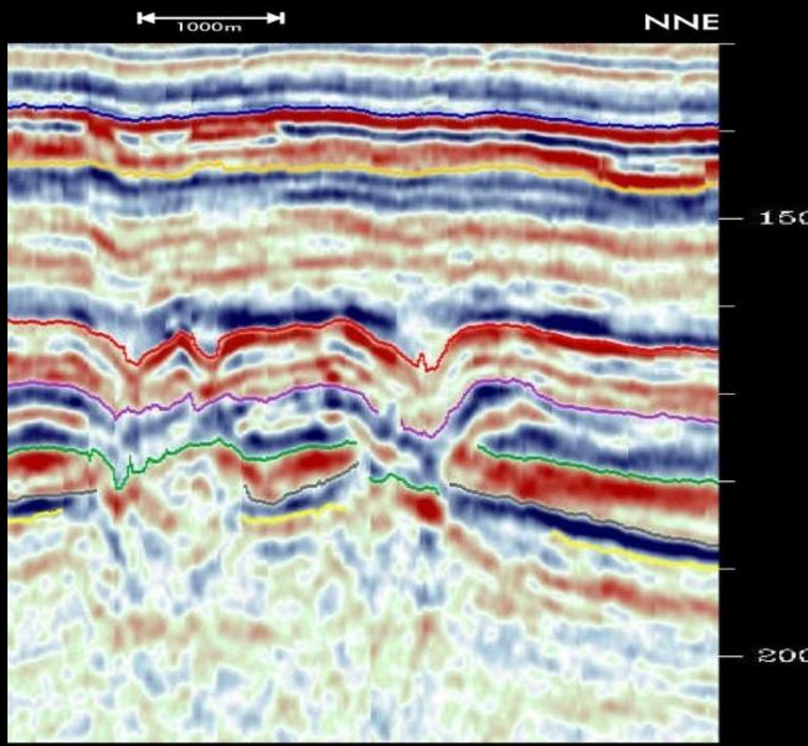
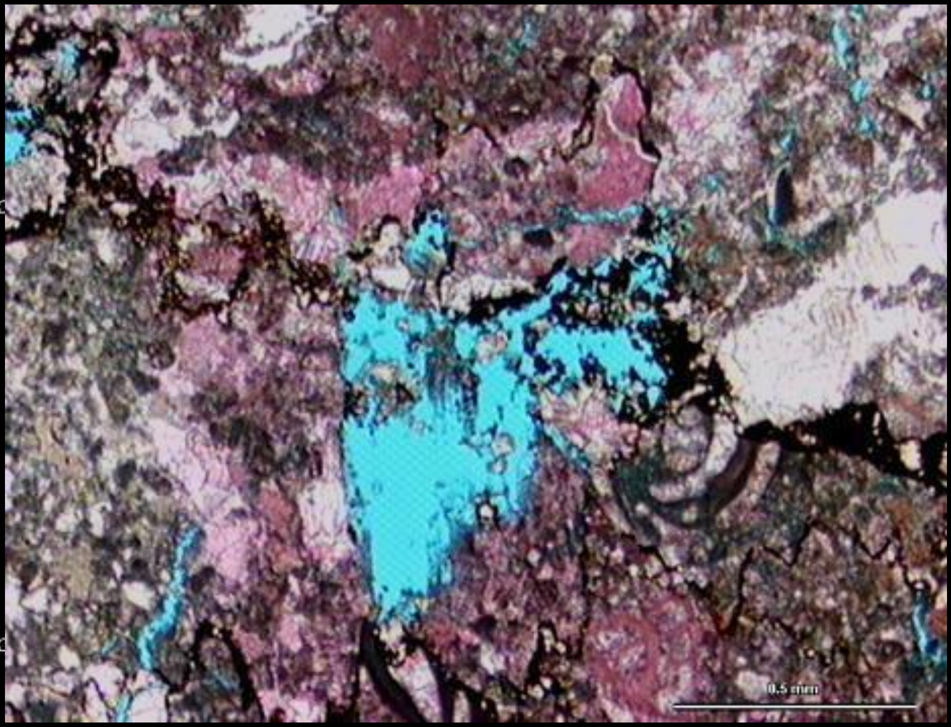
Hypogene Palaeokarst and Burial Corrosion

Paul Wright
PW Carbonate Geoscience





Take away points

Significant secondary porosity formation by dissolution, from the micro-to seismic scale can take place at depths of several kilometres in carbonate reservoirs, what is termed burial corrosion or mesogenetic dissolution

There is a problem over terminology with the use of “burial” or “ late” and it is more expedient to take a hydrological approach and see the key processes as due to burial fluids derived from below the reservoir – hypogene fluids

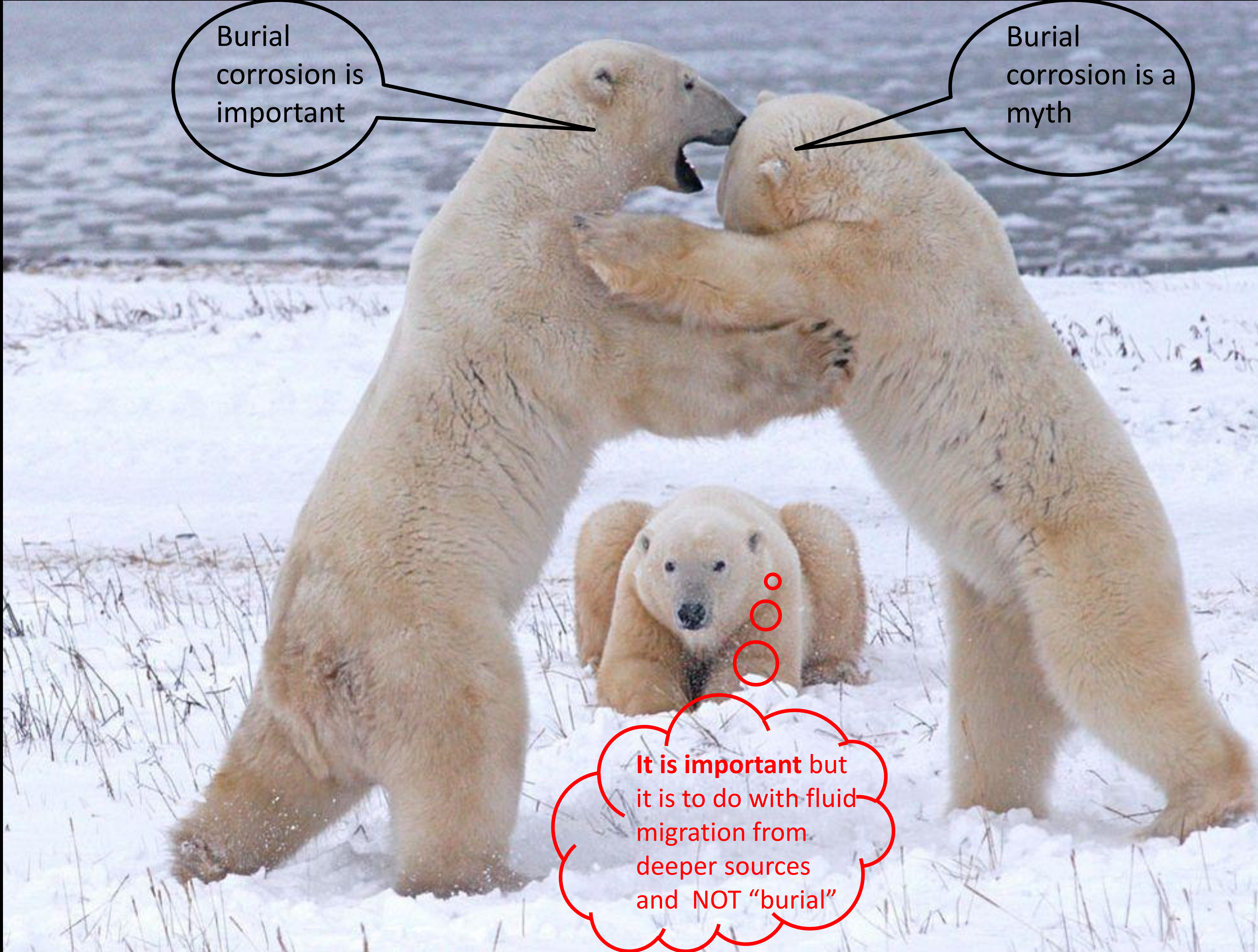
Some hypogene dissolution can occur relatively near surface

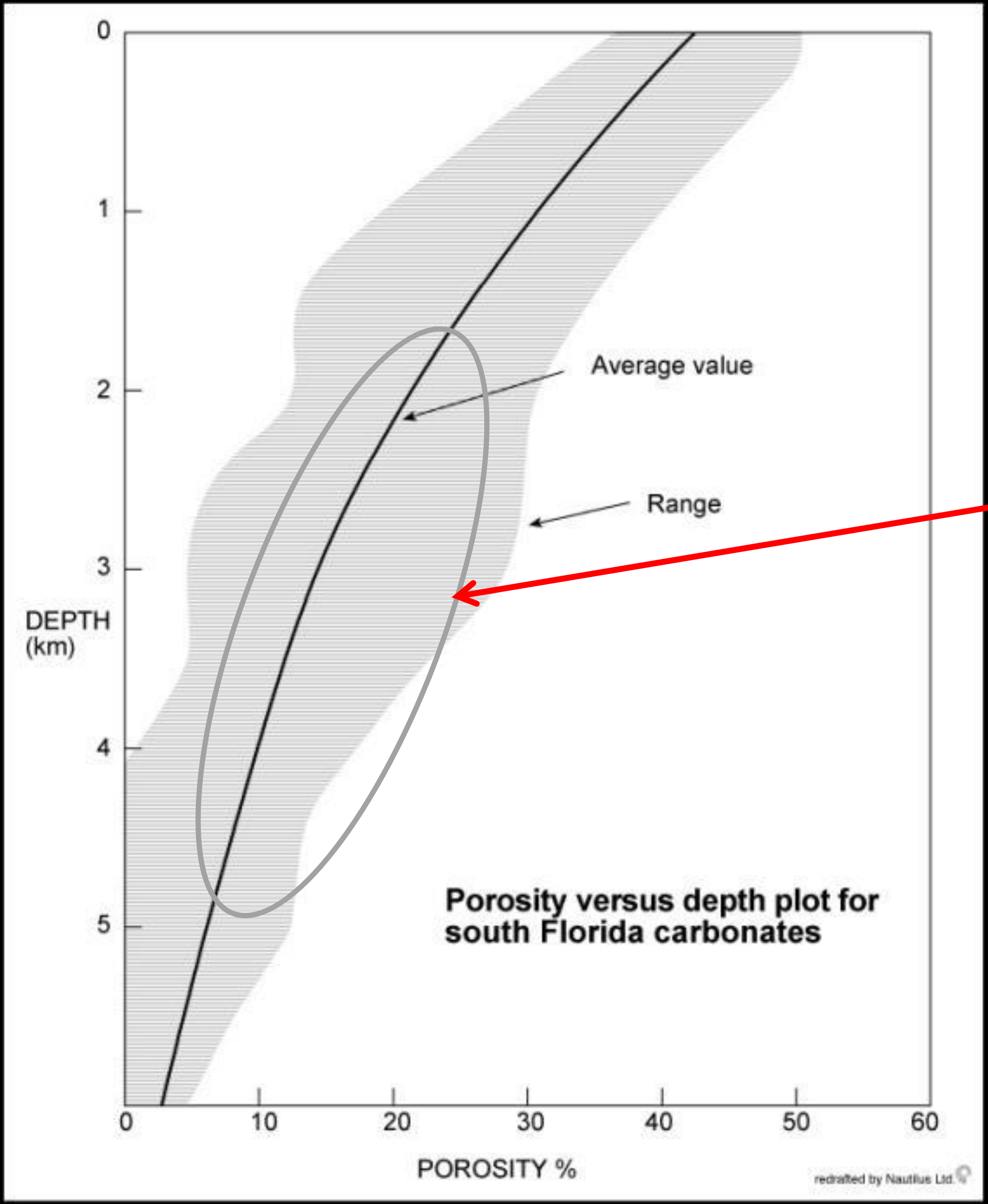
There are many fields proven to have been produced by this effect

There are a range of processes known to be able to cause this dissolution but identifying the process is difficult as they leave little trace

There are consistent relationships seen in hypogene diagenetic systems that may prove useful for exploration

For an alternative view see Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233


Burial corrosion is important
Burial corrosion is a myth
It is important but it is to do with fluid migration from deeper sources and NOT "burial"



The paradigm was - just porosity loss with depth

There is a large amount of evidence that extensive porosity formation occurs at depth, without any uplift into near surface settings

Sadly there is a real terminological problem

Unlike those clever sandstone diagenesis workers, carbonate specialists never agreed on a strict definition of burial diagenesis

Is this dissolution that is associated with elevated temps, pressures, is “late”, or “deep”?

Does it have to be any of these?

It manifests itself as porosity that formed after burial, typically after pressure solution took place, in formations which have not been brought back to near-surface depths

But the depths at which pressure solution takes place in carbonates is unresolved

Bearguin? Penbear?

Wright & Harris 2013* proposed that –

"burial corrosion/dissolution refers to porosity formation caused by fluids unrelated to recharge from the overlying land surface, or adjacent water bodies, but relates typically to a confined aquifer, and where the source of the fluid is ultimately from below the formation (hypogene)."

*AAPG Search and Discovery Article #50860

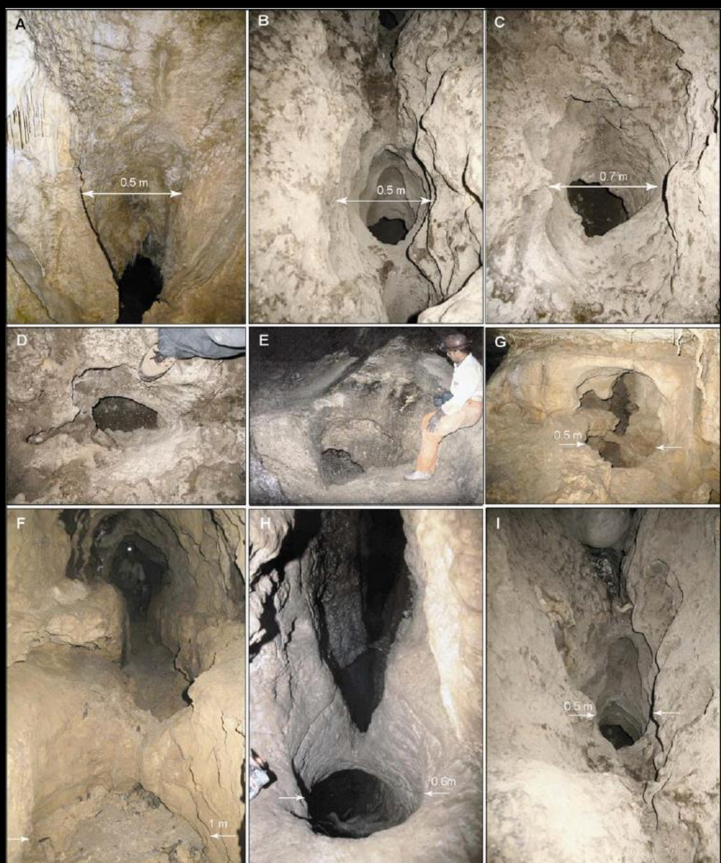
This would exclude meteoric waters driven by gravity, mixing zone processes driven by meteoric groundwater discharge in coastal areas, but includes dissolution caused by thermal convection such as Kohout convection.

This dissolution need not take place at depth but that the fluid was derived from a greater depth

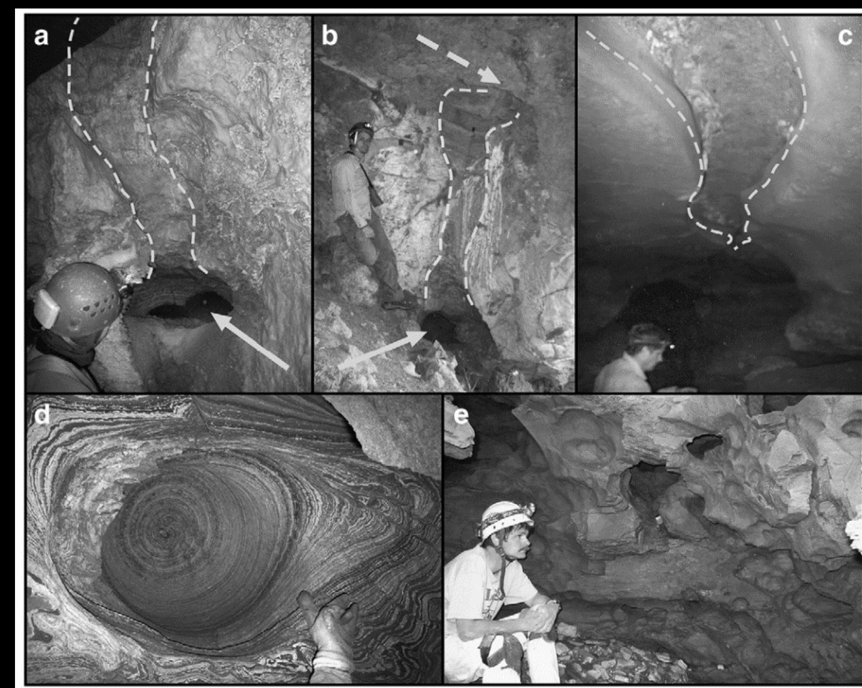
The critical issue is to identify the source of the fluid and mechanism as this may provide a predictive element.

Deep regional flow processes we know are capable of extensive dissolution, dolomitization and mineralization. For example 15% of accessible caves today are hypogenic (Palmer) …no doubt many more that are inaccessible.

Hypogene macroporosity - from many different regions

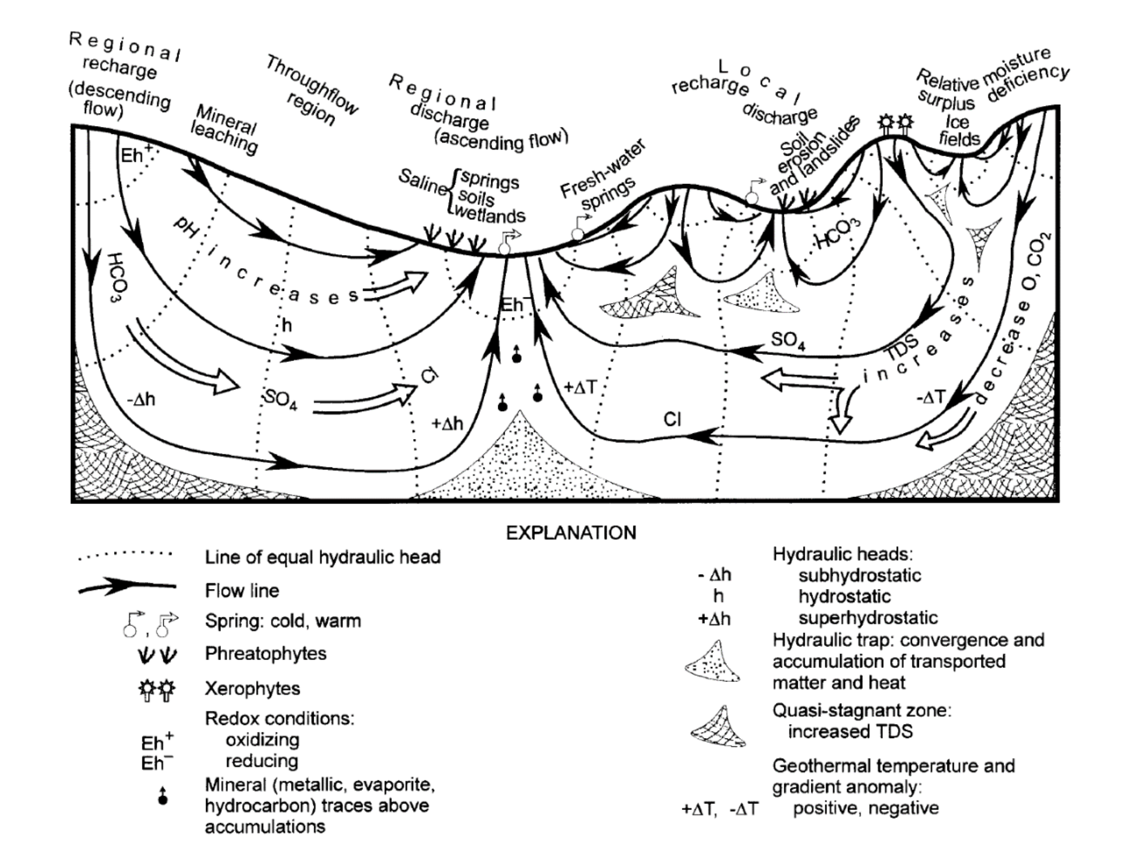


Klimchouk, A. B. 2007. Hypogene Speleogenesis: Hydrogeological and Morphogenetic Perspective. Special Paper no. 1, National Cave and Karst Research Institute, Carlsbad, NM, 106 pp.



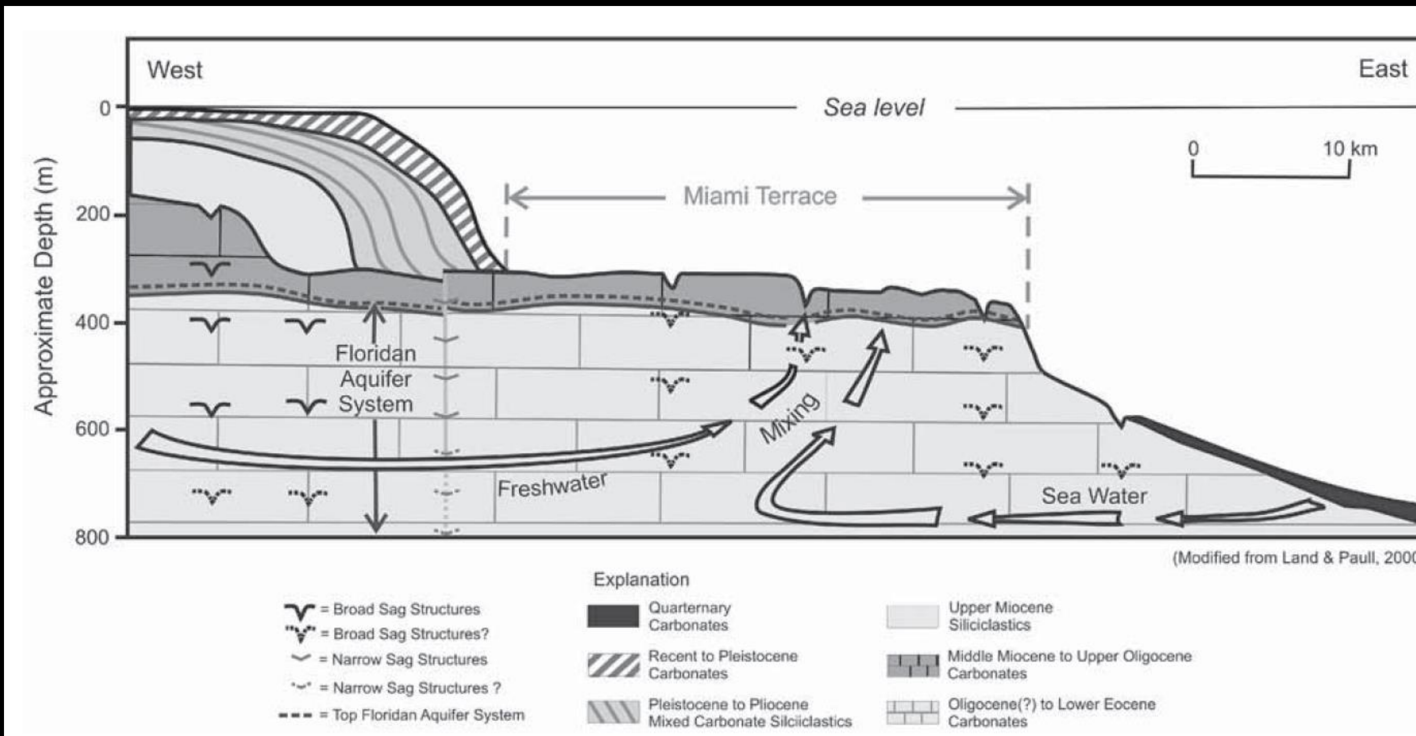
Palmer A N 2011 Geomorphology 134, 9–22

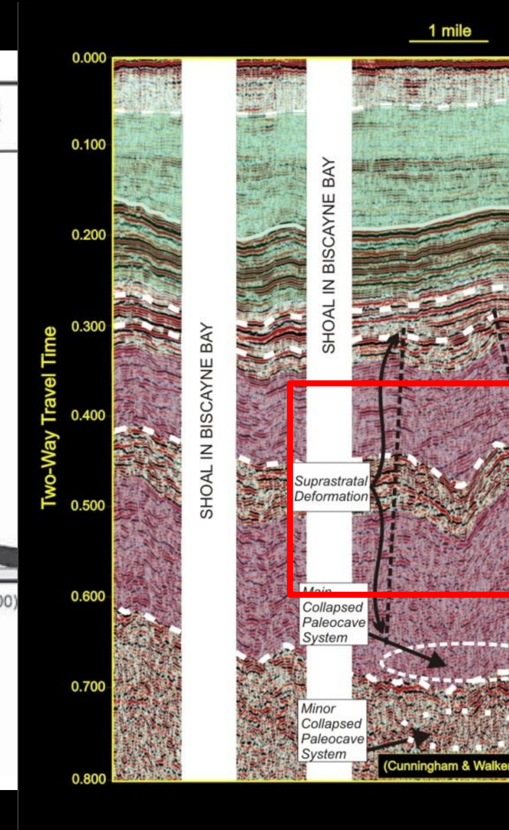
I think part of the reluctance of some specialists to invoke hypogene dissolution is best addressed by the following - " …a lack of understanding, or even awareness, of regional groundwater hydraulics by specialists of the various subdisciplines prevents them from recognizing the cause-and-effect relation between basinal groundwater flow and the particular phenomena that they may be studying." Toth, J 1999, Hydrogeology Journal 7:1–14



Toth, J 1999, Hydrogeology Journal 7:1–14

East Florida margin - Hypogenic dissolution along margin of Florida Straits linked to Kohout convection or H_2S from deeper evaporites?





From Cunningham K J & Walker C 2009 In: HYPOGENE SPELEOGENESIS AND KARST HYDROGEOLOGY OF ARTESIAN BASINS, *Ukrainian Institute of Speleology and Karstology, Special Paper 1, 2009*

Hypogene dissolution (corrosion) processes invoked in carbonates

- Migration of oil field gases such as CO_2 and H_2S, and carboxylic acids
- H_2S produced by thermochemical sulphate reduction in association with evaporites
- mixing corrosion
- thermal effects - retrograde solubility
- Pressure changes?
- Deprotonation of certain clays (Brazilian Pre-Salt model)

CO_2 and carboxylic acids as agents of burial corrosion?

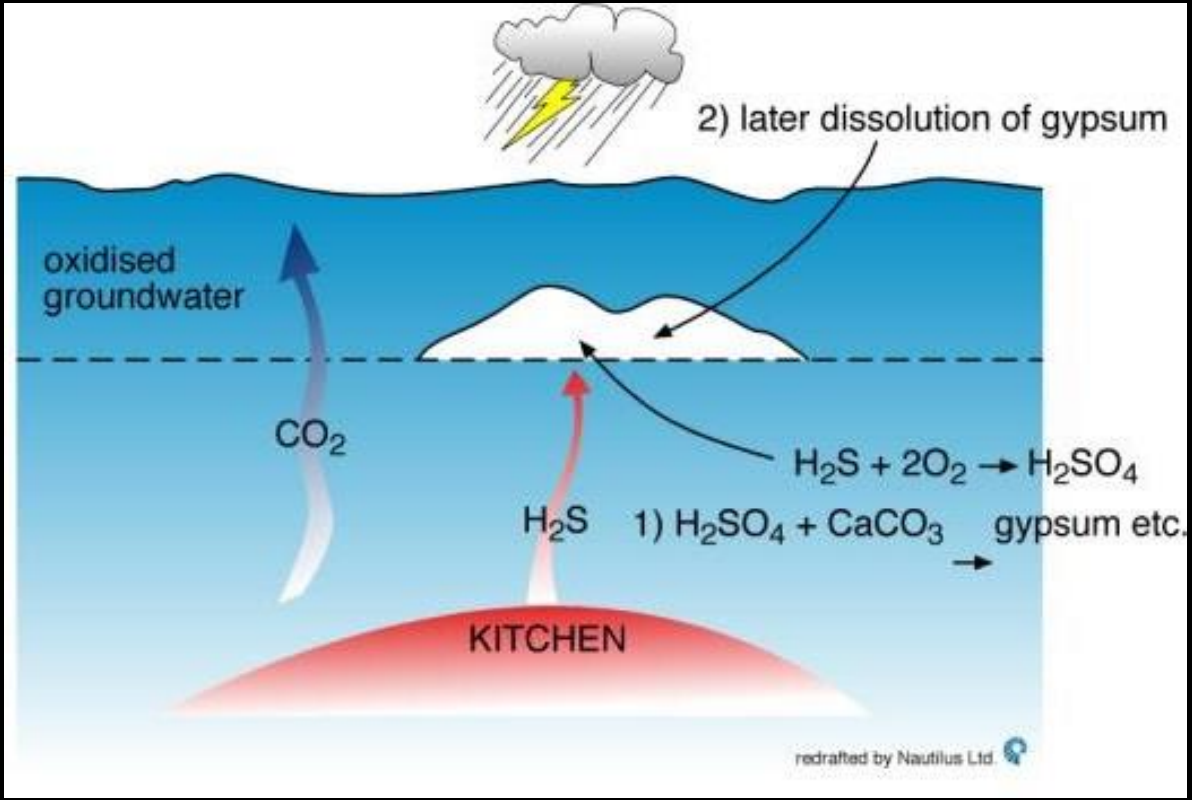
The source rock maturation CO_2 model has been discussed by Giles M R & Marshall J D (1986, Marine & Petrol. Geol., 3, 243-255) and their conclusion is that it is unlikely to have produced much secondary porosity

However, inorganic (magmatic) CO_2, focused into the reservoir by faults related to salt movement, has been invoked in the Eocene carbonate fields of the Gulf of Gabes (Didon, Zarat and Ashtart fields).

Or CO_2 generated by hydrothermal (magmatic-related) decomposition of oil (Pearl R Mouth Basin)

H_2S Karst

H_2S (such as produced by TSR) when oxidised produces sulphuric acid but this requires mixing with oxygenated groundwater. Thus H_2S–related dissolution, including caves is best developed in near-surface settings

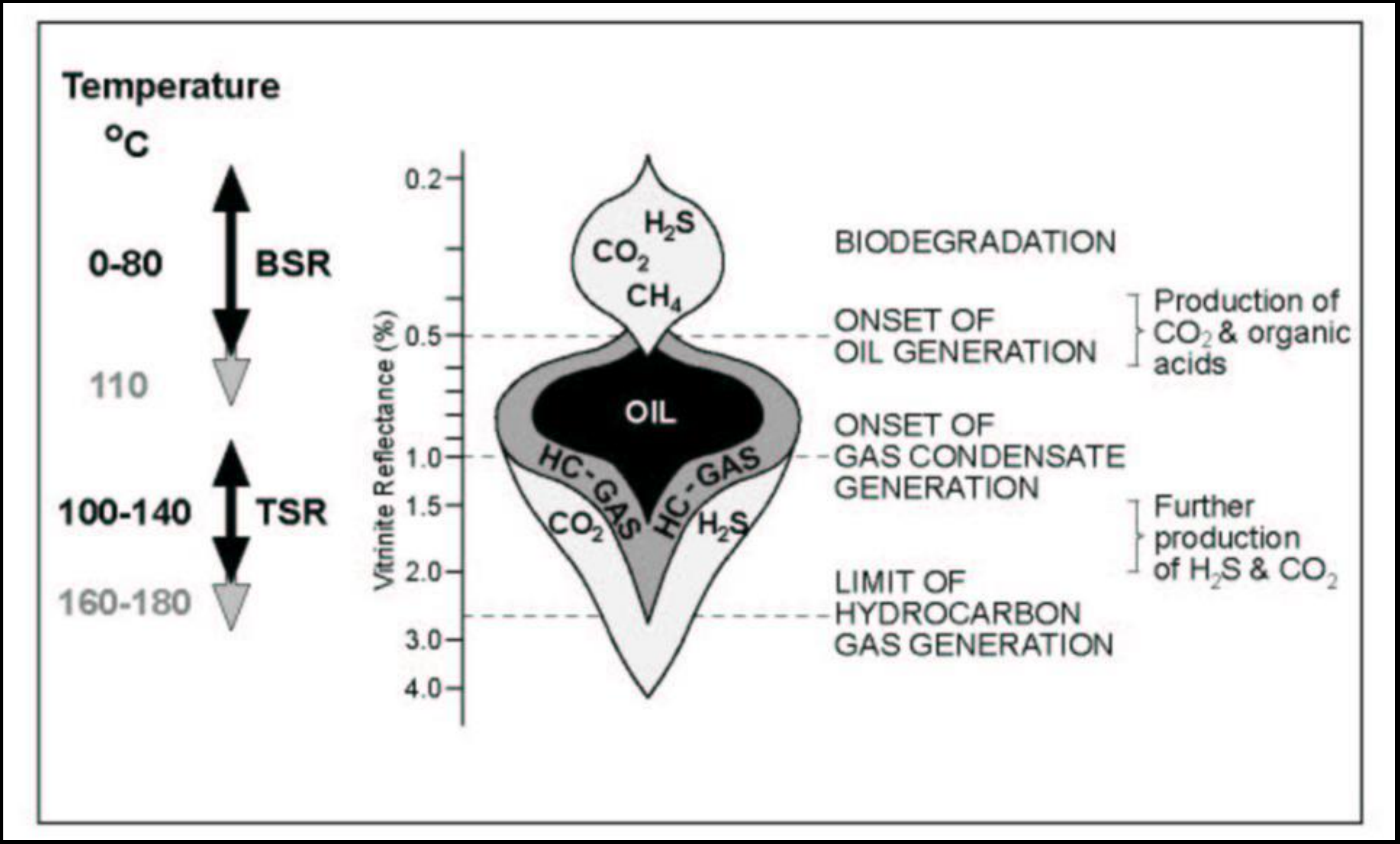


Volcanic sources can also supply the H_2S

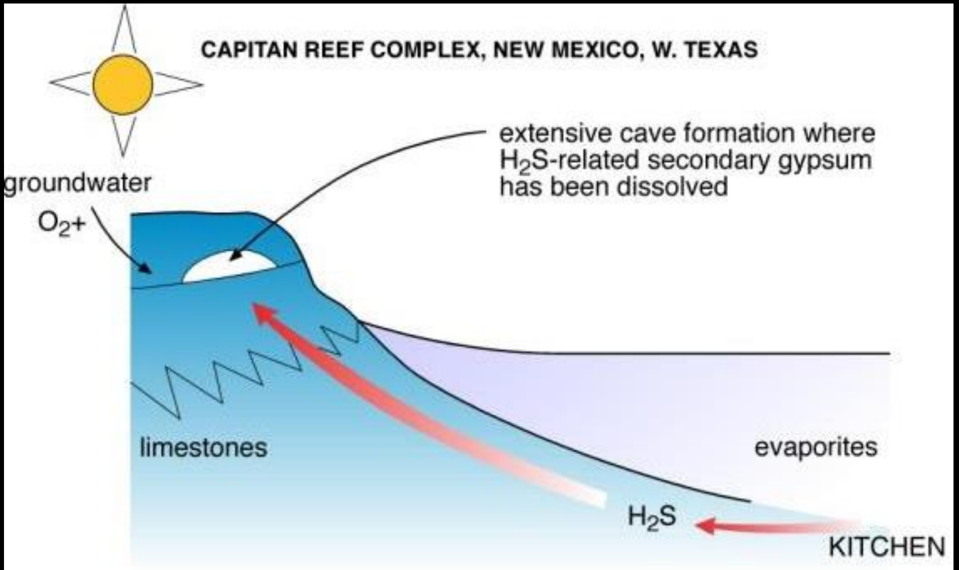
Thermochemical sulphate reduction – TSR

In temperature range 100-140C
Reaction with hydrocarbons and evaporites to produce sulphide and bicarbonate.
Sulphides can be oxidised to create acids and bicarbonate can trigger cementation
Likely only a relatively local process?
But has been invoked as a mechanism in some Pri-Caspian super-giant fields

Machel, H. G., 2001, Sedimentary Geology, 140, 143–175



The "oil field karst" model – Permian Basin



Snotties – Cueva de Villa Luz, Mexico
Sulphur eating bacteria that oxidize H_2S to produce sulphuric acid, which dissolves the rock – hypogenic karst

– hydrothermal H_2S-rich fluids, probably derived from an oil field 50km away in the coastal regions of southern Mexico.

Liuhua 11-1 Field, Pearl River Mouth Basin

Oil Field Karst due to CO_2 & H_2S

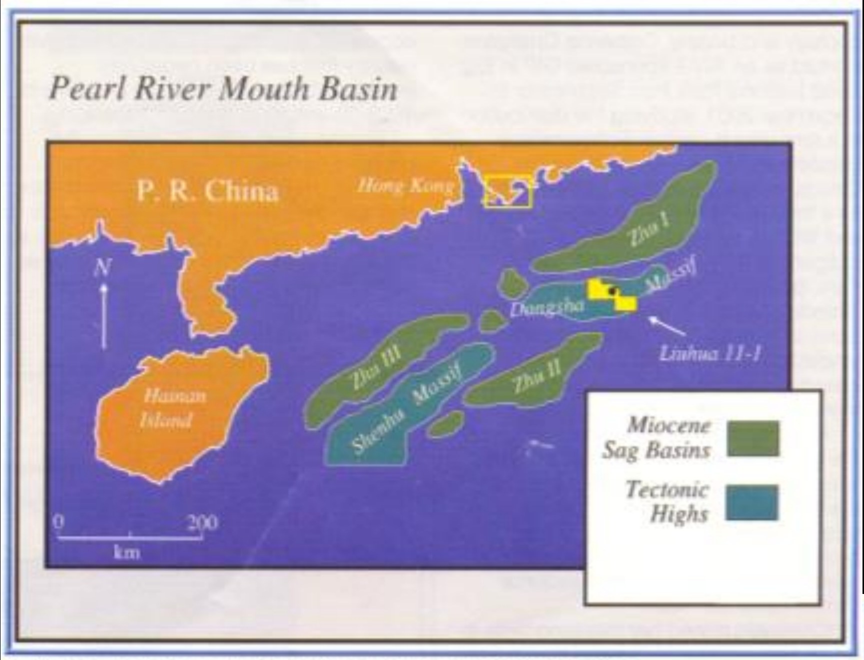


Figure 1 – Location map of Liuhua 11-1 Field, South China Sea.

Miocene reef with karstic collapse features

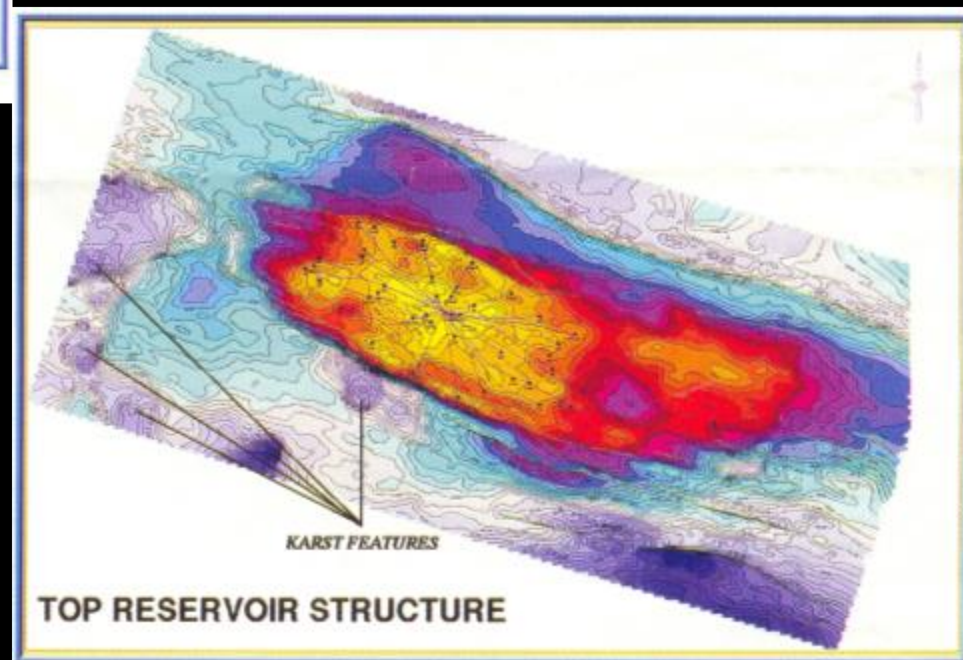
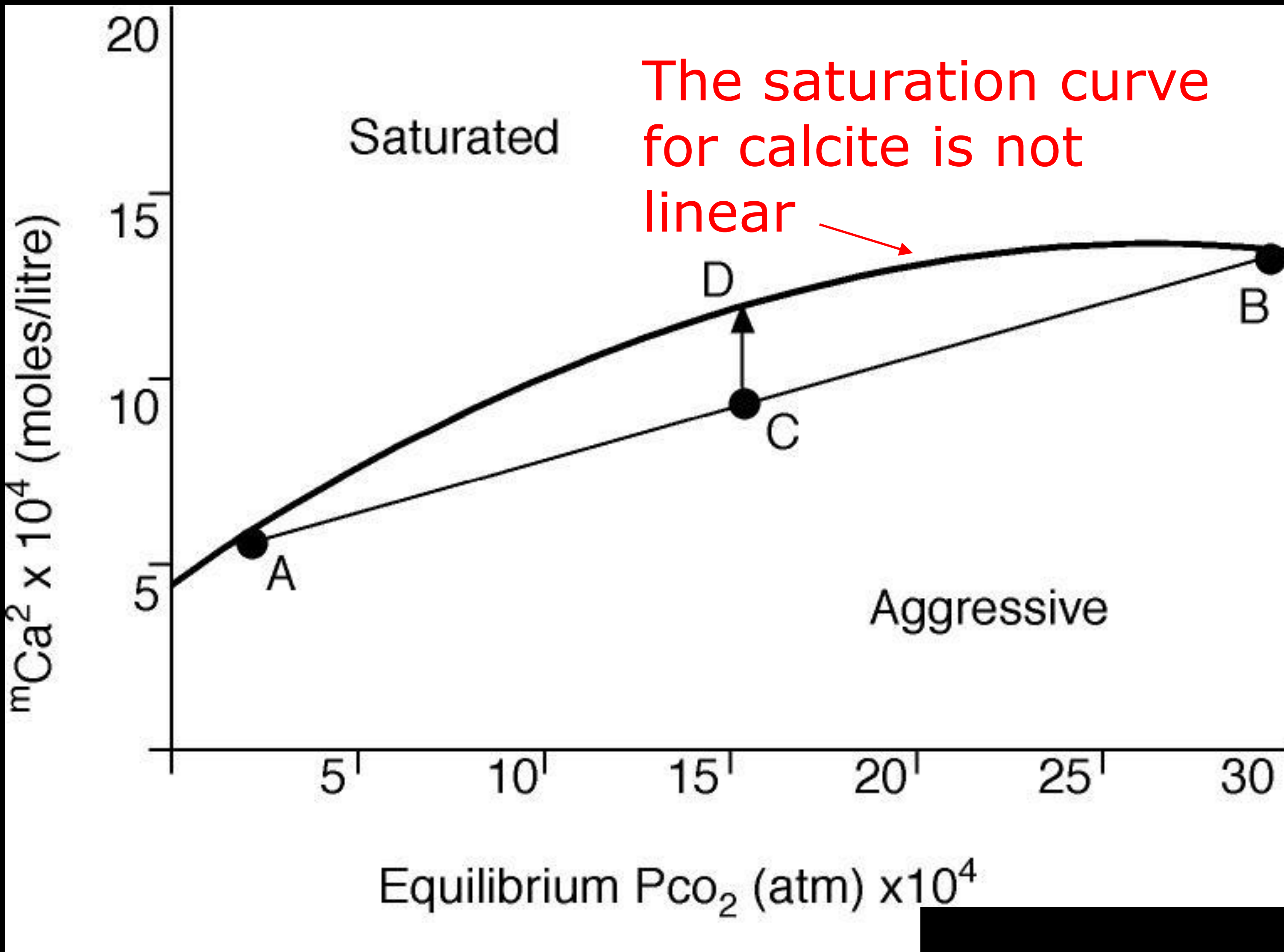


Figure 2 – Depth structure map showing central platform and directional wellbores. The map area is 14 X 7 kilometers. Major karst-collapse features shown.

For more information see - Story C et al., 2000. The Leading Edge; v.19, p. 834 – 844.

Mixing Corrosion



Retrograde solubility

The solubility of calcite is greater at lower temperatures so as a fluid cools it could cause dissolution.

This mechanism was earlier invoked to explain large scale dissolution in the Devonian gas fields of the Western Canada (HTD hydrothermal dolomite model).

And might play a role in the Smackover Black Creek Field (Upper Jurassic) of Mississippi – see Heydari E 2000 Bull. AAPG, 84, 100-111

Changes in pressure

A new mechanism used to explain corrosion and cementation (and bitumen formation) in the Tengiz reservoir in Pri-Caspian

Calcite solubility in carbonate reservoir groundwater generally increases with pressure.

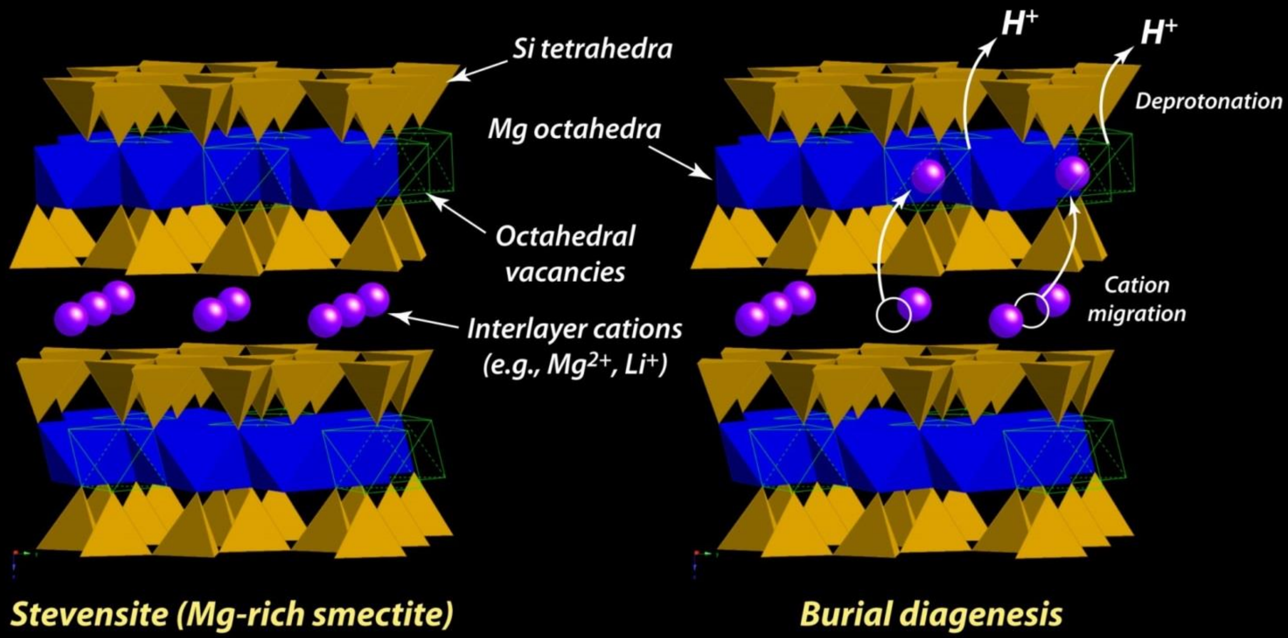
A geologically sudden pressure decrease at constant temperature would favour calcite precipitation due mainly to a decrease in solubility of CO_2(g) at the same time as bitumen drop-out from oil.

Subsequent re-pressurization at approximately constant temperature reverses this process, promoting calcite dissolution and temporarily halting bitumen formation.

Collins J E et al. 2013 SEPM Spec Publ. 105, 80-103

Very specific mechanism – the Hofman-Klemen Effect

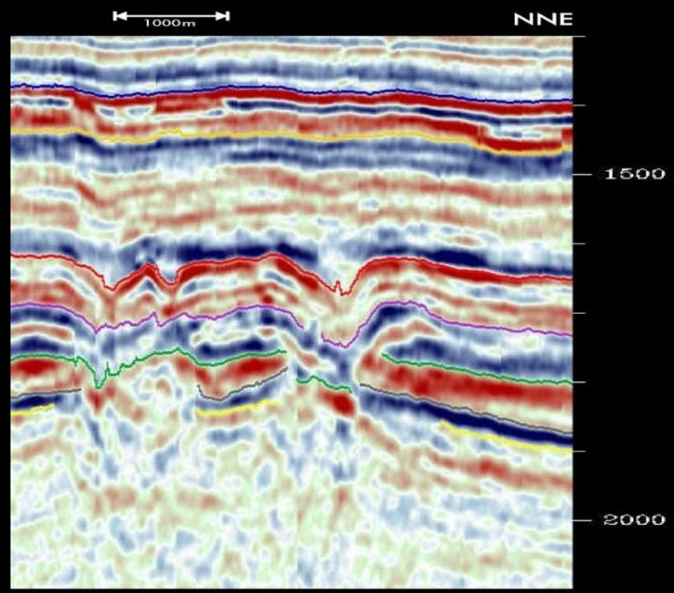
This has recently been invoked as one possible mechanisms for the late stage burial dissolution seen in the Brazilian Cretaceous Pre-Salt Barra Velha reservoirs –
There is a pH decrease due to deprotonation during the decay of Mg-clays such as stevensite (which itself produces extensive clay-mouldic porosity).



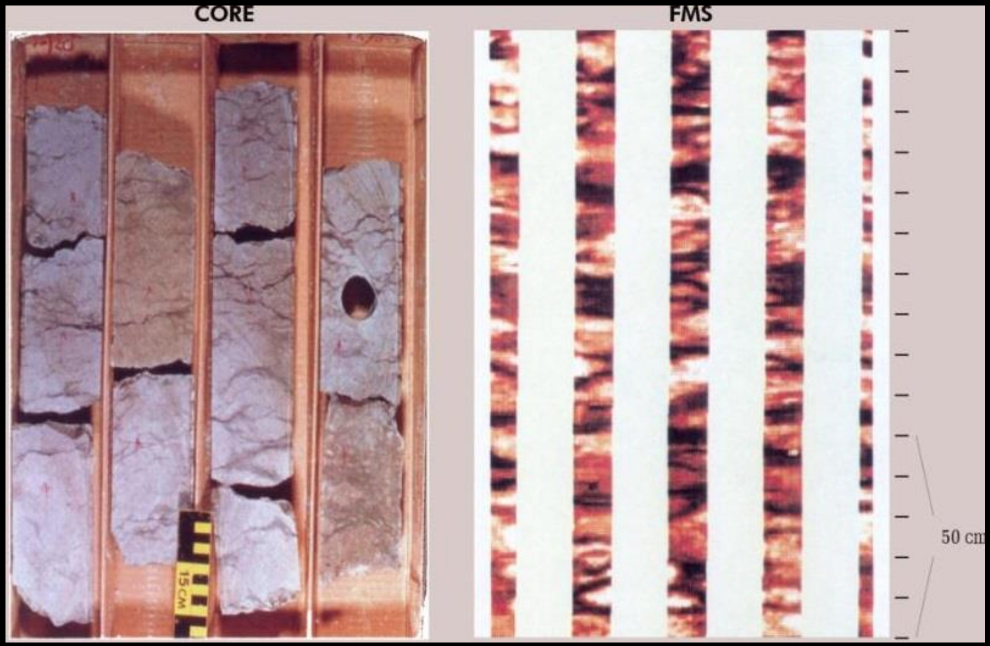
Tosca N & Wright V P 2015/16, Diagenetic pathways linked to labile Mg-clays in lacustrine carbonate reservoirs: A model for the origin of secondary porosity in the Cretaceous Pre-Salt Barra Velha Formation, offshore Brazil. In Armitage, P et al (eds) Reservoir Quality of Clastic and Carbonate Rocks: Analysis, Modelling and Prediction. Geological Society, London, Special Publication 435,

And Tosca N & Wright V P 2014 The formation and diagenesis of Mg-clay minerals in lacustrine carbonate reservoirs. AAPG Search and Discovery Article #51002

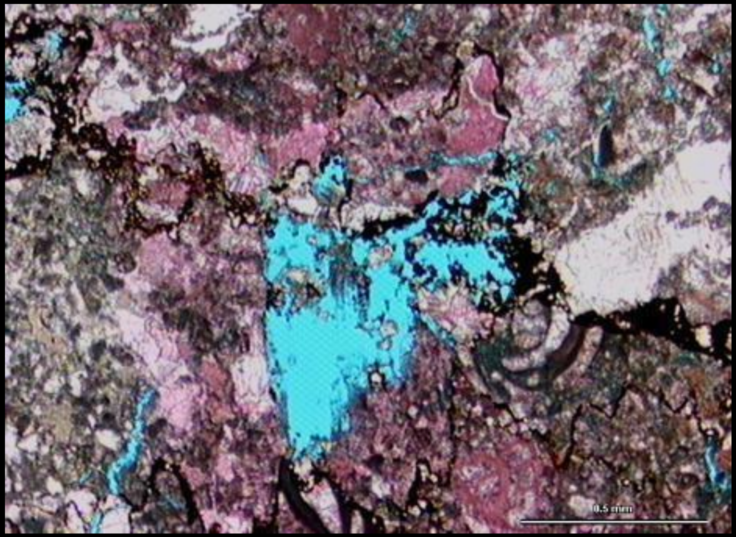
Criteria



From the seismic scale



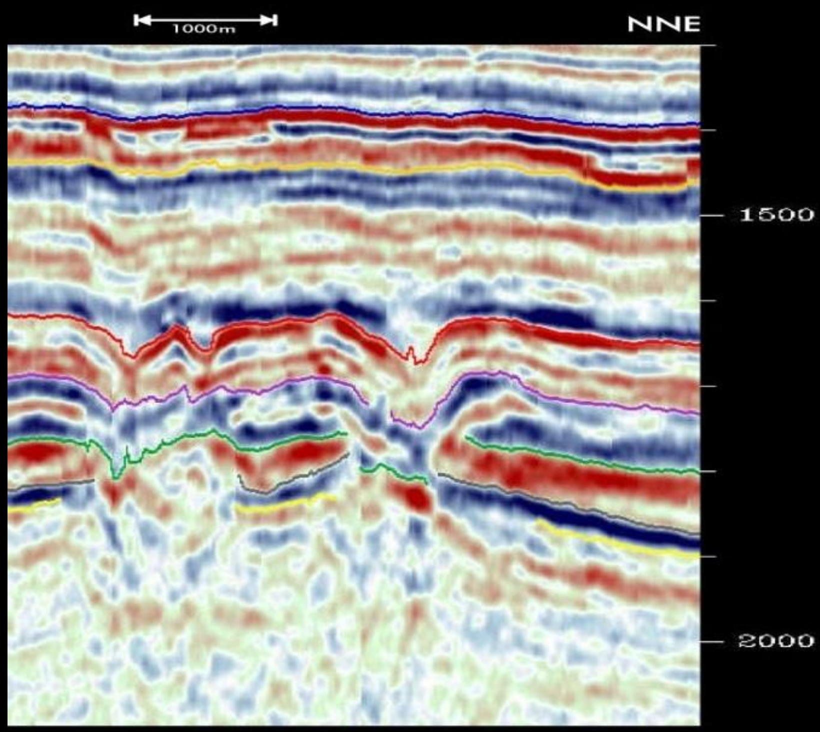
To the core scale



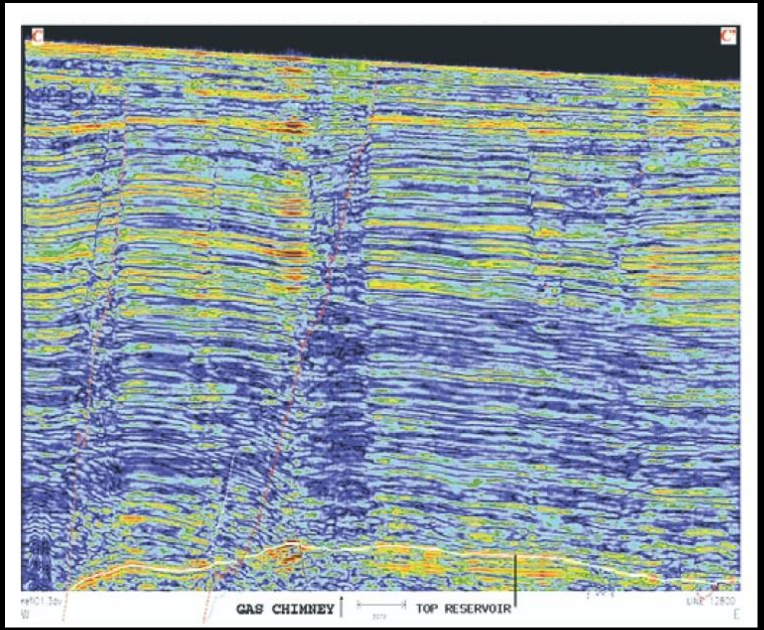
To the pore scale

Seismic scale – sags and collapse features

Normally hypogenic systems develop at depth and hence would not produce dolines at an unconformity. However, circular collapse features do develop and have vertical continuity in hypogenic systems and could be mistaken for surface dolines. There are means to distinguish collapse features of hypogenic from shallow meteoric karstic origins



Panna Field, offshore India



Liuhua 11-1 Field, Pearl River Mouth Basin. Collapse chimneys - Oil Field Karst due to CO_2 & H_2S. From Story C et al., 2000. The Leading Edge; v.19, p. 8

At the core scale - Corrosion along stylolites anfd fractures: Panna-Mukta fields, Bombay High, Offshore W India

Corroded stylolites – super KmD zones

Corroded stylolite –related fractures

Petrographic and mineralogical criteria for recognition

Mazullo, S.J. & Harris, P.M. 1992. AAPG Bulletin, 76, 607–620

Dissolution of a phase formed after significant burial-time

- *dissolution of saddle dolomite*
- *dissolution of late cements (especially in fractures)*
- *dissolution of cements with hydrocarbon inclusions*
- *dissolution along stylolites*
- *dissolution of compacted grains*
- *dissolution of stylolite-related fractures*

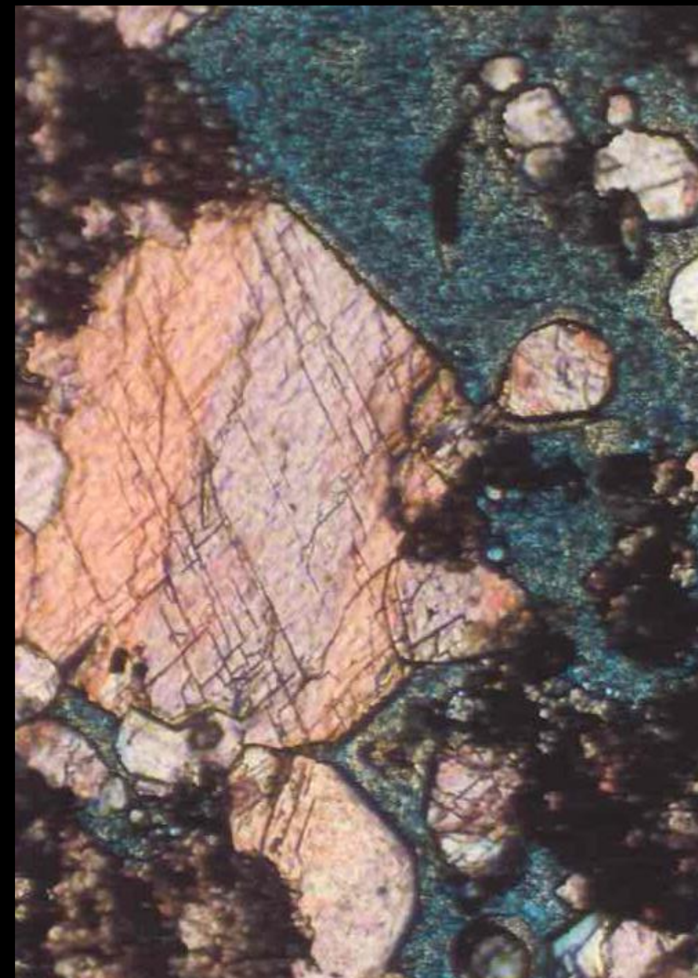
Associated minerals -

- dickite cements
- association with metal sulphides (MVT's)

Corrosion of vein calcite cement in a stylolite-related fracture

Eocene Bassein Fm, Mukta Field, offshore India

Corroded burial cements

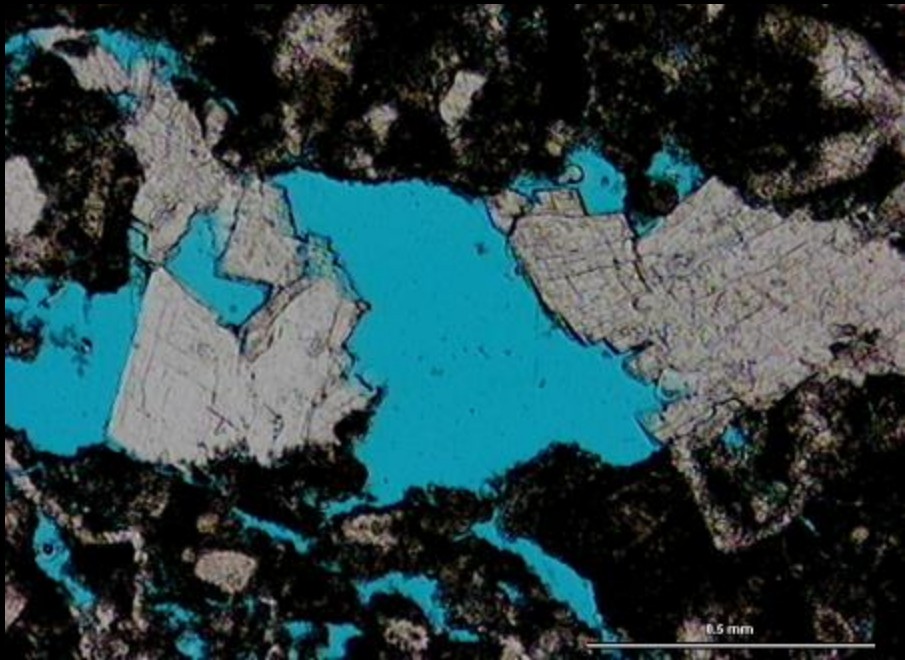


Cretaceous Mishrif Fm., Dubai FoV = 0.4mm

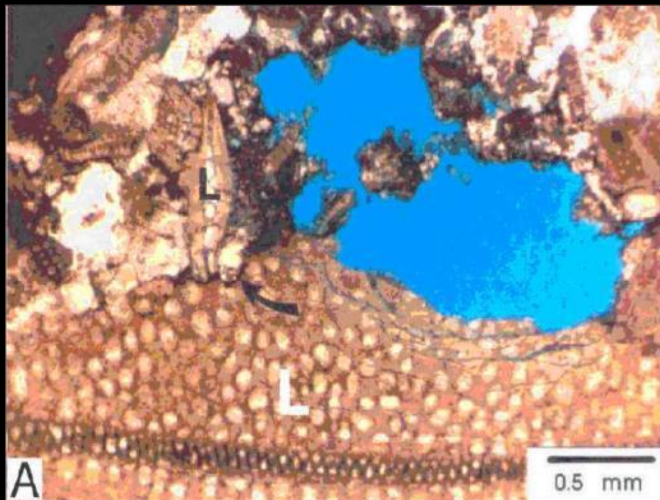
Etched late stage saddle dolomites

Devonian – WCSB

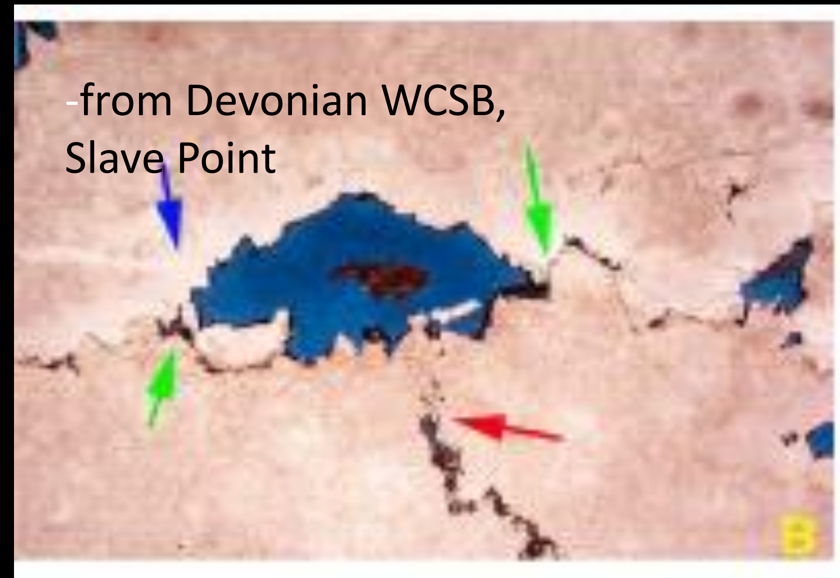
Eocene, Mukta, India



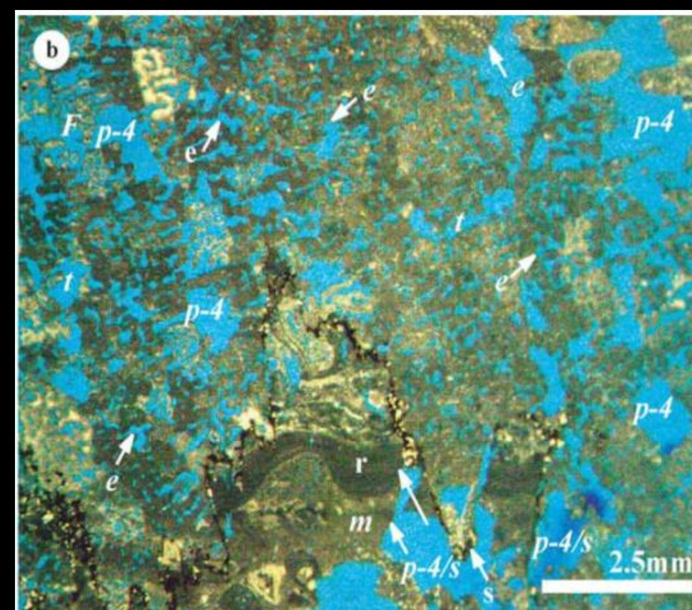
Corrosion along stylolites



Oligocene, Kerendan Platform, Indonesia



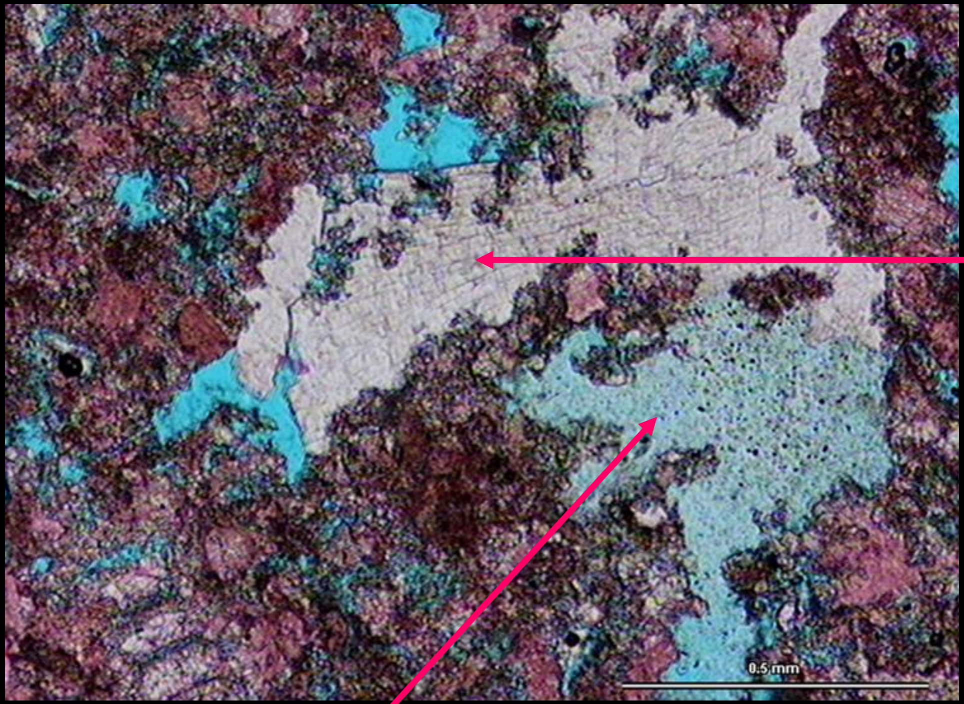
Carboniferous, Karachaganak Field, Kazakhstan

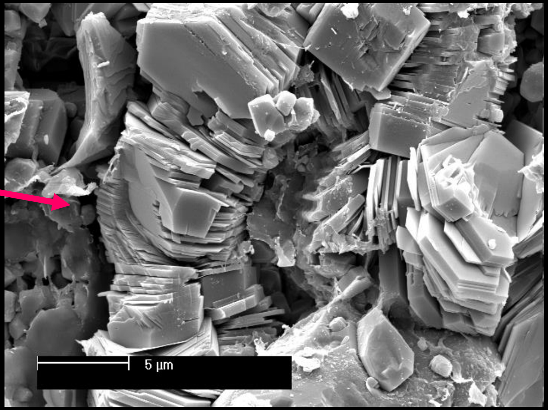


Liuhua 11-1 Field, Pearl River Mouth Basin, Miocene reef

Dickite seems to be present in a number of reservoirs affected by hypogene fluids – it is a kaolin mineral found in limestones and is regarded as evidence that acidic, organic -rich fluids have affected the rock, leaching Al and SiO_2.

Dickite and hypogene dissolution – Mukta Field, offshore India





Late stage diagenetic effects - saddle dolomite in a fracture has undergone corrosion followed by dickite precipitation

Can we predict the possible occurrence of hypogene dissolutional processes and porosity?

There are recurrent pathways and associations (including circulation systems) which could be a means of targeting possible hypogene reservoirs

…… but as in most carbonate exploration

… things are complicated

Pathways

1. Common association with faults (no surprise there), especially transtensional (strike slip) faults – includes aspects of the HTD model (hydrothermal dolomite model).

Examples:

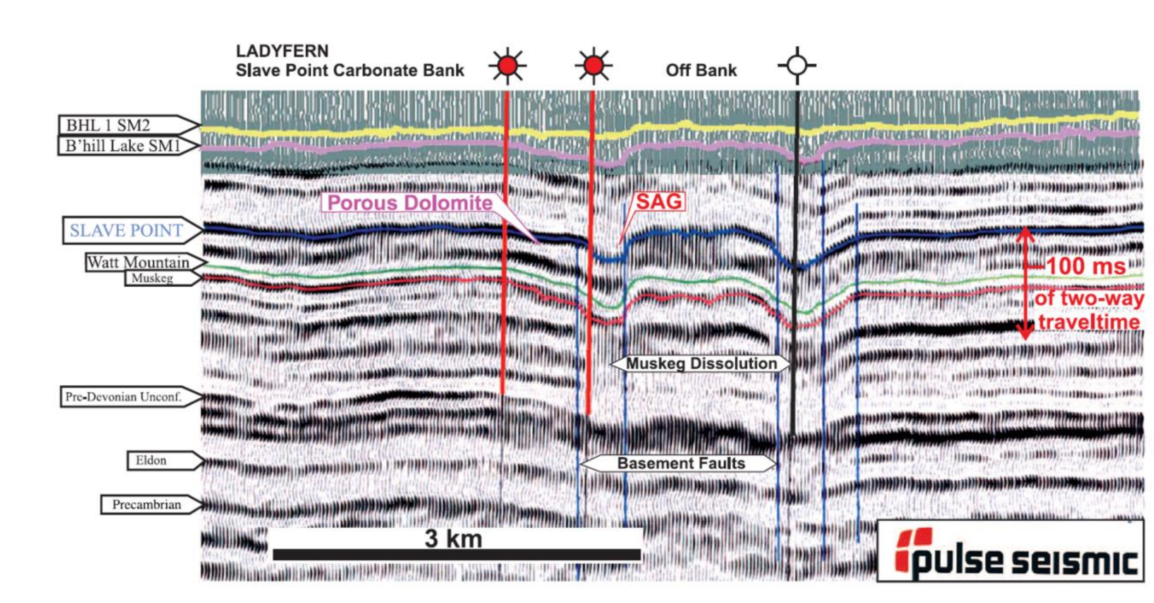
- *Devonian Slave Point of Western Canada*
- *Eocene Panna-Mukta fields, Bombay High*
- *Jurassic Deep Panuke of offshore Canada*

2. Platform slopes and margins form major pathways especially if have early fractures, are actually fracture-controlled, and can be close to kitchens or compacting shale basins - (squeegee-type flow mechanism)

Examples

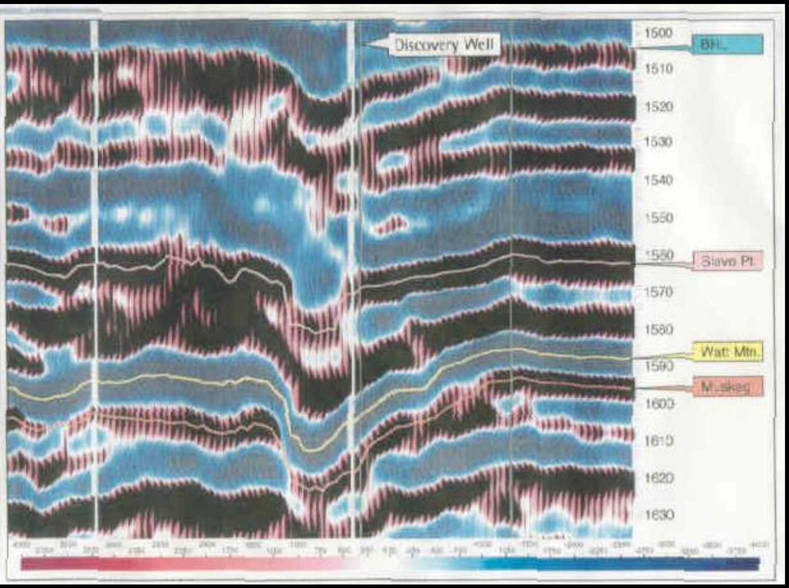
- *Jurassic Deep Panuke (Abenaki) Eastern Canada*
- *Late Carboniferous Dagger Draw field, New Mexico*
- *Early Carboniferous of PreCaspian (Tengiz & Kashagan margins)*
- *Oligocene Kerendan platform of Indonesia*

Transtensional Faults, Sags and HTD - hydrothermal dolomite



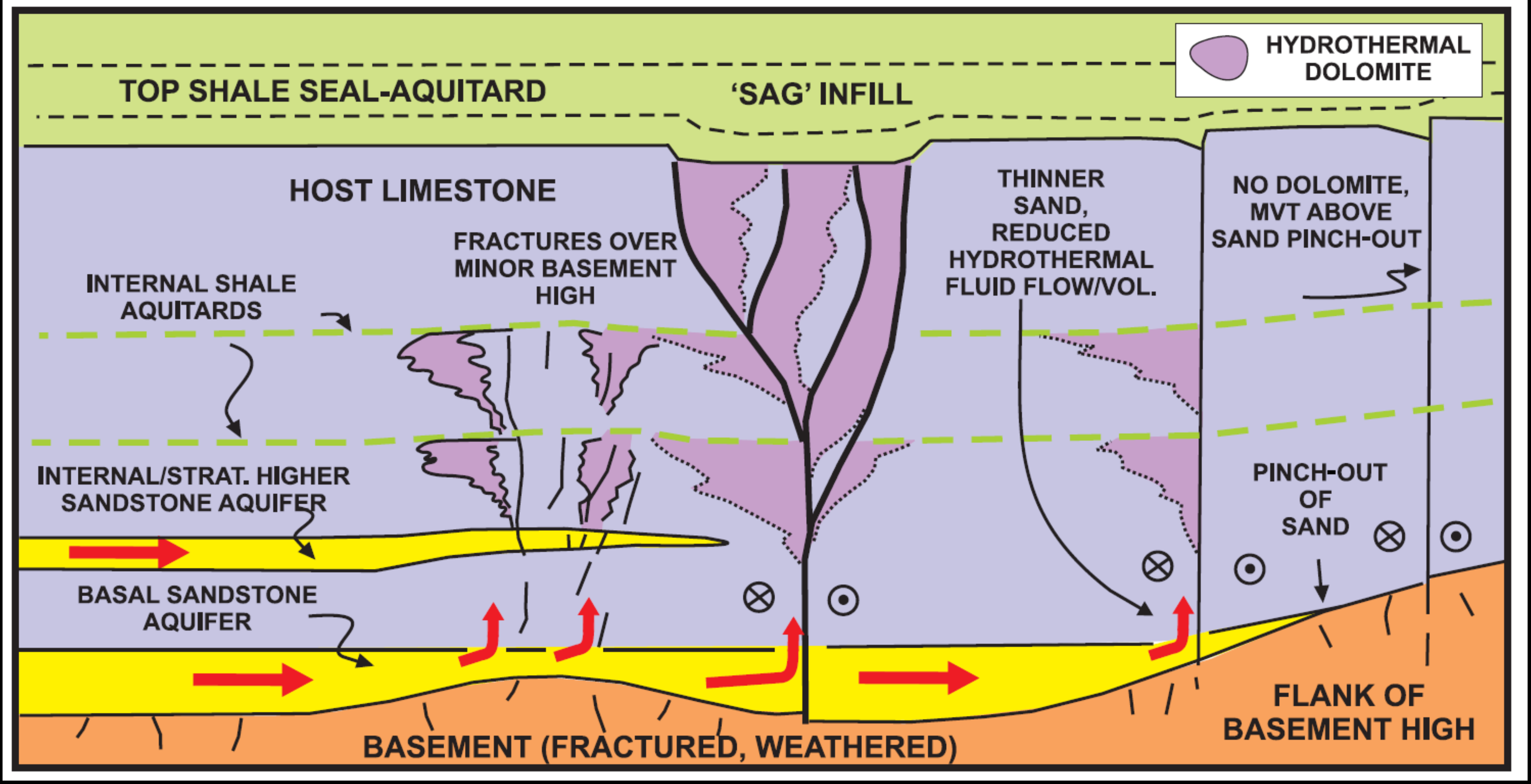
Western Canadian Devonian Slave Point fields such as Cranberry and Ladyfern

Dissolution & dolomitization linked to negative flower structures of basement-rooted strike-slip (transtensional) faults, but there are examples of hydrothermal alteration around other fault types



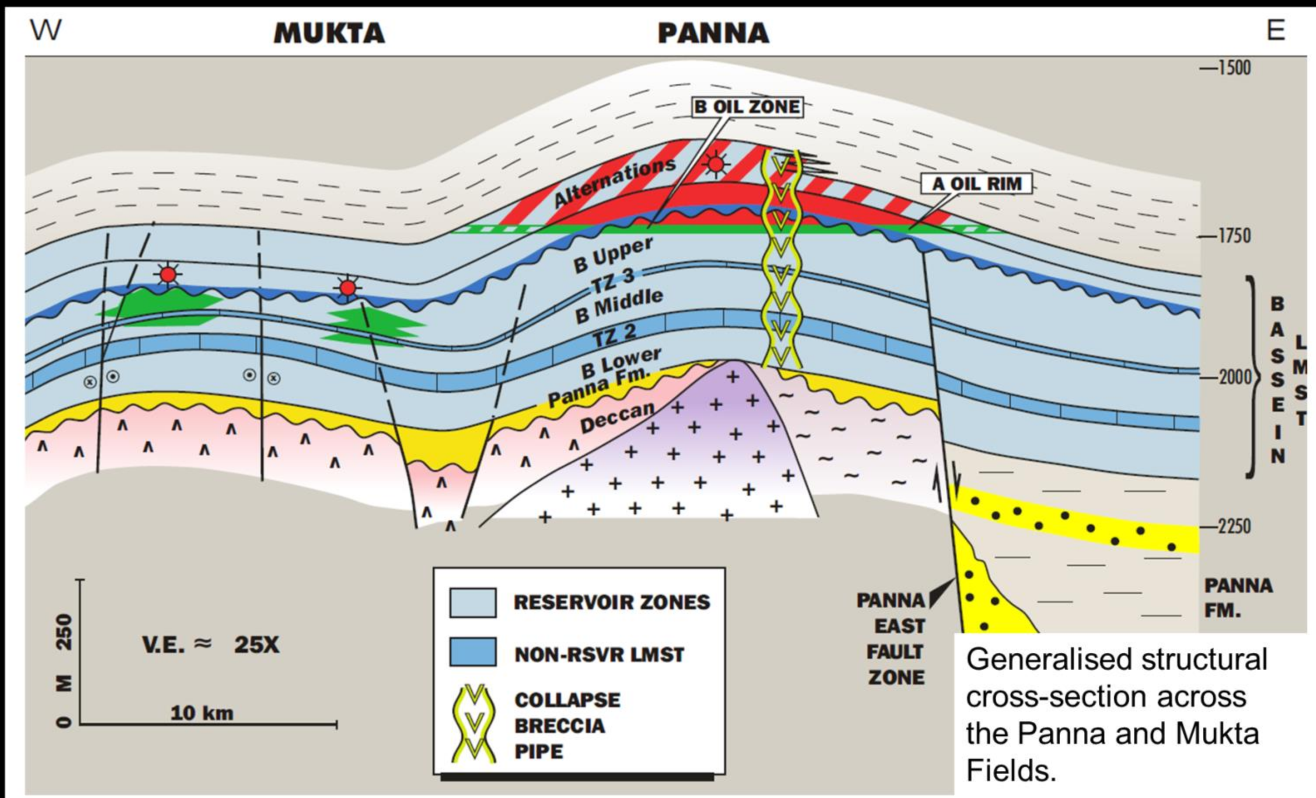
Main source – Davies G R & Smith L B Jnr 2006 AAPG Bulletin, 90, (November), 1641–1690 . This whole issue of AAPG Bulletin was focussed on HTD studies

Elements of this hydrological play - underlying aquifer

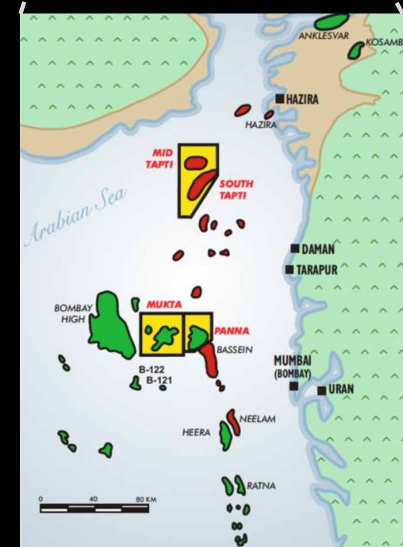


Besides the fault system other elements are needed in this paly including an underlying aquifer – see attached text. From Davies G R & Smith L B Jnr 2006 AAPG Bulletin, 90, (November), 1641–1690

Panna-Mukta Field, Bombay High, offshore W India

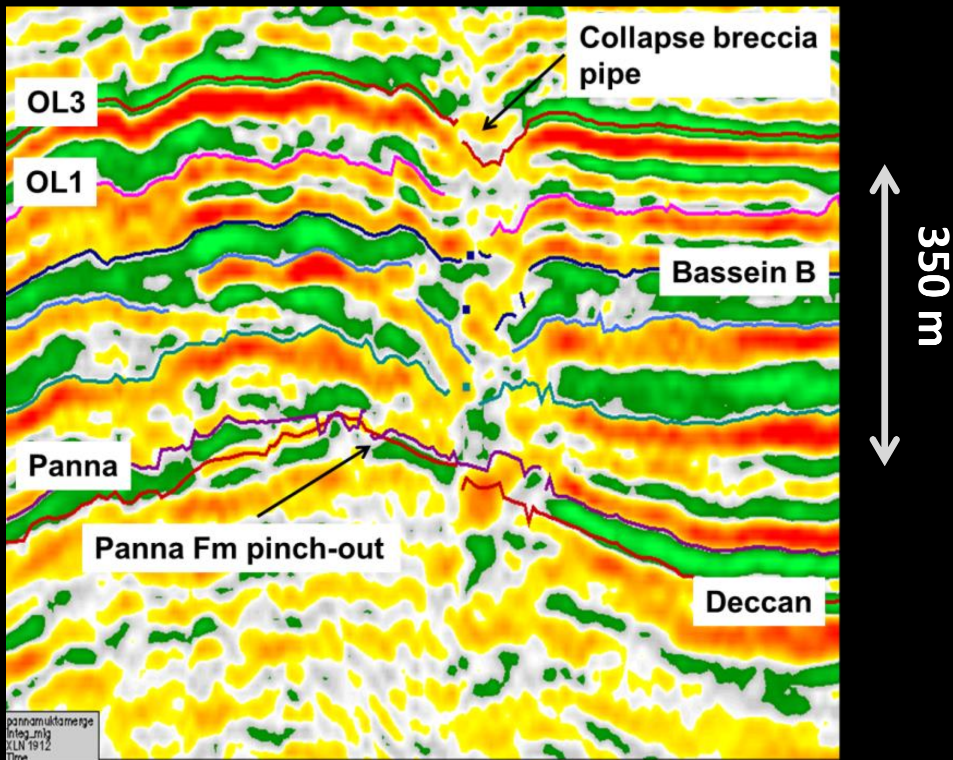


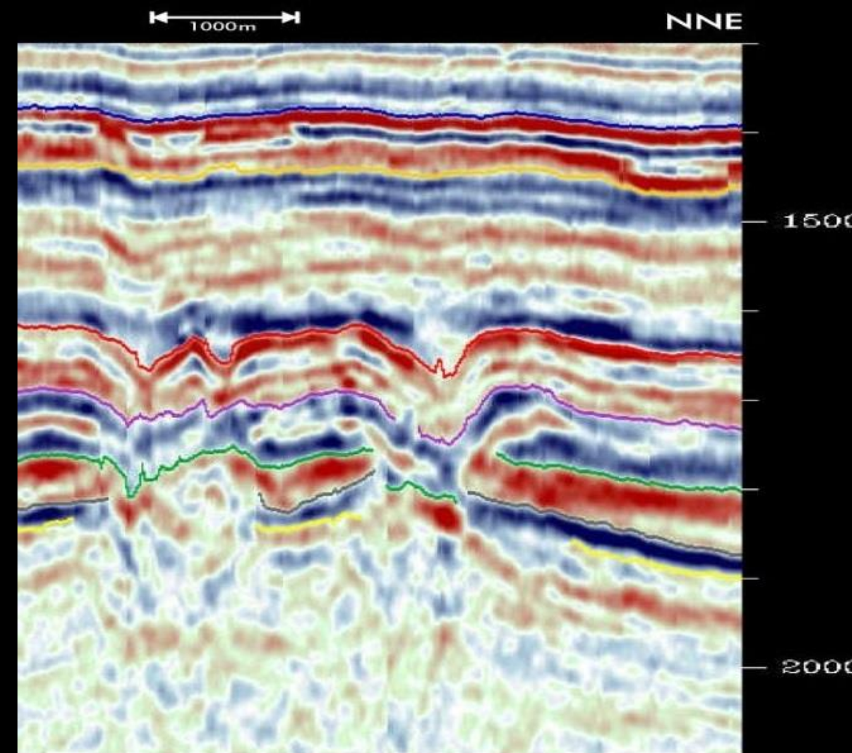
Generalised structural cross-section across the Panna and Mukta Fields.



Barnett A J et al., 2015/16. **Distinguishing between eogenetic, unconformity-related and meosgenetic dissolution: a case study from the Panna-Mukta Field, offshore Mumbai, India.** In Armitage, P et al (eds) Reservoir Quality of Clastic and Carbonate Rocks: Analysis, Modelling and Prediction. Geological Society, London, Special Publication 435,

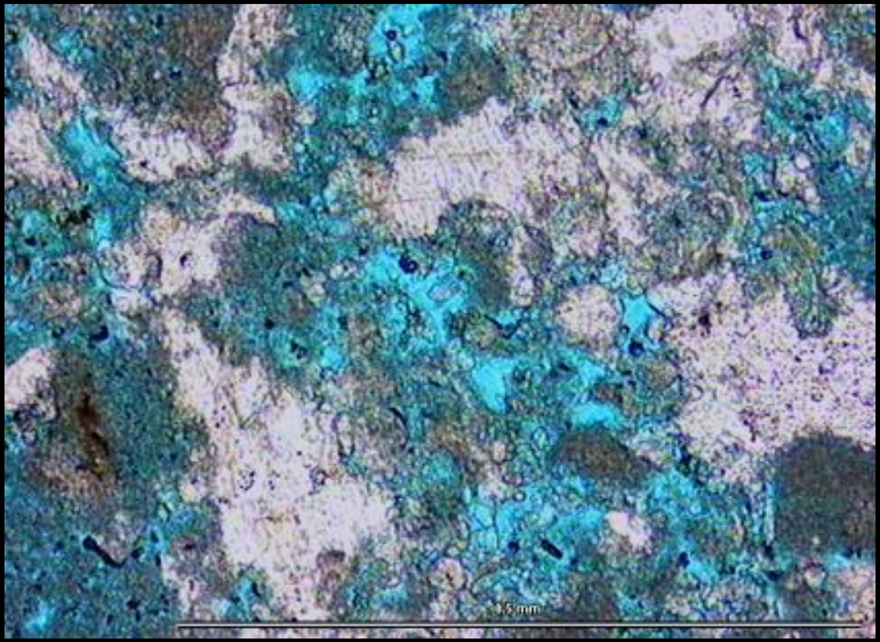
Panna-Mukta fields, Eocene, offshore India - breccia pipes





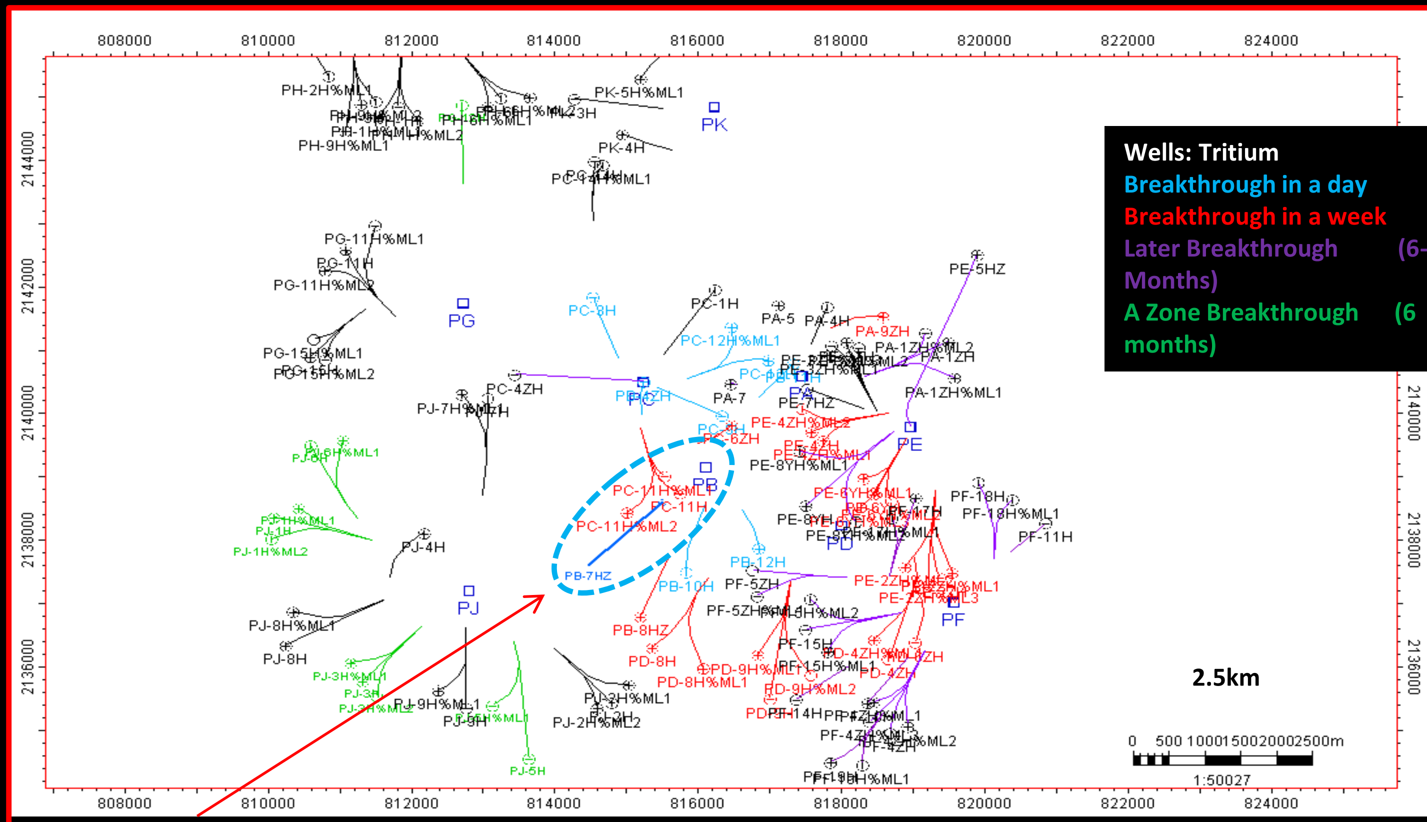
Huge breccia pipes occur around transtensional faults

Panna-Mukta fields, Eocene, offshore India – formation scale corrosion



yet extensive corrosion many kilometres from the main strike-slip faults

Panna-Mukta fields, Eocene, offshore India – super KmD zones



Tritiated water injected in PB-7HZ well on March 7th 2012

Corroded stylolites produce super-KmD zones

See Barnett A J et al., 2016. **Distinguishing between eogenetic, unconformity-related and meosgenetic dissolution: a case study from the Panna-Mukta Field, offshore Mumbai, India.** In Armitage, P et al (eds) Reservoir Quality of Clastic and Carbonate Rocks: Analysis, Modelling and Prediction. Geological Society, London, Special Publication 435, and associated cited papers by Chandra, V. et al on well bore upscaling and rock typing.

Pathways

Common association with faults (no surprise there), especially transtensional (strike slip) faults – includes aspects of the HTD model (hydrothermal dolomite model). There are reservoirs due to both pathway types

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Platform slopes and margins form major pathways especially if have early fractures, are actually fracture-controlled, and can be close to kitchens or compacting shale basins (squeegee-type flow mechanism)

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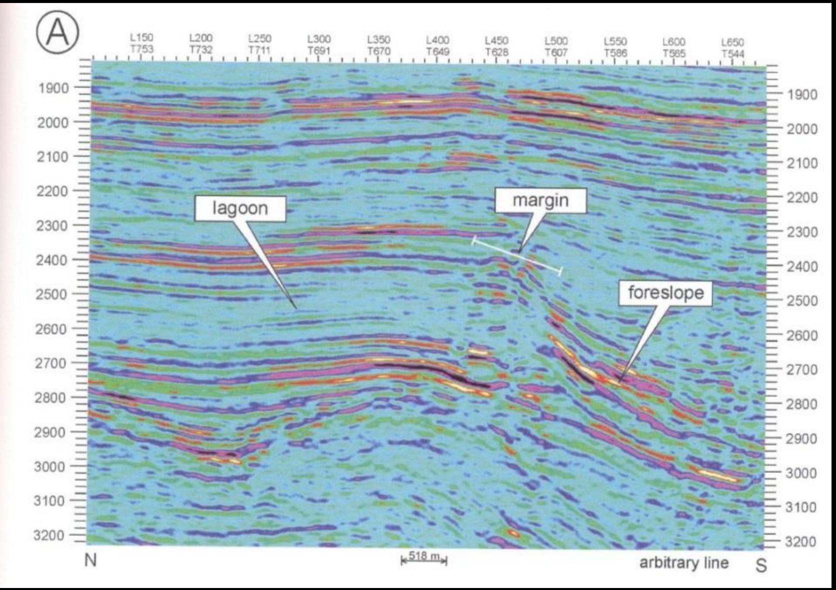
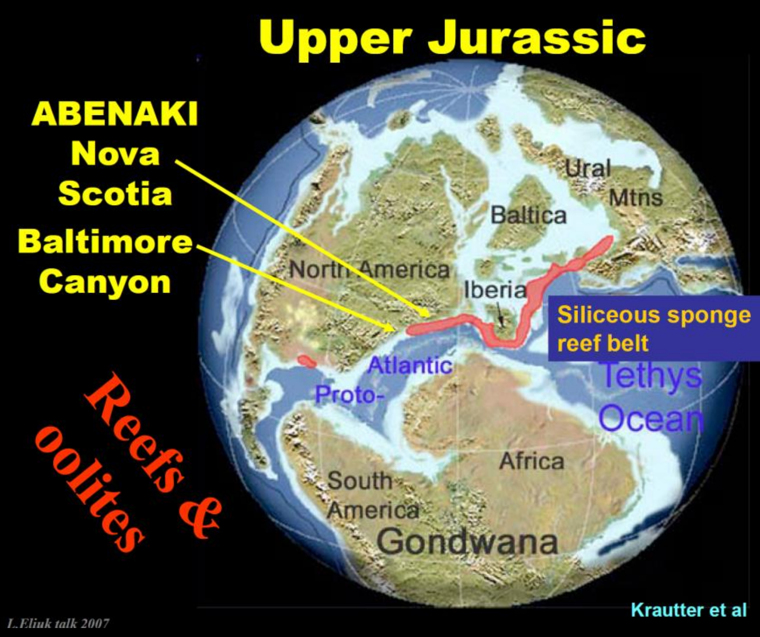
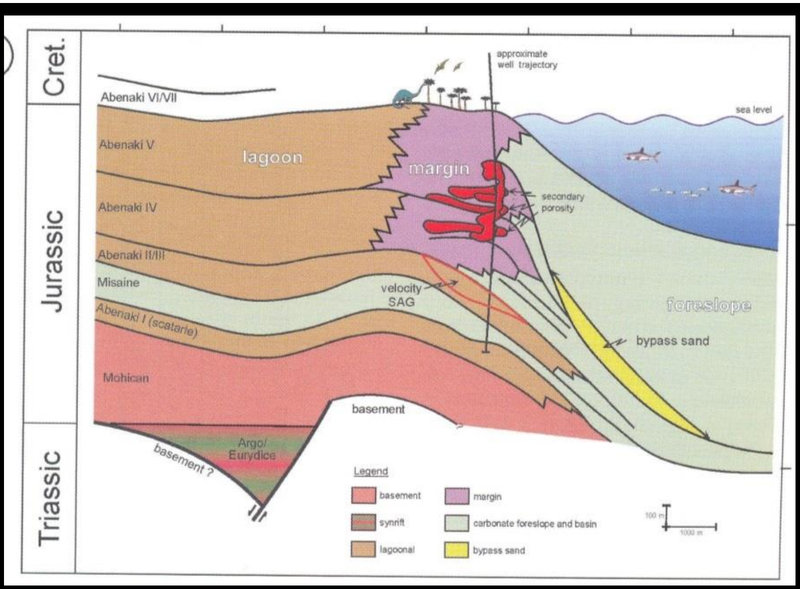
Abenaki Jurassic margin Deep Panuke reservoir – a hybrid model

Basement structural control on reef development, and reservoir viability depends on late stage dissolution (burial corrosion) linked to strike-slip faults.

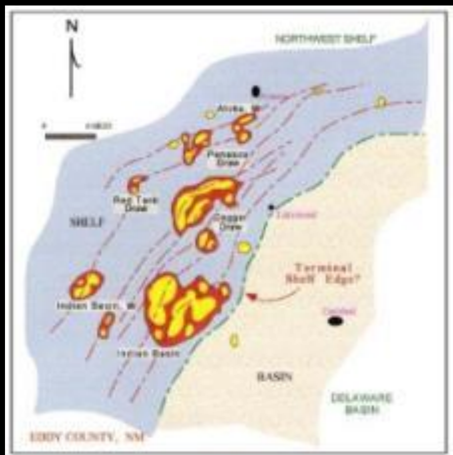


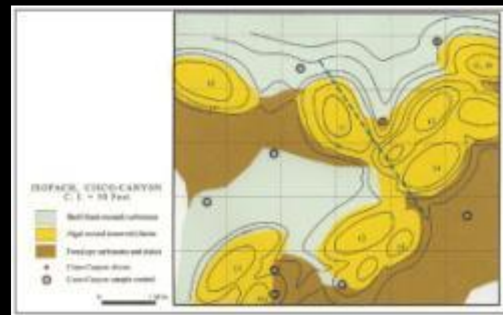


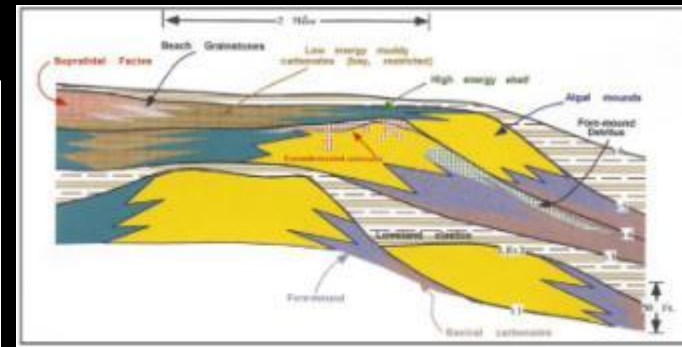


Source - Eliuk L 2010 AAPG Search & Discovery Article 10259 - Regional Setting of the Late Jurassic Deep Panuke Field, Offshore Nova Scotia, Canada – Cuttings Based Sequence Stratigraphy and Depositional Facies Assoc iations - Abenaki Formation Carbonate Margin; Weissenberger J A W et al 2006, pages 395-431 In AAPG Memoir 88 Giant Hydrocarbon Reservoirs of the World, ed by P M Harris & L J Weber.

South Dagger Draw Field, Late Penn., faulted ramp margin phylloid mounds near Carlsbad







Cisco-Canyon in age (uppermost Pennsylvanian = Missourian-Bursumian or Gzhelian-Kasimovian); Tinker S W et al., 2004, AAPG Mem 81, p.91-105

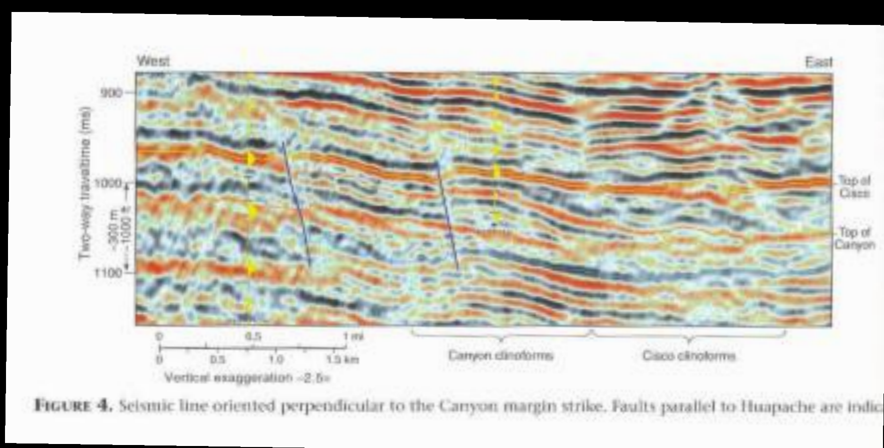
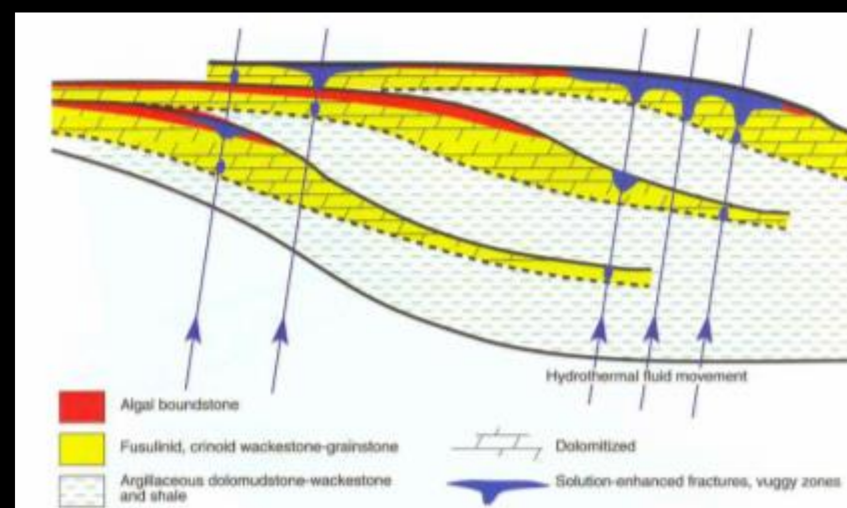
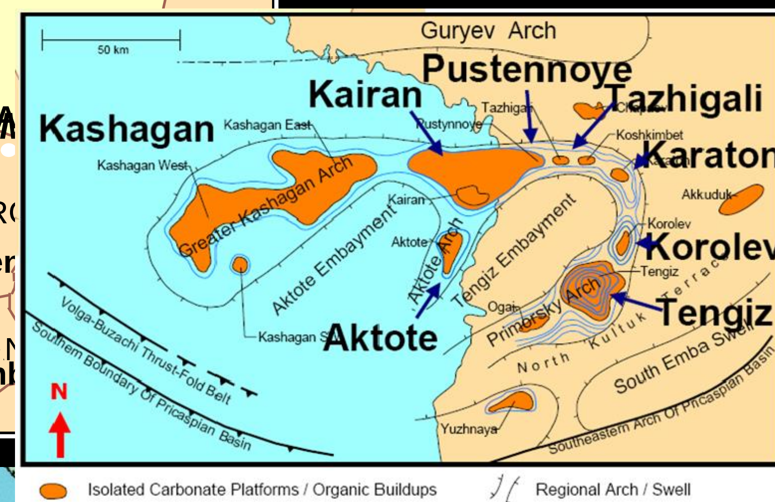
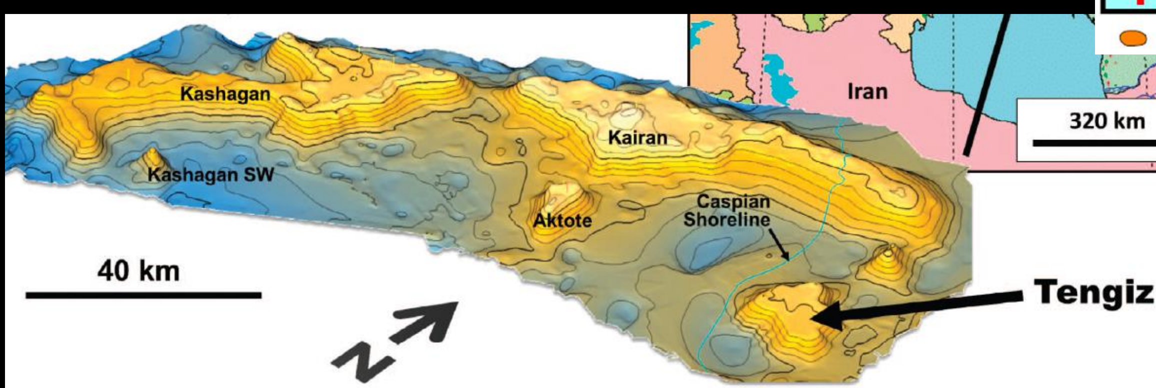


Figure 4. Seismic line oriented perpendicular to the Canyon margin strike. Faults parallel to Huapache are indic



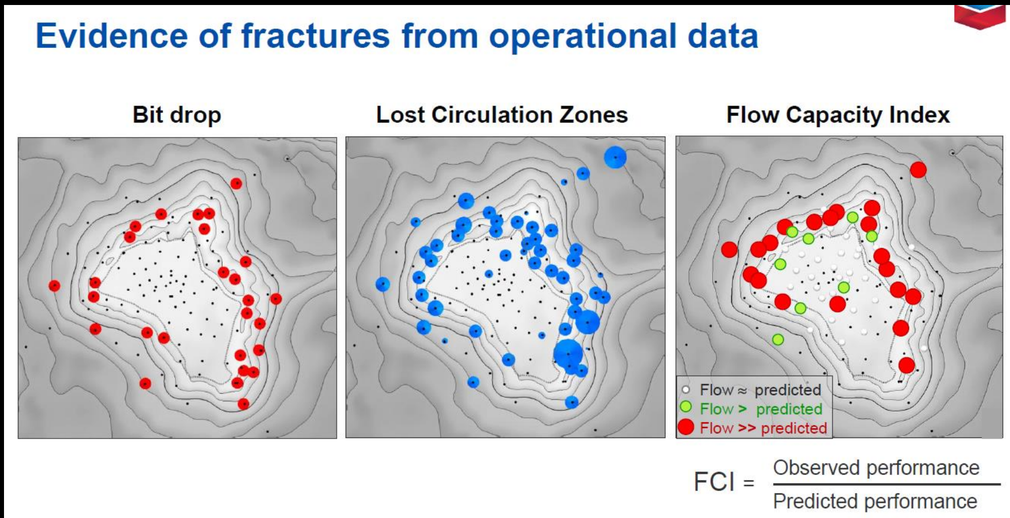
Hypogene fluids and dissolution in platform slopes and margins of the super-giant Tengiz and Kashagan fields, Pri-Caspian of Kazakhstan



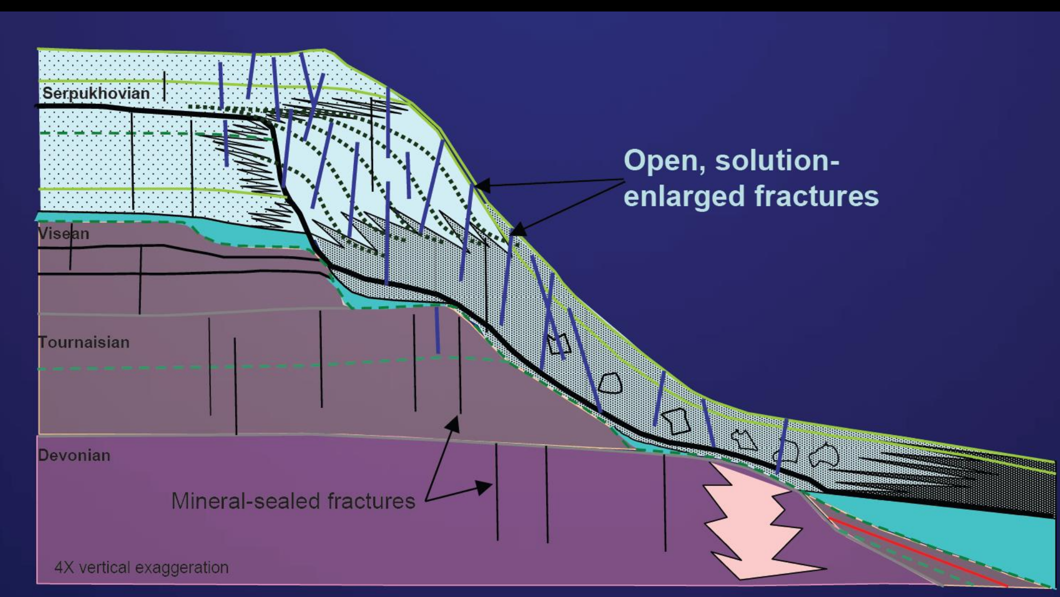


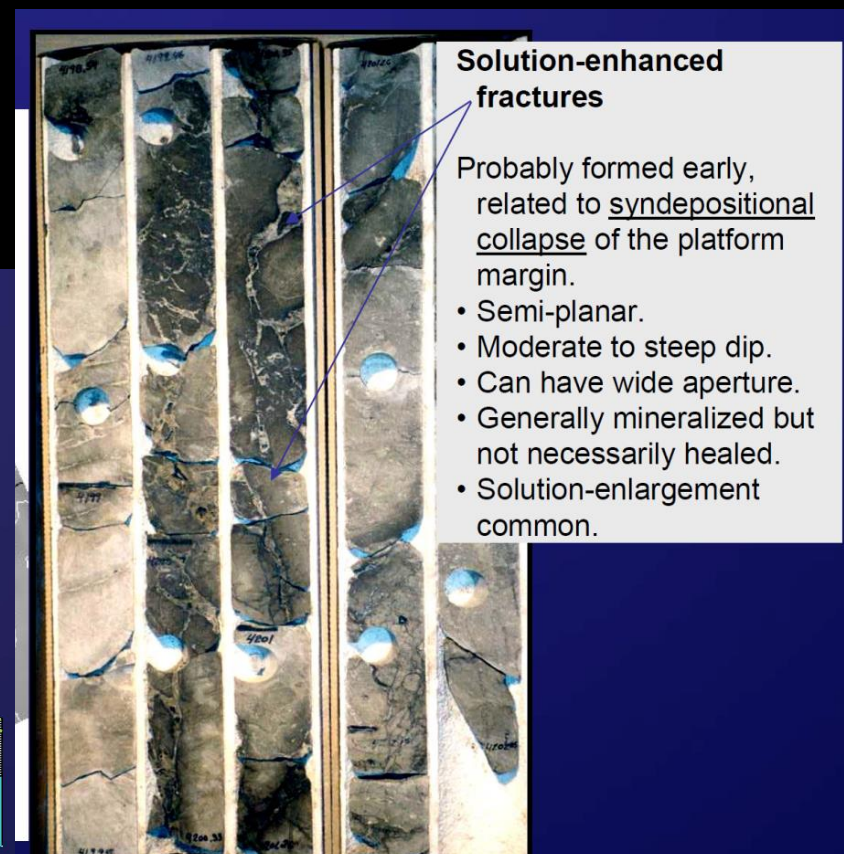
Tengiz

Burial solution enhanced early platform margin fractures play a key role in creating the high permeability zones

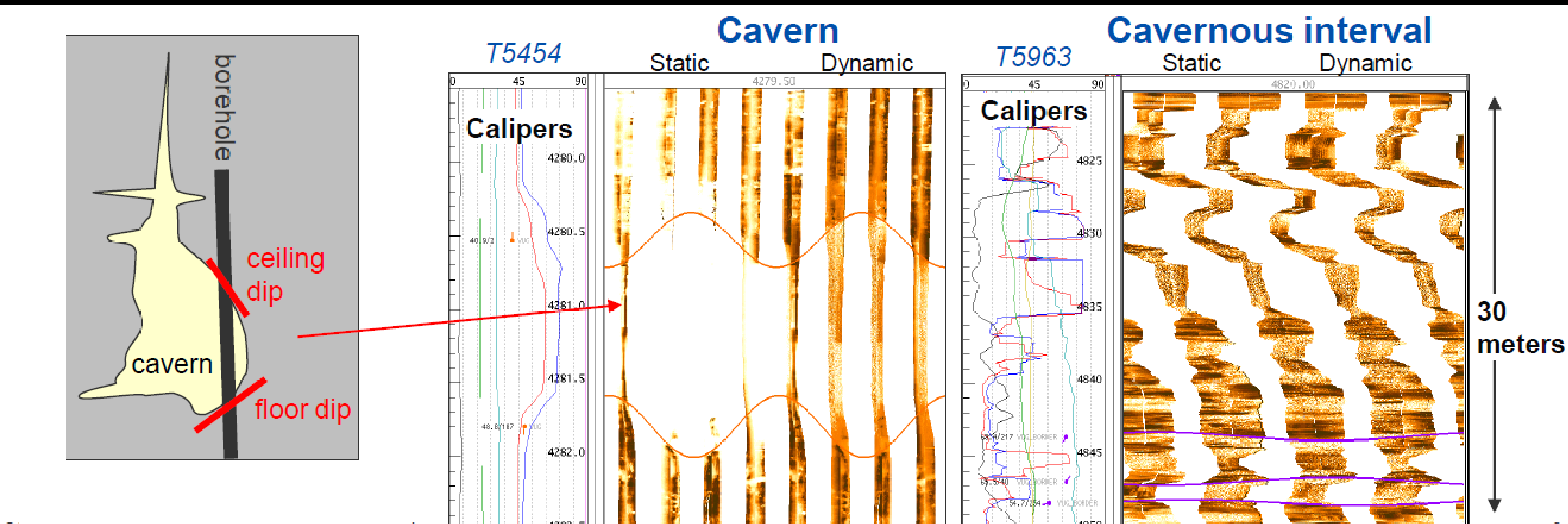


Narr W & Flodin E 2012 Fractures in Steep-rimmed Carbonate Platforms: Comparison of Tengiz Reservoir, Kazakhstan, and Outcrops in Canning Basin, NW Australia. Search and Discovery Article #20161 (2012)





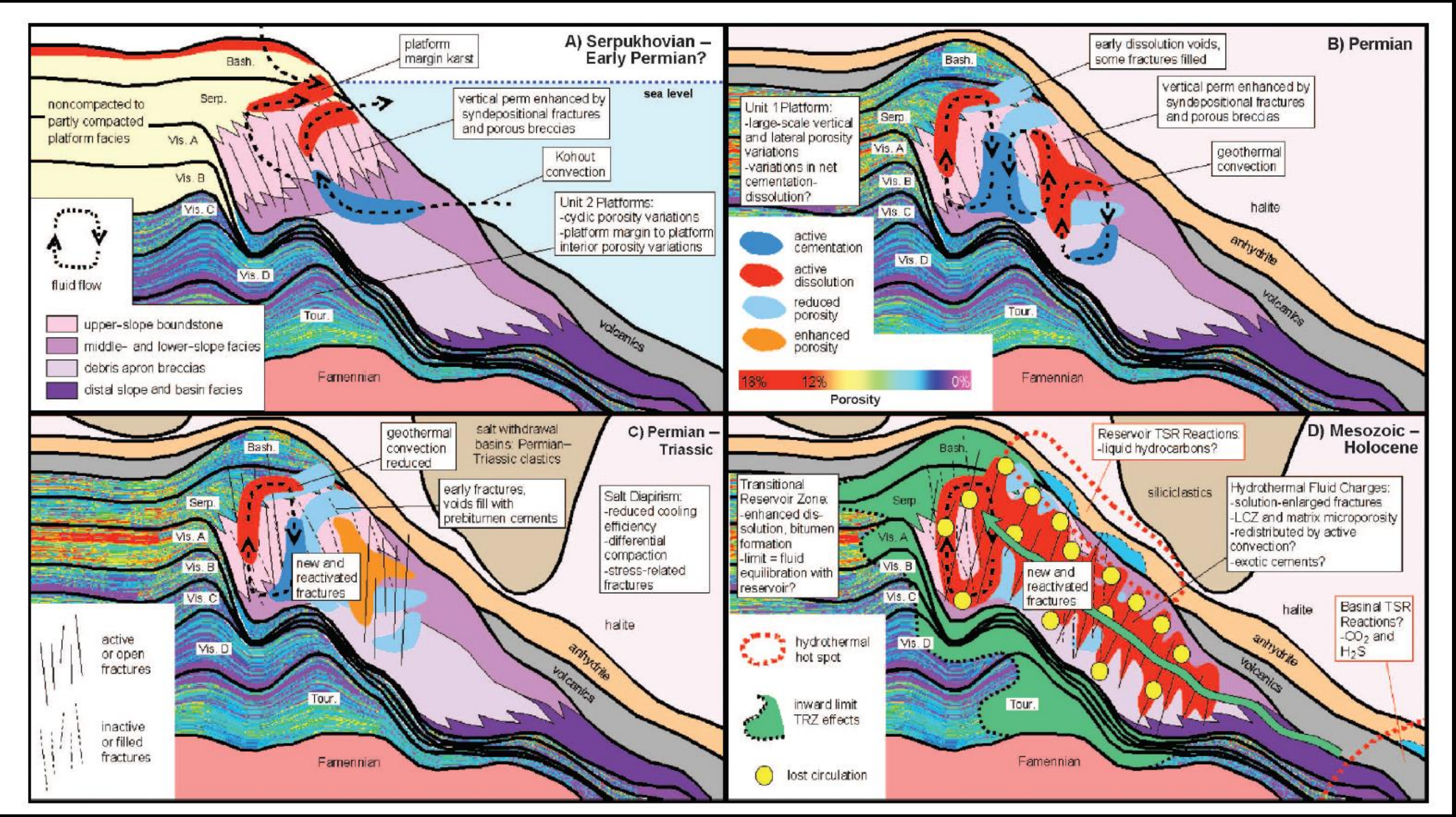
Tengiz – caverns including 6m cavern at 4kms depth



- *Conventional FMI, oil-based mud. Open fractures are resistive.*
- *Fractures range from narrow-aperture opening-mode to significant caverns.*

Narr W & Flodin E 2012 Fractures in Steep-rimmed Carbonate Platforms: Comparison of Tengiz Reservoir, Kazakhstan, and Outcrops in Canning Basin, NW Australia. Search and Discovery Article #20161 (2012)

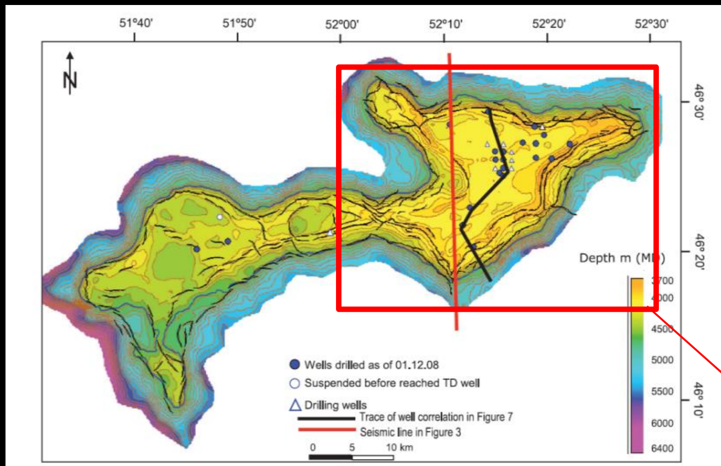
Tengiz - Evolution of the Tengiz rim and flank high-permeability reservoir

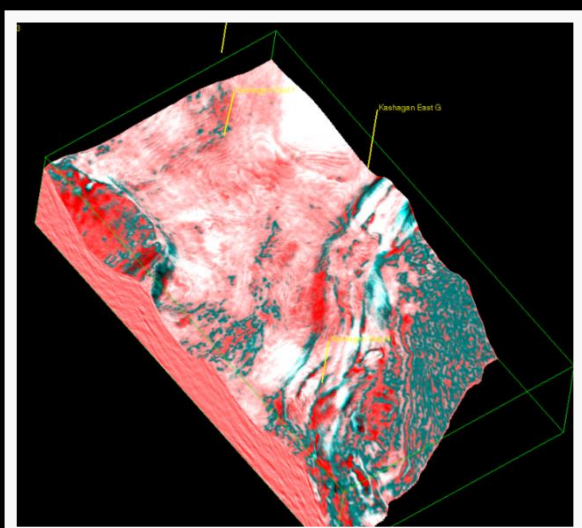


TSR & hydrothermal convection

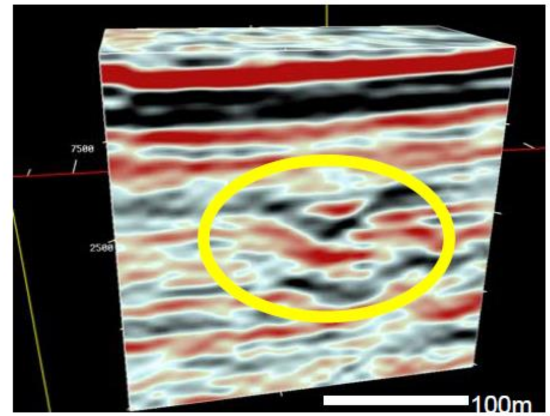
From: Collins, J. F. et al., 2006, Facies and reservoir-quality variations in the late Visean to Bashkirian outer platform, rim, and flank of the Tengiz buildup, Precaspian Basin, Kazakhstan. AAPG Memoir 88/SEPM Special Publication, p. 55–95.

Kashagan - extensive loss of circulation around the platform margin with evidence of meteoric, mixing zone and hypogenic processes

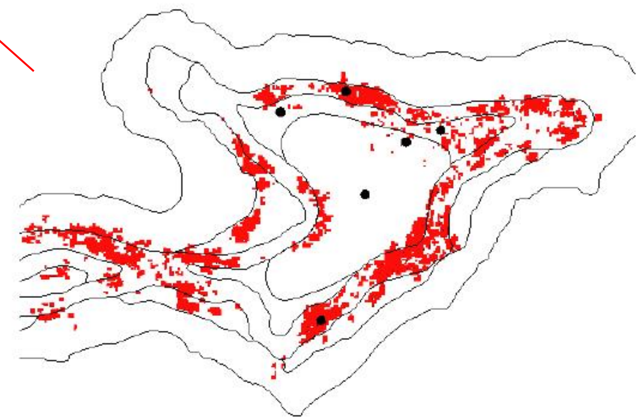




Platform-margin-parallel lineaments



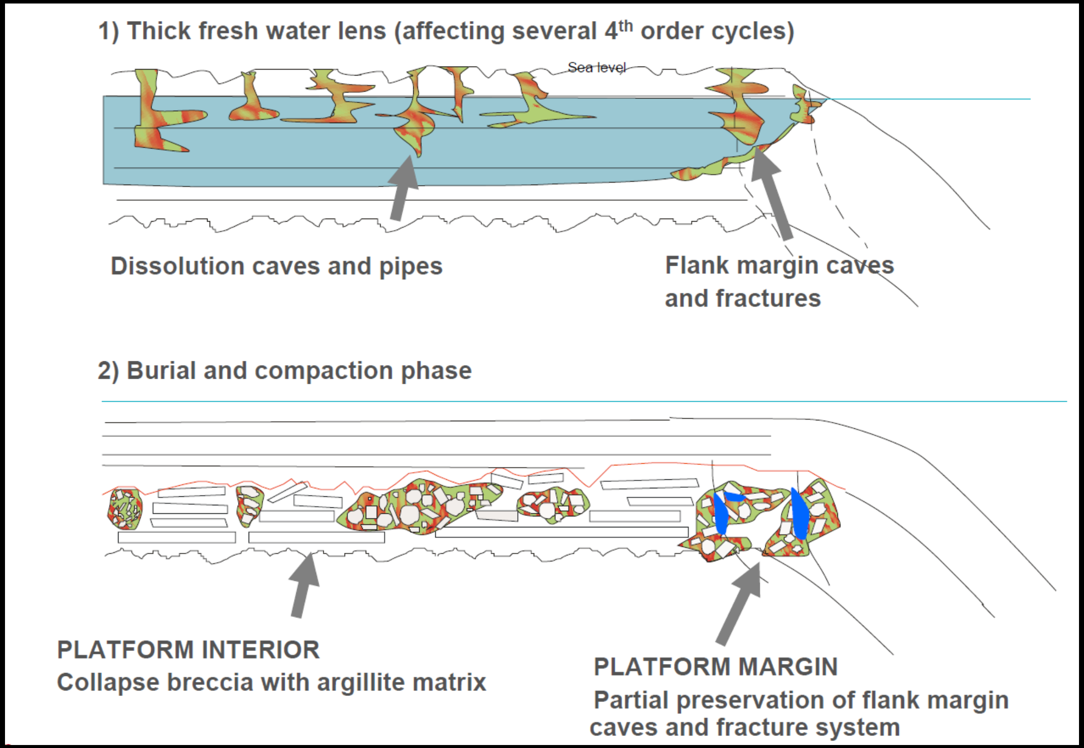
- V structure body at Top Upper Visean



- Seismic "geobodies" correspond to lost circulation zones

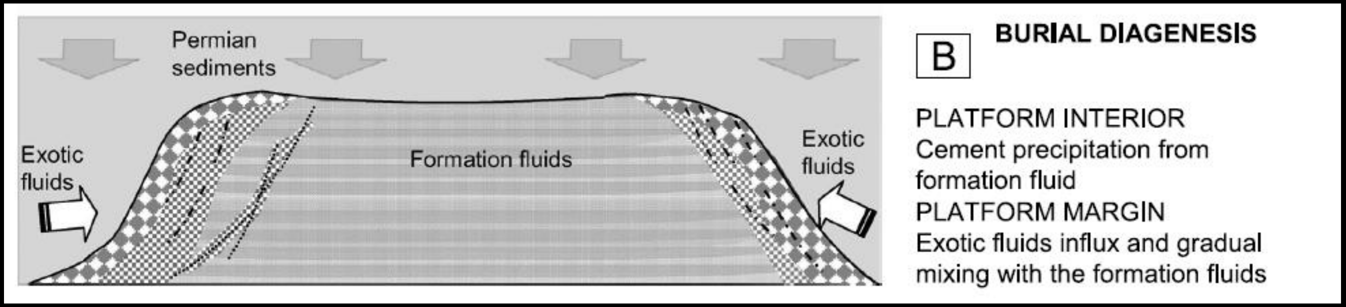
Partly from: Ronchi et al., 2009. AAPG Search and Discovery Article #50231

Kashagan - fractures and partially porous flank margin caves were conduits for extensive later burial corrosion



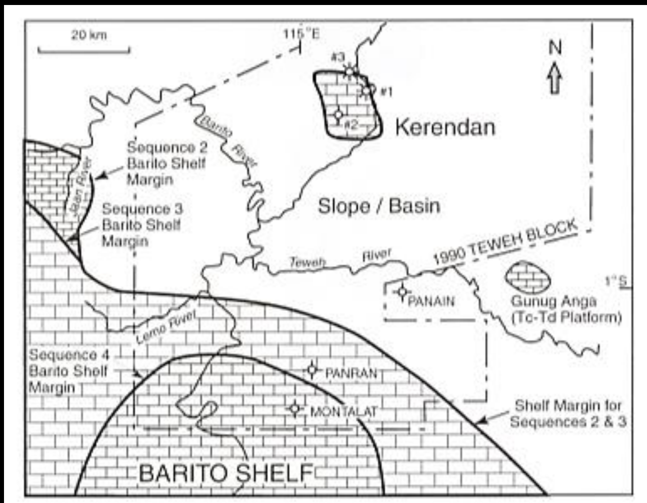
By a squeegee-type flow mechanism or simply by deep regional flow caused by the hydraulic head related to the Cimmerian orogenic belt?

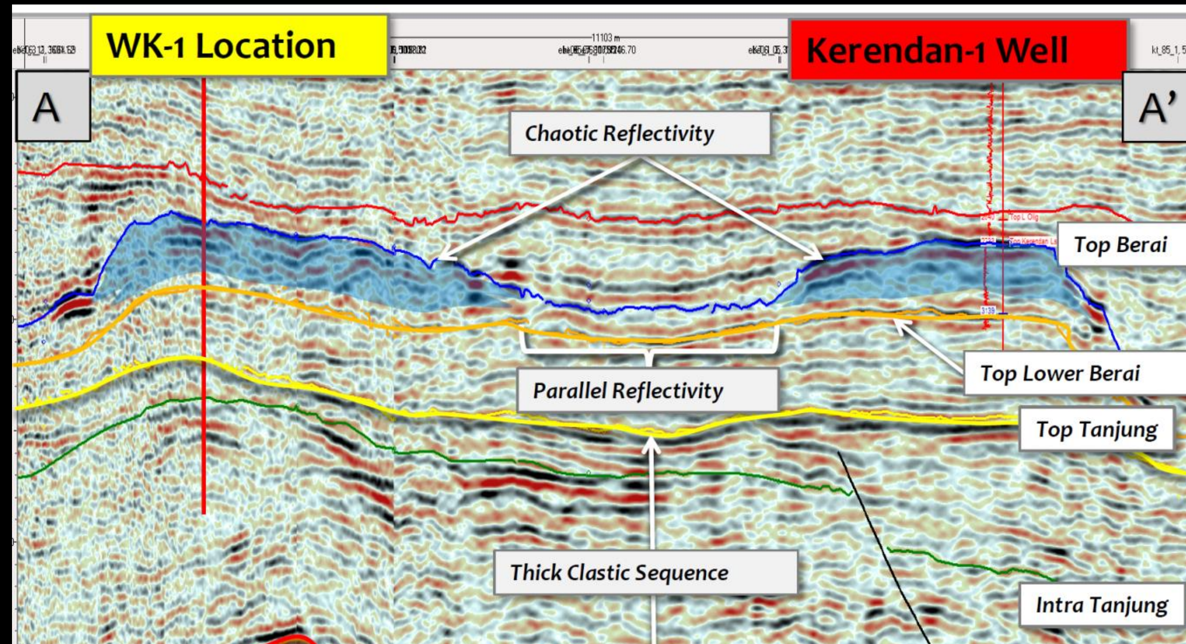
No evidence for TSR was found, unlike the case of Tengiz



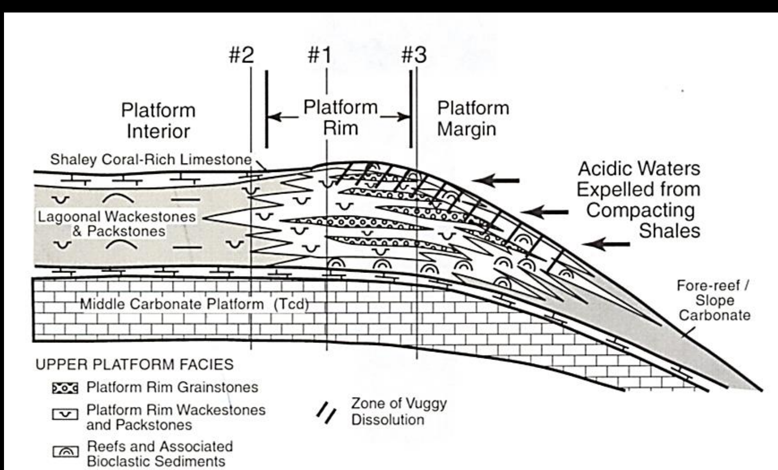
From: Ronchi et al., 2009. AAPG Search and Discovery Article #50231 and From Ronchi P et al. 2010 AAPG Bulletin, v. 94, no. 9 , pp. 1313–1348

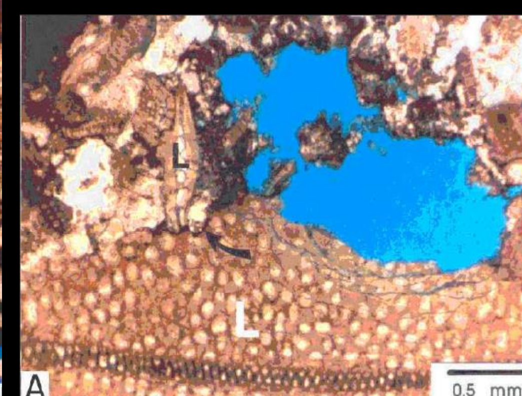
Kerendan platforms of offshore Indonesia
- porosity related to platform margin & caused by burial dissolution





Saller A H & Vijaya S 2002, J Petrol Geol., 25, 123-150





Associations

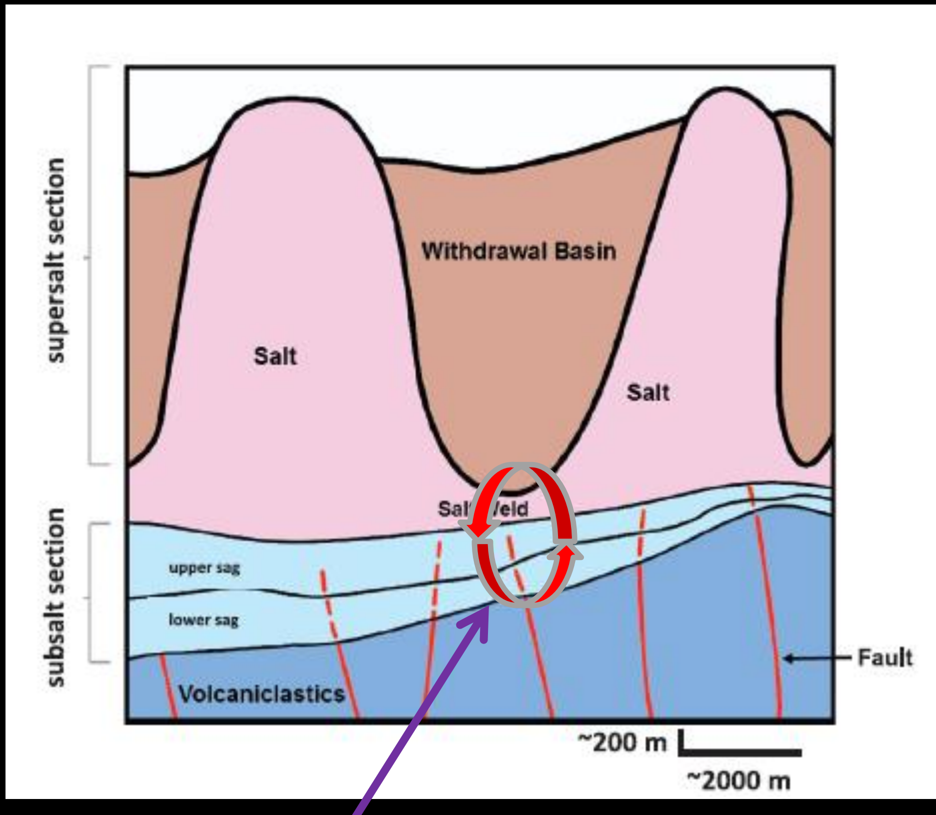
Kitchens – close proximity to the kitchen with H_2S , CO_2 and organic acid activity

Salt – salt causes increased circulation due to thermal conductivity and can theoretically cause dissolution by retrograde solubility or by increasing circulation of fluids with other properties

- Pre-Salt of Brazil?
- Eocene of Gulf of Gabes? - Didon, Zarat and Ashtart fields.

Intrusions – Pearl River Mouth Basin (and Gulf of Gabes?)

Modelling salt-generated convection and retrograde solubility - Pre-Salt, South Atlantic



Variations in temperature from contrasts in thermal conductivity between the evaporite and the underlying carbonates generate fluid density gradients that drive convective flow.

Conceptual South Atlantic half-graben tilted fault block model. Reaction transport modelling results demonstrate that geothermal convection persists in the subsalt carbonate reservoirs during and after evaporite deposition.

Simulations predict the greatest potential for dissolution at rates of 0.1 to 1 vol. %/m.y. occurs where salt welds, overlying permeable carbonates thin to 500 m (1640 ft) or less. With tens of million years residence times feasible, convection under these conditions could locally result in reservoir sweet spots with porosity modification of 1% to 10% and potentially an order of magnitude or more in reservoir permeability.

Jones, G. D. & Xiao, Y. 2013. AAPG Bulletin, v. 97, no. 8 (August 2013), pp. 1249–1271

Salt-related (and magmatic C02?) burial dissolution: Eocene El Garia Formation, offshore Tunisia

S.J. Beavington-Penney et al. / Sedimentary Geology 209 (2008) 42–57 43

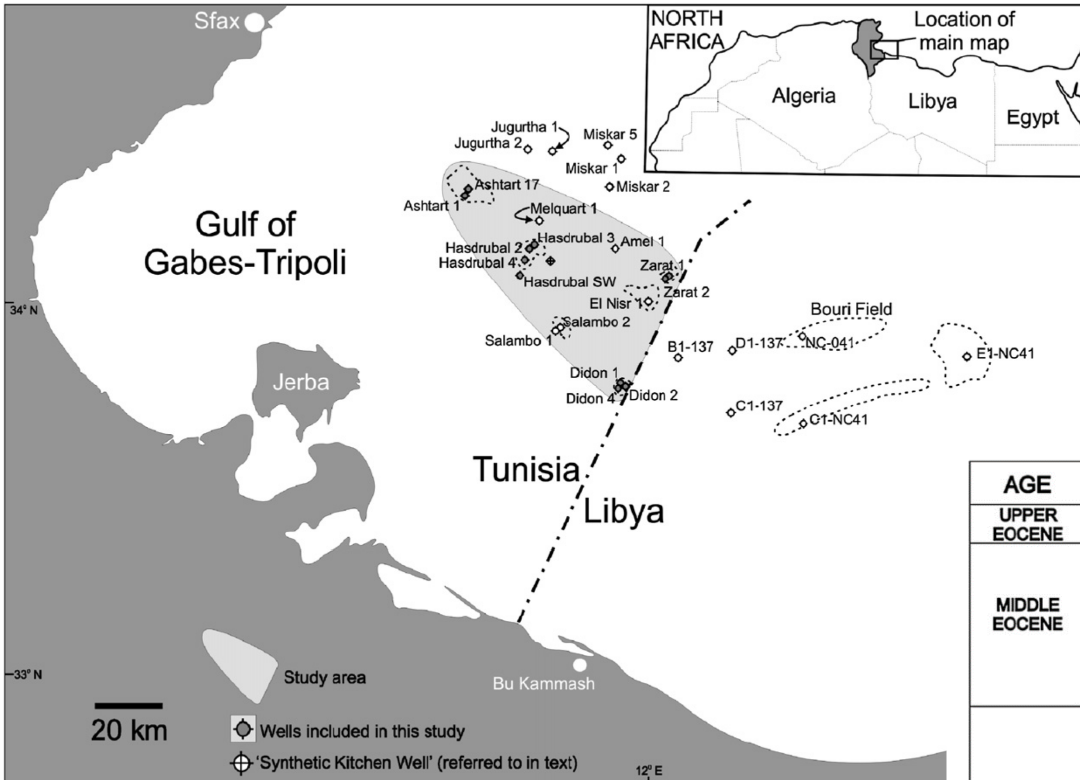
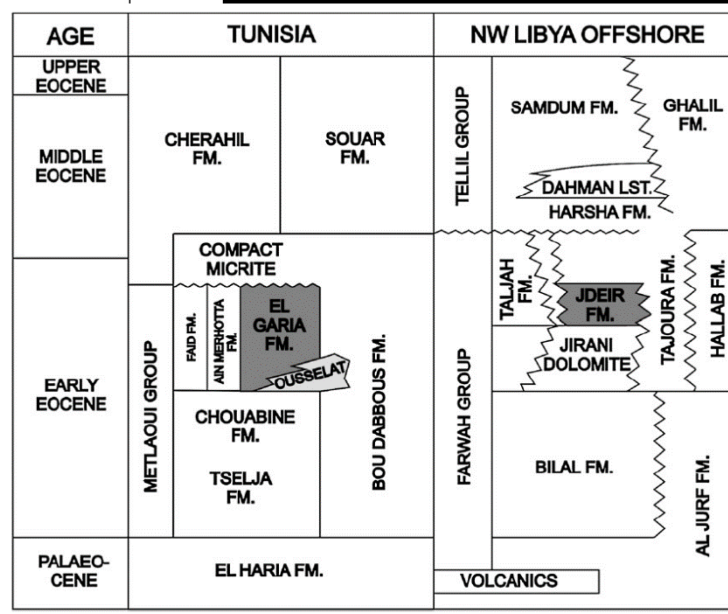


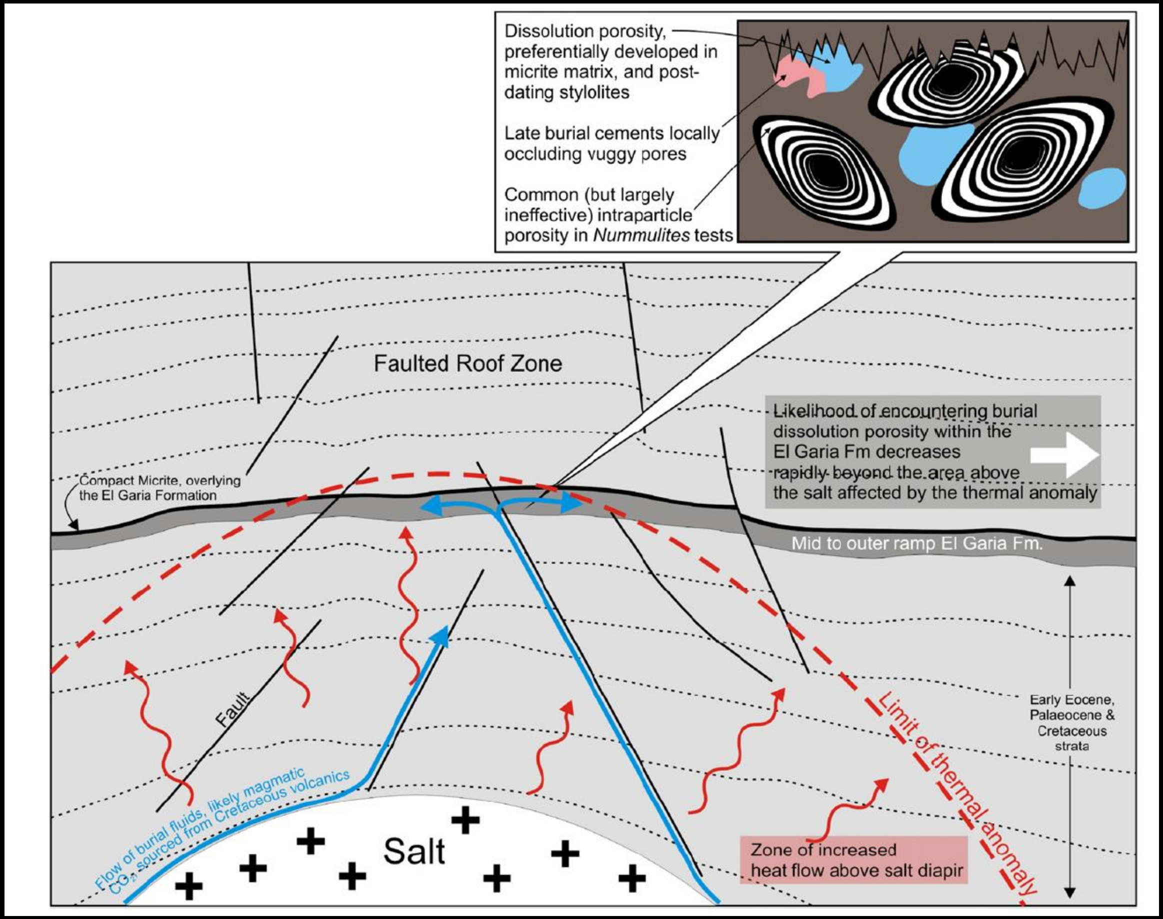
Fig. 1. Map of the Gulf of Gabes–Tripoli, showing the location of wells along the El Garia/Jdeir Formation trend. Modified from and BG G

Didon, Zarat and Ashtart fields.



From: Beavington-Penney, S J et al. (2008) Reservoir quality variation on an Eocene carbonate ramp, El Garia Formation, offshore Tunisia: Structural control of burial corrosion and dolomitisation. Sedimentary Geology 209 42–57

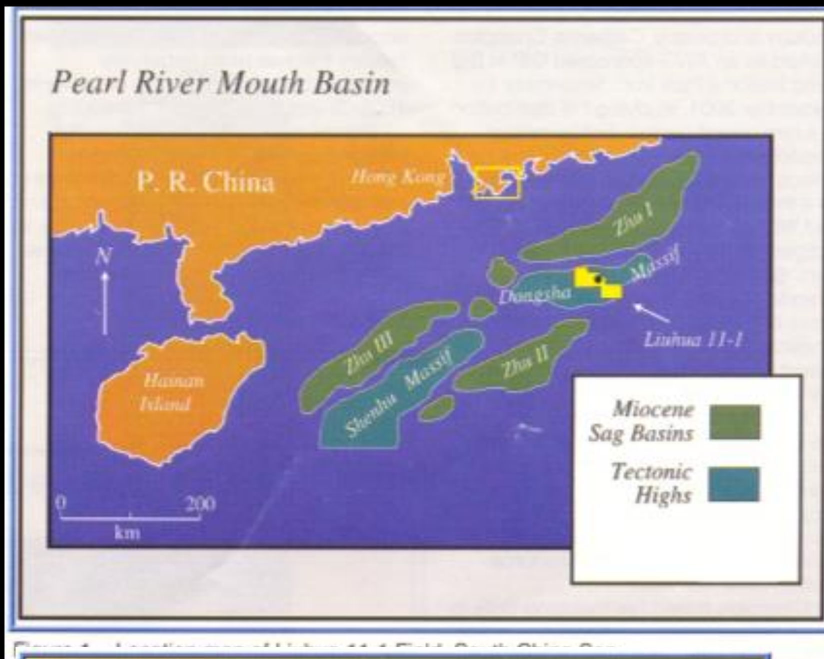
Eocene El Garia Formation, offshore Tunisia

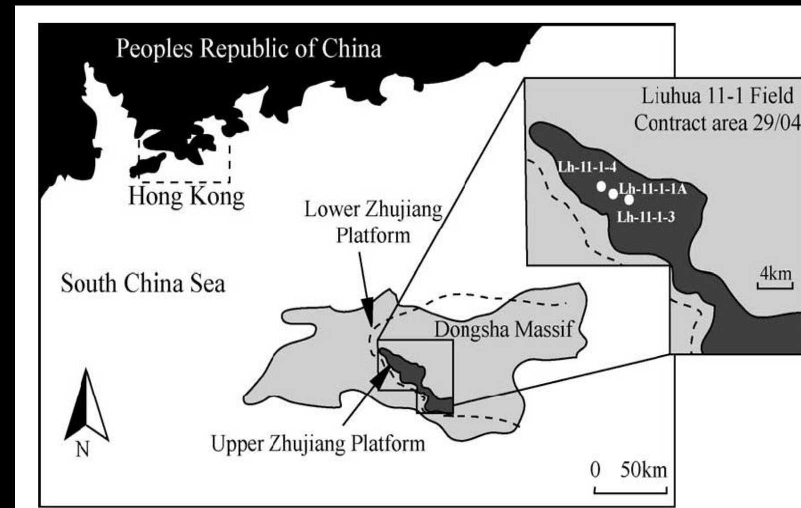


- For the Eocene El Garia Fm reservoirs in the Tunisian Gulf of Gabes–Tripoli area dissolution has been interpreted as due to inorganic CO2, focused into the reservoir by faults related to salt movement, is the most likely candidate responsible for the burial dissolution porosity observed in the Didon, Zarat and Ashtart fields.
- This burial dissolution porosity appears to be developed only in El Garia Formation sediments within the faulted roof zone immediately overlying salt diapirs.

From: Beavington-Penney, S J et al. (2008) Reservoir quality variation on an Eocene carbonate ramp, El Garia Formation, offshore Tunisia: Structural control of burial corrosion and dolomitisation. Sedimentary Geology 209 42–57

Liuhua 11-1 Field, Pearl River Mouth Basin -Oil Field Karst due to CO_2 & H_2S, Miocene reef





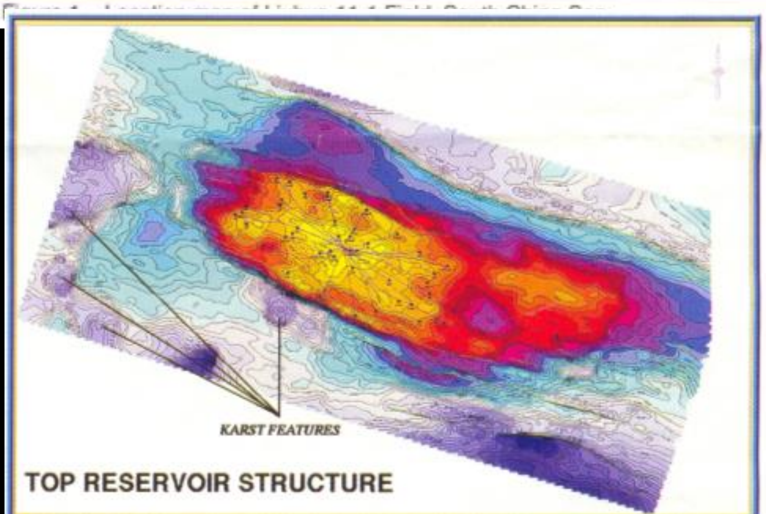
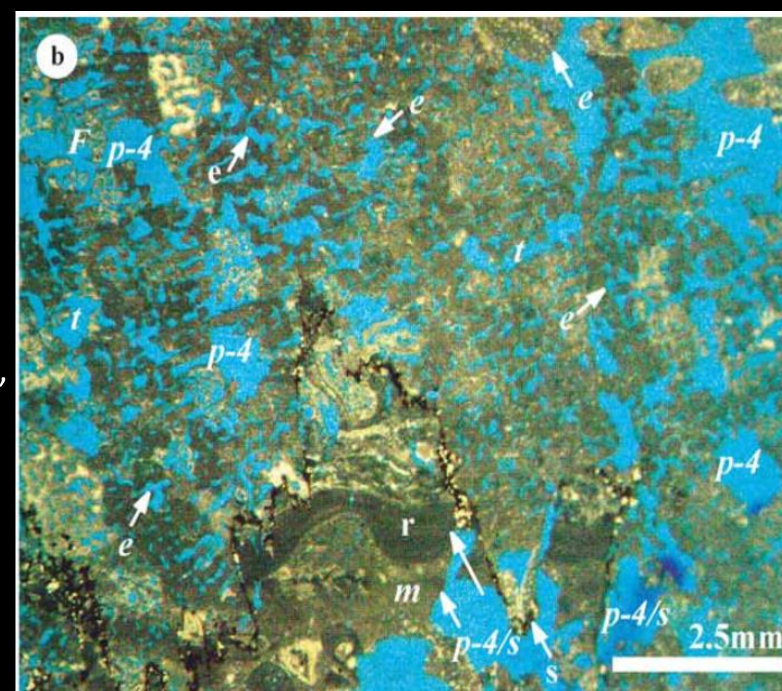
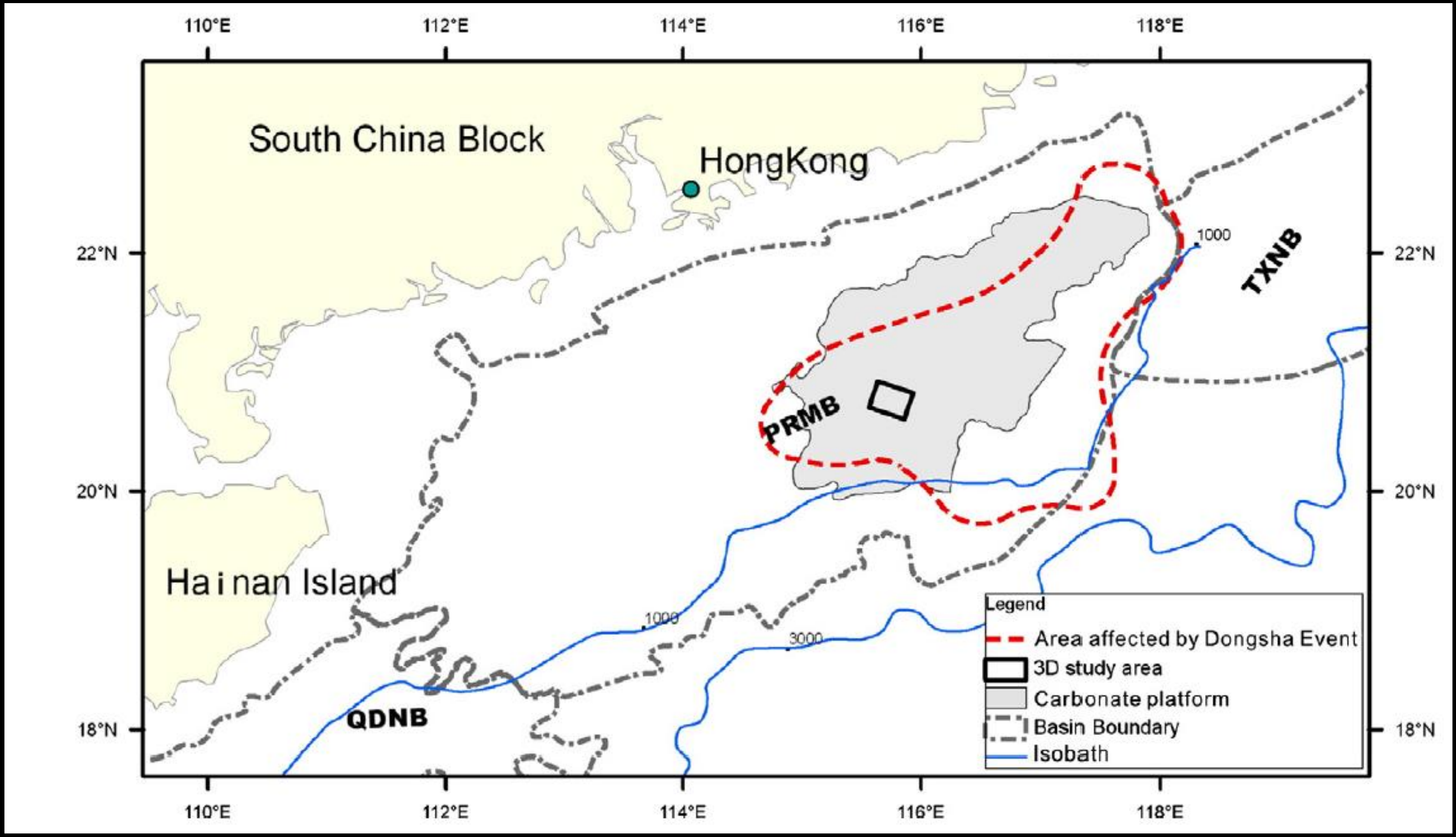


Figure 2 – Depth structure map showing central platform and directional wellbores. The map area is 14 X 7 kilometers. Major karst-collapse features shown.

Sattler, U et al. 2004, Mar & Petrol Geol., 21, 977-992



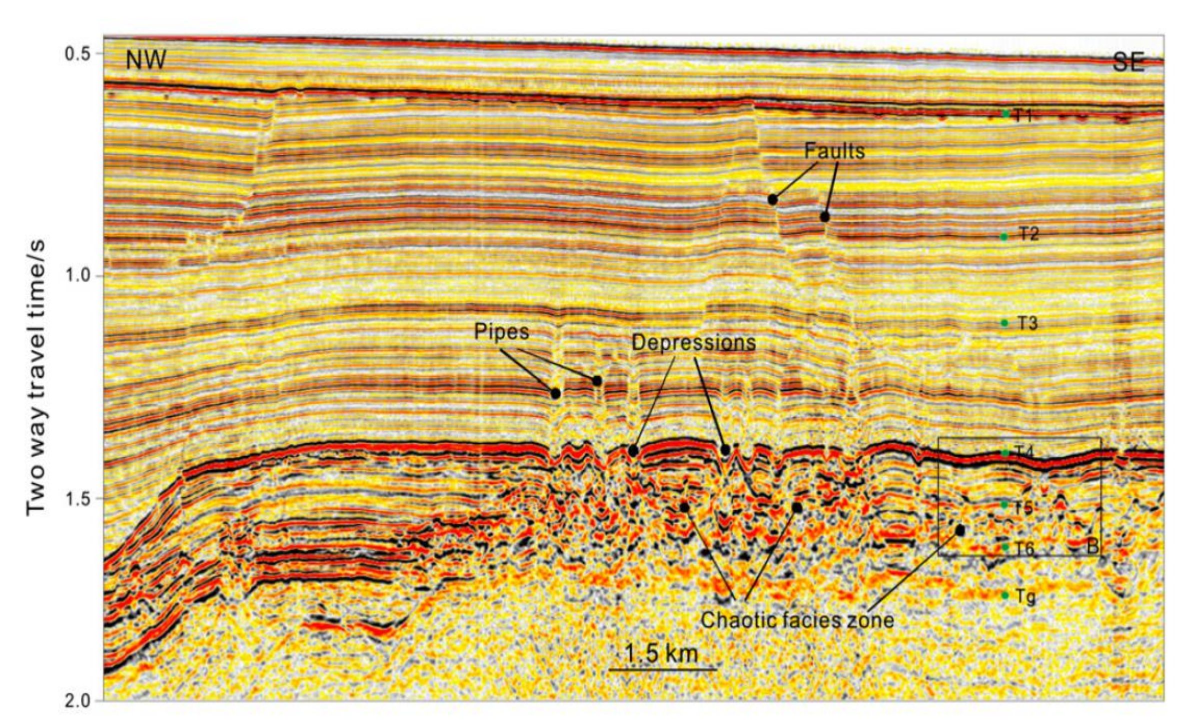
Hydrothermal Karst in Miocene, Pearl River Mouth Basin, South China Sea



Regional setting of the study area. PRMB: Pearl River Mouth Basin, QDNB: Qiongdongnan Basin, TXNB: Taixinan Basin. The area affected by the Dongsha Event and carbonate platform isFrom: Sun, Q. et al., 2013. Marine Geology 337, 171–181

Hypogene Karst in Miocene, South China Sea

Hypogene karst where either dissolution was caused by the hydrothermal fluids or from acid pore waters resulting from hydrocarbon degradation by the intrusion



Dissolution related to major intrusion in Miocene

221 dissolution-collapse pipe structures identified with diameters and heights of from c. 100 m to 710 m and c. 134 m to 1010 m, respectively. These pipes vary from cylindrical to a steep conical geometry, narrowing upwards.

From: Sun, Q. et al., 2013. Marine Geology 337, 171–181

Take away points

Significant secondary porosity formation by dissolution, from the micro-to seismic scale can take place at depths of several kilometres in carbonate reservoirs, what is termed burial corrosion or mesogenetic dissolution

There is a problem over terminology with the use of "burial" or " late" and it is more expedient to take a hydrological approach and see the key processes as due to burial fluids derived from below the reservoir – hypogene fluids

Some hypogene dissolution can occur relatively near surface

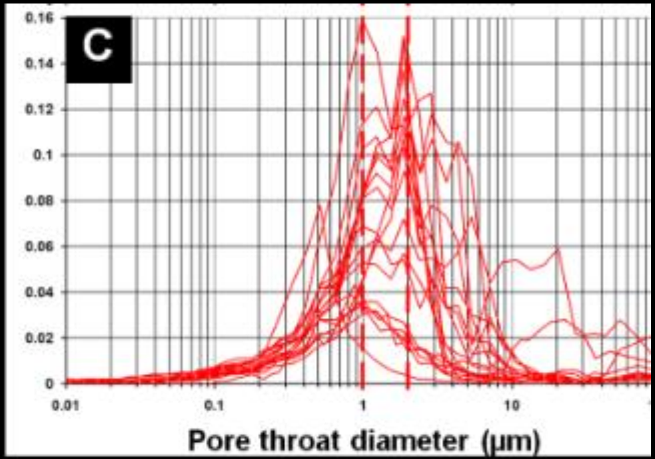
There are many fields proven to have been produced by this effect

There are a range of processes known to be able to cause this dissolution but identifying the process is difficult as they leave little trace

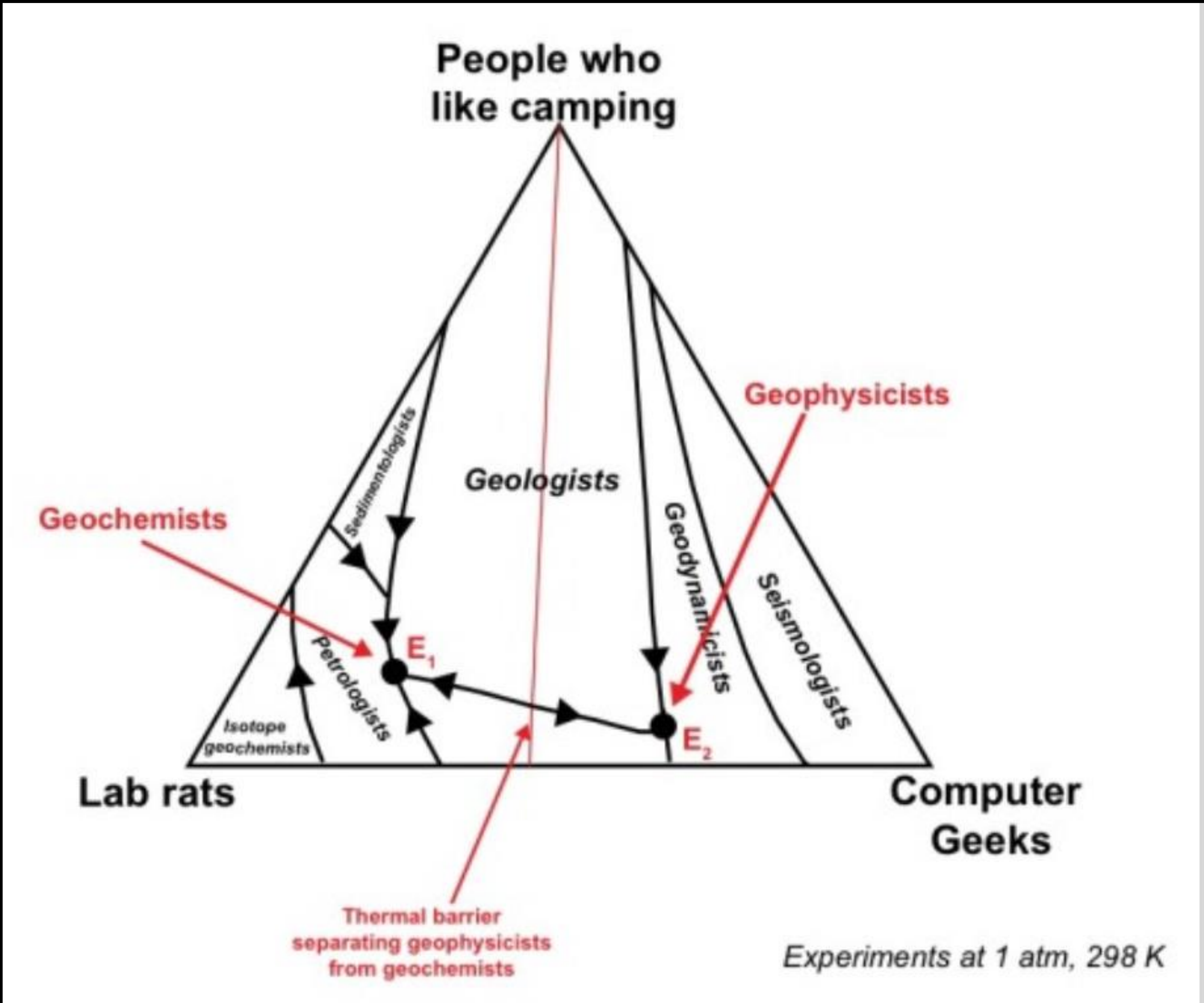
There are consistent relationships seen in hypogene diagenetic systems that may prove useful for exploration

For an alternative view see Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233

Is there a link between burial dissolution and certain types of microporosity?



Eocene Bassein Fm, offfshore India, burial corrosion in shallow ramp facies


People who
like camping
Geophysicists
Geologists
Sedimentologists
Geochemists
Geodynamicists
Seismologists
Petrologists
E1
E2
Isotope
geochemists
Lab rats
Computer
Geeks
Thermal barrier
separating geophysicists
from geochemists
Experiments at 1 atm, 298 K

Kashagan: Late Stage Corrosion

Several hypothesis have been proposed regarding the origin of these exotic, hydrothermal fluids:

1. By a squeegee-type flow mechanism or simply by deep regional flow caused by the hydraulic head related to the Cimmerian orogenic belt located to the south , as suggested by the fact that the late-burial dissolution and cements are more abundant in the southern Kashagan area.

2. Generation of low-salinity water from thermal sulfate reduction (TSR) but no evidence for TSR was found, unlike the case of Tengiz. The high amount of H_2S in the reservoir could have been produced by this process. A possible explanation is that TSR occurred along the migration path and/or in the deeper, uncored parts of the Kashagan slope.

Ronchi P et al. 2010 AAPG Bulletin, v. 94, no. 9 , pp. 1313–1348

Sandstone Diagenesis - a mainly temperature-based classification

Morad et al. 2000

Eogenesis - 30-70C

Mesogenesis - >30-70C and <200C

- Shallow mesogenesis = 2-3km burial, 70-100C
- Deep mesogenesis= >3km, >100C but before onset of low grade metamorphism at >200C