

Carbonate Dissolution and Porosity Development in the Burial (Mesogenetic) Environment*

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Abstract

The early paradigm for porosity formation in carbonate rocks stressed subaerial exposure and attendant shallow meteoric diagenesis. Mazzullo and Harris argued in the early 1990s that porosity formation also occurs in deep-burial, or mesogenetic, settings where brines charged with organic acids, carbon dioxide, and/or hydrogen sulfide derived from organic-matter diagenesis and thermochemical sulfate reduction were likely fluids to cause significant dissolution, and they suggested that the mesogenetic origin of some porosity may go unrecognized as there are similarities between mesogenetic and shallow-meteoric pore types. Subsequently, numerous authors have interpreted deep-burial dissolution in carbonate reservoirs, and some have proposed that significant volumes of porosity were created in this manner.

Ehrenberg and others have recently argued that the burial dissolution model violates important chemical constraints on mass transport in that the ubiquitous presence and rapid kinetics of dissolution of carbonate minerals causes the mesogenetic porewaters to be always saturated and buffered by carbonates, therefore providing little opportunity for the preservation of significantly undersaturated water chemistry during upward flow, even if the initial generation of such pore waters could occur. They also strongly argue that the burial dissolution model is unsupported by empirical data in that their review of the literature where this model has been advanced reveals a consistent lack of quantitative treatment.

The term burial dissolution (corrosion) is in itself confusing as such effects can take place at depths potentially affected by near-surface, meteoric processes, such as when ascending hydrothermal fluids cool to produce corrosion by retrograde solubility. The issue is not burial but is that the fluids causing dissolution are derived from depth and are not linked to near-surface processes associated with either high-order sequence boundaries or to telogenetic (low-order surfaces) effects. A critical consideration is that eogenetic dissolution is commonly controlled by mineral instabilities in the carbonate sediment; however during burial stabilized minerals are dissolved. Critical flow pathways are linked to the structural grain of the limestone (faults, fractures, pressure-solution effects), and are hydrologically unconnected to fluid flow from any subaerial surface.

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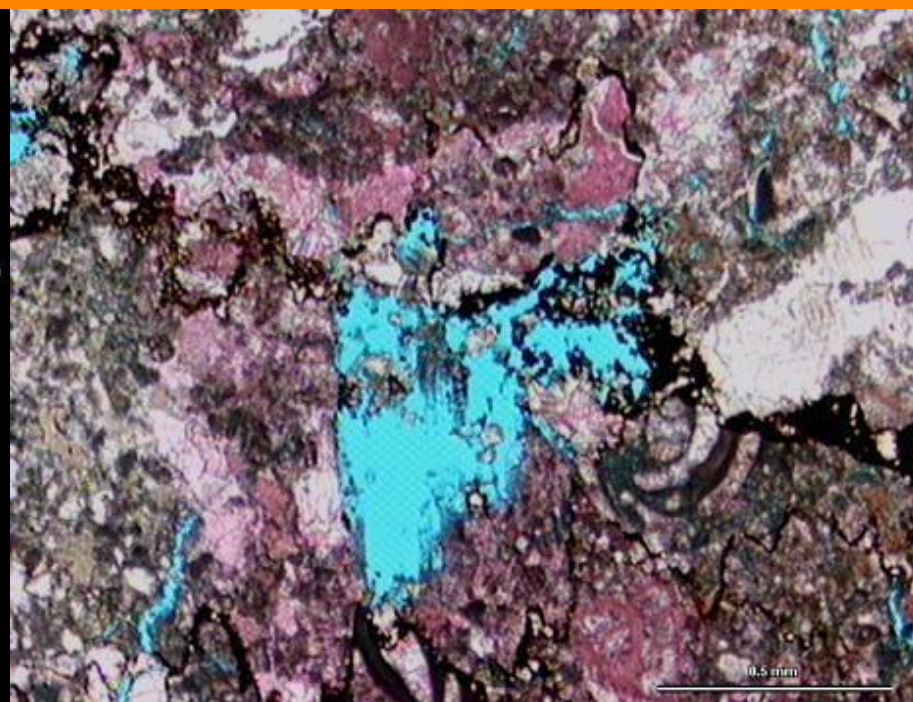
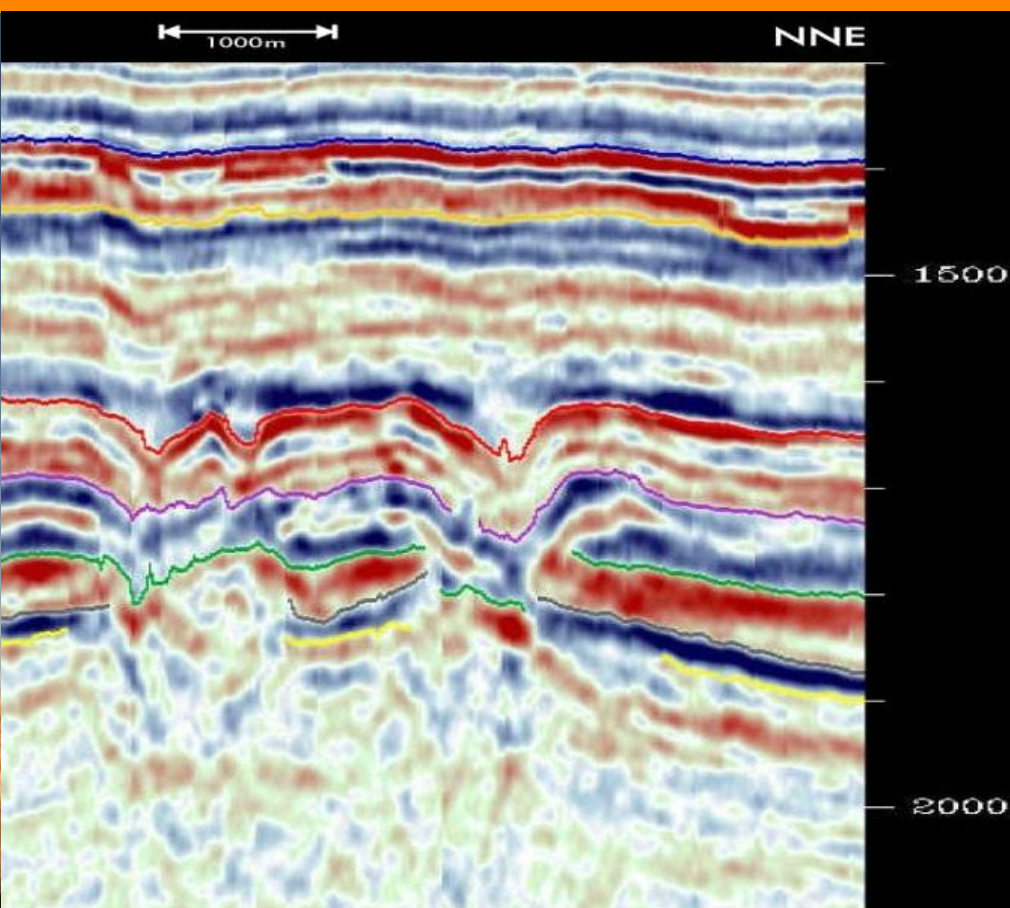
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Carbonate Dissolution and Porosity Development in the Burial (Mesogenetic) Environment

Paul Wright & Paul (Mitch) Harris



The aim of this talk is to evaluate some of the criticisms of the mesogenetic dissolution concept made recently and to make some suggestions about how we might progress

We leave it to the following speakers to provide the evidence that mesogenetic dissolution is indeed a real process

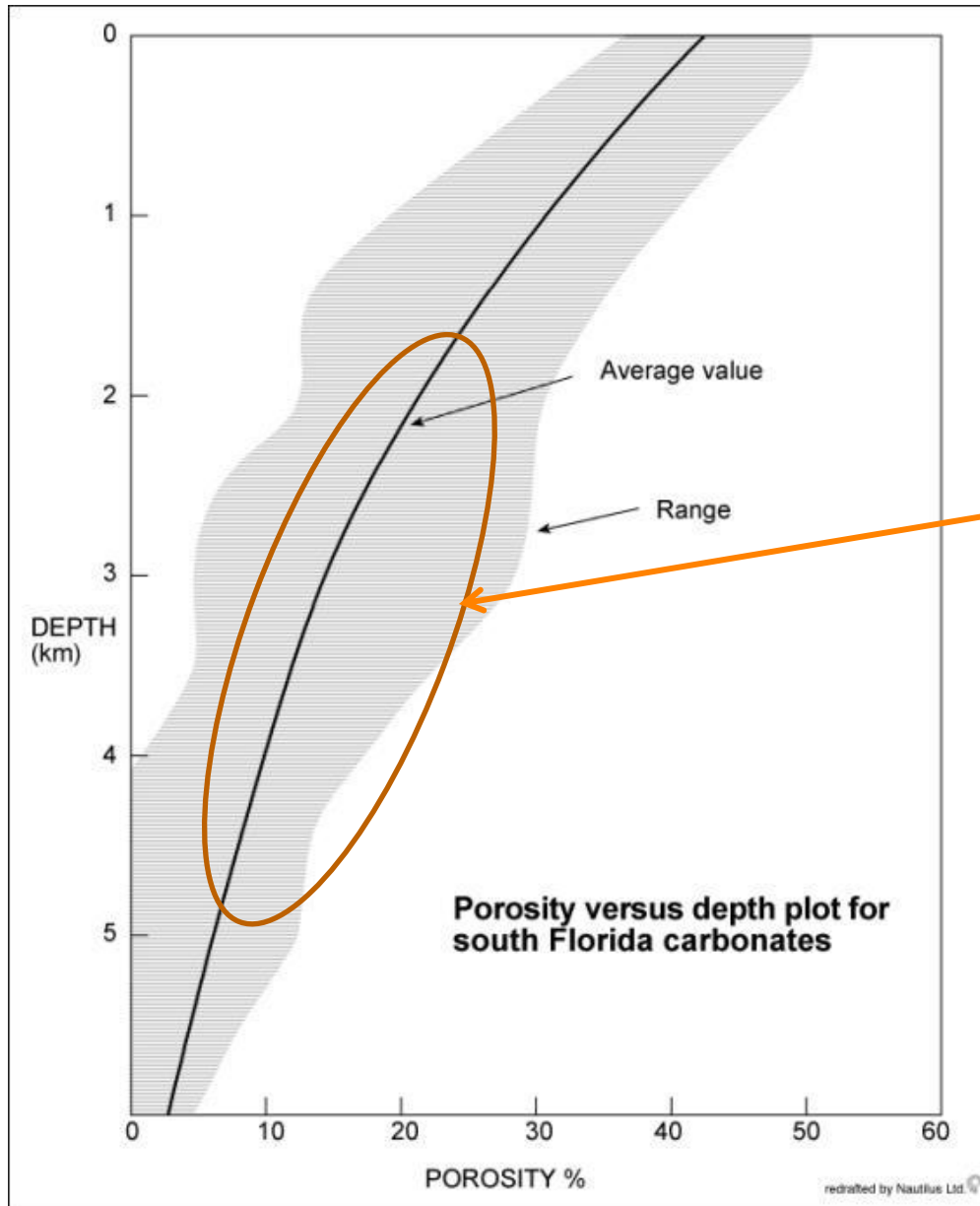
Take away points –

In carbonates, the definition of mesogenetic diagenesis needs considerable refinement.

We normally rely on petrographic “timing” as a main criterion for identifying dissolution at depth (mesogenetic dissolution). Are we really identifying the effects of dissolution at “depth” -or- those produced by burial derived (hypogene) fluids which can cause dissolution at any depth?

We generally recognize highly localized dissolution, commonly non-fabric selective and in part controlled by deformation features which have allowed fluids access to matrices, even affecting microporosity.

We propose taking a hydrological approach, borrowing from the karst literature, and trying to identify the source and pathways of that fluid as this may provide a predictive element. Fixating on the depth or timing is less likely to provide a predictive understanding than understanding the fluid and its pathways.



The paradigm was - just porosity loss with depth

What is being questioned by some is the growing evidence that extensive porosity formation occurs at depth, without any uplift into near-surface settings

Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96,
217-233

“Like the Emperor’s new clothes, the model of mesogenetic carbonate porosity creation is supported by personal opinion and reference to the many who have believed it before.”

Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233

“Like the Emperor’s new clothes, the model of mesogenetic carbonate porosity creation is supported by personal opinion and reference to the many who have believed it before.”

The first issue to tackle is how the term “mesogenetic”



Is mesogenetic dissolution -



Late

Deep

Associated with elevated pressures

Hydrothermal (or geothermal...5C issue)?

Does it have to be any of these?

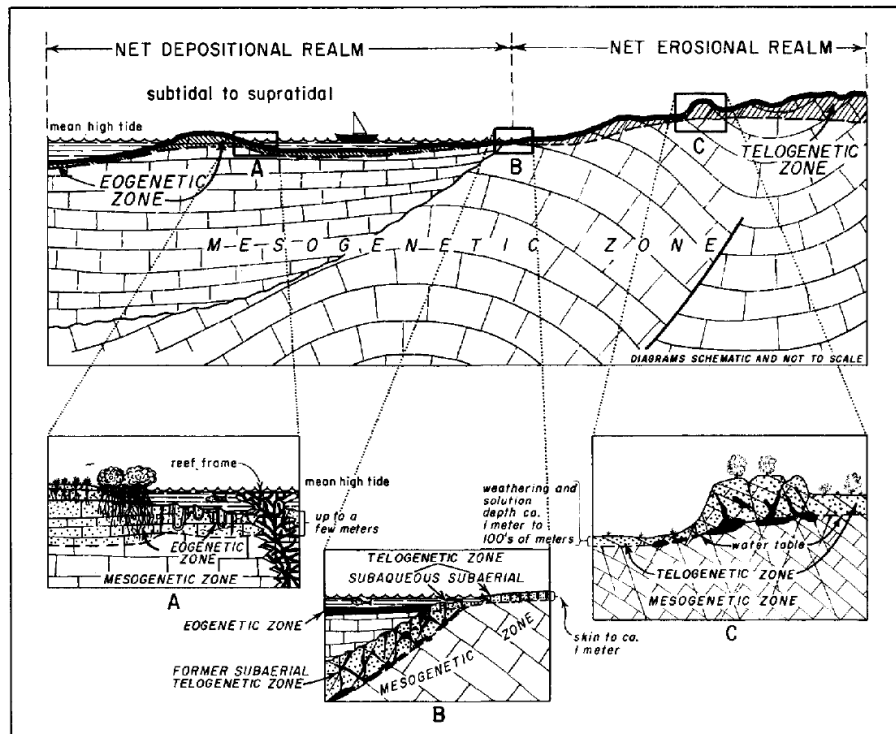
We usually can't characterise the fluids as it leaves no trace, only try to bracket it by determining origin of pre- & post-dissolution phases.

Have the fluids come from below - hypogene - likely to be following faults and related structural features?

Does that provide a framework for prediction? But we still have to identify the effects of such fluids?

Burial, “late” - mesogenetic diagenesis

Are we using clearly defined terms?



Meaning? Unconfined aquifer?

Choquette & Pray's definition, as used by Ehrenberg et al 2012 –

“We refer to the time of early burial as *eogenetic*, the time of deeper burial as *mesogenetic*,”

Caption to Fig . 1

“*Eogenetic zone* extends from surface of newly deposited carbonate to depths where processes genetically related to surface become ineffective. *Telogenetic zone* extends from erosion surface to depths at which major surface-related erosional processes become ineffective. Below a subaerial erosion surface, practical lower limit of telogenesis is at or near water table.

Mesogenetic zone lies below major influences of processes operating at surface.

The three terms also apply to time, processes, or features developed in respective zones.”

Sandstone Diagenesis - a mainly temperature-based classification

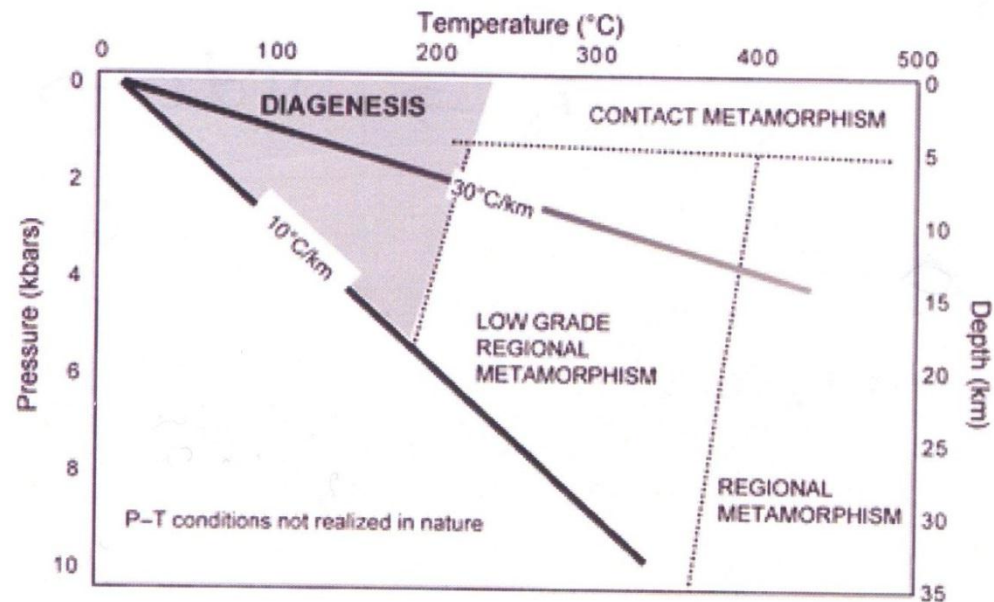
Morad et al. 2000

Eogenesis - 30-70C

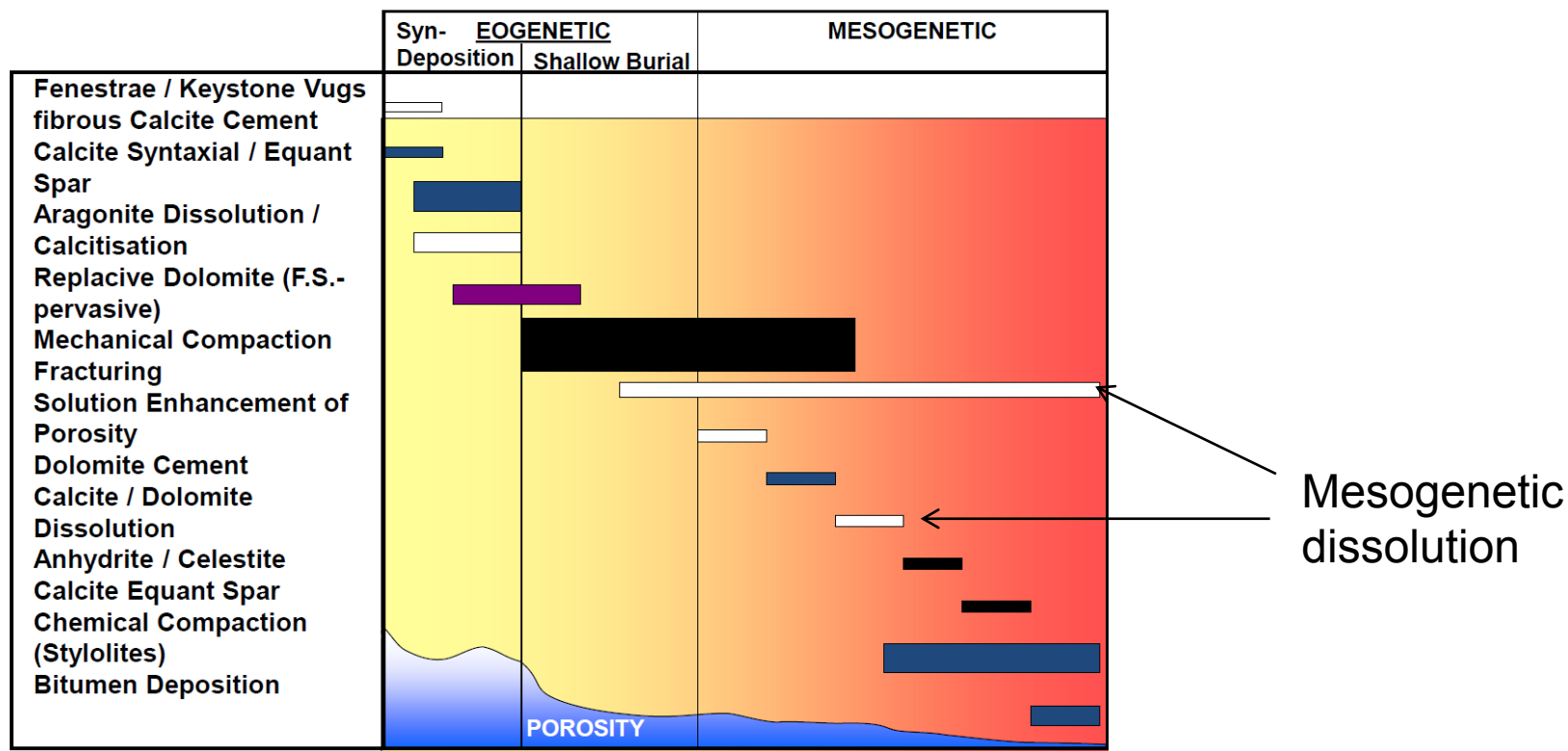
Mesogenesis - >30-70C and <200C

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

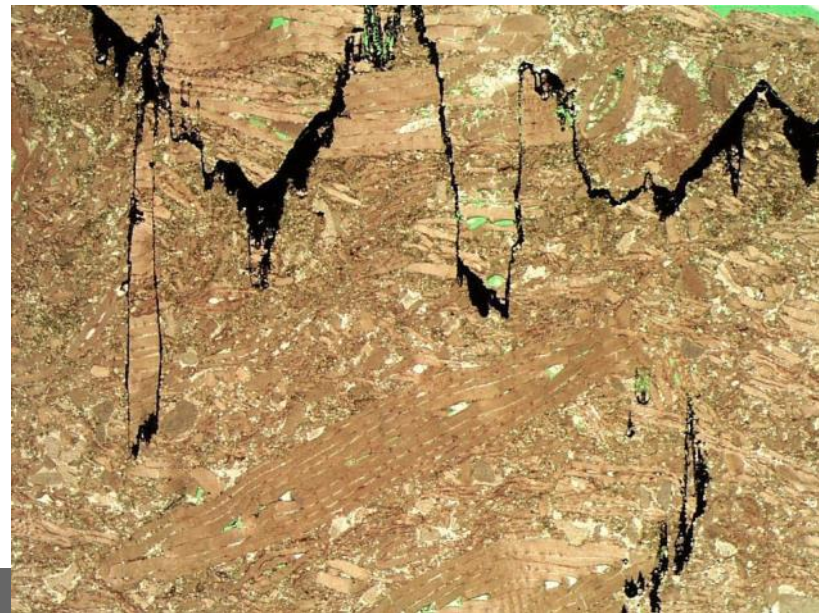
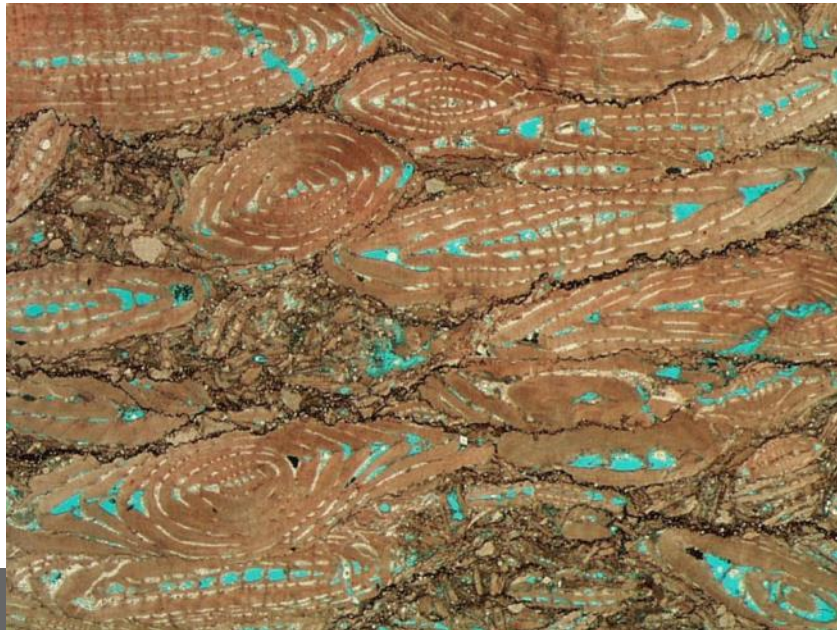
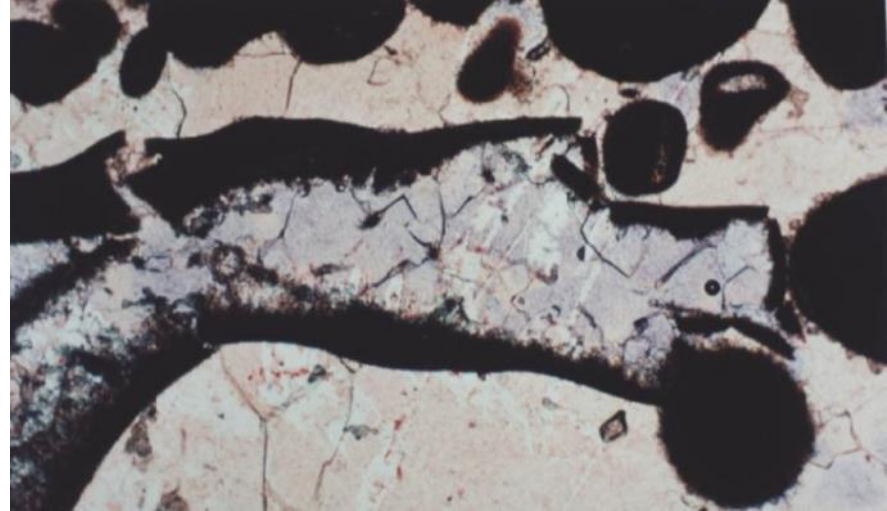
What about hypothermal basins?



We tend to identify mesogenetic processes from petrography



Mesogenetic (burial diagenesis) is defined as that which is after compaction or onset of pressure solution— valid?



So when does pressure solution start?

- Dunnington 1967 - 600m minimum depth
- Buxton & Sibley 1981 - 1500m in Devonian of Michigan Basin
- Neugebauer 1974 - in chalk begins around 200m but significant when buried >1000m
- Saller 1984 - Enewetak - ...not <800m
- Meyers & Hill 1983 & Bathurst 1975 - effects can be much shallower
- Budd 2002 Avon Park Fm - pressure solution important after 335m?
- Mallon & Swarbrick 2008 – pressure solution begins around 50-200m depth and stylolites around 800m
- Fabricius & Borre 2007 - in North Sea chalks stylolites appear around 830m depth

Pre-Salt ...4kmsno stylolites and patchy pressure solution?
What about overpressured systems?

Does burial dissolution refer to hydrothermal dissolution?

If we base a definition on the normal use of hydrothermal - from Smith L B Jnr & Davies G R 2006 AAPG Bulletin, 90, 1635 –1640.

Discrimination of hydrothermal diagenesis from what is commonly designated as deep burial diagenesis is important. Hydrothermal diagenesis may and commonly does occur at relatively shallow burial depths of less than 1000 m (3200 ft) and in many cases less than 500 m (1600 ft), but at pressures and temperatures typically associated with much greater depths.

Hydrothermal, where the diagenetic fluids are at a higher temperature (and pressure) than the ambient conditions

Geothermal, which is diagenesis that occurs at the ambient pressure and temperature by very slowly migrating fluids (sensu Machel and Lonnee, 2002).

Hydrothermal - Hydrothermal dolomites are those produced by fluids introduced via fault or other conduits at a temperature that exceeds the ambient temperature of that formation by at least 5C.



FLOW



Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233

*“the concept of introducing highly undersaturated waters into reservoir strata is fundamentally unrealistic. Even if calcite-undersaturated pore water did flow through a limestone bed, dissolution would be localized at the points of influx because of high reaction rates (described below). It is, therefore, **implausible to envisage net dissolution distributed throughout the interior of the limestone bed.**”*

The most striking feature of most descriptions of “burial dissolution” is that it is strongly controlled by “localized points of influx” such as faults, fractures, stylolite conduits and related fractures – it is rarely fabric selective.

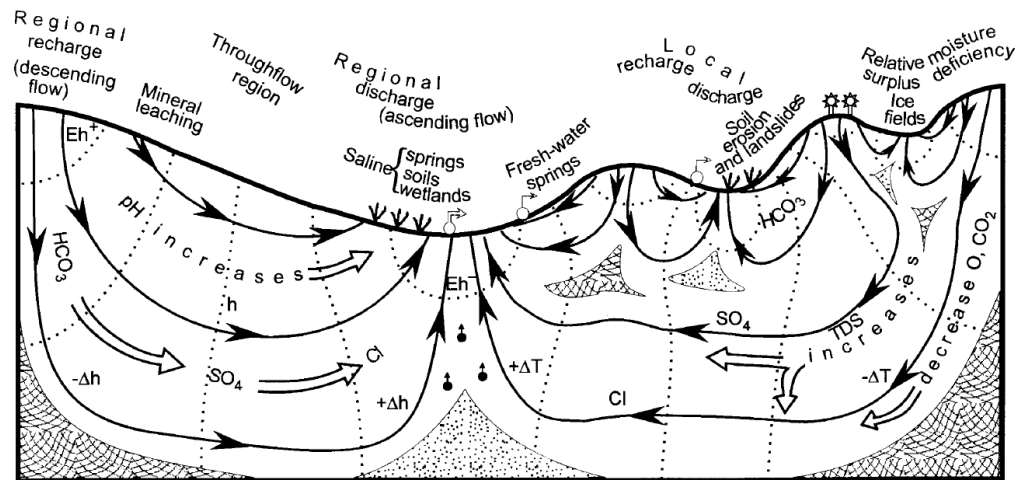
Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233....and only discuss compactional flow

*“The theory that dissolution by acid pore water has produced significant net increases in bulk porosity **has not been supported by quantitative data or models of mineral solubility and fluid flow.**”*

“As no rational mechanism can explain the formation of mesogenetic secondary porosity, the occurrence of such porosity cannot be predicted or modelled.”

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

“...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

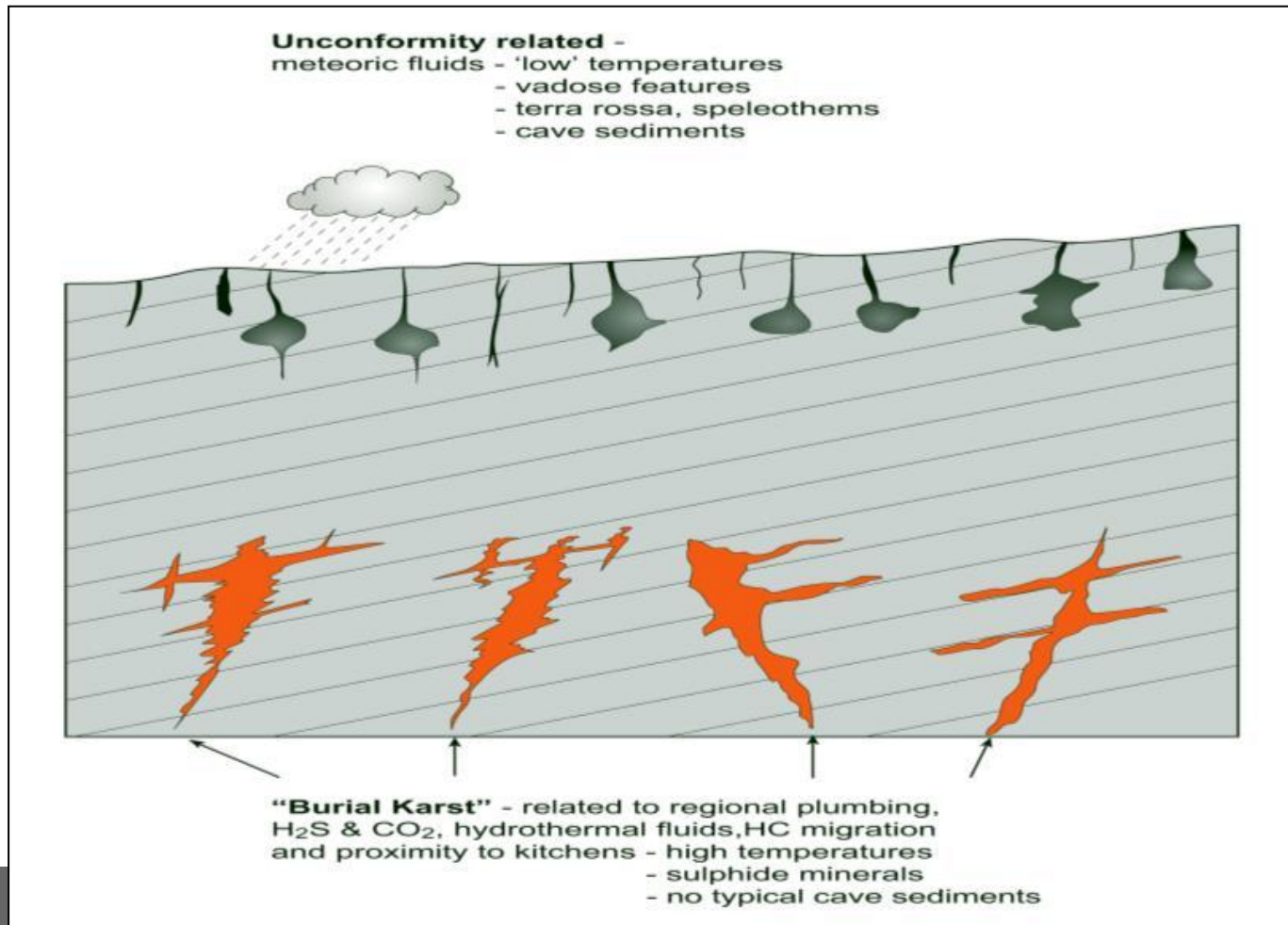


EXPLANATION

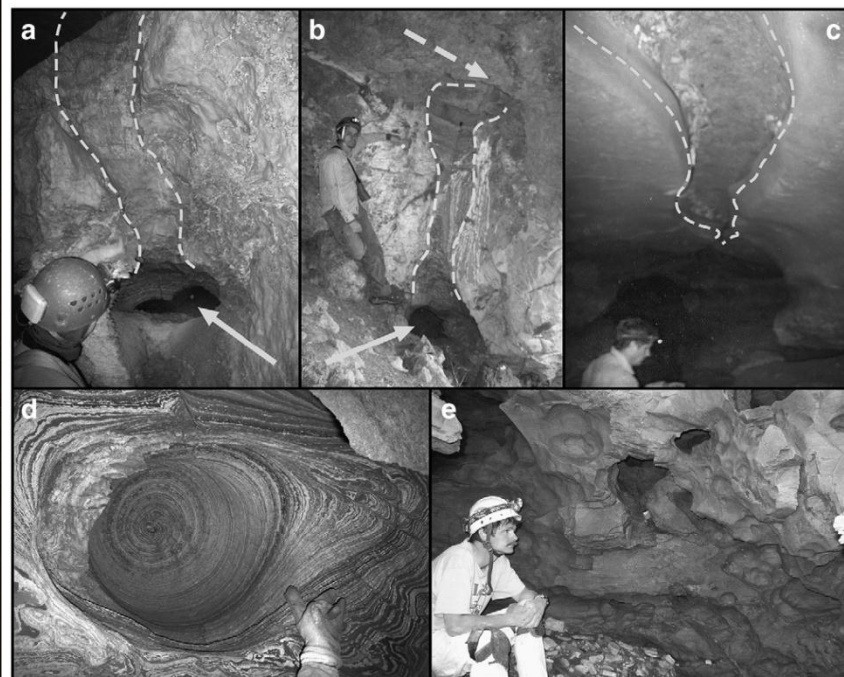
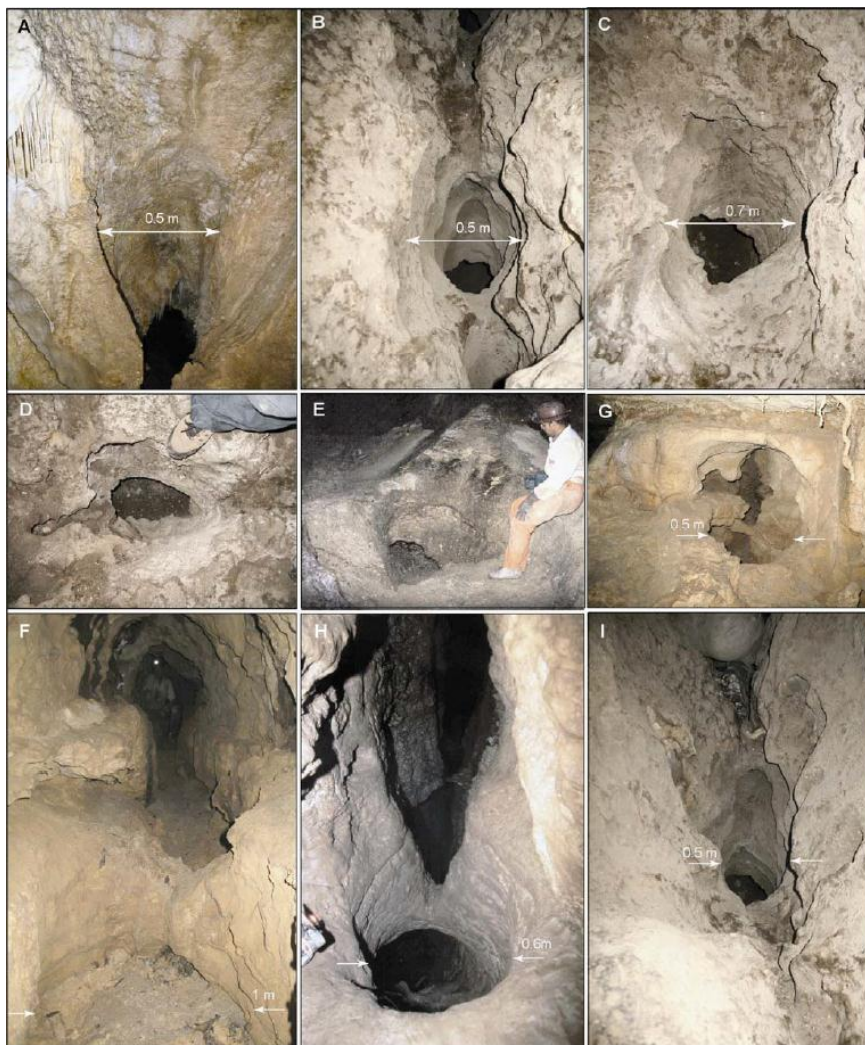
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|--------|-----------------------------------------------------------------------|------------------------|-----------------------------------------------------------------------------|
| | Line of equal hydraulic head | | Flow line |
| | Spring: cold, warm | | Phreatophytes |
| | Xerophytes | | Redox conditions: |
| Eh^+ | oxidizing | Eh^- | reducing |
| | Mineral (metallic, evaporite, hydrocarbon) traces above accumulations | | Hydraulic trap: convergence and accumulation of transported matter and heat |
| | Quasi-stagnant zone: increased TDS | | Geothermal temperature and gradient anomaly: positive, negative |
| | | $+\Delta T, -\Delta T$ | |

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

These authors ignore the literature on hypogene karst (dissolution by ascending fluids – Klimchouk and others)



Hypogene macroporosity - from many different regions



Palmer A N 2011
Geomorphology 134, 9–22

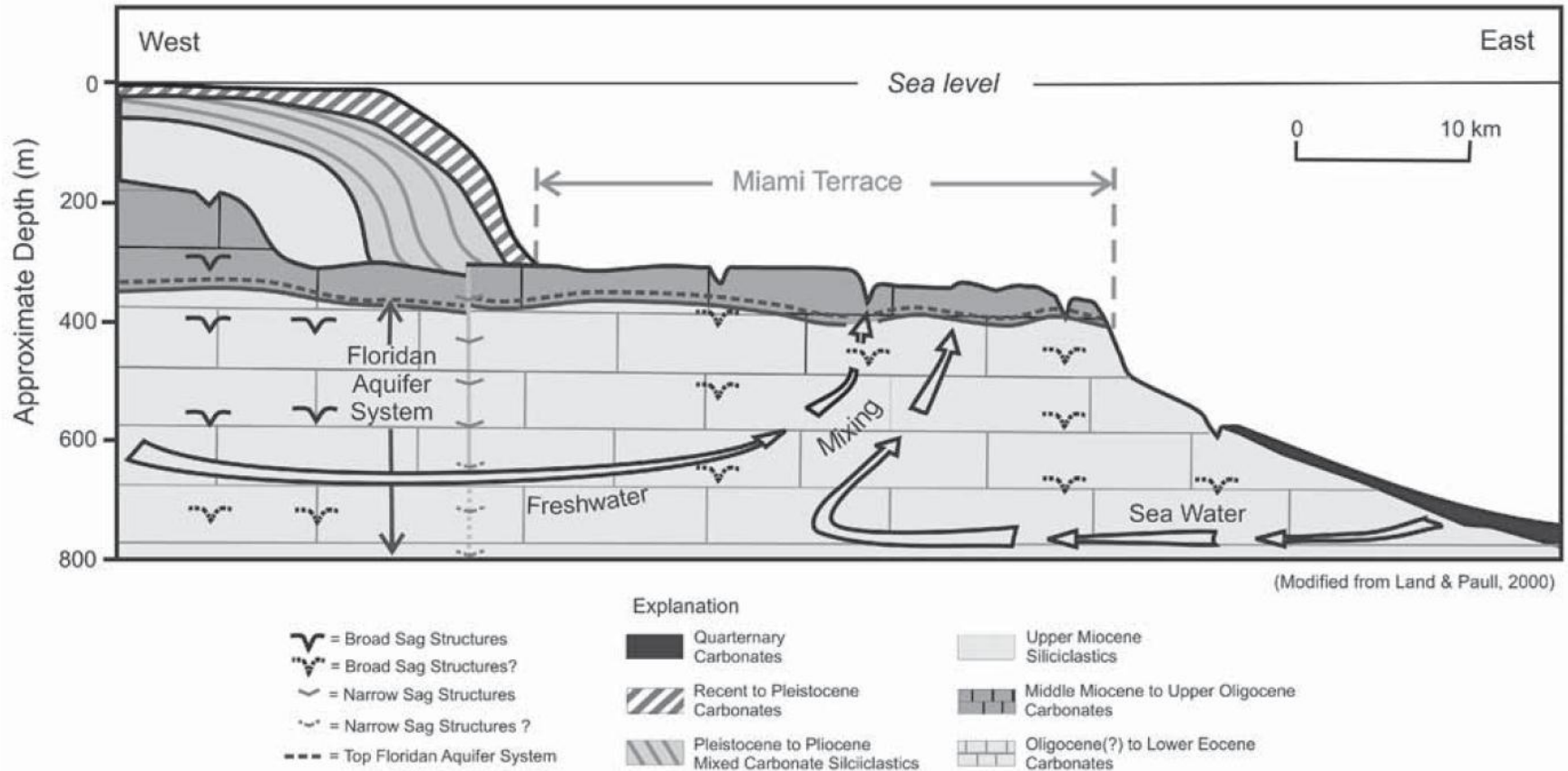
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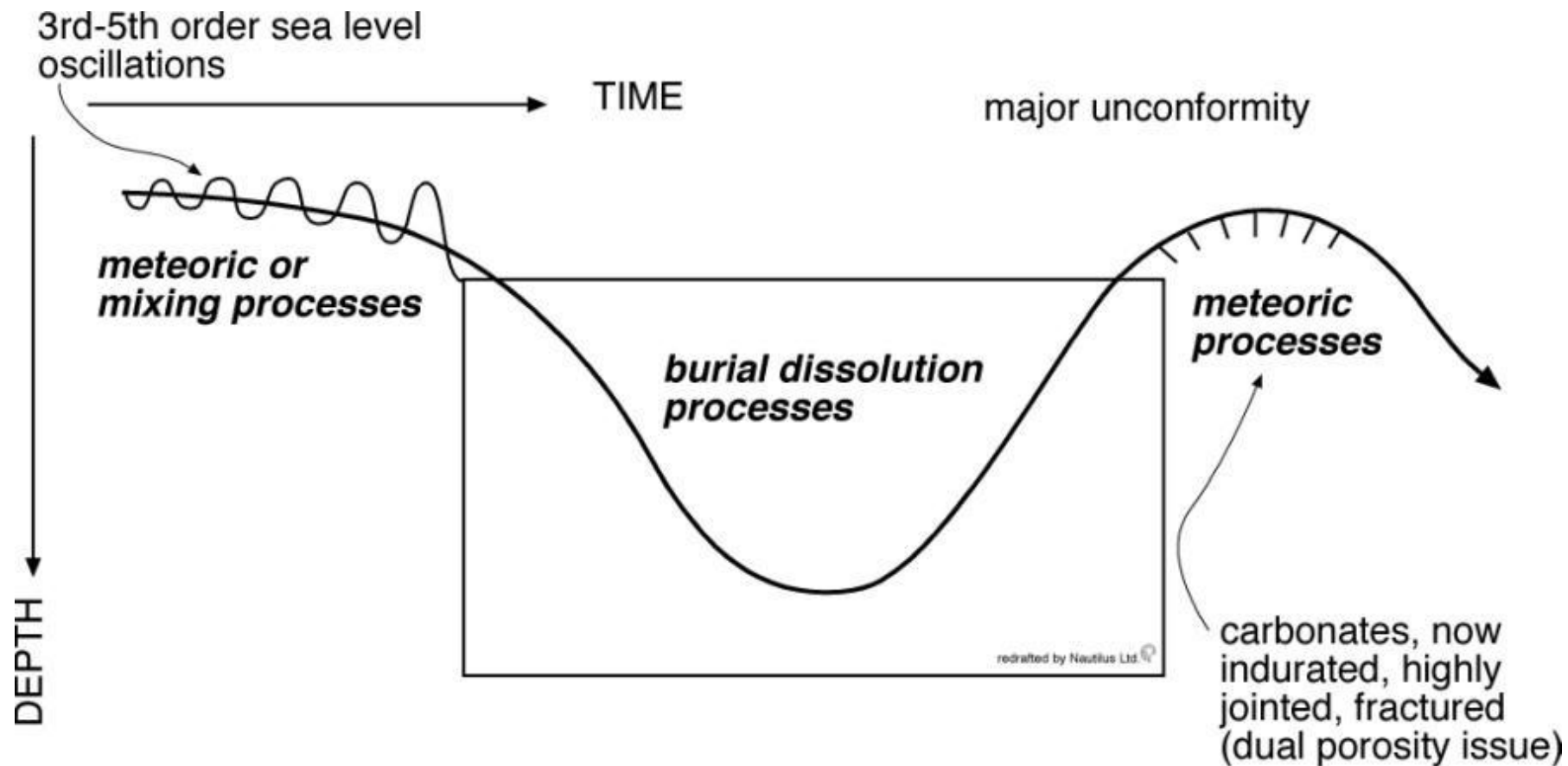
And Kohout convection?



East Florida margin - Hypogenic dissolution along margin of Florida Straits linked to Kohout convection or H₂S 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*





We propose that –



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

This would exclude meteoric waters driven by gravity, mixing zone processes driven by meteoric groundwater discharge in coastal areas, but include dissolution caused by thermal convection such as Kohout convection. This dissolution need not take place at depth if that the fluid were derived from a greater depth; porosity formation could take place in carbonates uplifted and unconfined; this could still be hypogenic in origin, but not necessarily mesogenetic.

The fluids may be hypogene and buria derived, as an event “late” in the history of the carbonate, but the dissolution can be much shallower.

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

Evidence

Ehrenberg, Walderhaug & Bjorlykke 2012 AAPG Bull 96, 217-233

“In any case, however, authors should actively consider and discuss the possibility that much or all of the pore space in any deeply buried carbonate reservoir was inherited from earlier times instead of created at depth.”

“Consideration should also be given to the possibility that observed pores, especially along sites of mechanical weakness like fractures or clay-lined stylolites, are in part artifacts of coring or thin-section preparation.”

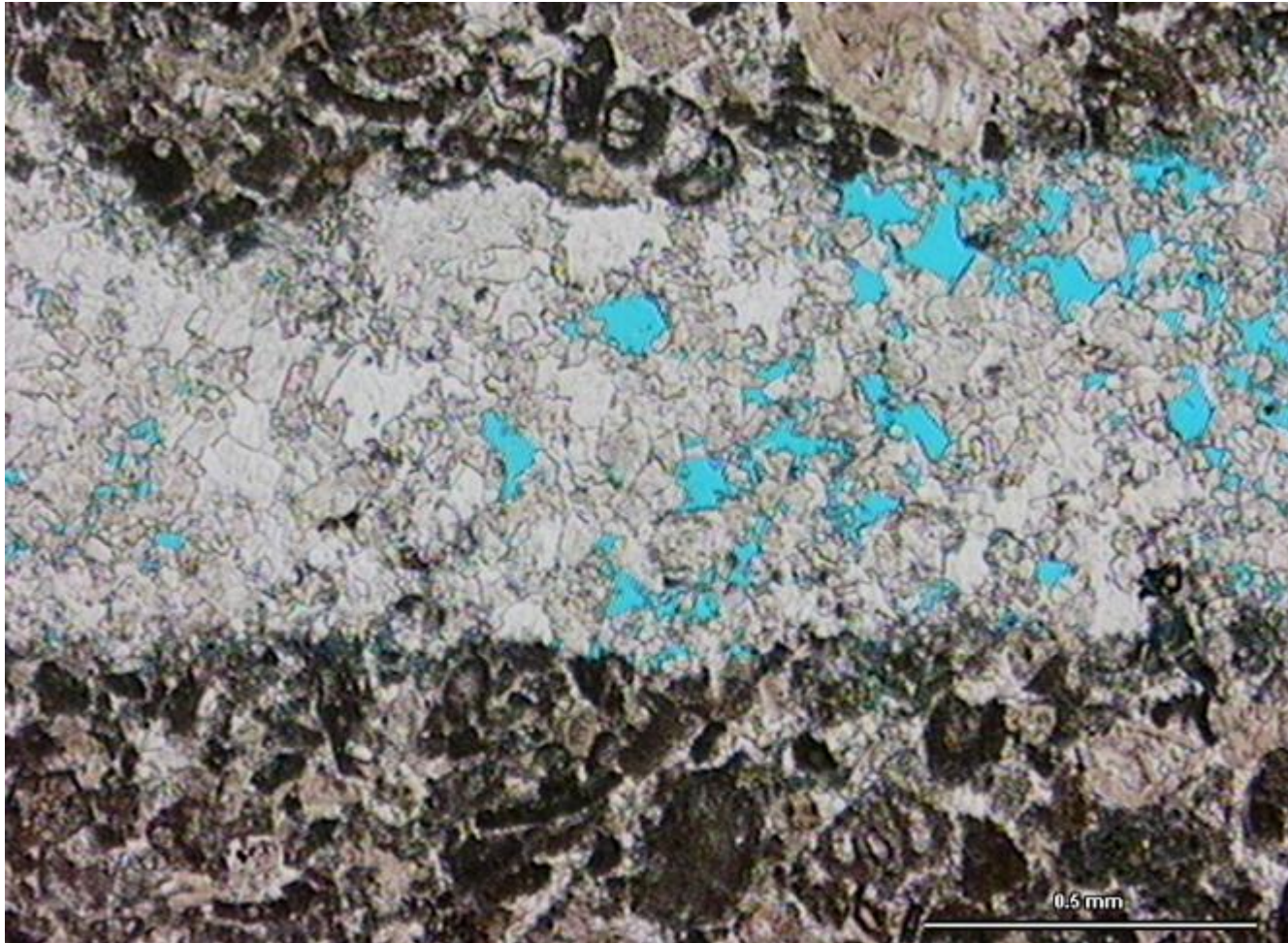
But we have robust criteria - which were outlined by Mazzullo & Harris 1992

Criteria for recognition of burial corrosion

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

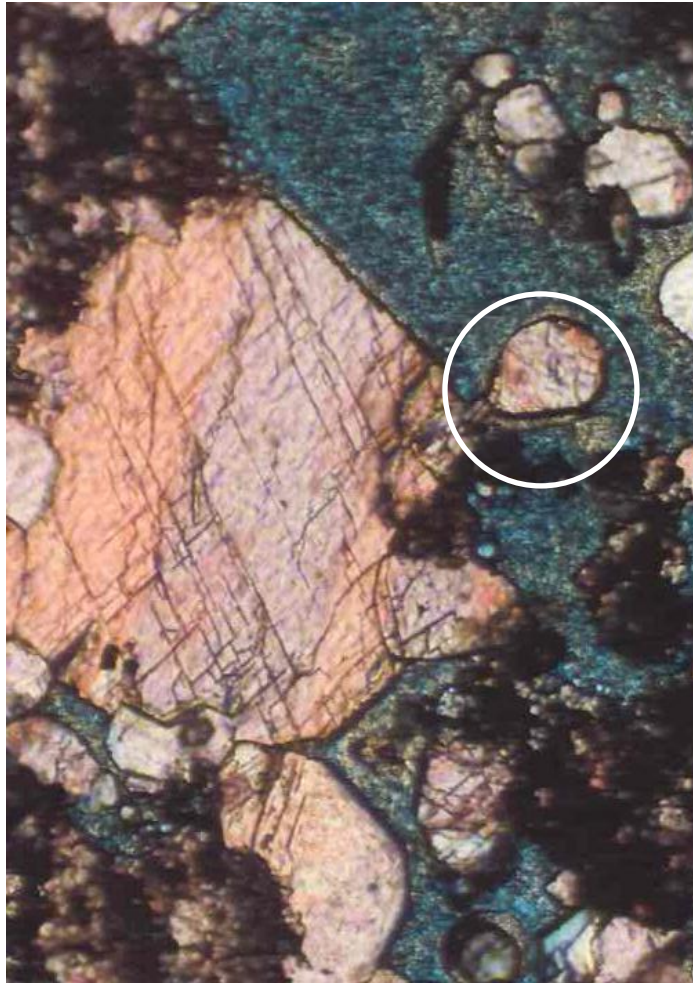
We have never seen these features associated with telogenetic effects!

Corroded calcite cement in a fracture

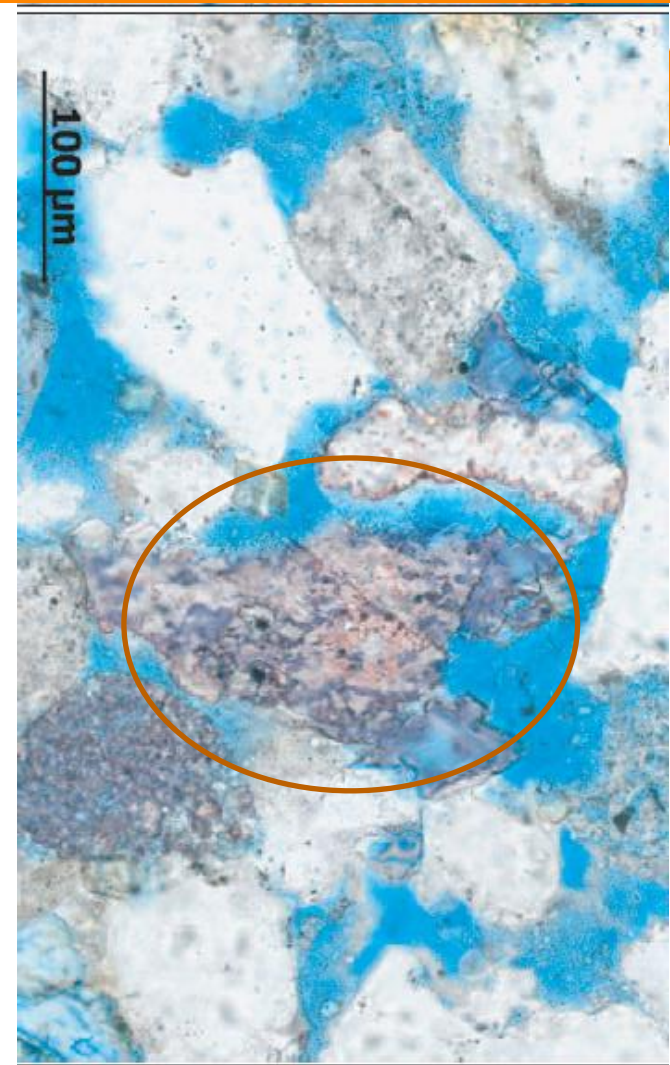


Eocene, Mukta, India

Corroded burial cements

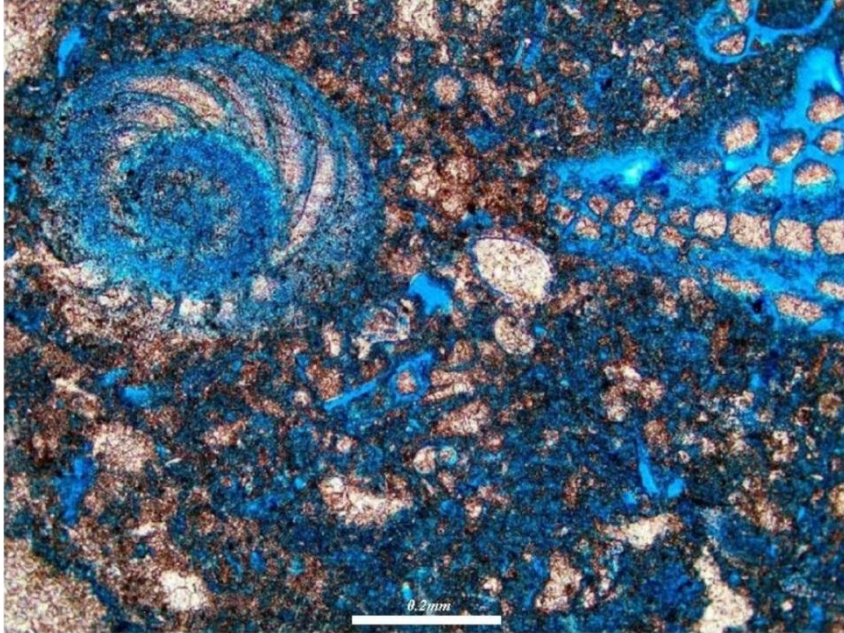


Corroded zoned cements, including a late stage ferroan cement; from mouldic pores in rudist grainstone. Cretaceous Mishrif Fm., Dubai FoV = 0.4mm



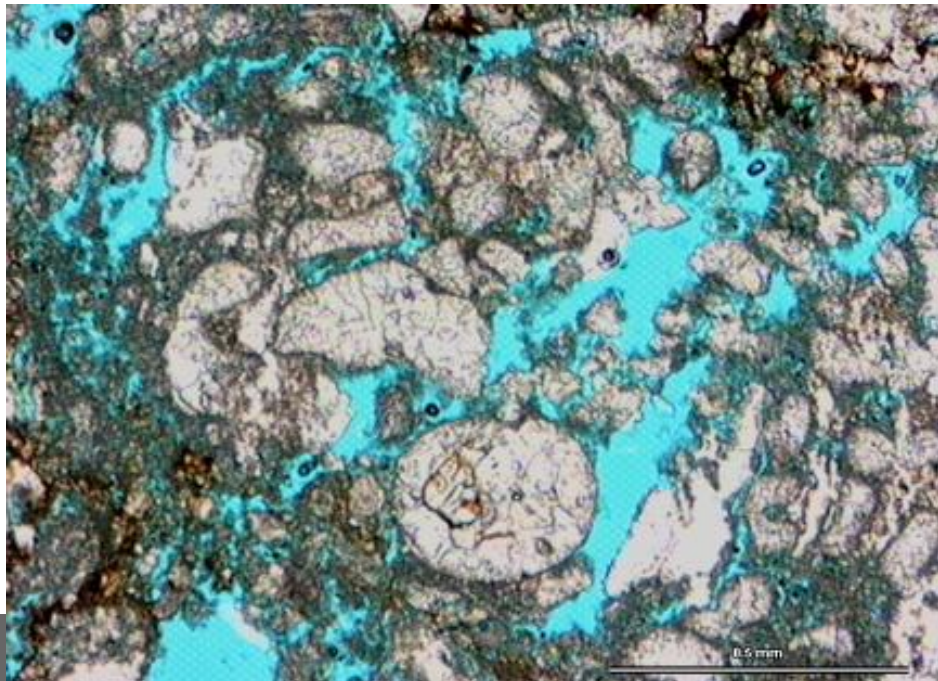
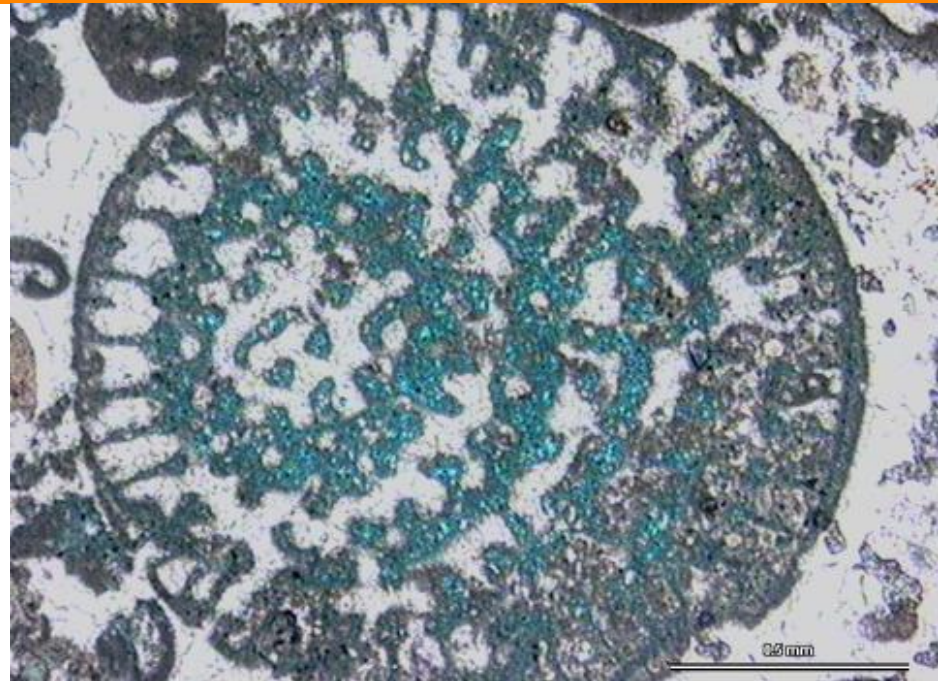
Corroded remnants of ferroan calcite cement (mauve): middle Miocene reservoir sandstones from Picaroon field, offshore Texas. Taylor T R et al., 2010AAPG Bulletin, 94, 1093–1132

Cement dissolution after dissolution of the host microporous foram walls (former HMC) dissolved



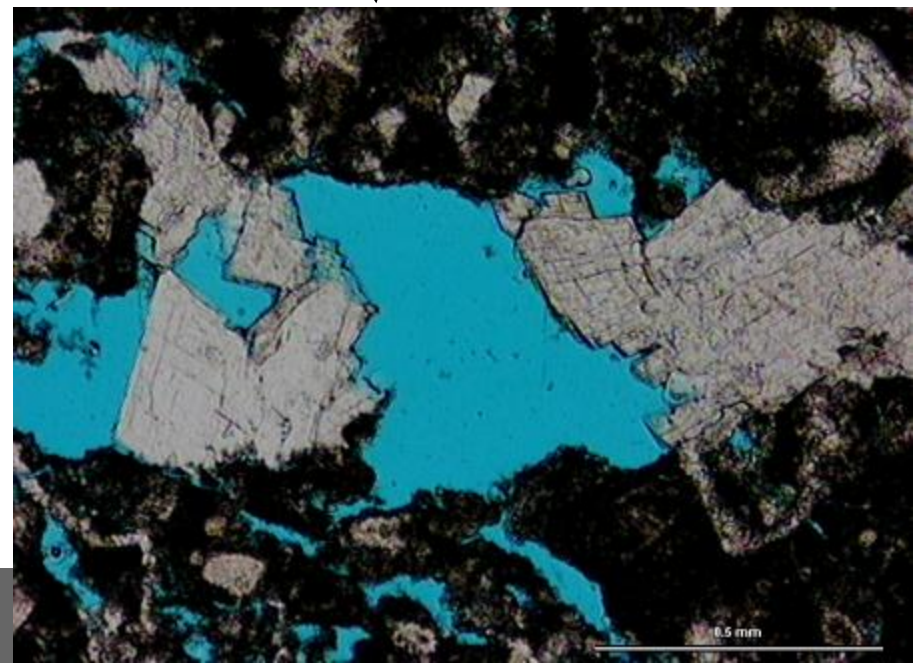
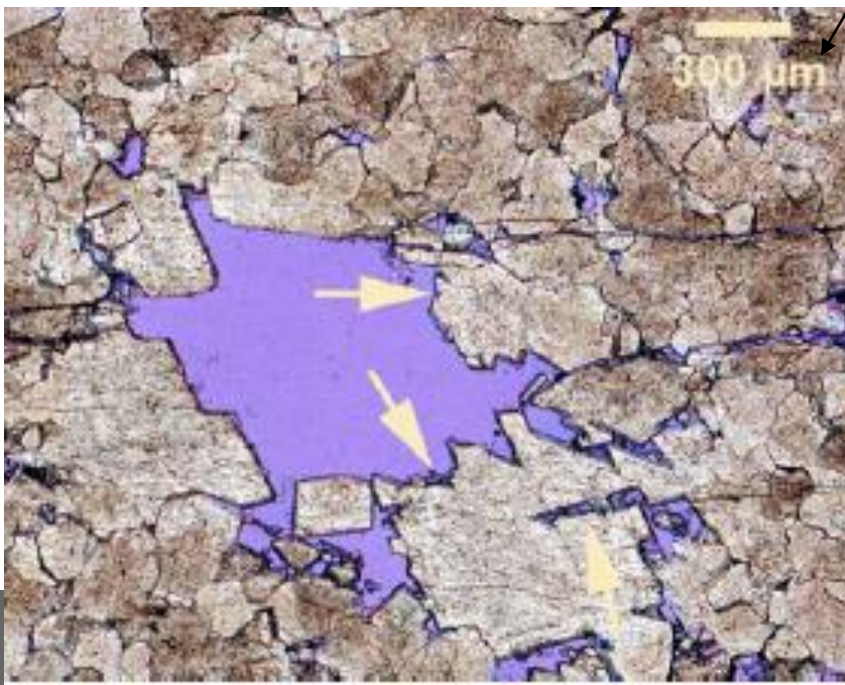
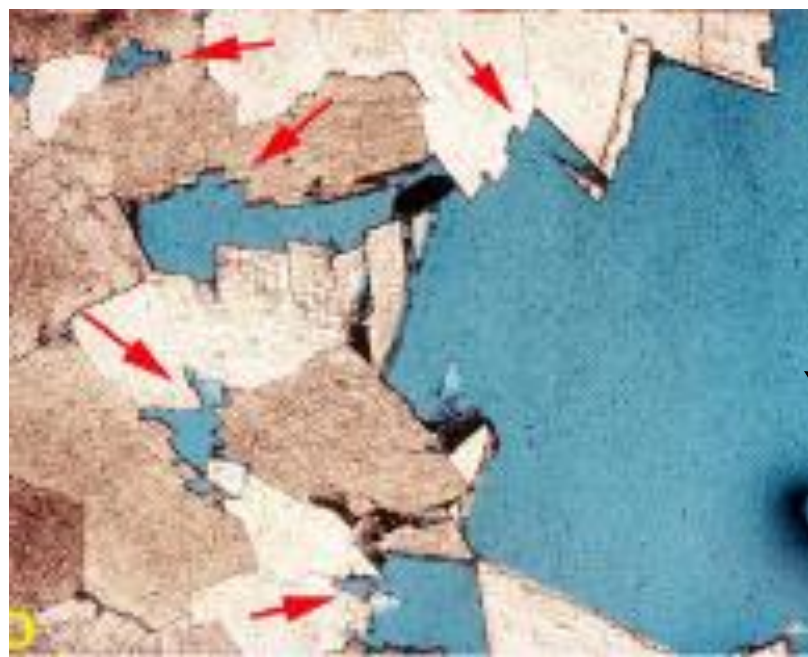
Oligo-Miocene Berai reservoir,
Ruby Field, Sebuku Block,
Makassar Straits, Indonesia.
Pireno G E et al., IPA, 2011 -
33rd Annual Convention
Proceedings, 2009 **IPA09-G-005**

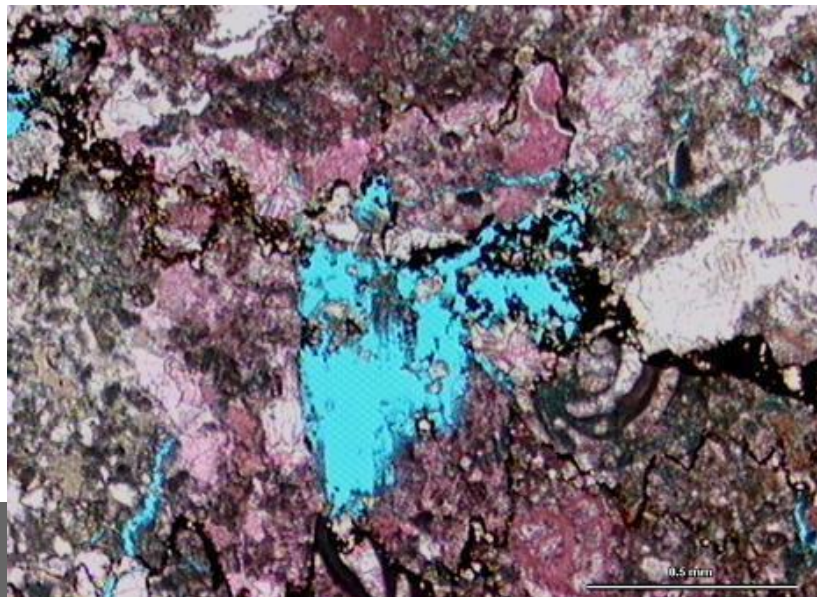
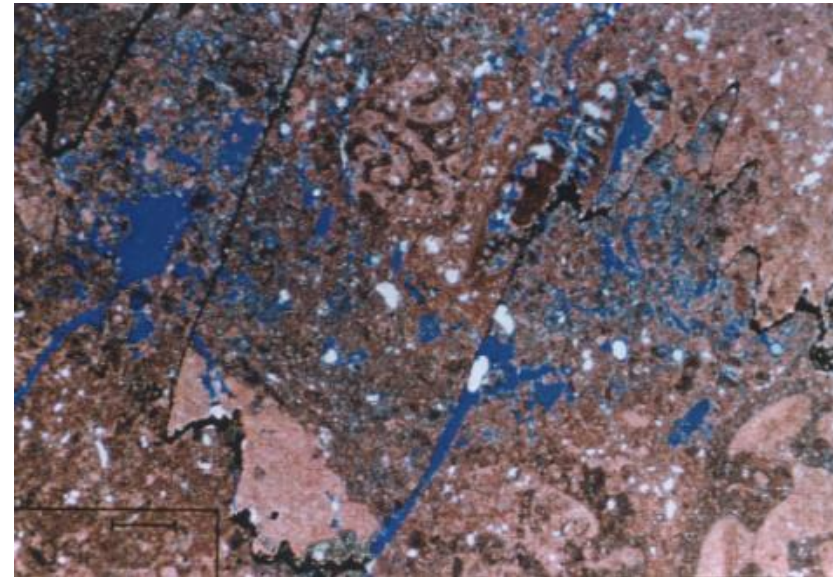
Eocene Bassein Limestone, Mukta
Field, offshore India



Etched burial dolomites

Devonian – WCSB;
Eocene, Mukta, India

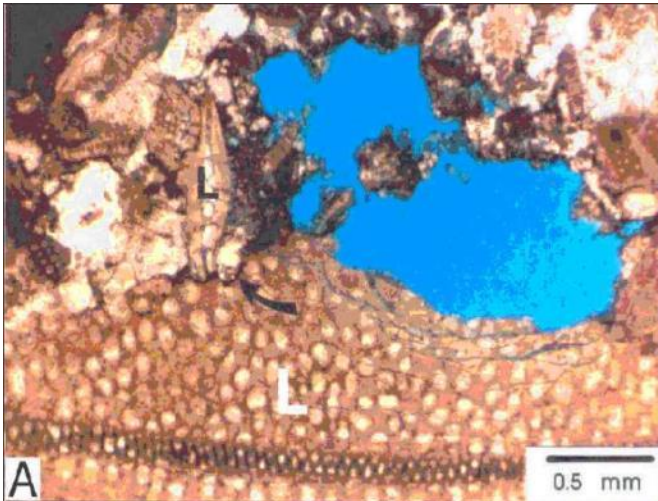




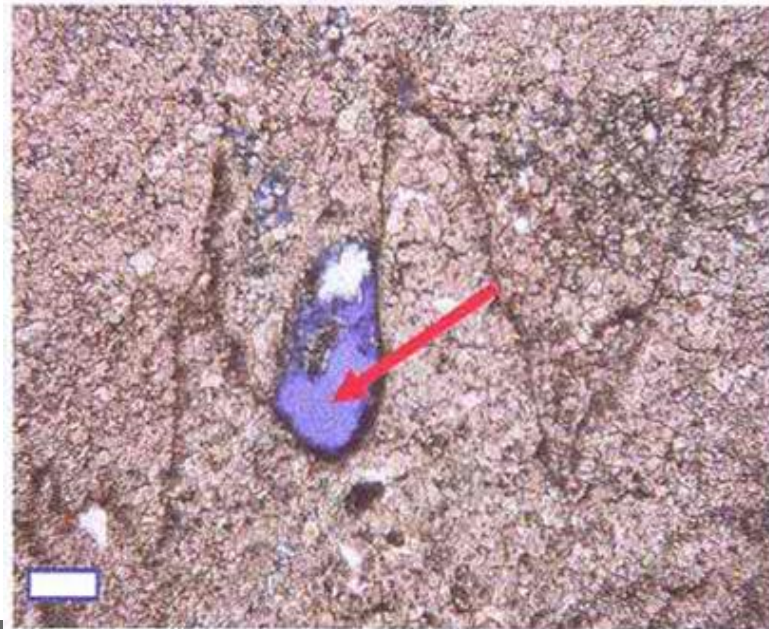
Corroded stylolites & pyrite

More dissolution along stylolites

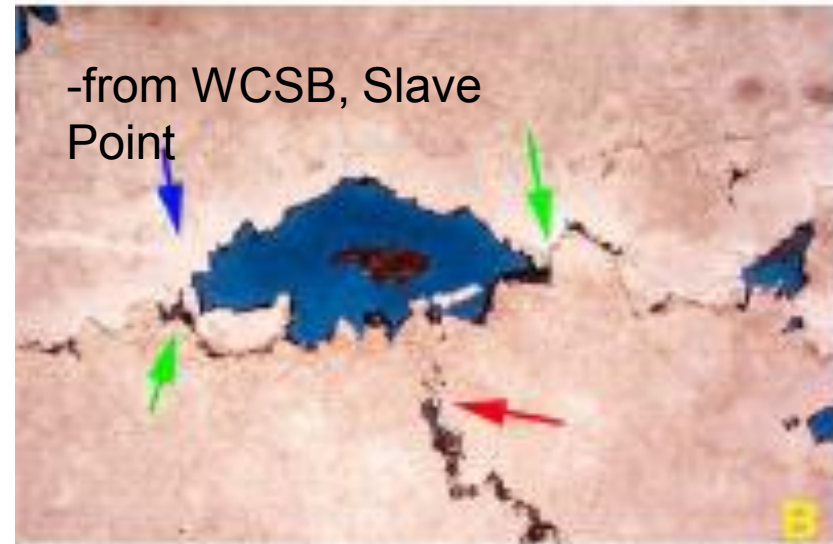
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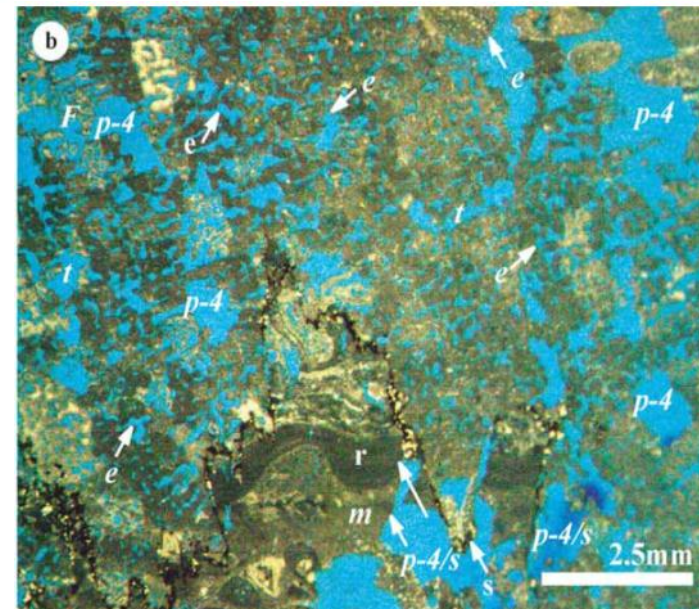
Oligocene, Kerendan Platform, Indonesia



Carboniferous, Karachaganak Field, Kazakhstan



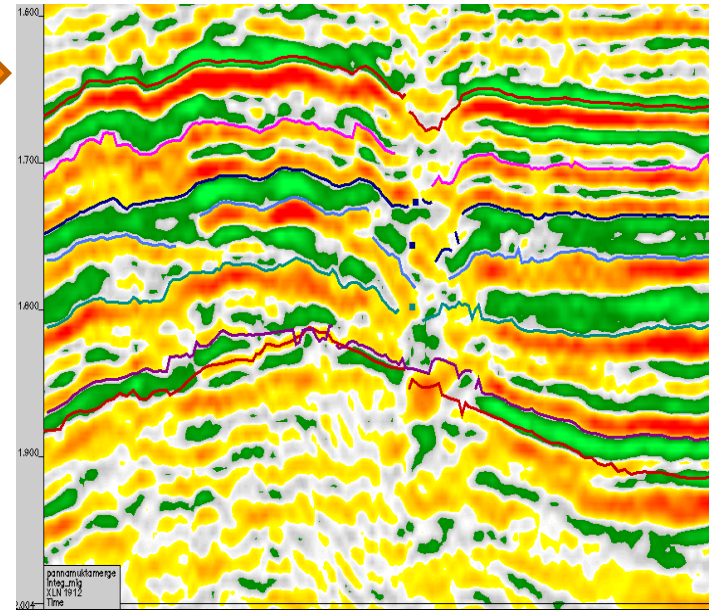
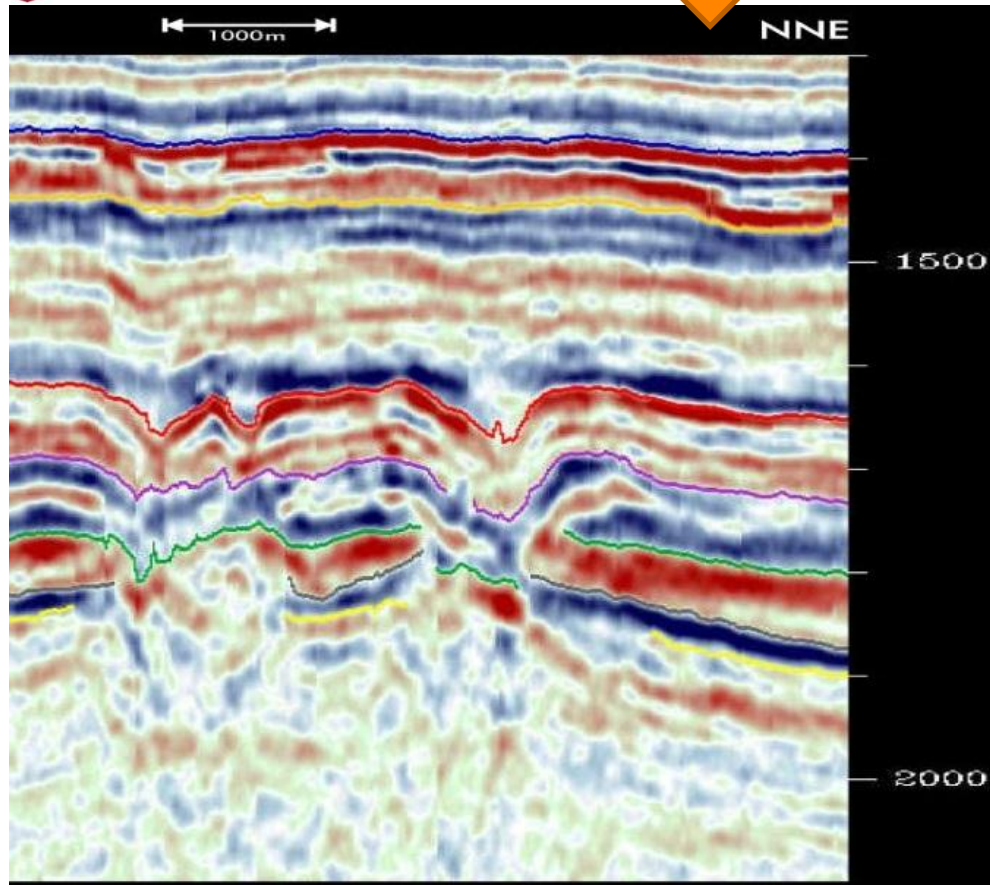
-from WCSB, Slave Point



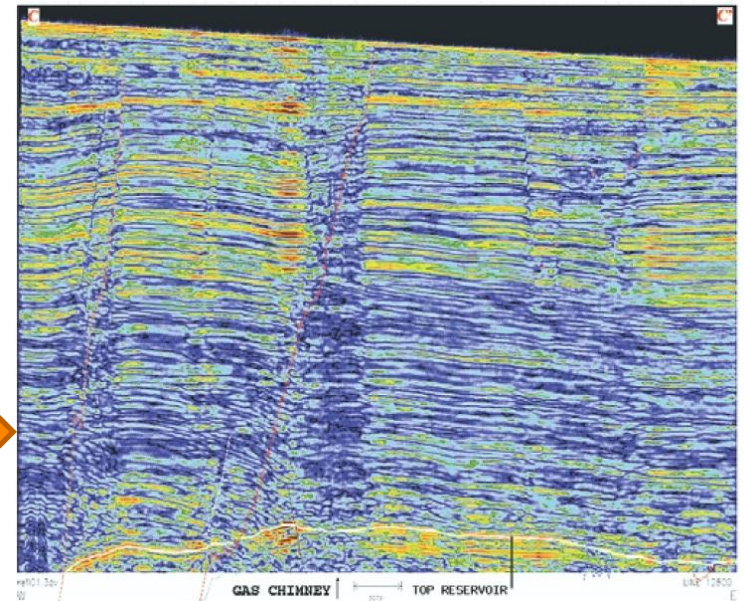
Liuhua 11-1 Field, Pearl River Mouth Basin, Miocene reef



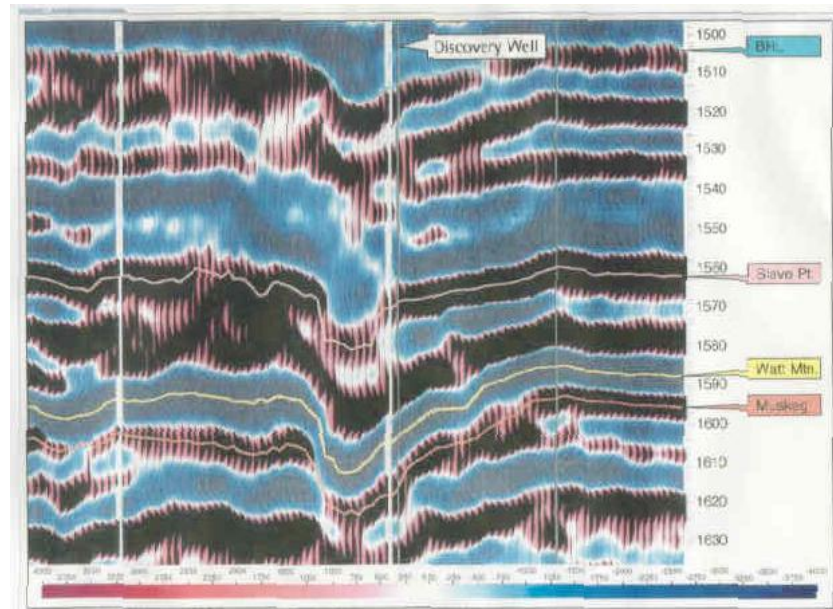
Panna Field, offshore India



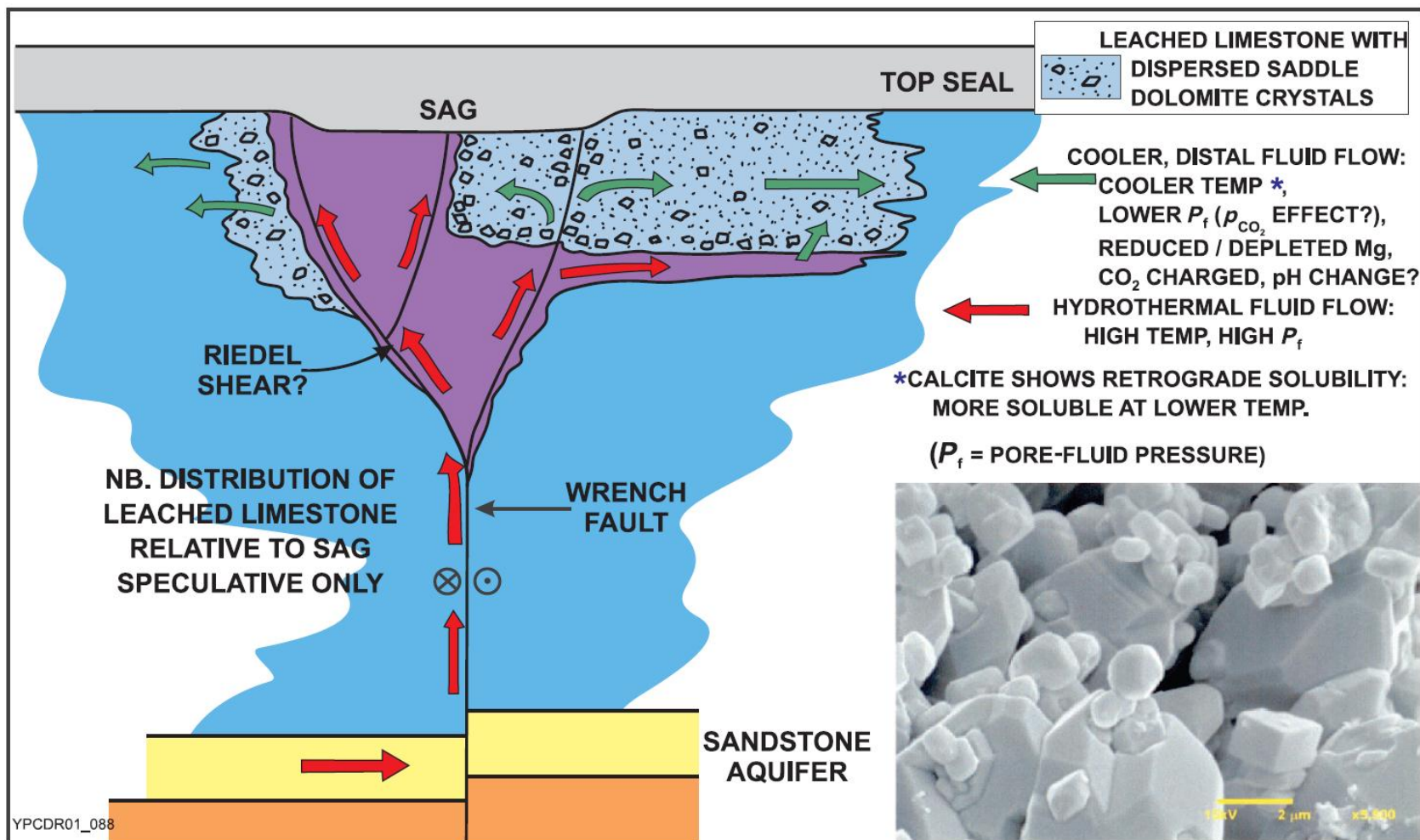
Liuhua 11-1 Field, Pearl River Mouth Basin. Collapse chimneys - Oil Field Karst due to CO₂ & H₂S. From Story C et al., 2000.
The Leading Edge; v.19, p. 8



Slave Point sags - Hotchkiss Embayment WCSB linked to HTD's

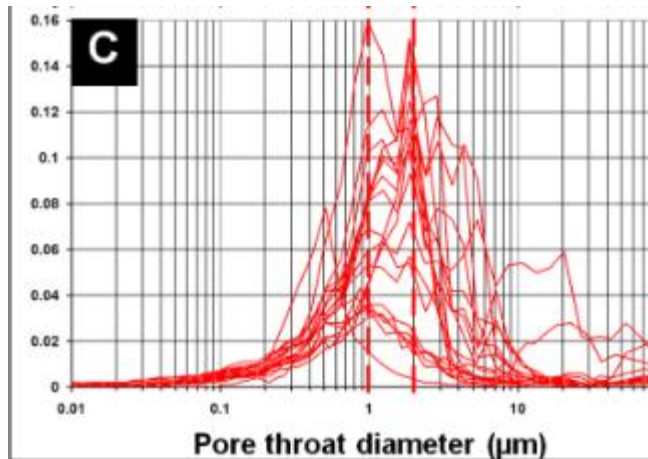


HTD and “leaching”

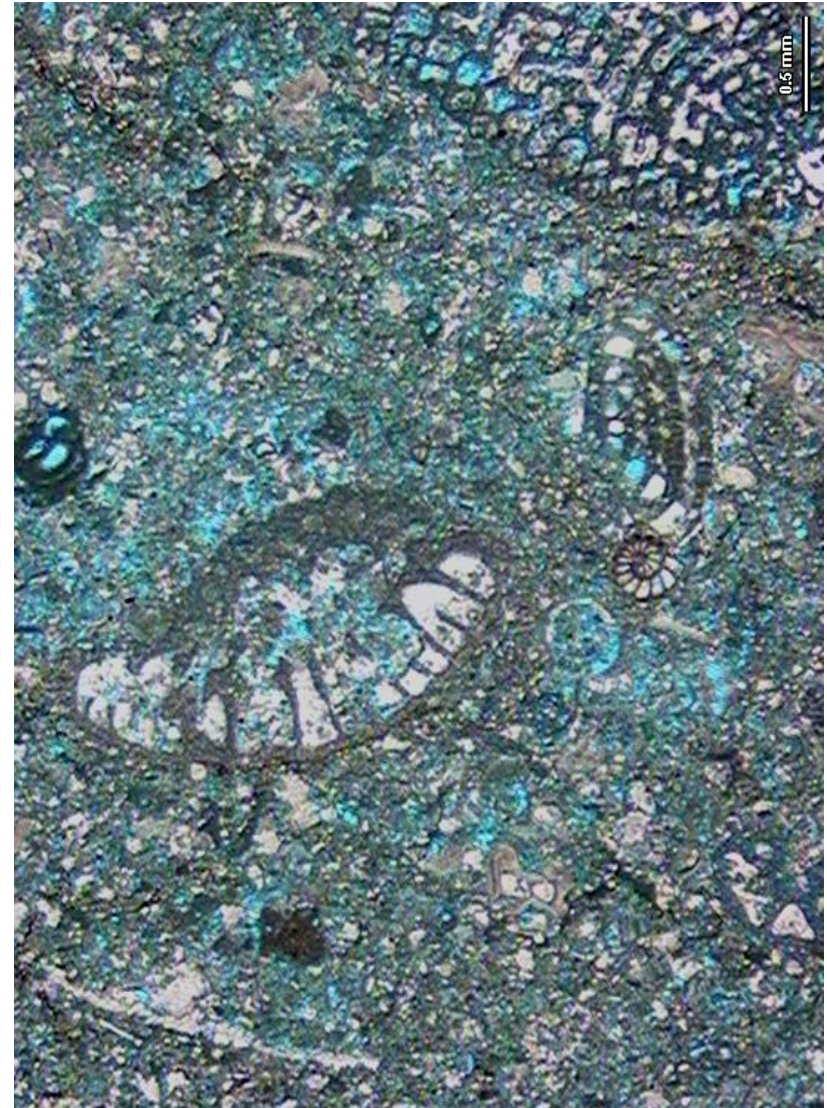


Davies G R & Smith L B Jnr 2006 AAPG Bulletin, 90, (November), 1641–1690 .

Is there a link between burial dissolution and microporosity?



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





Ehrenberg *et al.* do a service in highlighting how little we still know about burial corrosion.

They do a disservice in criticising a large body of carefully qualified examples.

Do we need to redefine mesogenesis and burial dissolution more rigorously, more formally?

Burial corrosion is identified on grounds of timing relative to deeper burial effects but the fluids responsible can cause dissolution at shallow depths.

They over-emphasize the role of compactional drive when deep regional confined flow producing hypogene dissolution is a well established mechanism.