# Origin of the Raised Rim in the Kashagan Buildup, Kazakhstan: A Hypothesis for Diagenesis Associated With Fractures and Burial Compaction*

**Joel F. Collins[1], Gareth D. Jones[1], Jackson Haffener[1], Sony R. Mohammad[1], Marat Nauryzgaliyev[2], and Roza Nursaidova[2]**

Search and Discovery Article #20365 (2016)**
Posted August 15, 2016

*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 16-22, 2016


[1]ExxonMobil Development Co., Spring, Texas (joel.f.collins@exxonmobil.com)
[2]North Caspian Operating Co, Atyrau, Kazakhstan

## Abstract

Kashagan Field is a Carboniferous isolated platform complex that features a structurally elevated margin 100-200 m higher than the platform interior. The margin contains fractured, mechanically rigid facies that were more resistant to compaction than the facies in the interior. Numerical models of compaction are consistent with formation of the elevated margin by differential compaction during burial under hydrostatic conditions; however, under the state of overpressure that exists today, such compaction would not occur. Development of overpressure probably occurred during rapid early burial of the Kashagan buildup under thick Permian evaporites (mainly halite). The margin elevation formed when the reservoir pressure dropped temporarily from an overpressured state to a near-hydrostatic state. Fluid inclusions from calcite cements, precipitated contemporaneously with formation of bitumen, indicate depressurization during the early stages of the hydrocarbon charge ~150 Ma (Late Jurassic), when both oil and water were present in the reservoir. Th(aq) in the calcite indicate a reservoir temperature of ~90-100°C while variable Th(oil) in two-phase inclusions indicate decreasing oil density corresponding to a pressure decrease of ~6000 psi, culminating in formation of asphaltene-rich bitumen. In addition to structural compaction, the pressure variations fueled burial diagenesis associated with fractures and stylolite formation. Diagenesis is characterized by fracture reactivation and dissolution, modification of pre-existing karst features, and matrix dissolution/cementation in the vicinity of the elevated margin resulting from organic acids, renewed circulation of groundwater, and temperature disequilibrium between the reservoir and the active fluids.

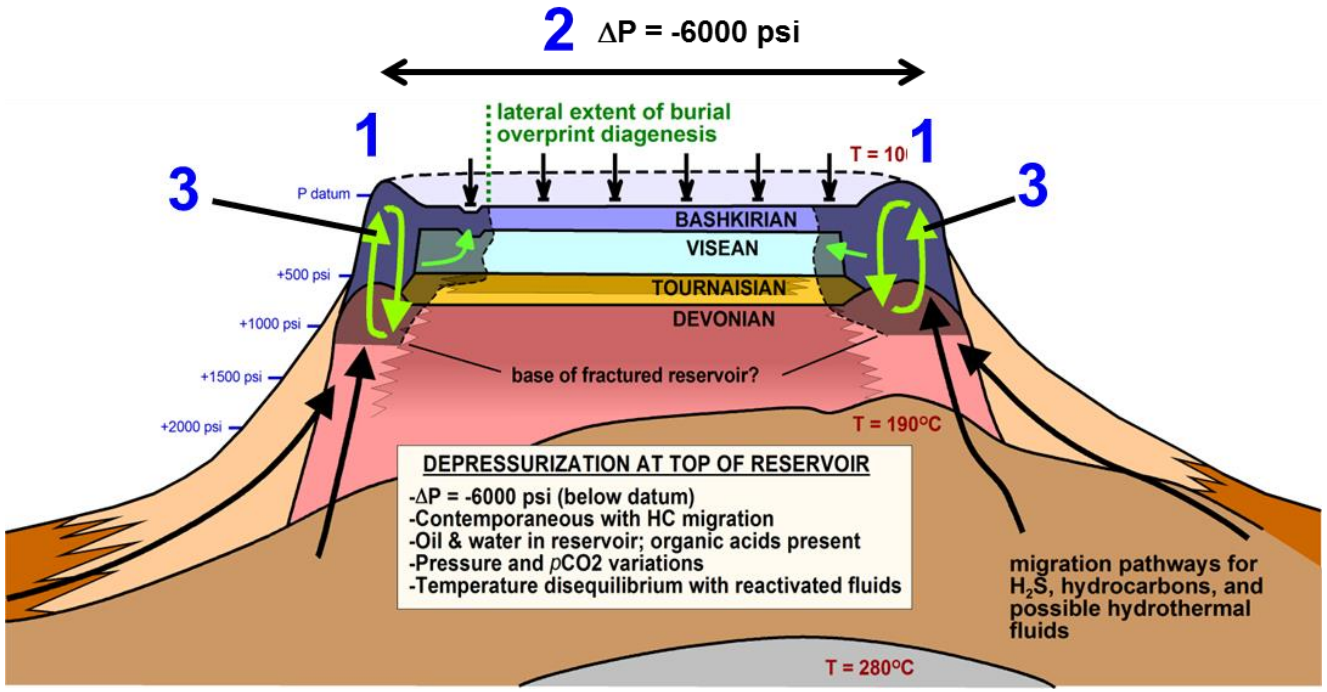
## References Cited

Anissimov, L., E. Postnova, and O. Merkulov, 2000, Tengiz Oil Field: Geological model based on hydrodynamic data: Petroleum Geoscience, v. 6, p. 59-65.

Ronchi, P., A. Ortenzi, O. Borromeo, M. Claps, and W.G. Zempolich, 2010, Depositional setting and diagenetic processes and their impact on the reservoir quality in the late Visean-Bashkirian Kashagan carbonate platform (Pre-Caspian Basin, Kazakhstan): AAPG Bulletin, v. 94/9, p. 1313-1348.

# Origin of the Raised Rim in the Kashagan Buildup, Kazakhstan: A Hypothesis for Diagenesis associated with Fractures and Burial Compaction

J.F. Collins, G.D. Jones, J. Haffener, S. Mohammad,
M. Nauryzgaliyev, R. Nursaidova




**1. RAISED RIM FORMED BY DIFFERENTIAL COMPACTION DURING BURIAL**

**2. COMPACTION OCCURRED RAPIDLY (geologically), DUE TO RESERVOIR DEPRESSURIZATION**

**3. DEPRESSURIZATION TRIGGERED DIAGENESIS IN A TRIPLE POROSITY-PERMEABILITY SYSTEM (matrix, fractures & karst, large-scale collapse)**

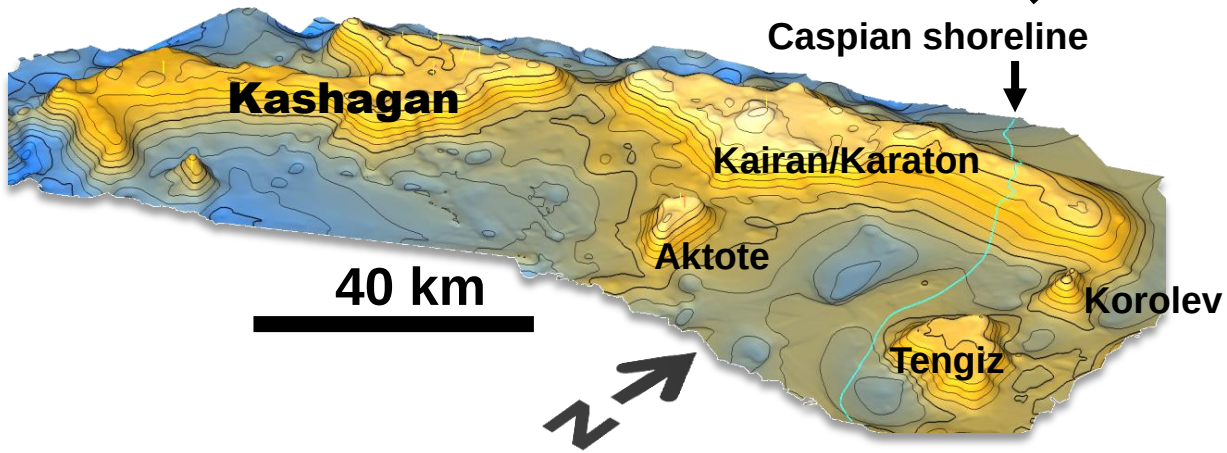
# INTRODUCTION


*modified from Collins et al. (2013)*

## ISOLATED DEVONIAN-CARBONIFEROUS BUILDUPS

- Common depositional and diagenetic histories
- Elevated margins (raised rims)
- Depth at top of Kashagan = ~4000 m
- Kashagan buildup height = ~1700 m

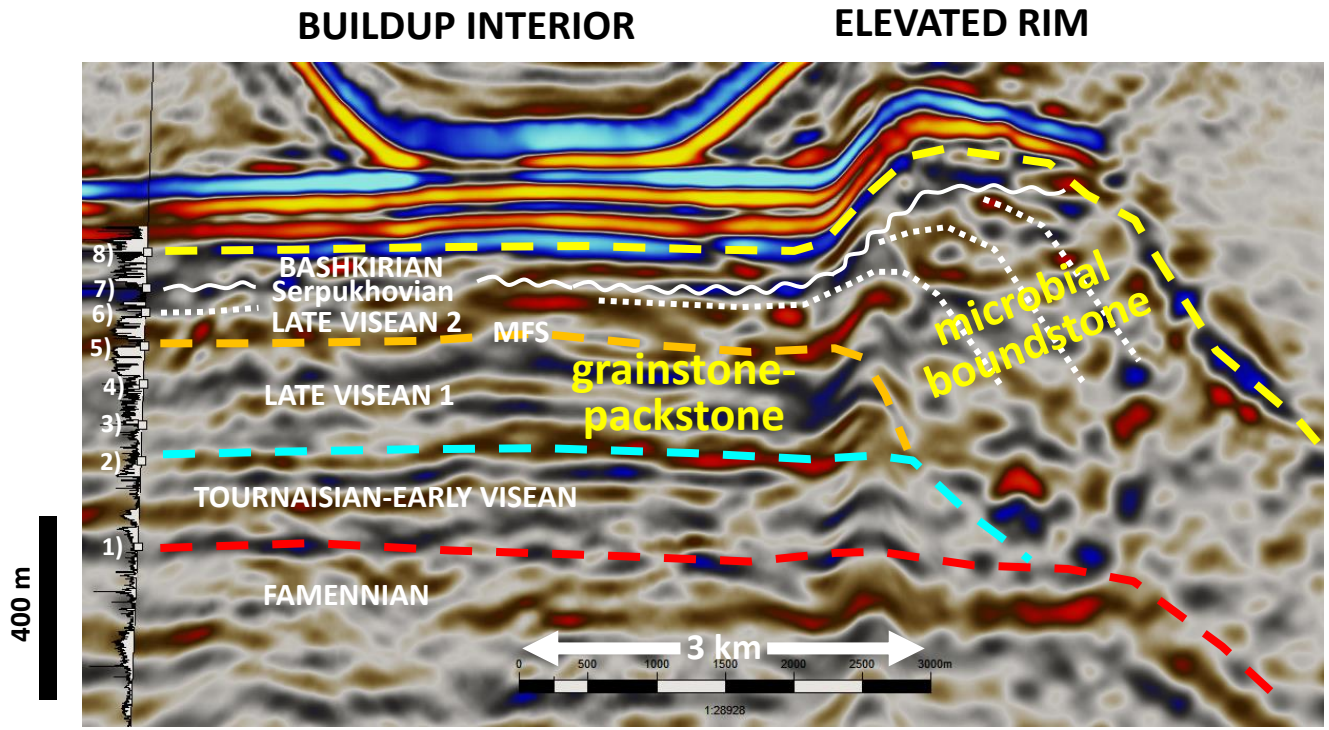
**PRIMORSK ARCHIPELAGO**

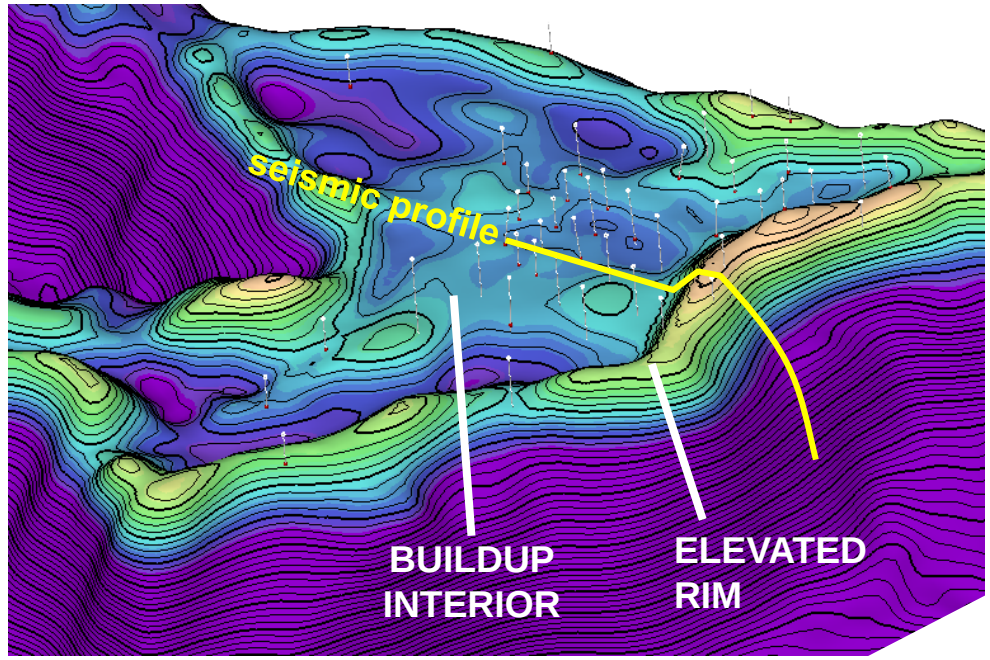


# 1. RAISED RIM FORMATION DURING BURIAL (COMPACTION)

## KASHAGAN EAST RIM

- Average elevation above interior = 160 m
- Controlled by turnaround from aggradation to progradation
- Rigid slope microbial facies adjacent to porous platform-top grainstones

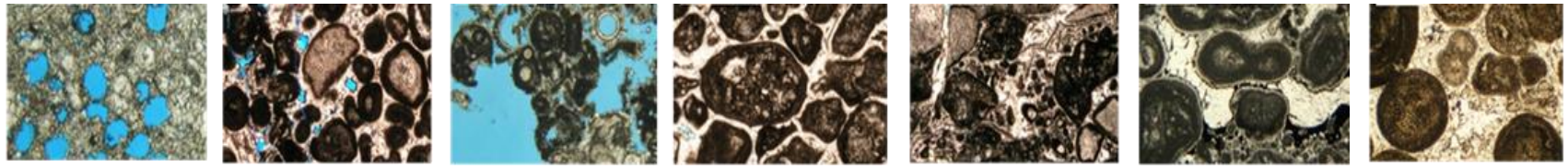


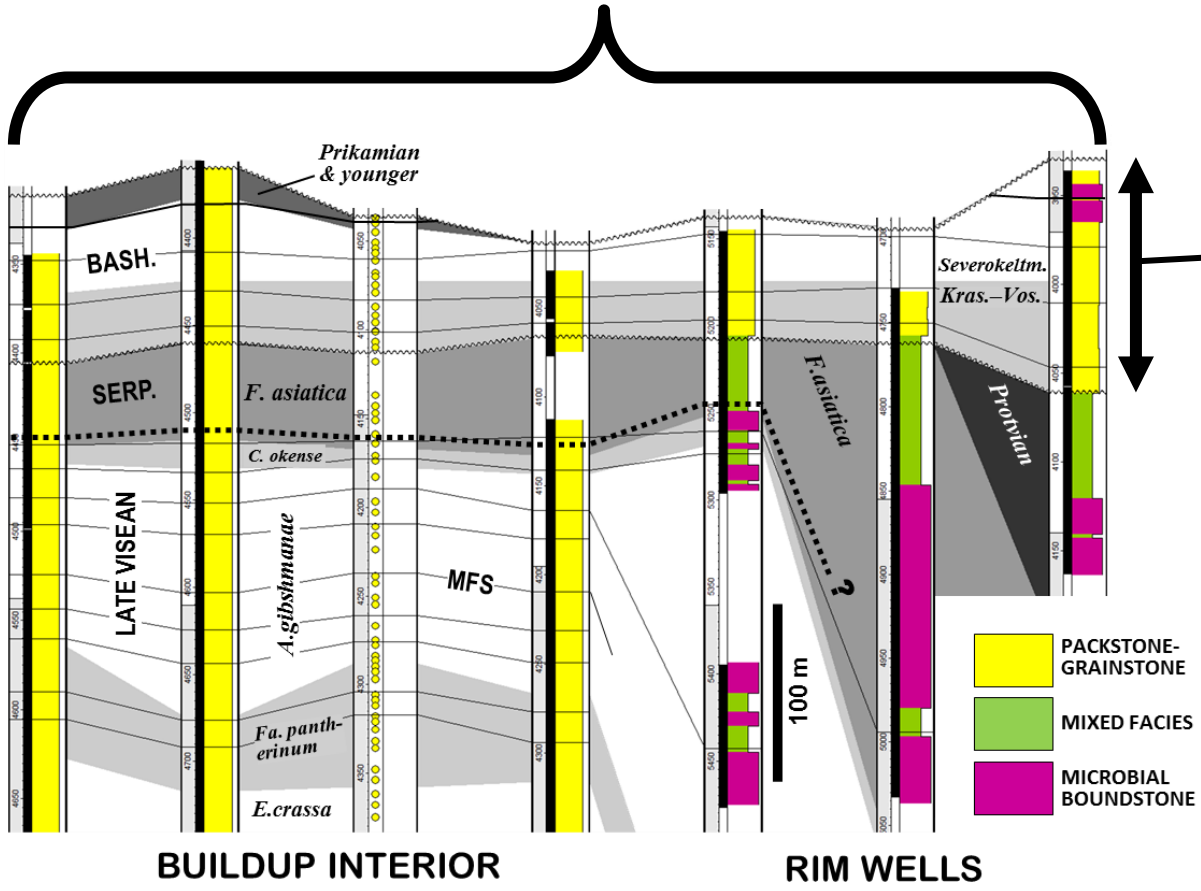



# 1. RAISED RIM FORMATION DURING BURIAL (COMPACTION)

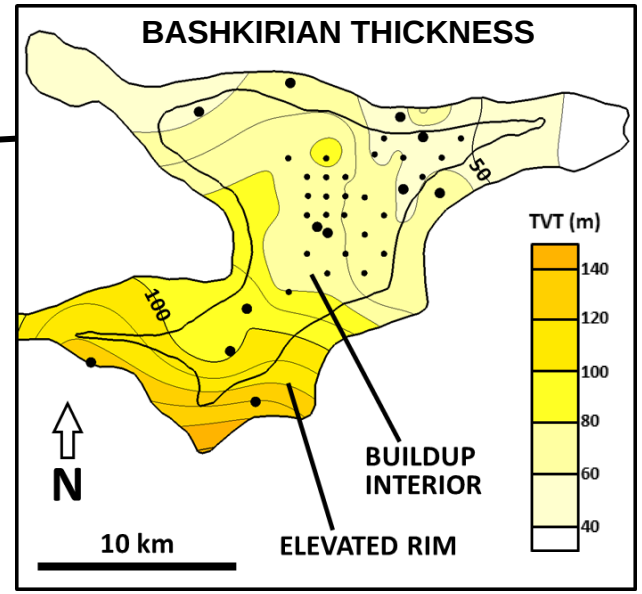
## HORIZONTAL BASHKIRIAN STRATA, LATE VISEAN-SERPUKHOVIAN CLINFORMS

- shallow Bashkirian EoD and horizontal biozones; grainstone, no bioconstruction
- expanded late Visean-Serpukhovian biozones became younger basinward






- cross-cut by erosional pattern



# 1. RAISED RIM FORMATION DURING BURIAL (COMPACTION)

## COMPACTION STUDY (2015)

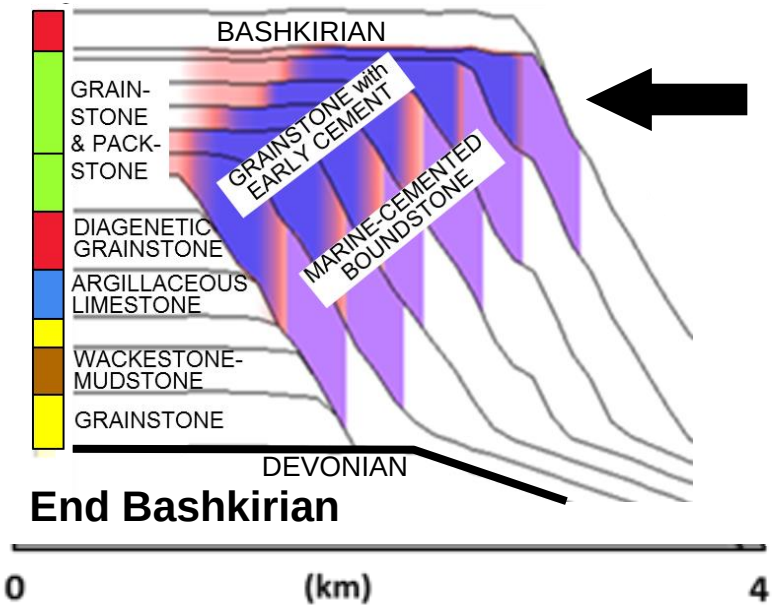
| | RIM | | | | INTERIOR | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | INITIAL THICKN. | FINAL THICKN. | COM-PACTION | BASE DEPRESSION | INITIAL HEIGHT | FINAL HEIGHT | COM-PACTION | DIFFERENTIAL COMPACTION | RIM ELEVATION |
| **DIFFERENTIAL** | 800 | 800 | 0% | 0 | 800 | 640 | 20% | 20% | 160 |
| **BASIN2®** | 900 | 875 | 3% | 50 | 900 | 700 | 22% | 19% | 125 |

## INTERIOR COMPACTION ESTIMATE

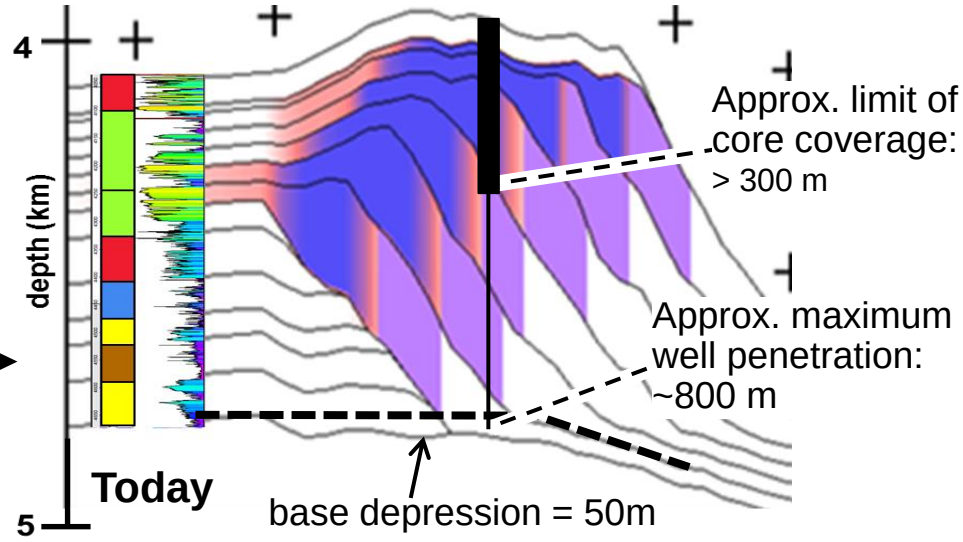
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **COMBINED** | 900 | 800 | 11% | 0 | 900 | 640 | 29% | 18% | 160 |

- Use BASIN2® initial thickness (900 m)
- No base depression

- Interior compaction = 29%
- Differential compaction = 18%




- De-compacted platform well estimate of pre-burial interior thickness (900 m)
- Progradational geometry fixed by biostratigraphy
- 2D compaction of profile and known facies in wedge using BASIN2®



# 1. RAISED RIM FORMATION DURING BURIAL (COMPACTION)

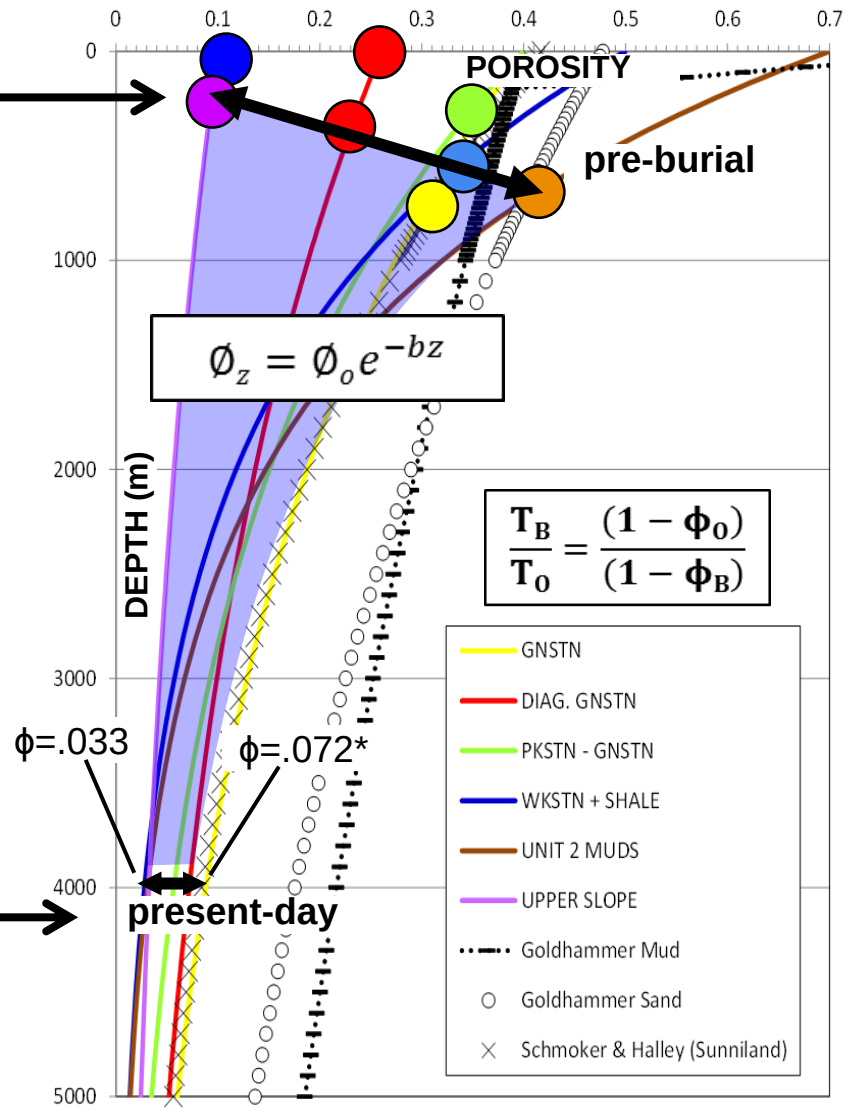
**PRE-BURIAL**

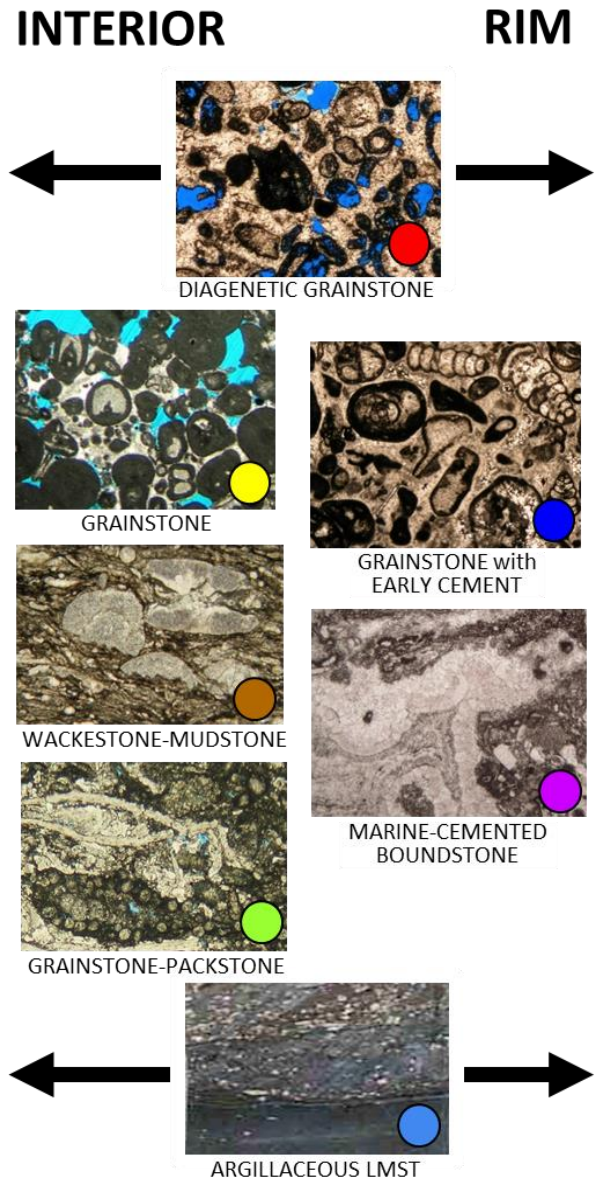
depth and porosity ranges at end of Bashkirian

**PRESENT DAY**

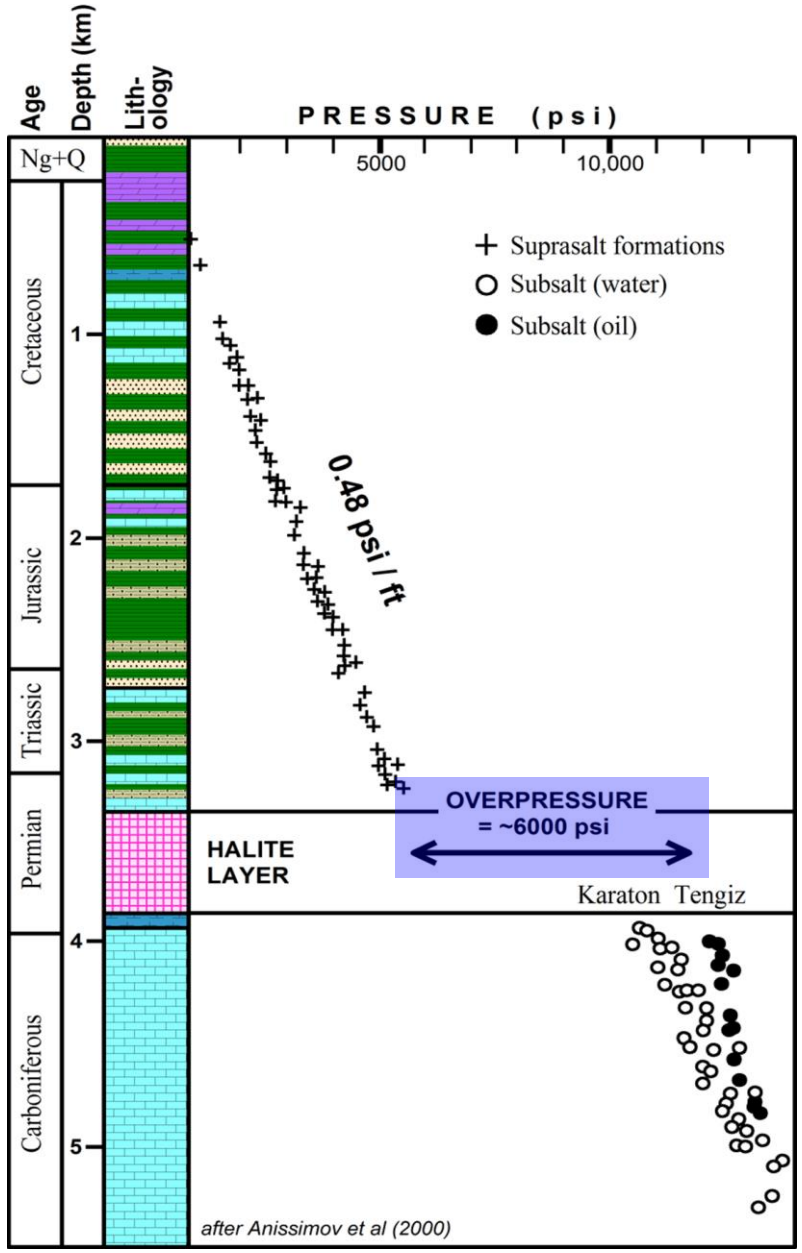
MIN = average porosity in boundstone facies from core

MAX = average porosity in interior grainstone and packstone facies from core



# 2. RAPID COMPACTION




## INTERIOR COMPACTION DELAYED by EARLY DEVELOPMENT of OVERPRESSURE

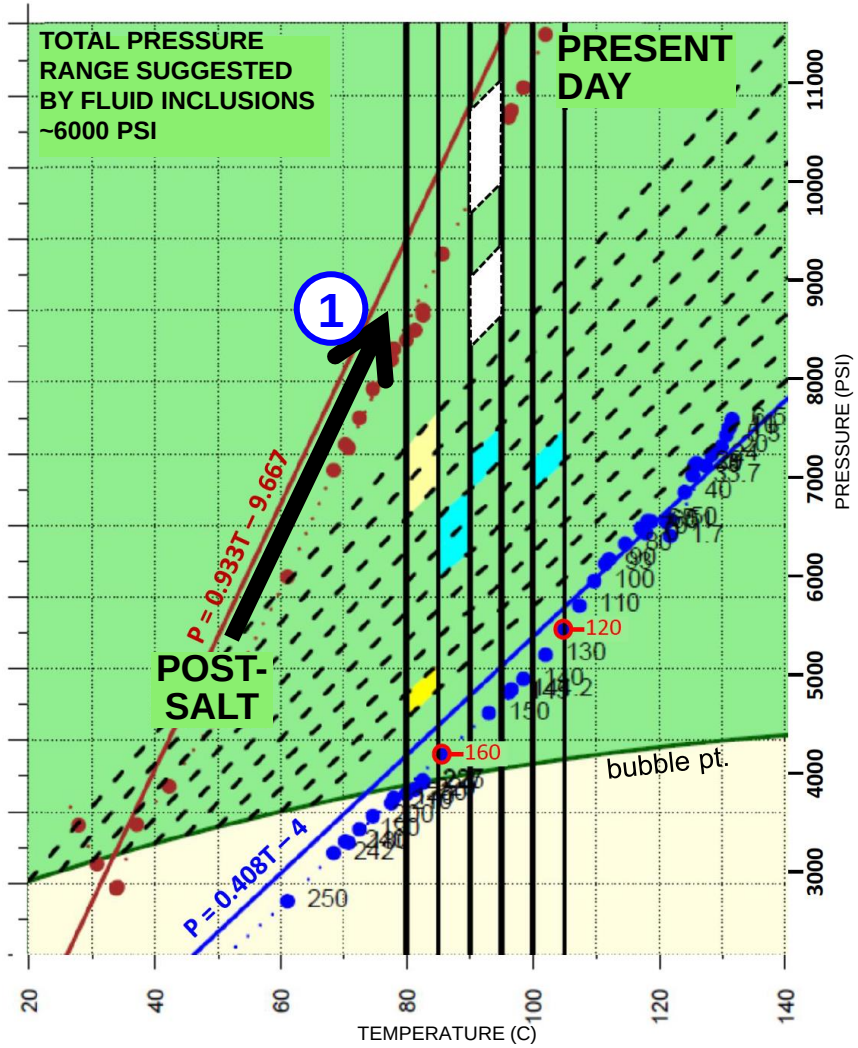
- Original BASIN2® simulations used **hydrostatic pressure**
- Current overpressure = ~6000 psi
- Developed after early rapid burial by 500-1000 m salt

- **BASIN2®: with early overpressure, compaction is only ~9%**
- **Presence of the elevated rim implies temporary reservoir depressurization**

# 2. RAPID COMPACTION

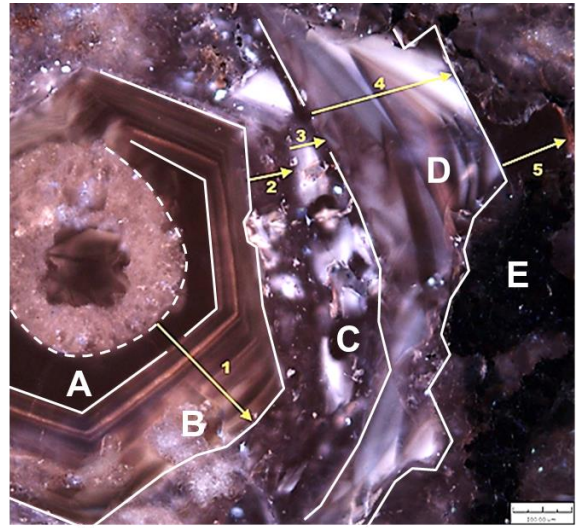
## INITIAL OIL MIGRATION

- Burial depth @ ~80-100ºC
- 160 Ma ?
- Lithostatic Pressure




**1 OIL & WATER in RESERVOIR**

- Paired water and oil inclusions in cement “E”




**YELLOW FL. OIL**

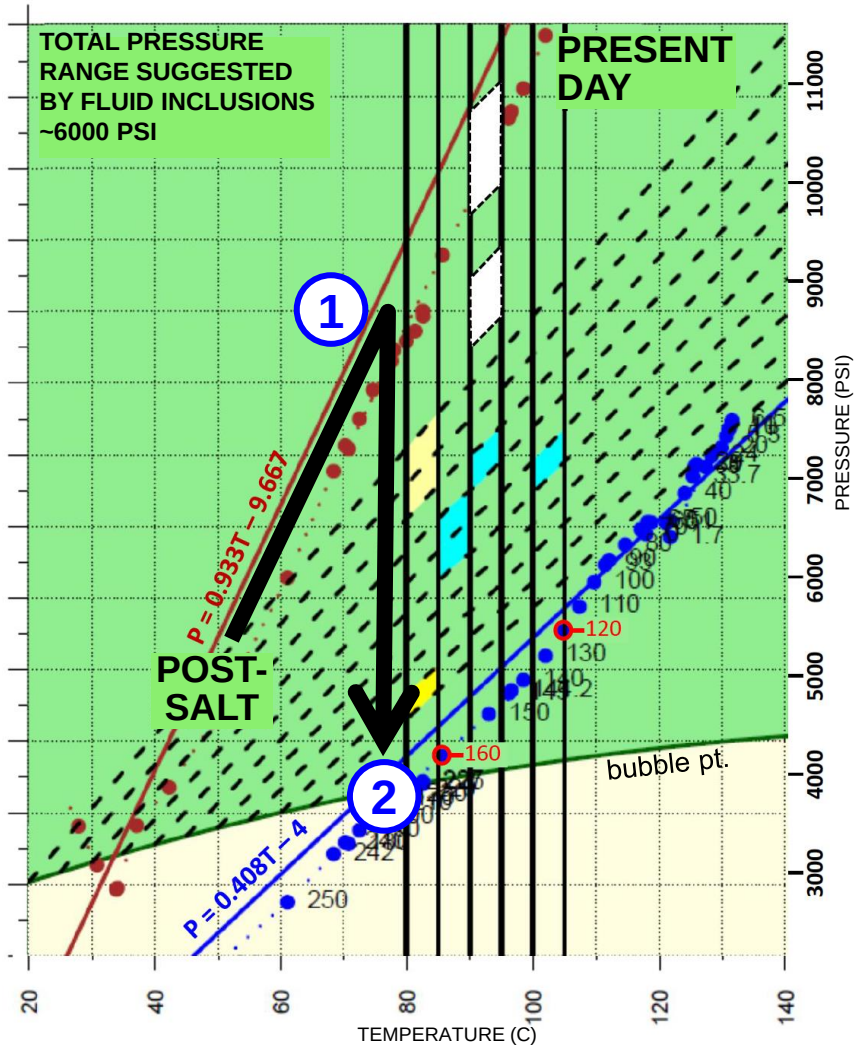
**BLUE FL. OIL**

**OIL FL. UNKNOWN**

# 2. RAPID COMPACTION

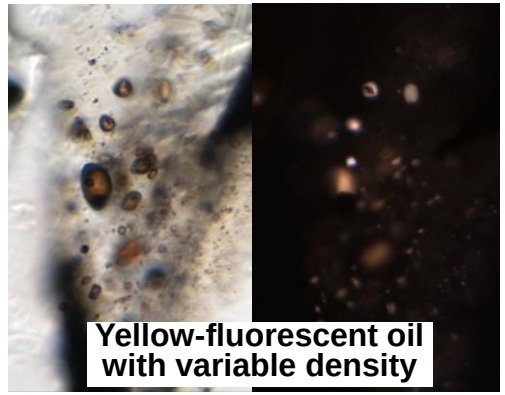
## DEPRESSURIZATION

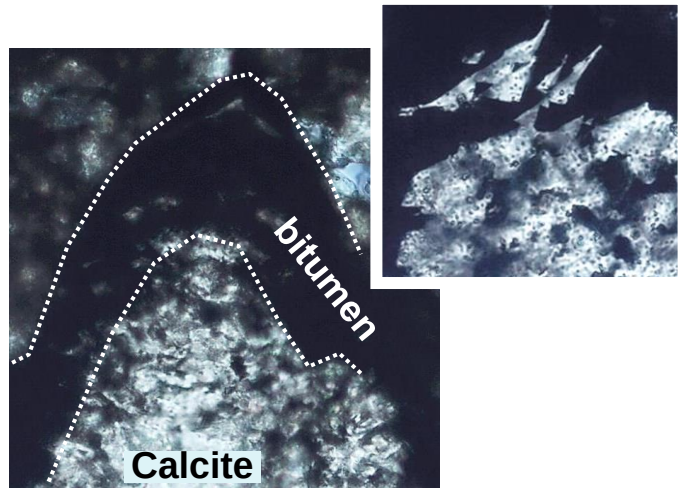
- Burial depth @ ~80-100ºC
- 160 Ma ?
- ΔP = 4000-6000 psi




## 2 PRESSURE FALLS to HYDROSTATIC?

- Cement “E” precipitates as pressure drops
- Oil density increases at constant temperature
- Bitumen forms as pressure nears bubble point

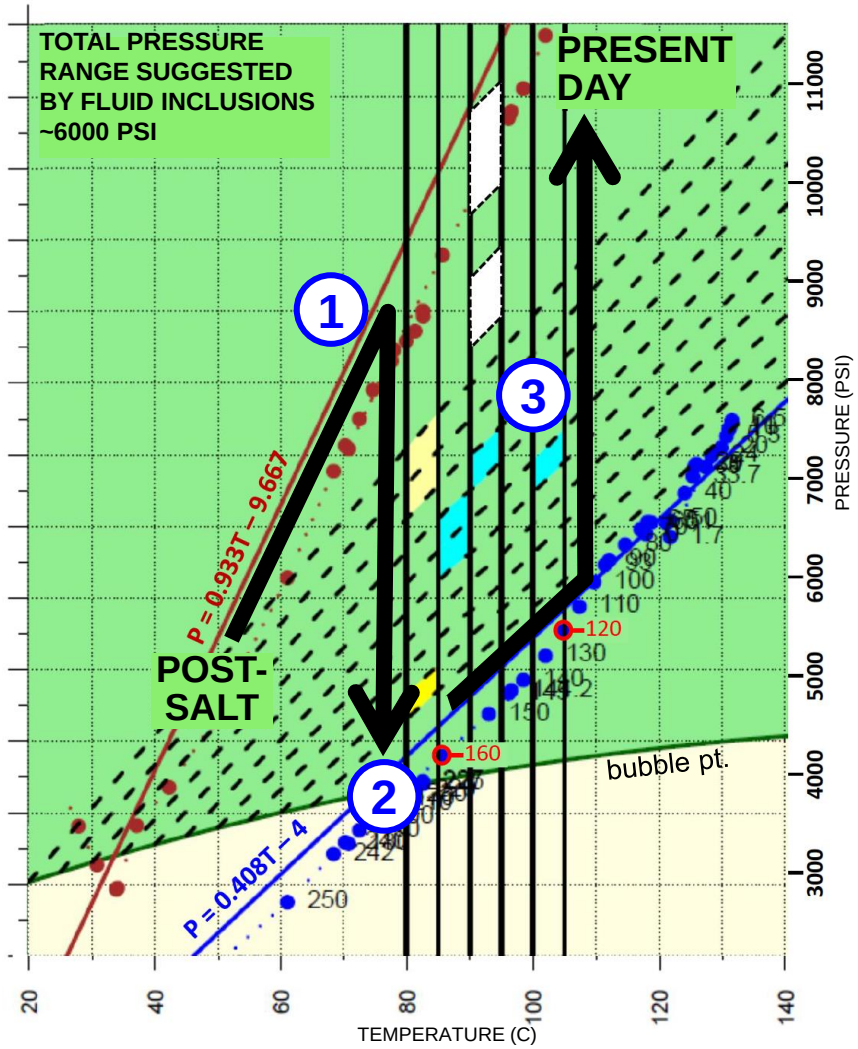


# 2. RAPID COMPACTION

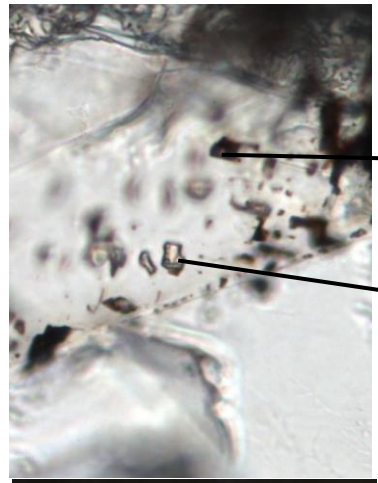
## COMPACTION WINDOW

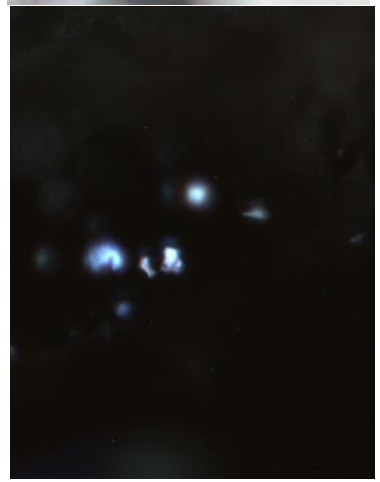
- **Burial depth @ ~105ºC ?**
- **120 Ma ?**
- **Overpressure restored**




## ③ MODIFIED OIL or LATER MIGRATION?

- Microfracture planes in cement “E”

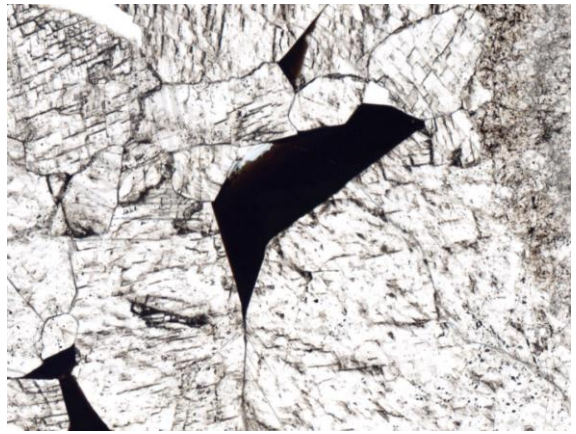


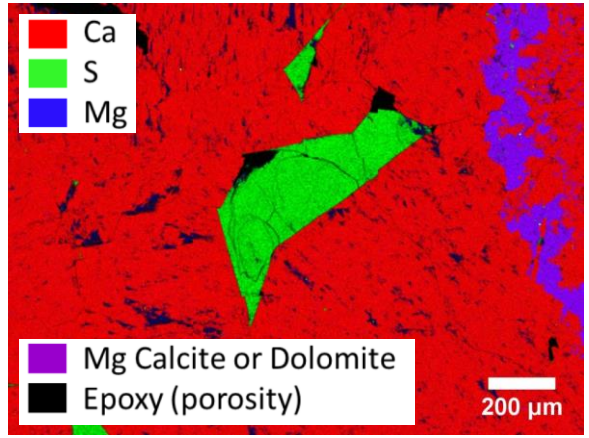
blue fluo-rescence similar to present-day oil

# 2. RAPID COMPACTION

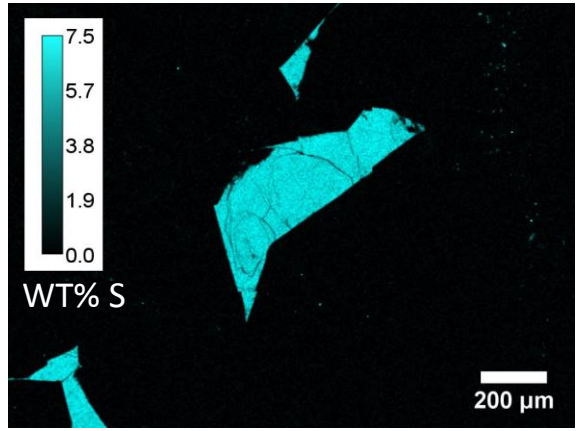
## ELECTRON MICROPROBE DATA: UNIFORM BITUMEN COMPOSITION (~7% SULFUR by weight)



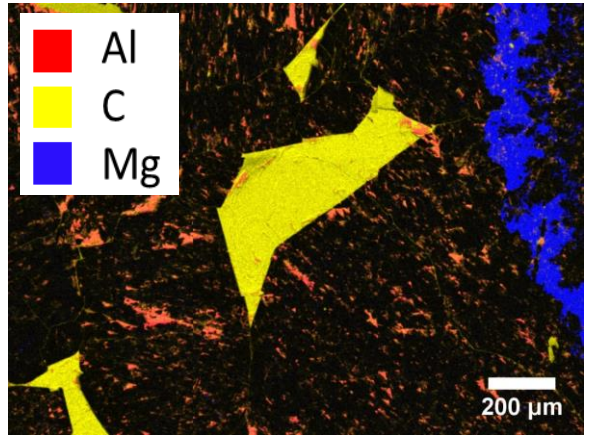
PLANE-POLARIZED LIGHT




COMPOSITE ELEMENT MAP




QUANTITATIVE ELEMENT MAP

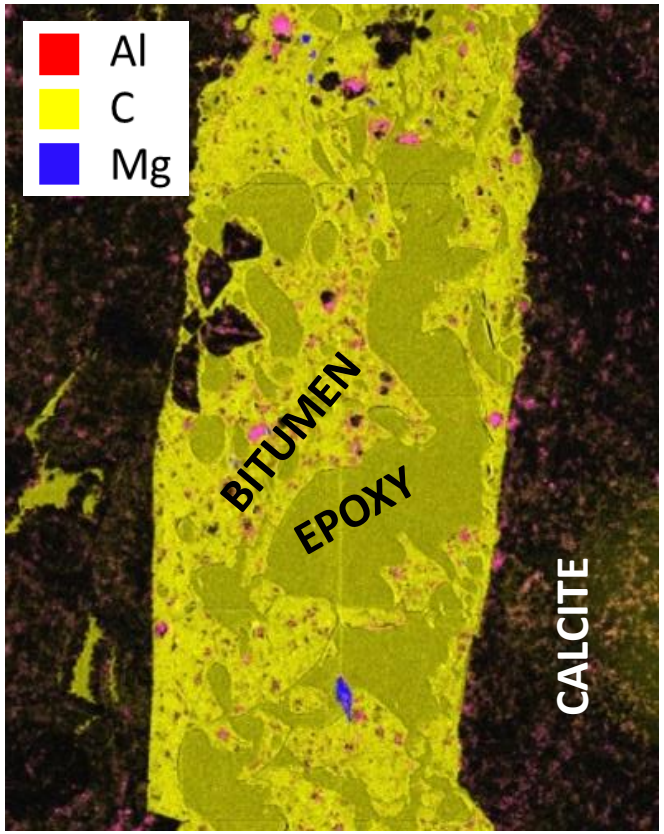



COMPOSITE ELEMENT MAP

# 2. RAPID COMPACTION

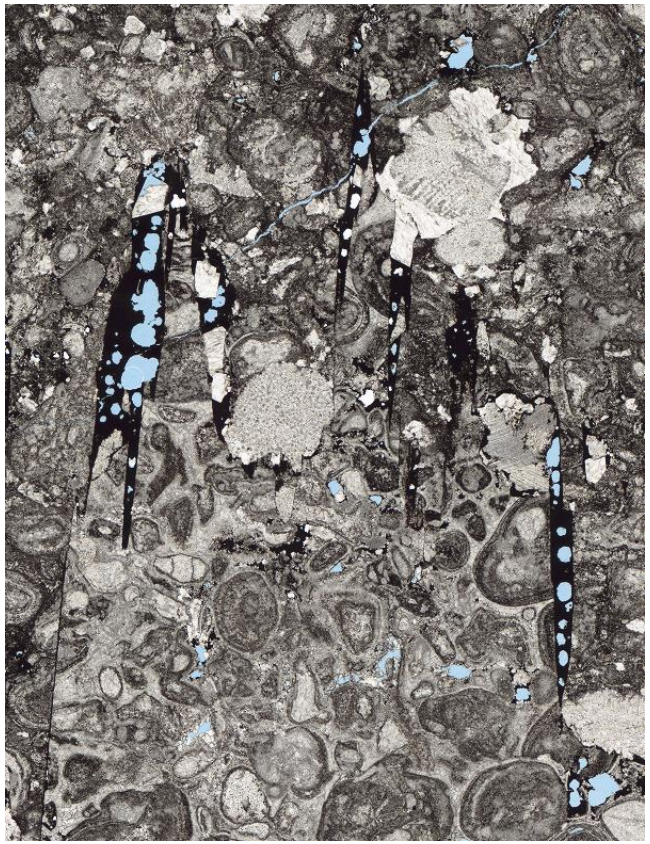
## BITUMEN-FILLED STYLOLITES FORMED DURING DEPRESSURIZATION

>60% C by weight*

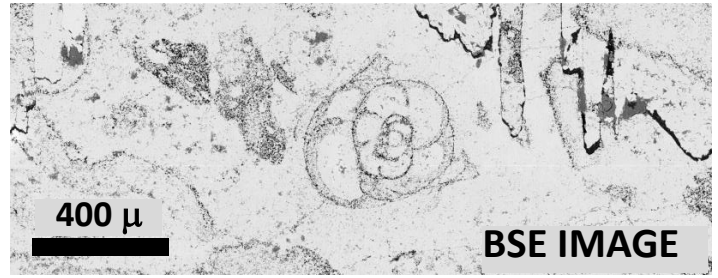


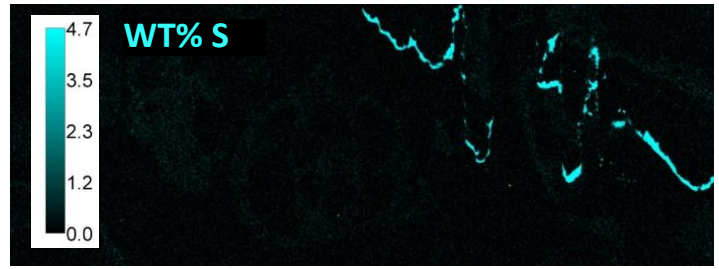

* Avg. Kashagan bitumen = 75% C

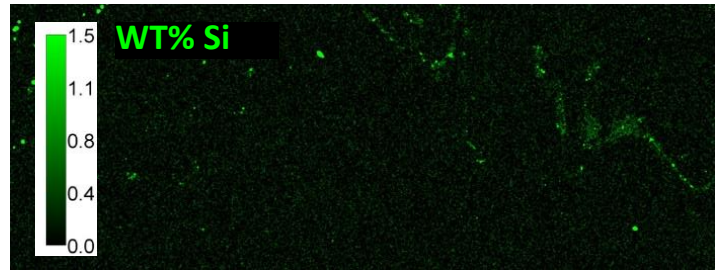
cement “E” crystals, oil bubbles?

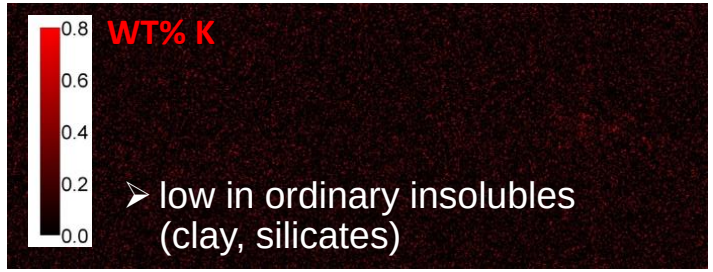


Bitumen with 7% sulfur in stylolites



# 3. DIAGENETIC RESPONSE

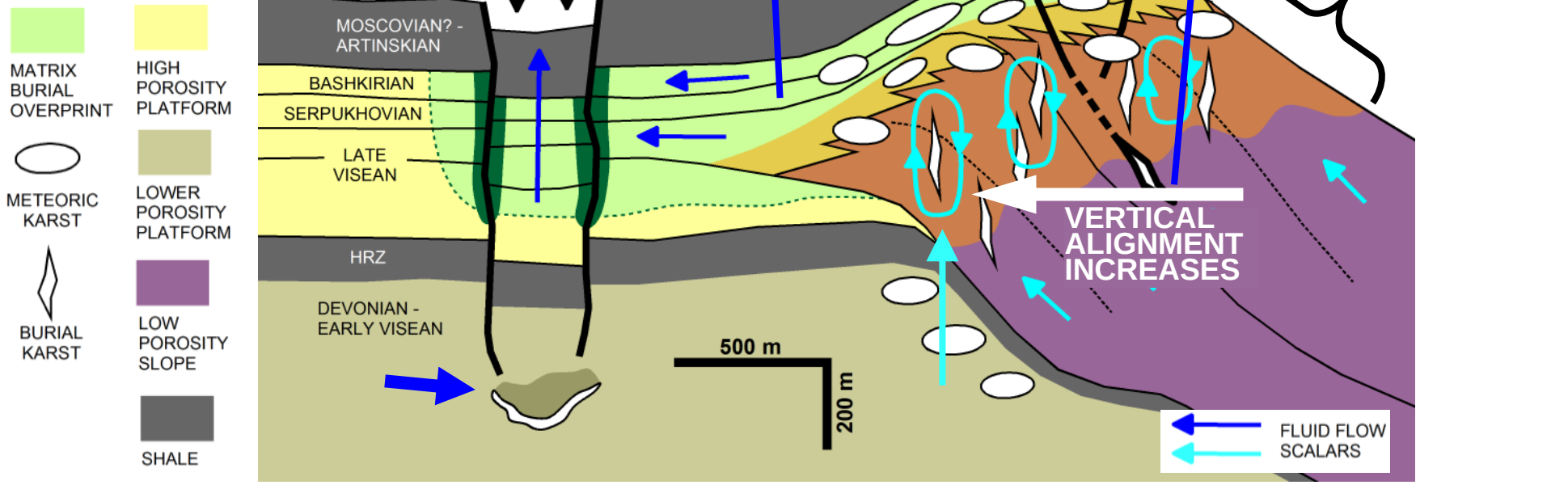
## RESPONSE TO DEPRESSURIZATION

- LARGE-SCALE COLLAPSE FEATURES FORMED MAJOR CONDUITS
- ACTIVE FLUID CIRCULATION DRIVEN BY INCREASED ΔP
- MIGRATION TOWARD COLLAPSE FEATURES VIA KARST & FRACTURE SYSTEM
- MATRIX AFFECTED BY BURIAL DIAGENESIS ALONG MIGRATION PATHWAYS

**COLLAPSE FEATURES**
- Margin faults
- Interior sinkhole

**MATRIX DIAGENESIS**
- Halos around fractures and karst in rim
- Local interior regions

**SECONDARY PATHWAYS**
- Connected early fractures, burial fracture swarms, and karst system



# 3. DIAGENETIC RESPONSE

## MATRIX DIAGENESIS

- Main products are bitumen, calcite cement, dissolution
- Variable PVT conditions
- Organic acids, *p*CO2, *p*H drivers

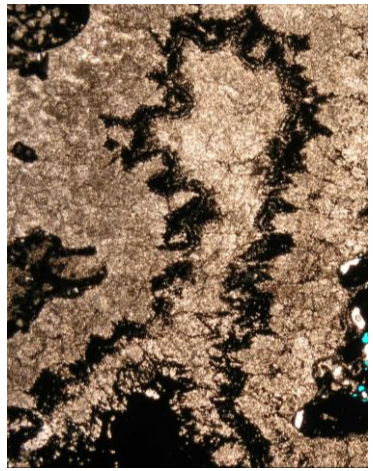
**PRESSURE (*p*CO2)** $H_2O(v) + CO_2(v)$ ↑↓

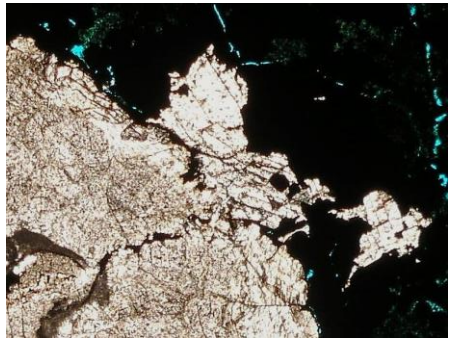
**OIL+WATER (*p*H)** $2H^+ + CO_3^{-2}$ ↑↓

$$CaCO_3(s) + H_2CO_3(aq) \leftrightarrow Ca^{2+} + 2HCO_3^-$$

**PRECIPITATION** **DISSOLUTION**

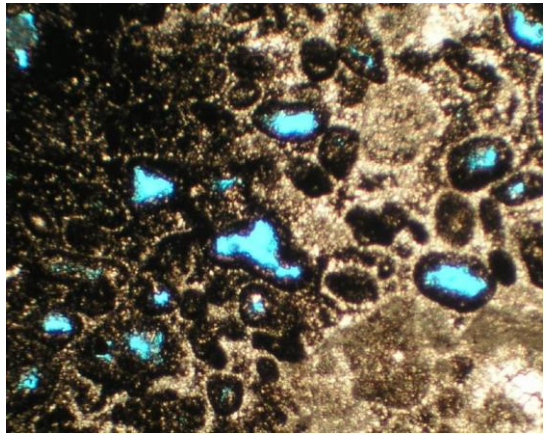
### BITUMEN & CEMENT "E"

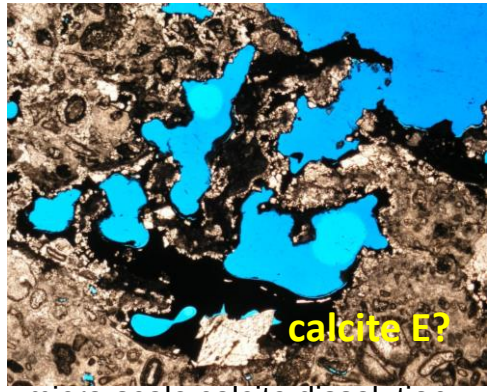




-multiple calcite-bitumen layers and etched calcite indicates pressure fluctuations?

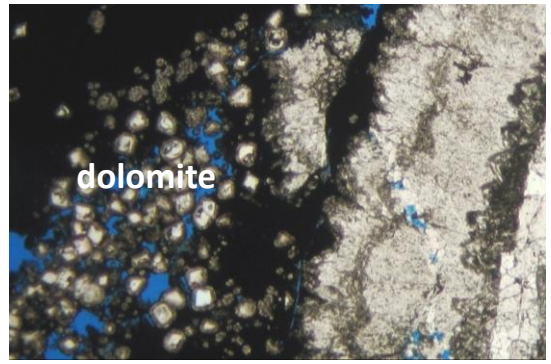
### DISSOLUTION

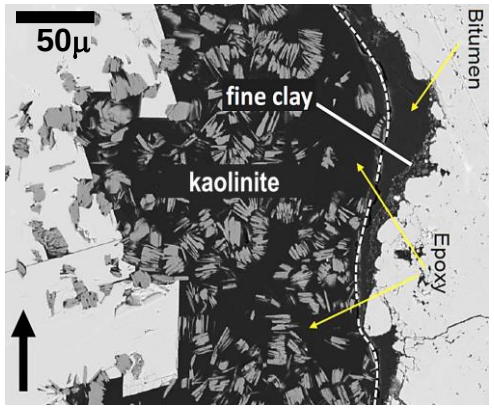





-micro-scale calcite dissolution
-local late porosity enhancement

### ALTERATION OF FRACTURE / KARST FILL



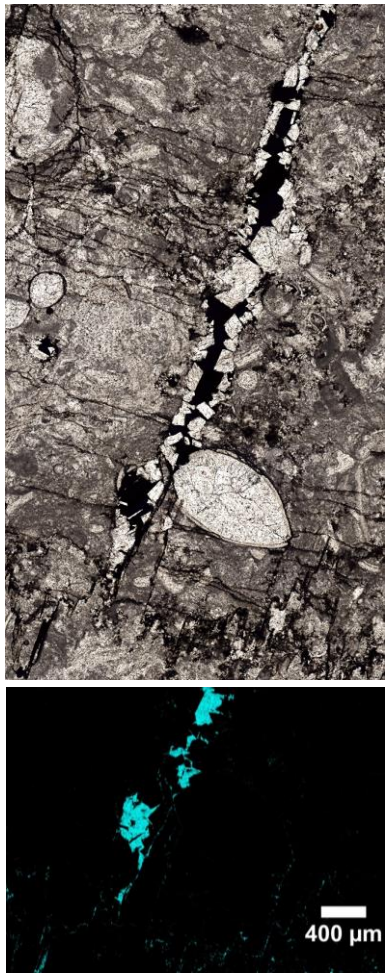




-high temperature fluids in voids
-clay altered to kaolinite
-released ions form secondary minerals

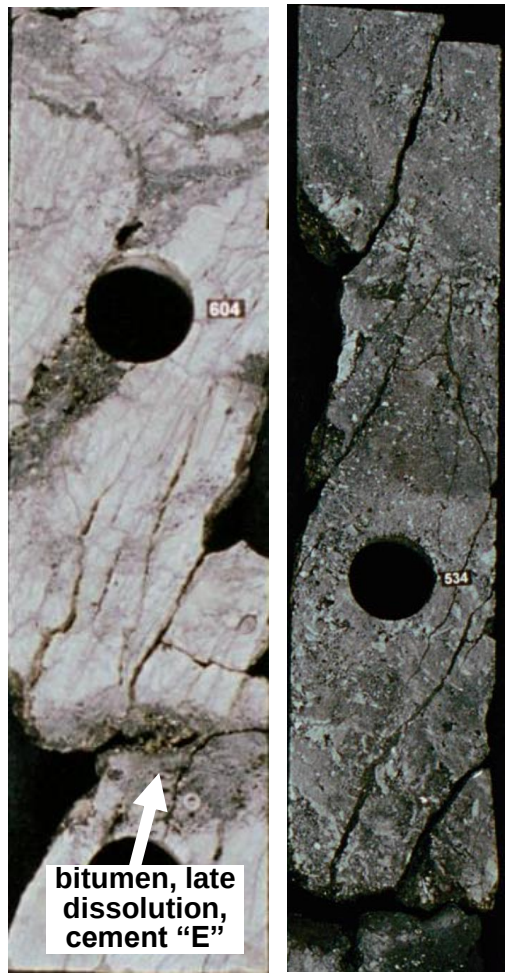
# 3. DIAGENETIC RESPONSE

## BURIAL FRACTURE SWARMS

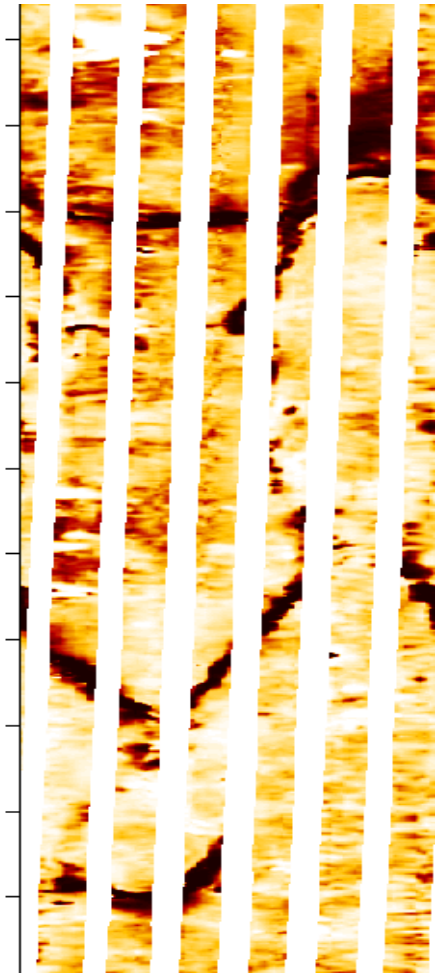
- Late diagenetic halos in adjacent matrix
- Solution-enlarged fractures formed feeder network into major conduits?
- Mobile fluids: solution-enlarged and cement-filled fractures both possible




Fracture and stylolite with 7%-S bitumen



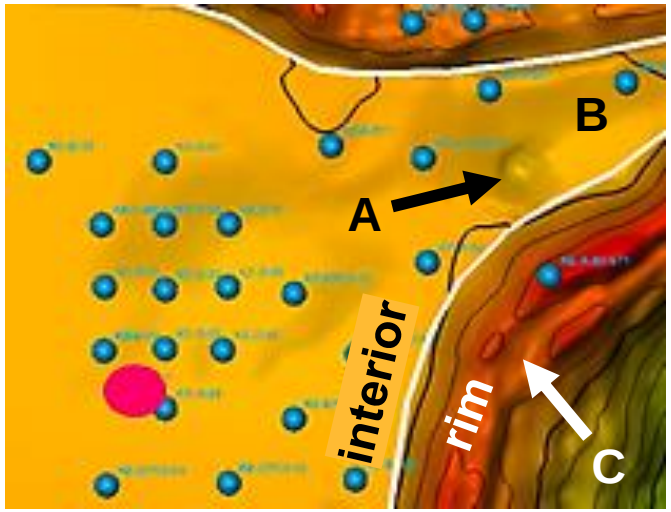

Burial fracture swarm with late diagenetic halos

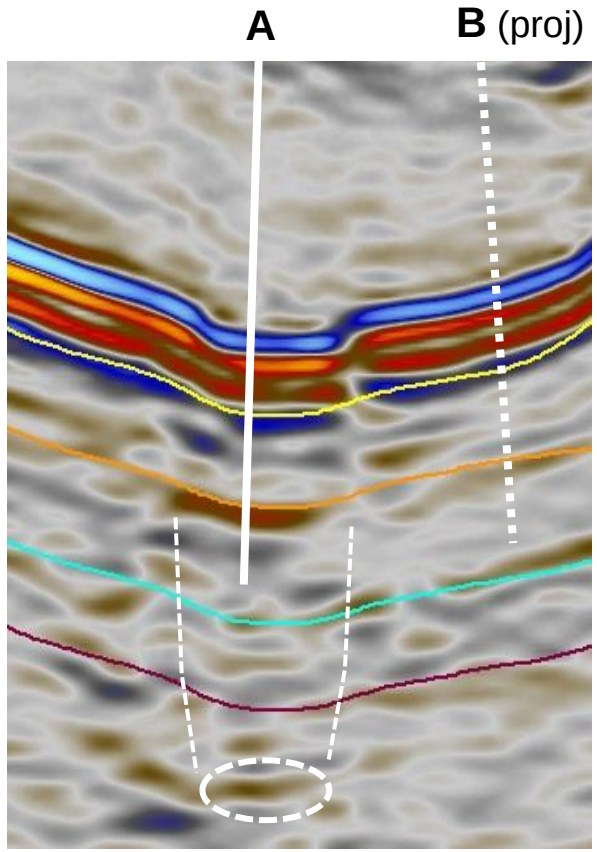


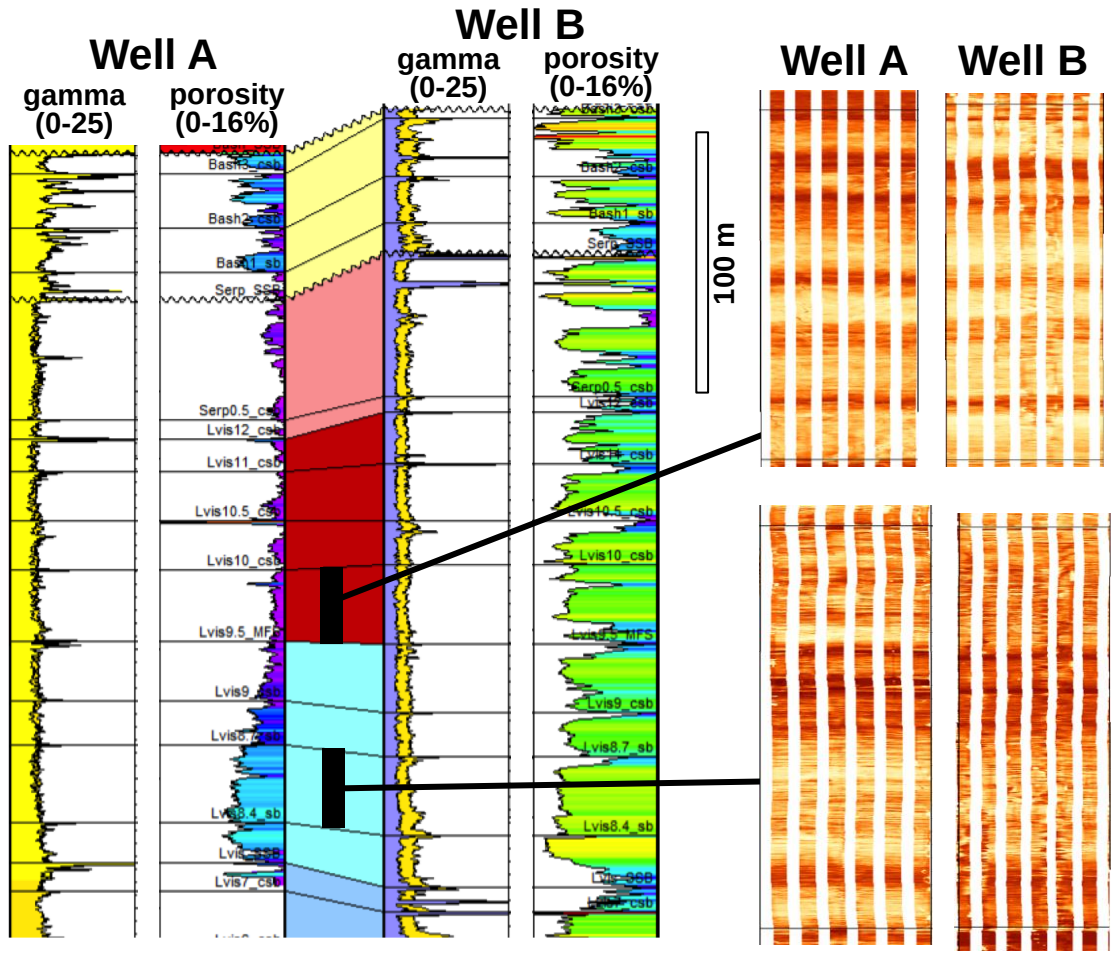
Solution-enlarged early fractures

## LARGE-SCALE COLLAPSE FEATURE WITH REDUCED POROSITY

- Well A: depositional cycles with anomalous low porosity
- Stratigraphy identical to Well B confirmed with image logs
- Low porosity attributed to bitumen (preserves resistivity contrast)
- Deep collapse (below well), but feature not visible on seismic
- Rim bifurcation (C) another collapse feature?



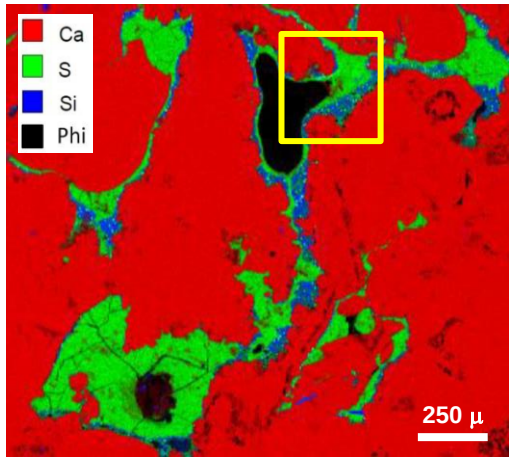



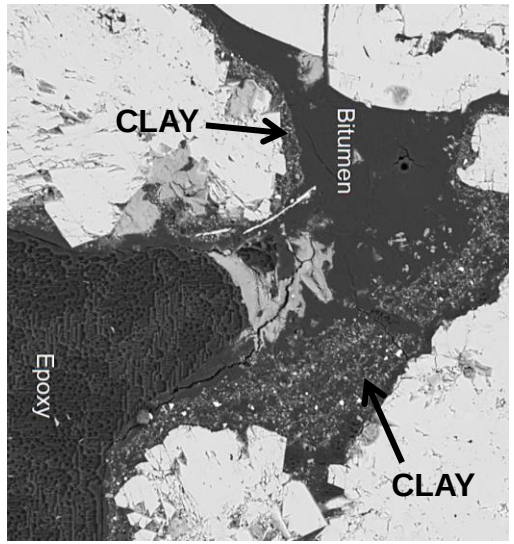



# 3. DIAGENETIC RESPONSE

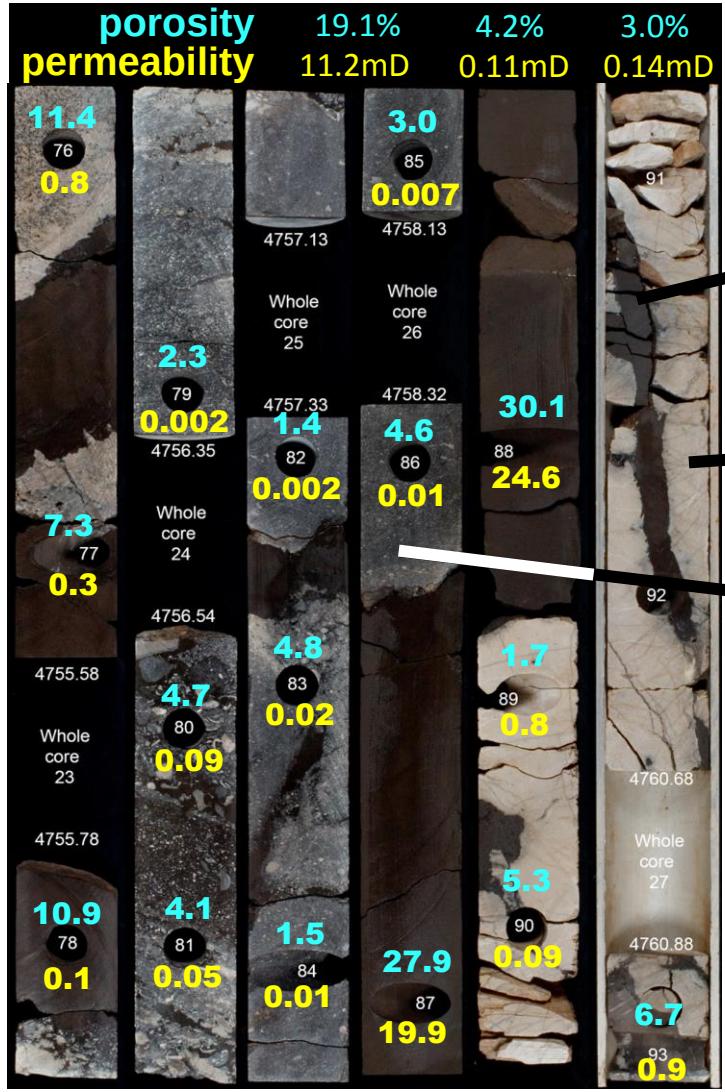
## ACTIVE FLUIDS

- Non-geopetal occurrence of clay impurities in bitumen
- Banded clays: combination of settling and flow




## OVERALL RESERVOIR QUALITY IMPACT




Increased permeability in fracture-karst system

-permeable fill

-solution-enlarged examples

Unaltered matrix

Altered matrix RQ looks better next to unaltered matrix, but improvement not indicated by data

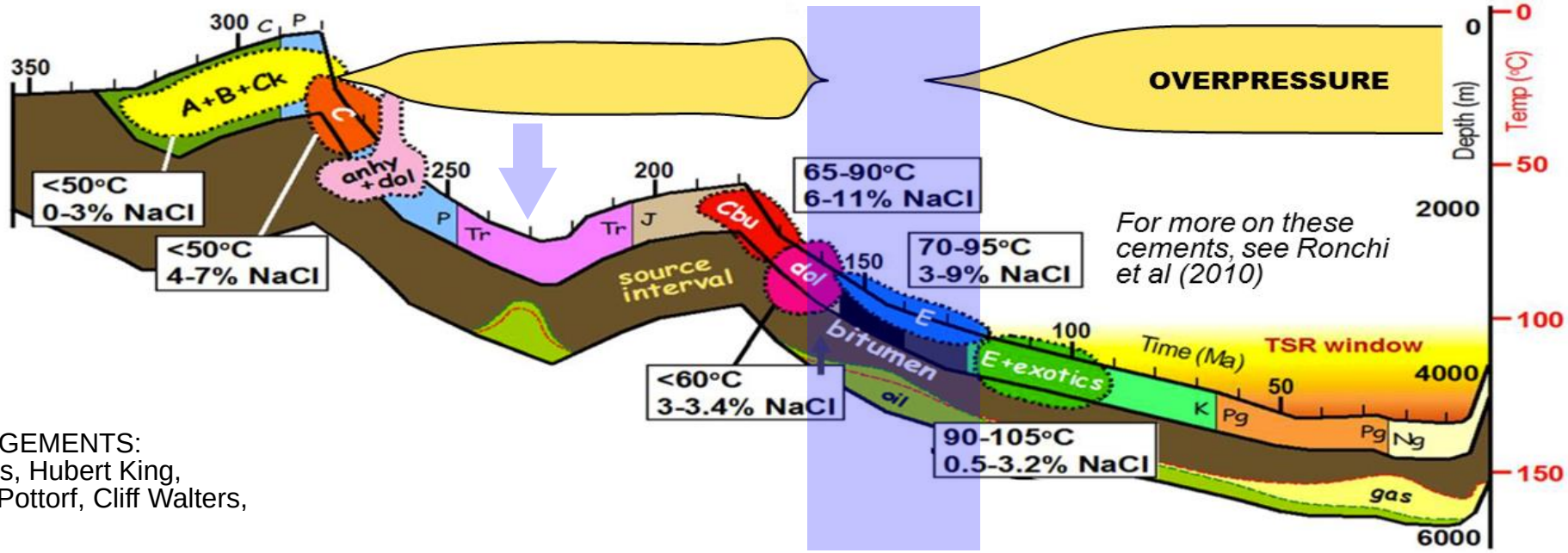
Altered matrix in buildup interior has lower RQ than un-altered matrix

# CONCLUSIONS and IMPLICATIONS

**(1) Elevated margin formed by rapid differential compaction during a temporary loss of reservoir overpressure and may be a diagenetic indicator**

**(2) Depressurization triggered increased circulation of oil and water in fractures, bitumen formation, and carbonate diagenesis driven by pressure variations**

**(3) Main reservoir quality impacts were improved fracture permeability in the rim, and locally reduced matrix porosity-permeability in buildup interior**




ACKNOWLEDGEMENTS:
NCOC Partners, Hubert King, Bill Horn, Bob Pottorf, Cliff Walters, Steven Becker