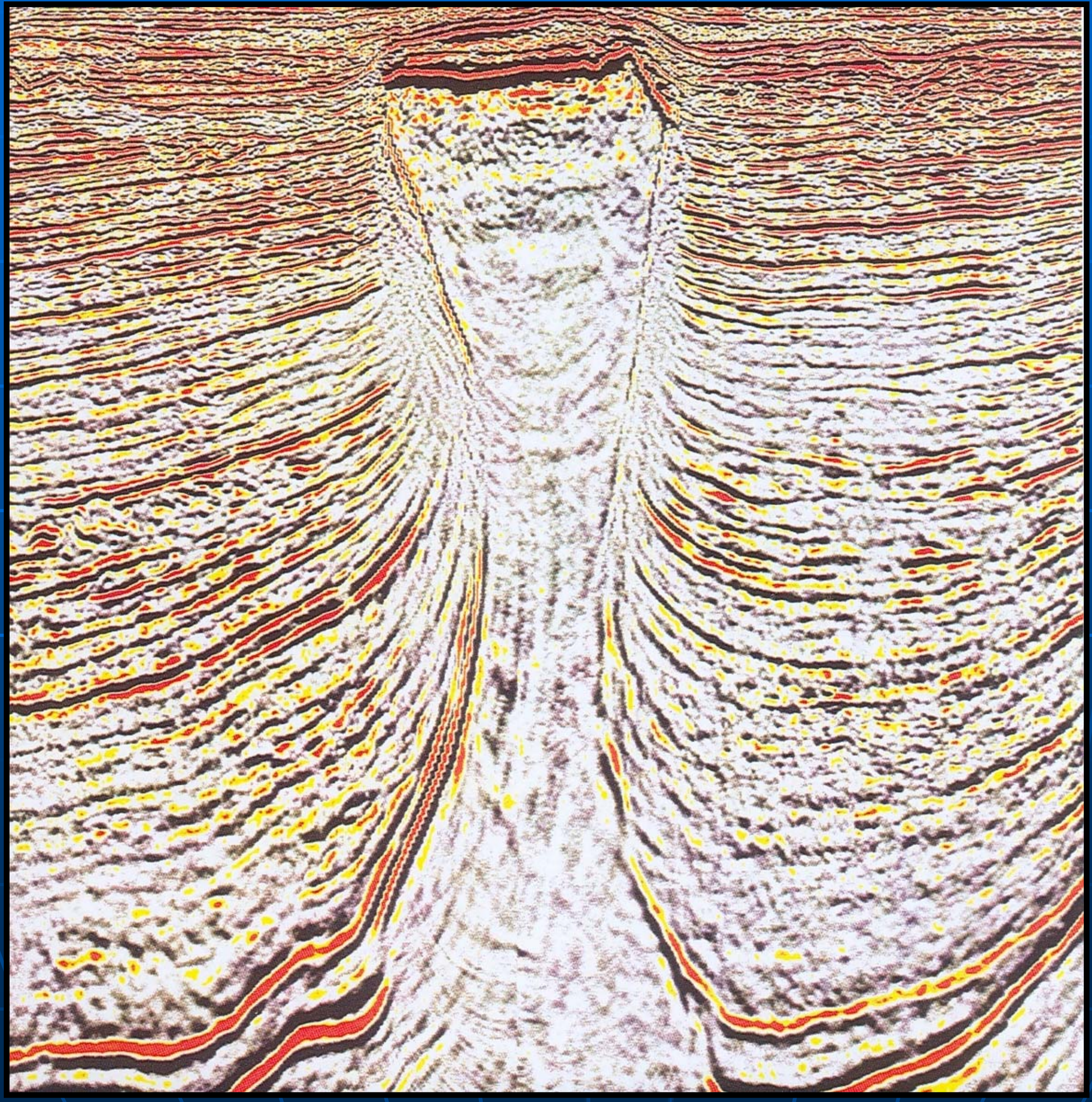
Concept Applicability
Modern Passive Diapirs



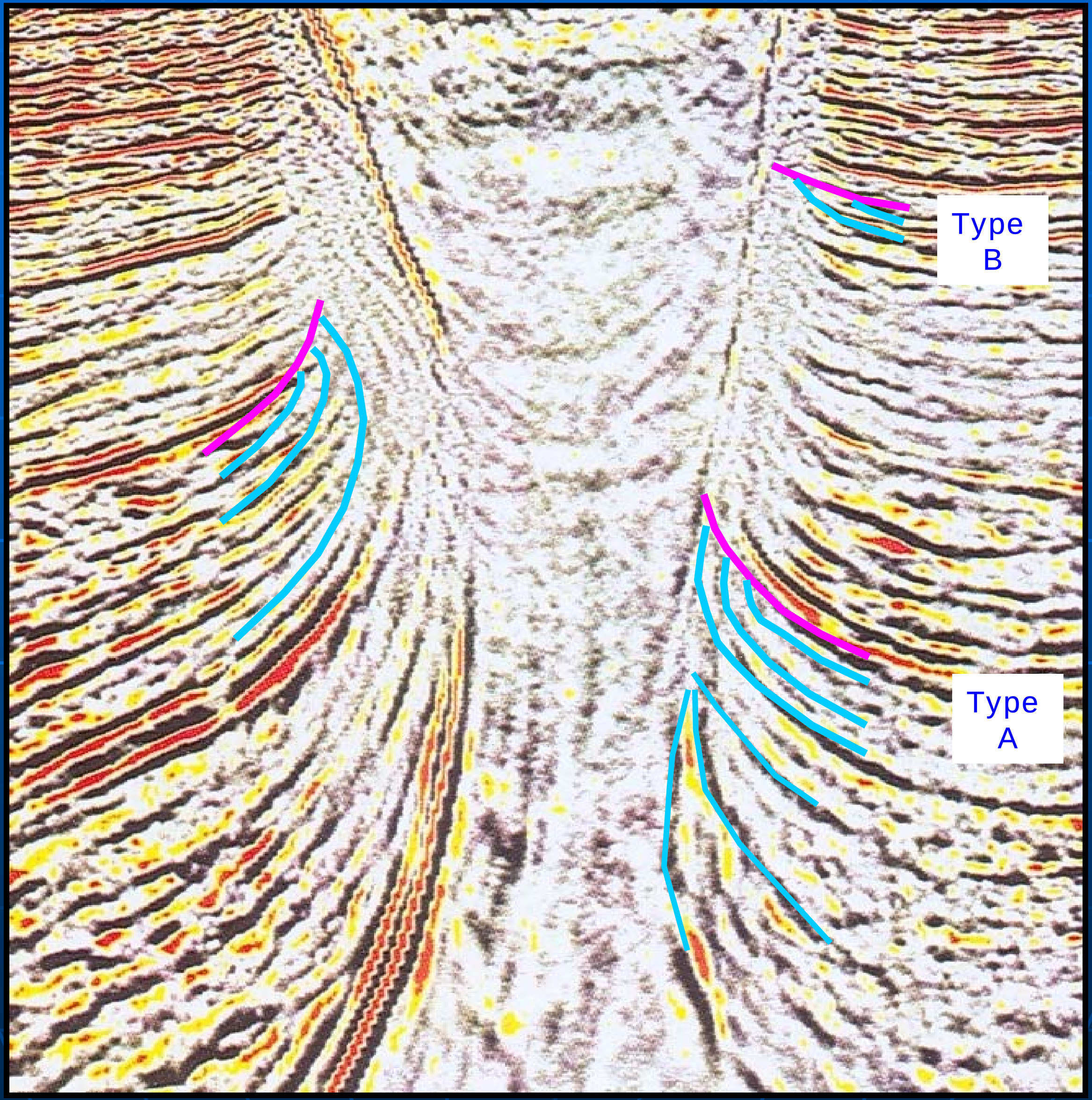
Stacked "Christmas Tree" Branches



Seismic Line of Passive Diapir
Northern Gulf of Mexico



Interpreted Seismic Line
Northern Gulf of Mexico



Conclusions

- La Popa Basin strata influenced by passive diapirism, display ubiquitous halokinetic sequences.
- Three types of halokinetic sequences are recognized in La Popa Basin
- Halokinetic sequence type controlled by roof beam thickness
- Similar types of halokinetic sequences predicted wherever passive diapirism is taking place.