Burial Cementation and Dissolution in Carboniferous Slope Facies, Tengiz Field, Kazakhstan: Evidence for Hydrothermal Activity*

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Abstract

Tengiz Field is an isolated carbonate buildup in Kazakhstan that produces hydrocarbon from Carboniferous platform-top grainstones, slope microbial boundstones, and basinal breccias occupying a progradational buildup margin 800 to 1,000 m. thick within the oil column. Hydrocarbon production from this margin is controlled by non-matrix permeability (enlarged fractures and caverns), much of which was affected by burial dissolution. Corrosive fluids were distributed by early fractures associated with depositional instability, and compactional fractures formed during shallow burial.

The distribution of non-matrix porosity and dispersion of corrosion into adjacent matrix varies according to facies. Upper slope boundstones feature extensive destruction of original matrix porosity by early calcite cement, with burial dissolution initiated mainly along early fractures. Dissolution operated over sufficient time to form a network of small caverns along connected fractures. The overlying platform-top facies had early matrix porosity partly destroyed by burial calcite cement and bitumen and has fewer caverns because it contains fewer large fractures. The basinal breccias were too deep for gravitational fractures to be present, thus late dissolution occurred along stylolites and burial fractures. Reduced early cement volumes resulted in local preservation of matrix porosity that was enhanced by late burial dissolution. Cavernous porosity is predicted to be less important also in this facies, due to absence of the early fracture system.

Burial dissolution occurred in two stages. An early stage of in-situ corrosion followed a reservoir pressure decline and temporary evacuation of hydrocarbons that formed bitumen and burial cement. Cathodoluminescence, stable isotopes, and clumped isotope data show that burial cements include inorganic geothermal and hydrothermal calcite up to 225°C. During re-pressurization, calcite corrosion occurred along fracture walls and adjacent matrix in areas where bitumen is present, forming low-permeability pathways through the reservoir. A later stage of dissolution likely involved large-scale circulation of a corrosive fluid. Migration of an external fluid and lateral confinement by fractures explains a general vertical pattern of local matrix dissolution in basinal facies, dominantly fracture/cavern permeability in the slope facies, and partial matrix porosity occlusion by late calcite cement and bitumen in the platform-top facies.

Selected References

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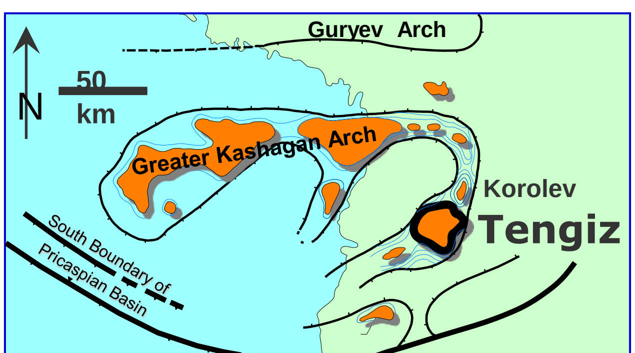
INTRODUCTION

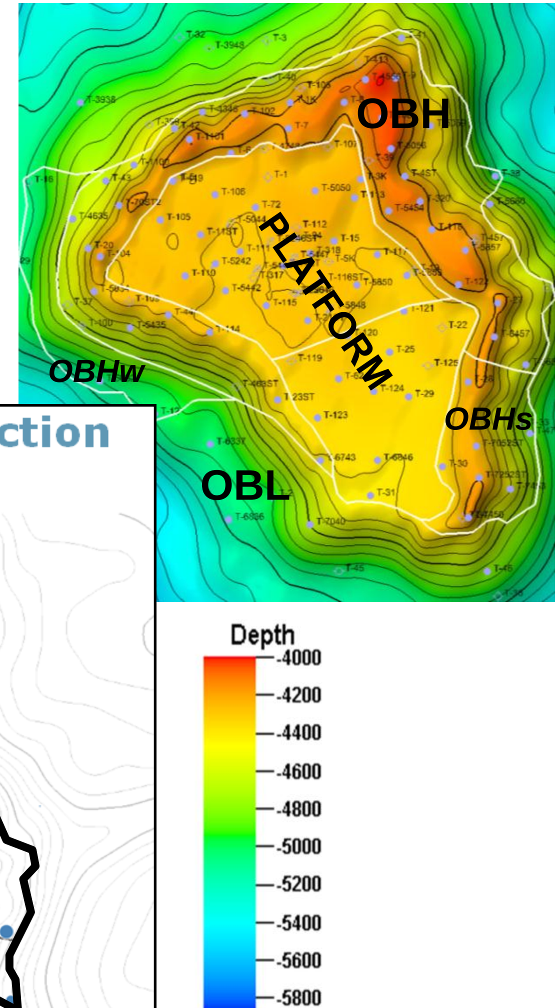
modified from Kenter et al., 2007

Isolated Carbonate Platforms / Organic Buildups

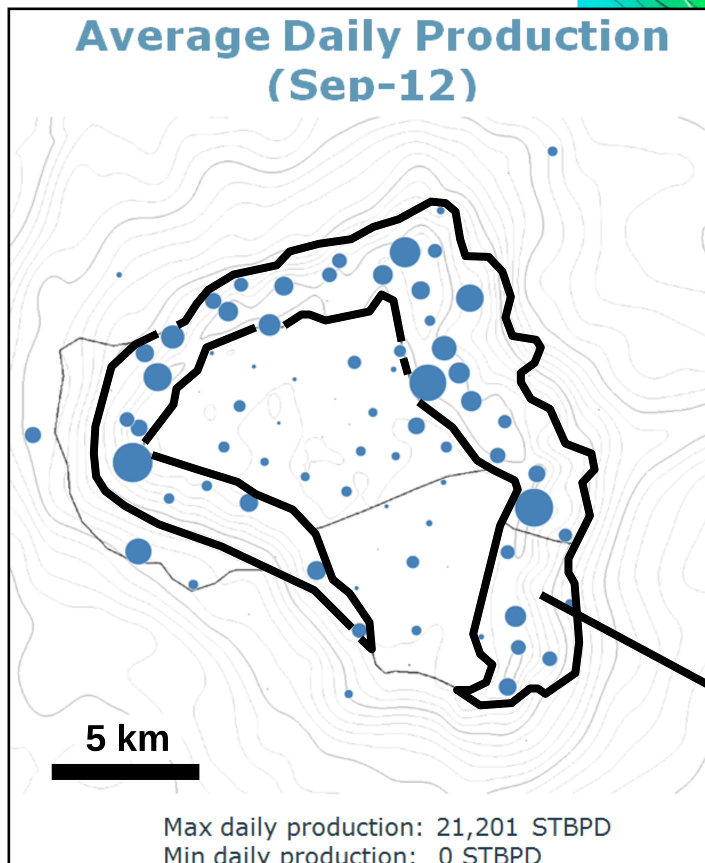


Tengiz Development Regions

OBH – Outboard high fracture
OBHs – Outboard high fracture south
OBHw – Outboard high fracture west
OBL – Outboard low fracture

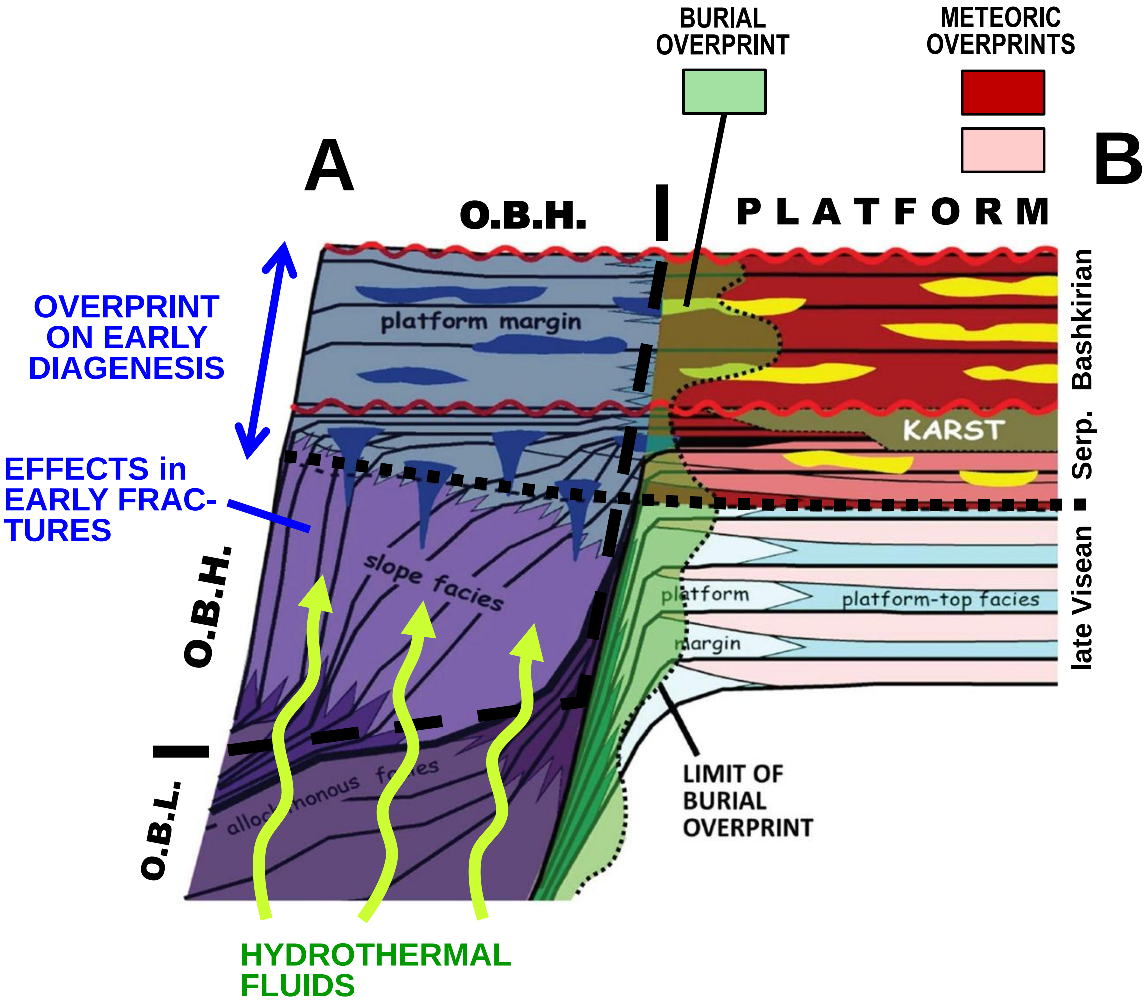


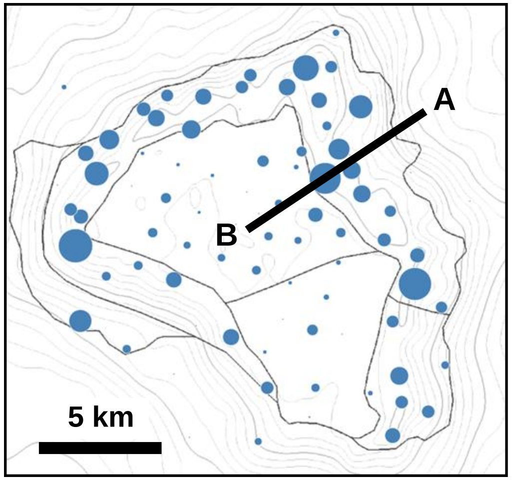
O.B.H. AREAS ENCOMPASSING FRACTURED SLOPE FACIES



OBH + OBHs:
1800–24,200 bopd

BURIAL DIAGENETIC OVERPRINT DISTRIBUTION





-PROGRADING MARGIN and ADJACENT PLATFORM REGION

-ENLARGED FRACTURES and CAVERNS in SLOPE (MICROBIAL) FACIES

-MATRIX ADJACENT TO ENLARGED FRACTURES

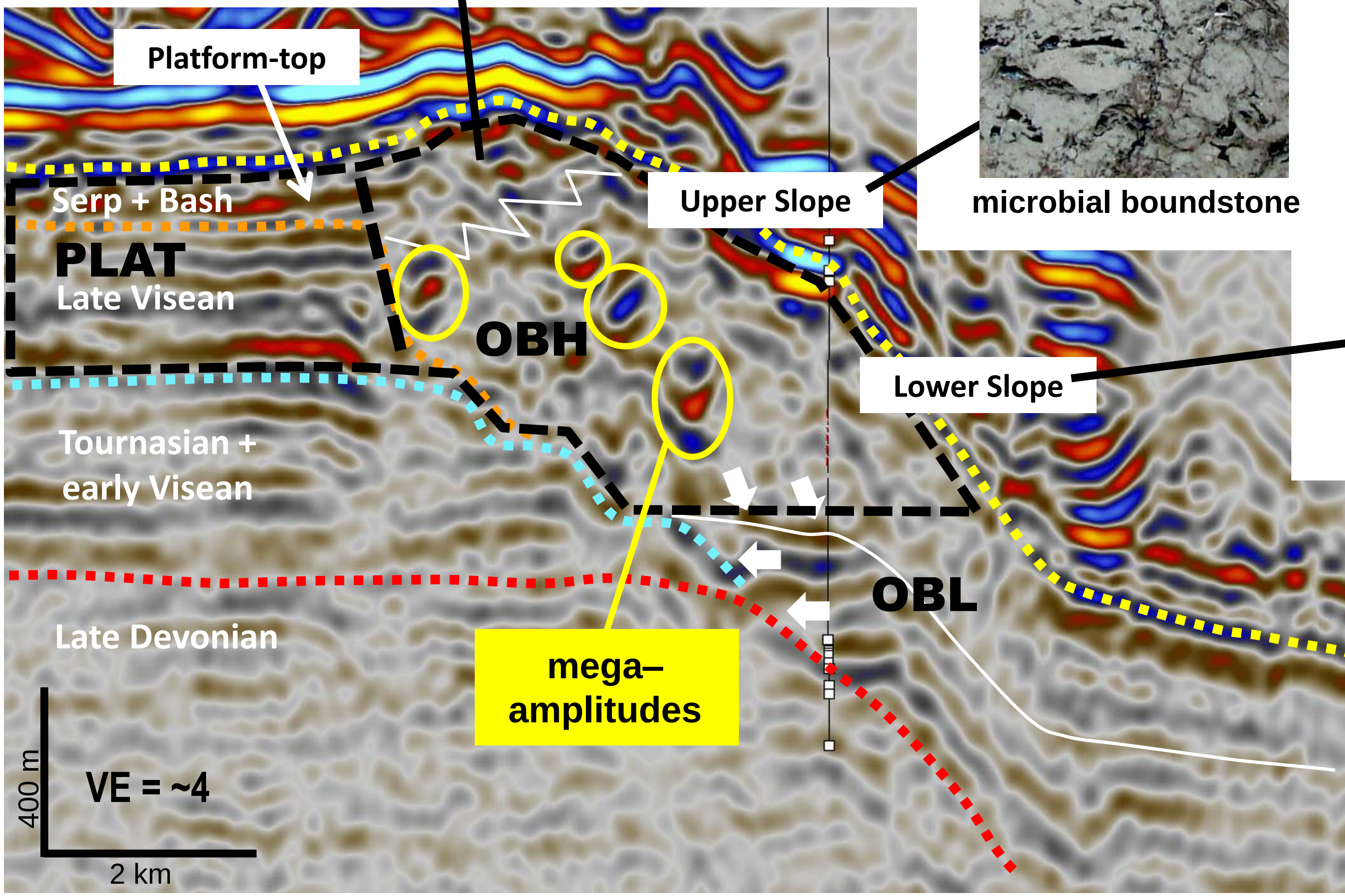
CAVERNOUS POROSITY CONCENTRATED in MICROBIAL FACIES

platform-top grainstone

microbial boundstone

1 cm

boundstone breccia



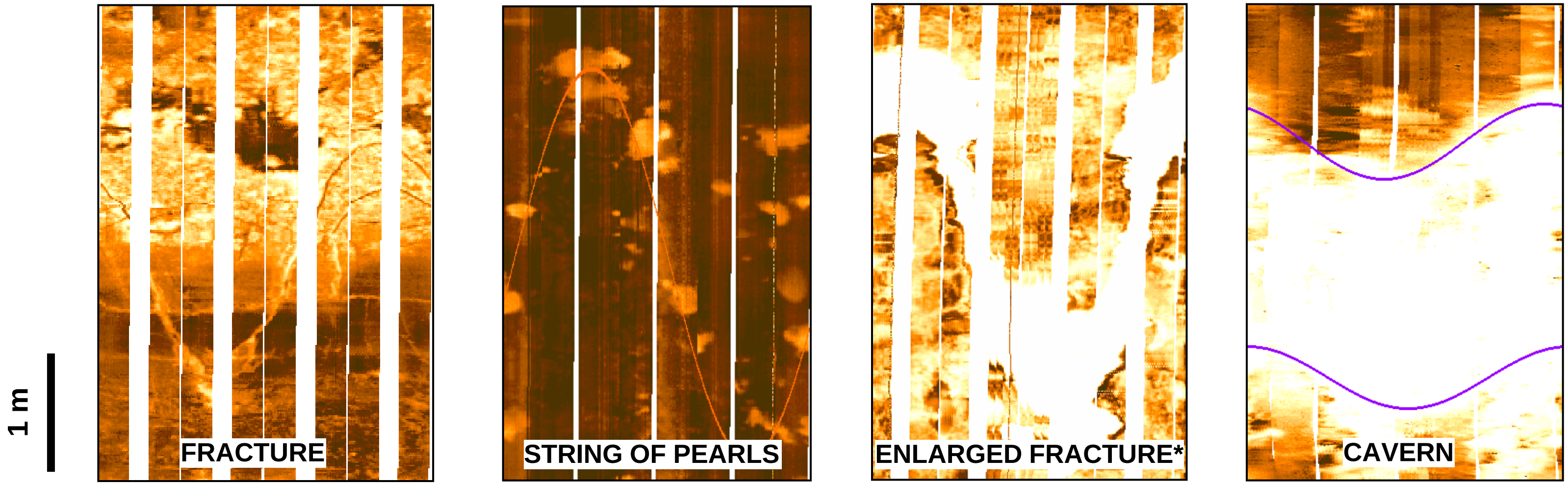
MASSIVE BOUNDSTONE BRECCIA in LOWER SLOPE

IN-SITU BOUND-STONE IN UPPER SLOPE

CAVERNOUS POROSITY VISIBLE on SEISMIC

EFFECT of BURIAL DIAGENESIS on FRACTURES

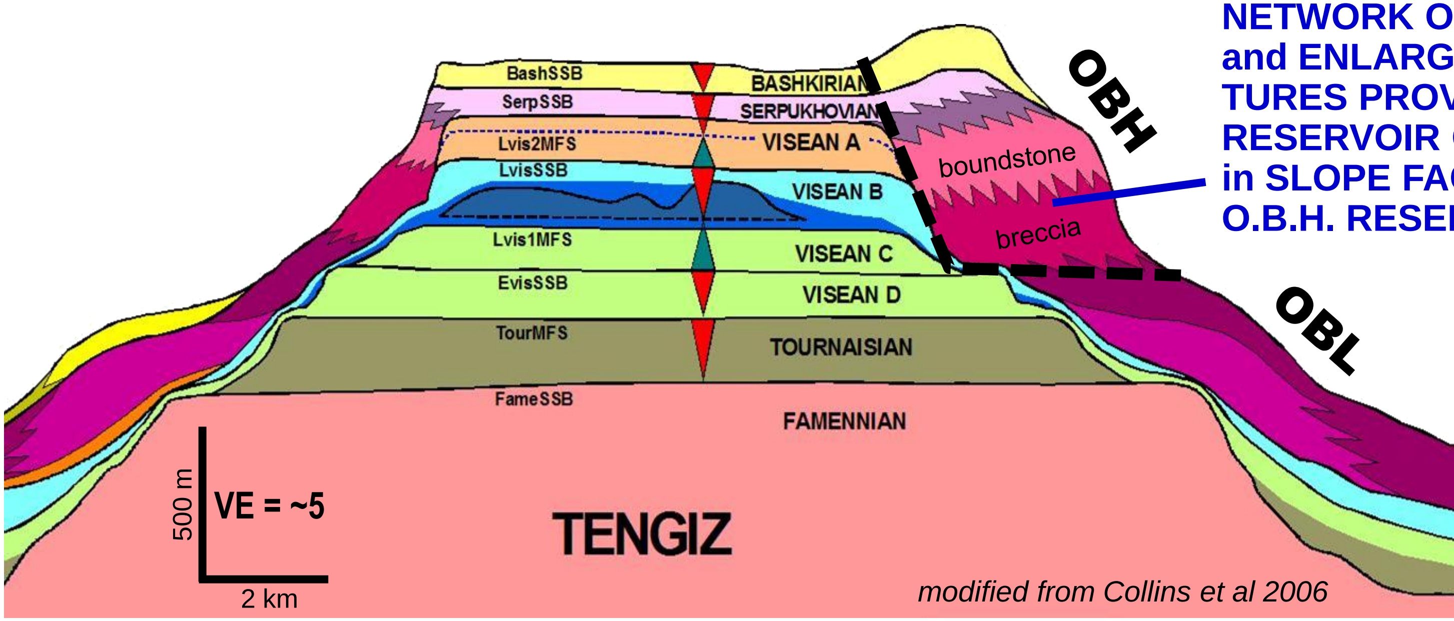
ENLARGEMENT of EARLY FRACTURES



*open fractures appear bright (oil-base mud)

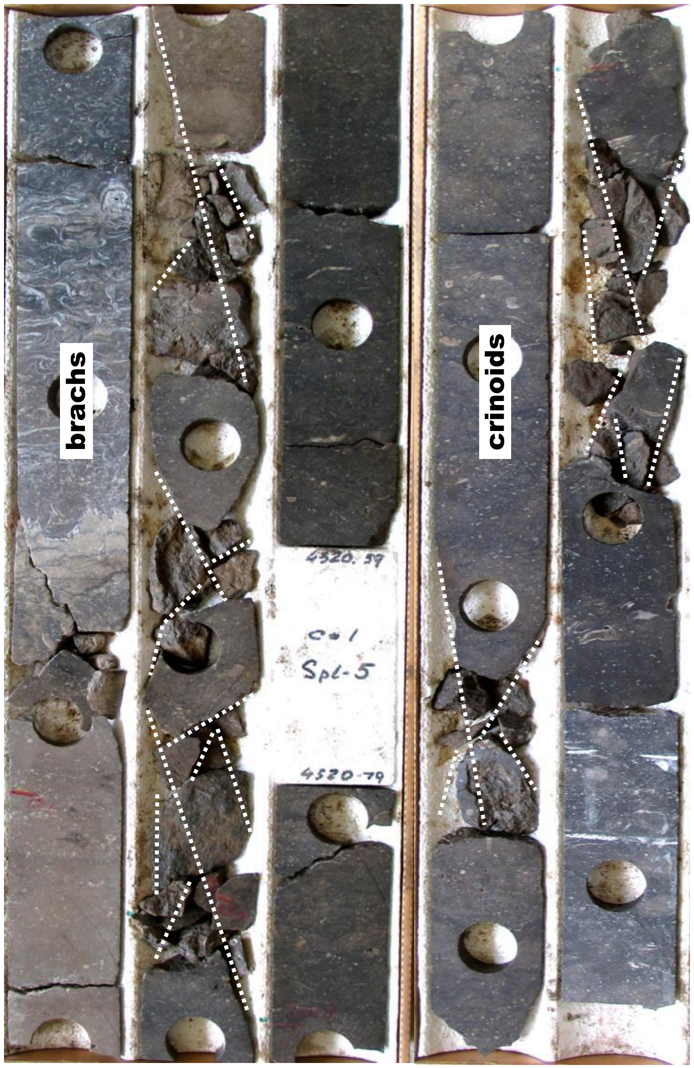
fracture flow – dissolution feedback mechanism (Palmer 1991)
fracture permeability increases with time

NETWORK OF CAVERNS and ENLARGED FRACTURES PROVIDES HIGH RESERVOIR CONTINUITY in SLOPE FACIES of O.B.H. RESERVOIR

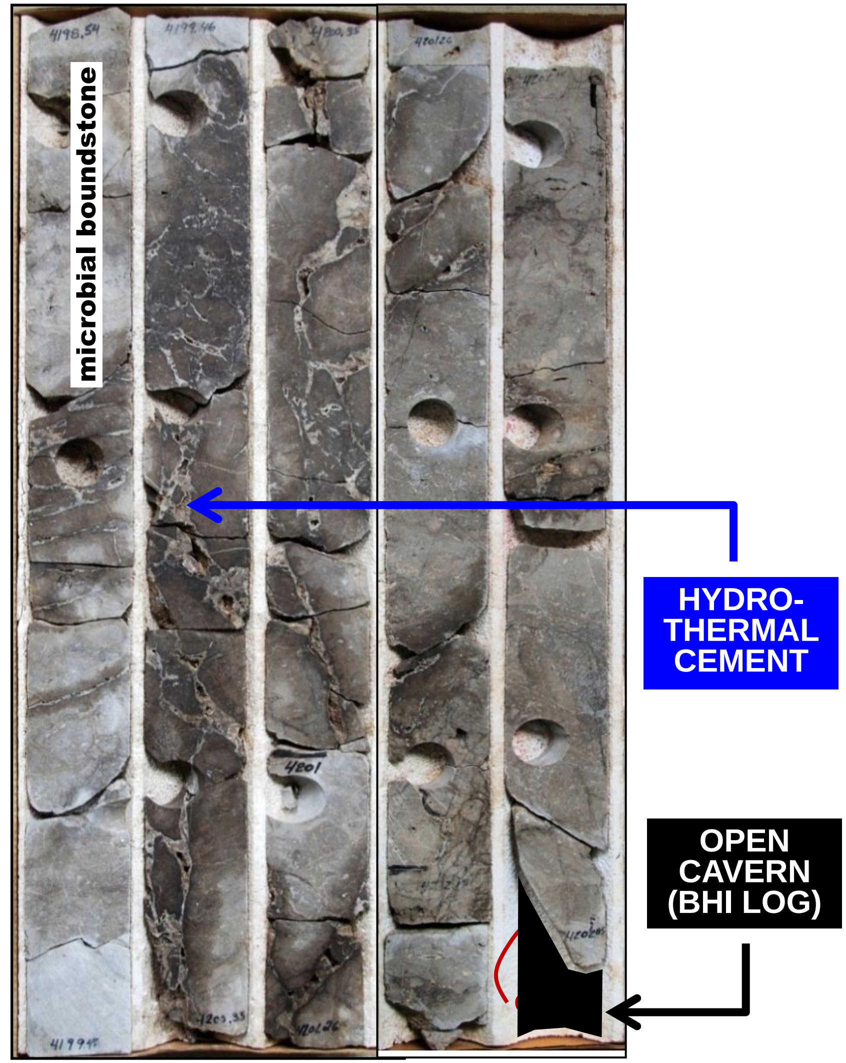


BURIAL OVERPRINT IN MATRIX AROUND FRACTURES

HIGHER MATRIX PERMEABILITY:
"THICK" FRACTURE / RUBBLE ZONES THAT COULD HAVE SOME LATERAL CONTINUITY

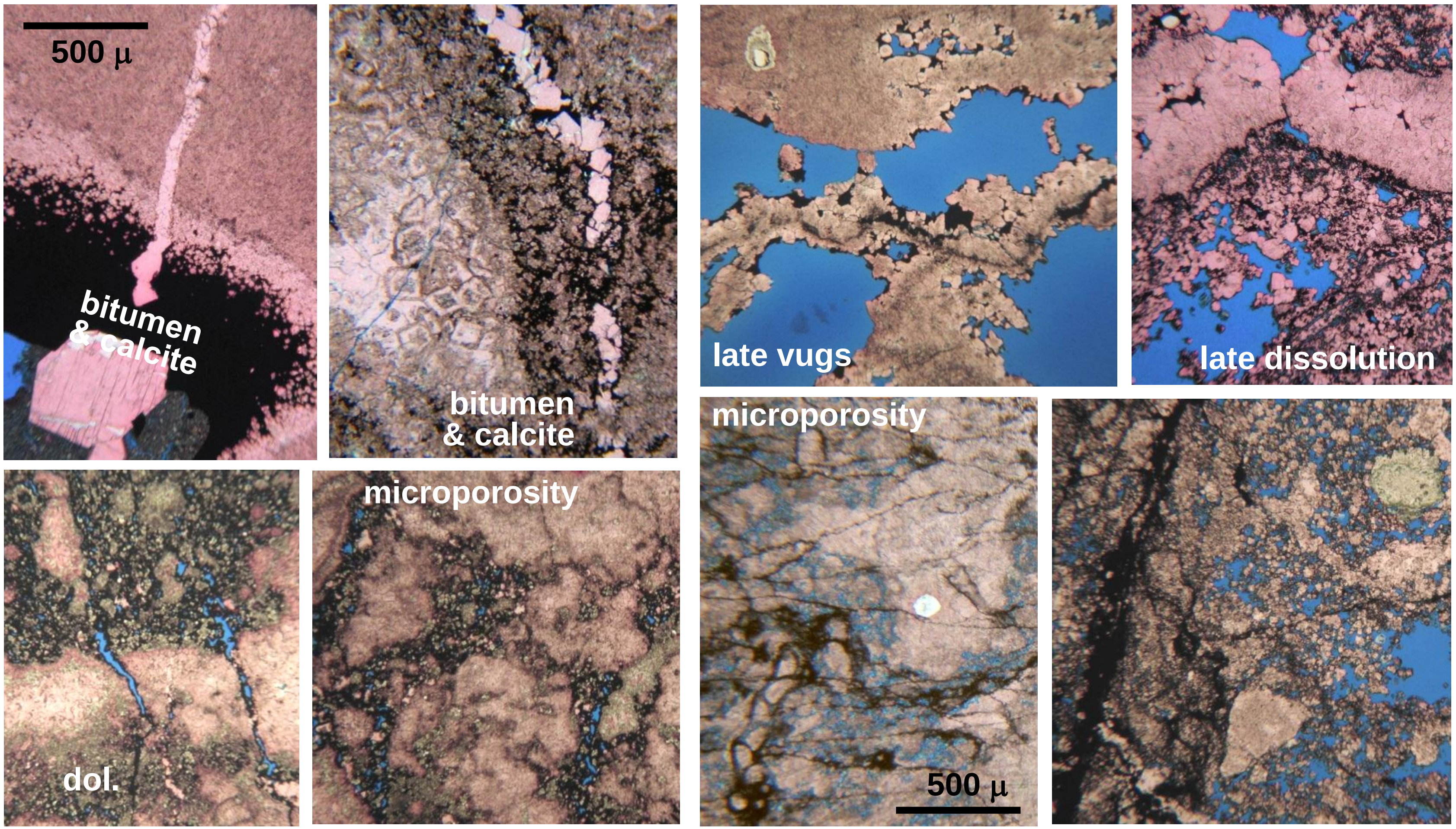


LOWER MATRIX PERMEABILITY:
THIN HALOS AROUND ENLARGED FRACTURES (+/- COARSE SPAR CEMENT)



MATRIX BURIAL OVERPRINT

(1) CALCITE–BITUMEN CO-PRECIPITATION & DISSOLUTION
(2) MATRIX MICROPOROSITY ENHANCEMENT
(3) POST-BITUMEN DISSOLUTION

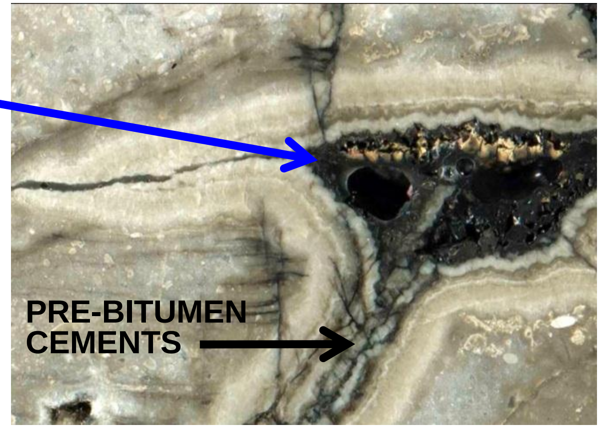


TIMING for BURIAL OVERPRINT

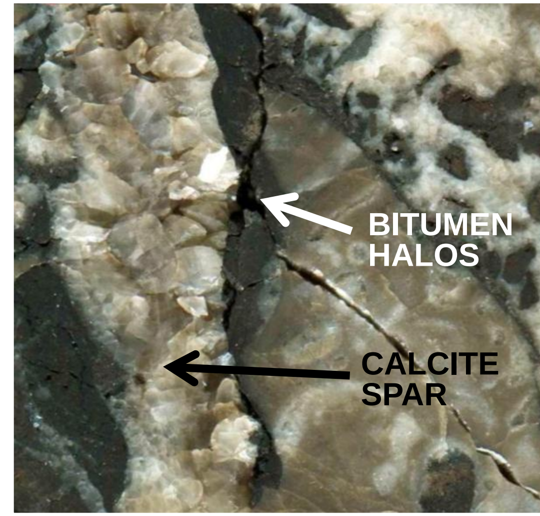
ESTABLISHED BY 90^{O}C FLUID INCLUSION TEMP-ERATURES FROM CALCITE SPAR IN BITUMEN

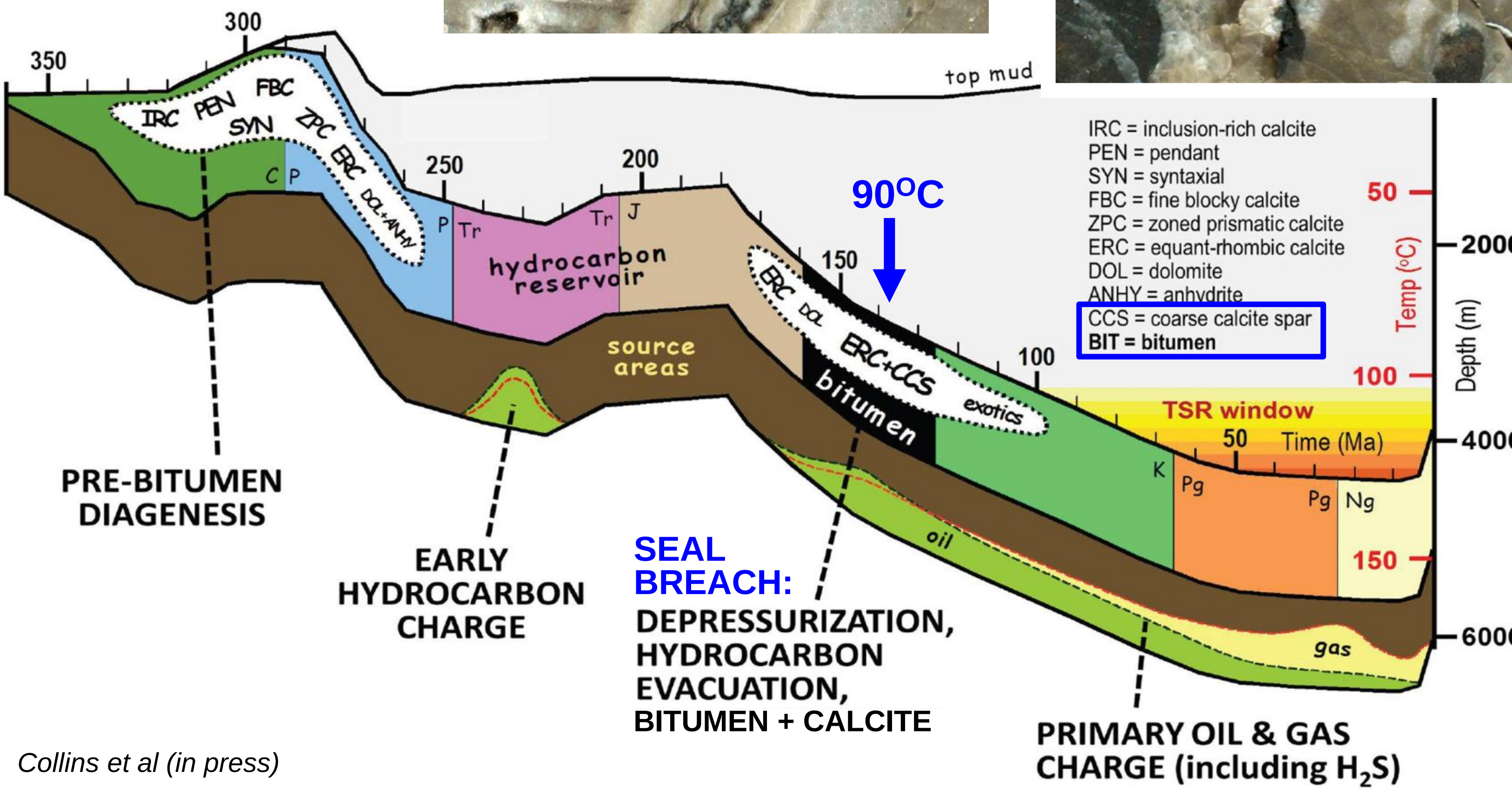
ASSUMED PRECIPITATED AT AMBIENT RESERVOIR TEMPERATURES

LATE PASSIVE PORE-FILL PHASE



VEINS & FRACTURES





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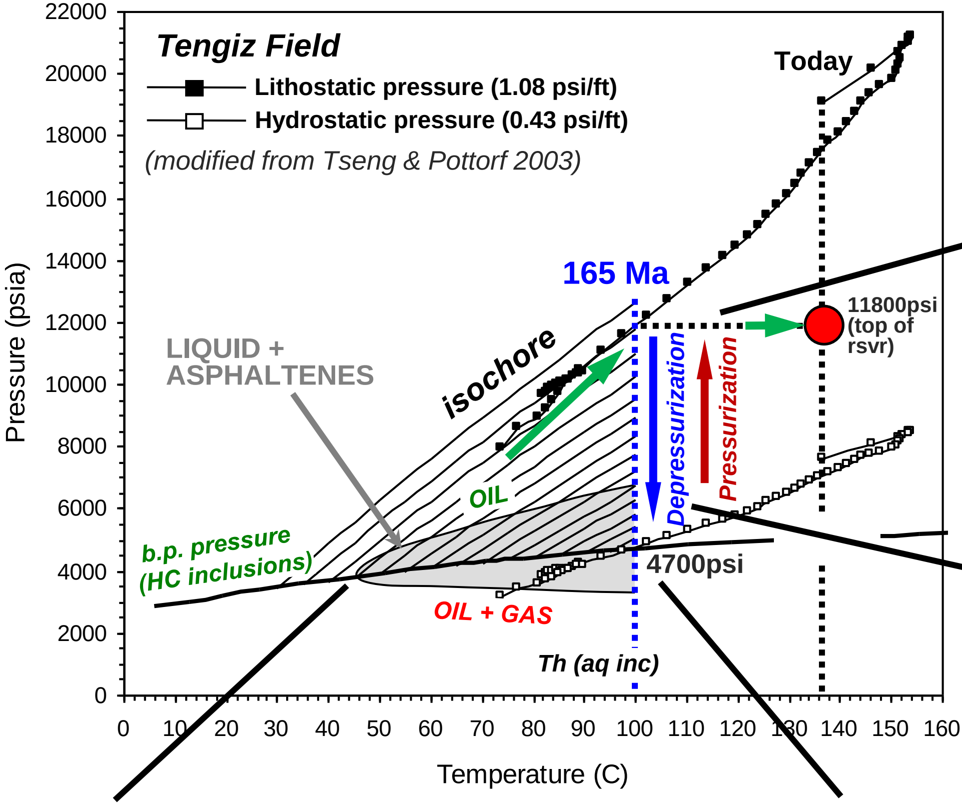
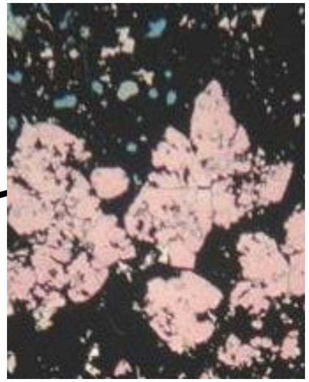
ORIGIN of the BURIAL OVERPRINT

MULTIPLE PRESSURE FLUCTUATIONS → "IN-SITU" DIAGENESIS

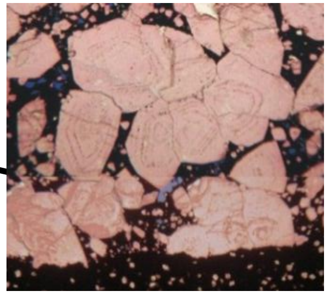




HIGH PRESSURE

-calcite dissolution

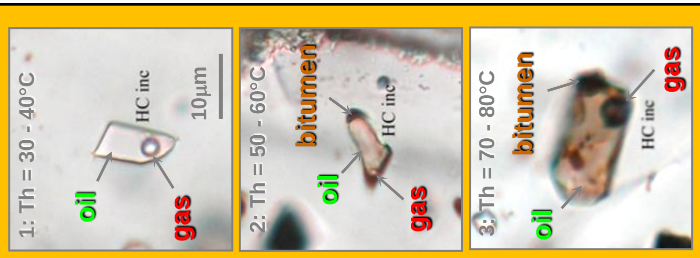
-bitumen stops forming



LOW PRESSURE

-calcite + bitumen co-precipitate

-fluid inclusions in new growth bands



Bitumen precipitation (T_{trap} = 90 – 100°C)

-oil density increases
-bitumen in fluid inclusions
-oil & water inclusions in same cement

<u>TOPSEAL FAILURE</u>:
-reservoir near seal fracture pressure
-reservoir T = 90–100°C (water inclusions)
-pressure drop @ ~constant T (oil inclusions)
-pressure differential of ~6000–7000 psi
-hydrocarbon flux (migration and evacuation)
-diagenetic potential from organic acids

Diagenetic potential from large-scale fluid flow?

ROLE OF FRACTURES DURING BURIAL DIAGENESIS

-EARLY FRACTURES COLLECTED ADDITIONAL CEMENT (BITUMEN + CALCITE)
-BURIAL FRACTURES FORMED (BITUMEN + CALCITE)
-REACTIVATION OF SOME EARLY FRACTURES?
-LATE DISSOLUTION and CEMENTATION OF EARLY FRACTURES

IN-SITU FILL?

SOME EARLY FRACTURES REACTIVATED DURING PRESSURE FLUCTUATIONS?

BURIAL FRACTURES

SECONDARY FRACTURES with BITUMEN + CALCITE (associated with stylolites)

FRACTURE – CAVERN NETWORK

CONDUITS for HYDROTHERMAL CEMENT and DISSOLUTION?

TECTONIC?

LATE FRACTURES NOT DISSOLVED

CLUMPED-ISOTOPE ANALYSES

CLUMPED ISOTOPES

SENSITIVE to PRECIPITATION TEMPERATURE for CALCITE

ISOTOPIC ANALYSIS of MOLECULAR (C-O) BONDS in $CaCO_3$:

PROPORTION OF ^{13}C–^{18}O BONDS ARE TEMPERATURE SENSITIVE, INDEPENDENT OF BULK COMPOSITIONS:

$$Ca^{12}C^{18}O^{16}O_2 + Ca^{13}C^{16}O_3 \longleftrightarrow Ca^{13}C^{18}O^{16}O_2 + Ca^{12}C^{16}O_3$$

HOTTER CALCITES ⟵ ⟶ COLDER CALCITES

-Eiler (2007)

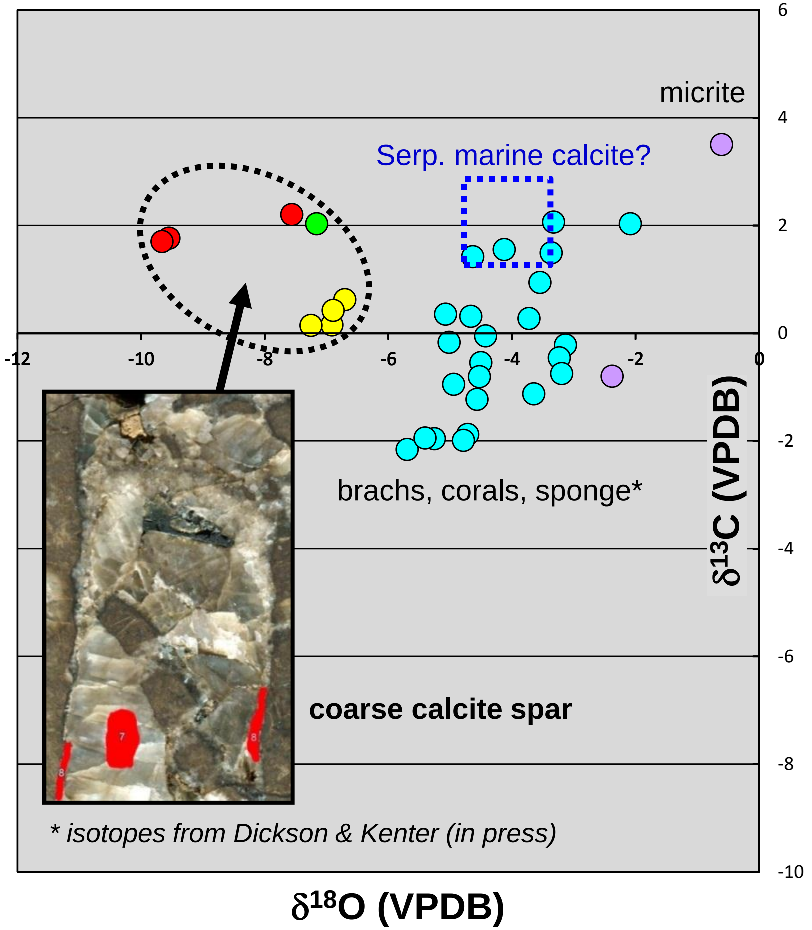
-LIMITED TENGIZ FLUID INCLUSION DATA

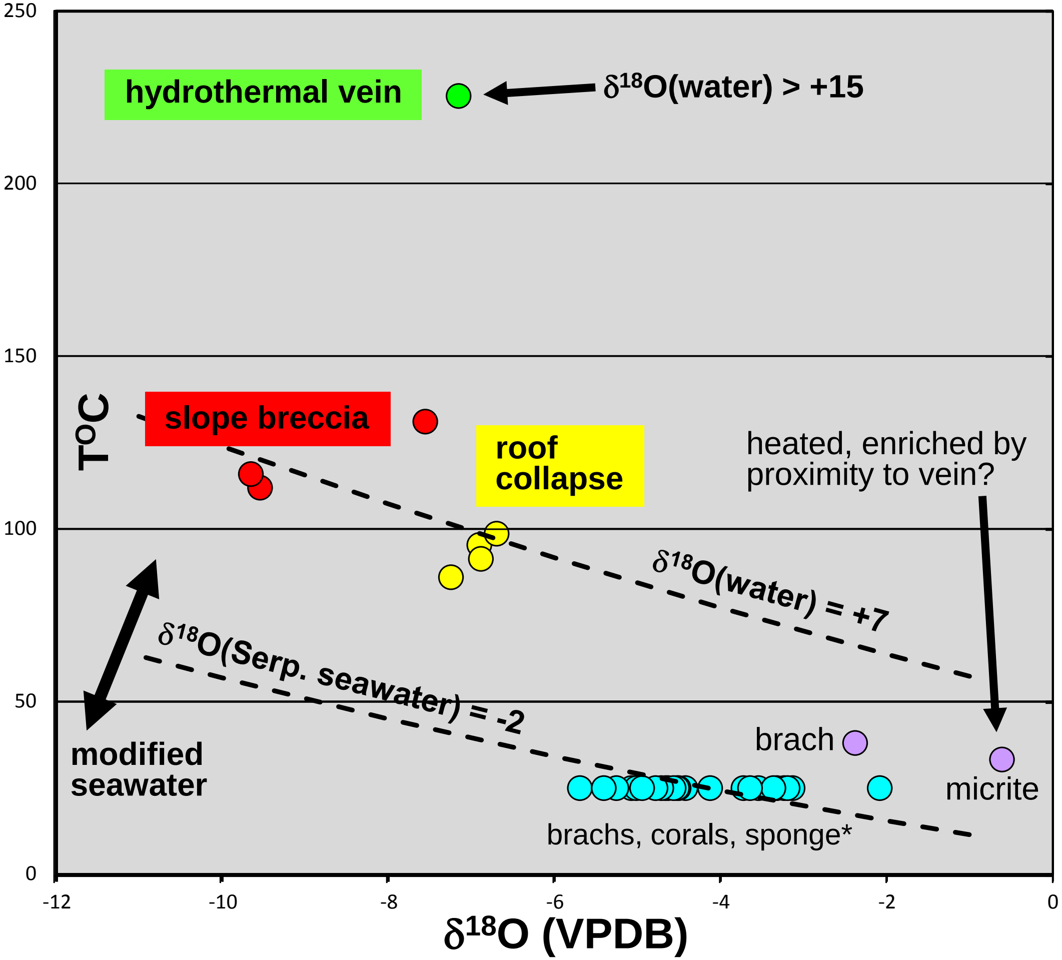
-USEFUL BETWEEN FREEZING AND 300°C

-USE WITH CONVENTIONAL ISOTOPIC RATIOS ($^{13}C/^{12}C$, $^{18}O/^{16}O$) TO ANALYZE FLUID COMP.

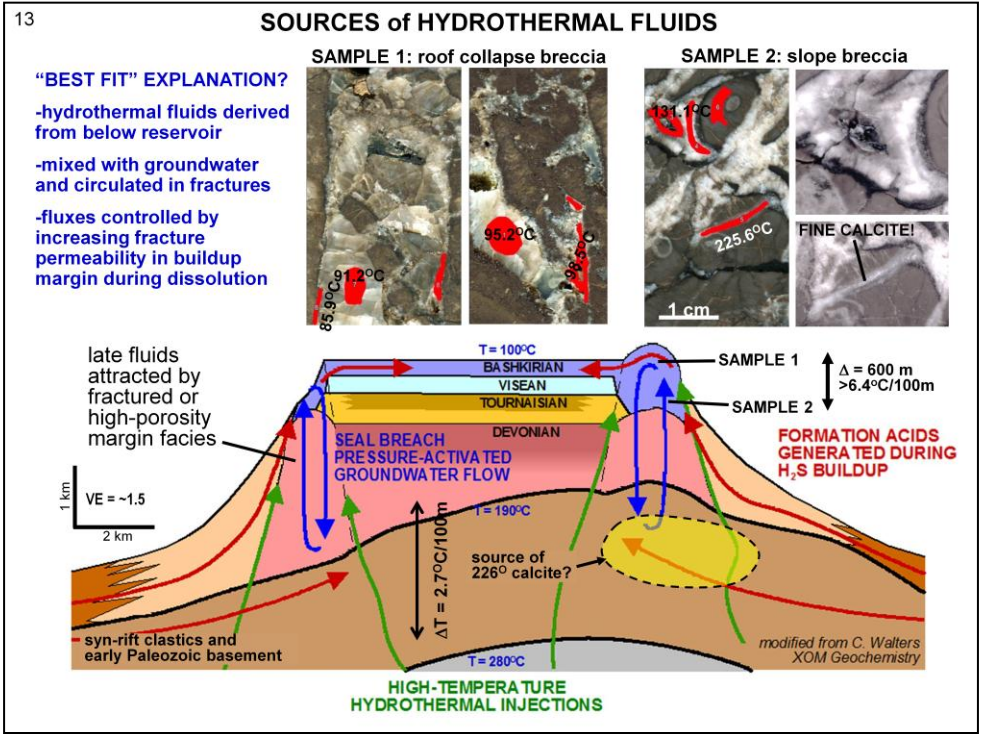
TENGIZ RANGE: 86 – 226°C (MOST WERE ABOVE RESERVOIR TEMPERATURE)

TENGIZ RESULTS





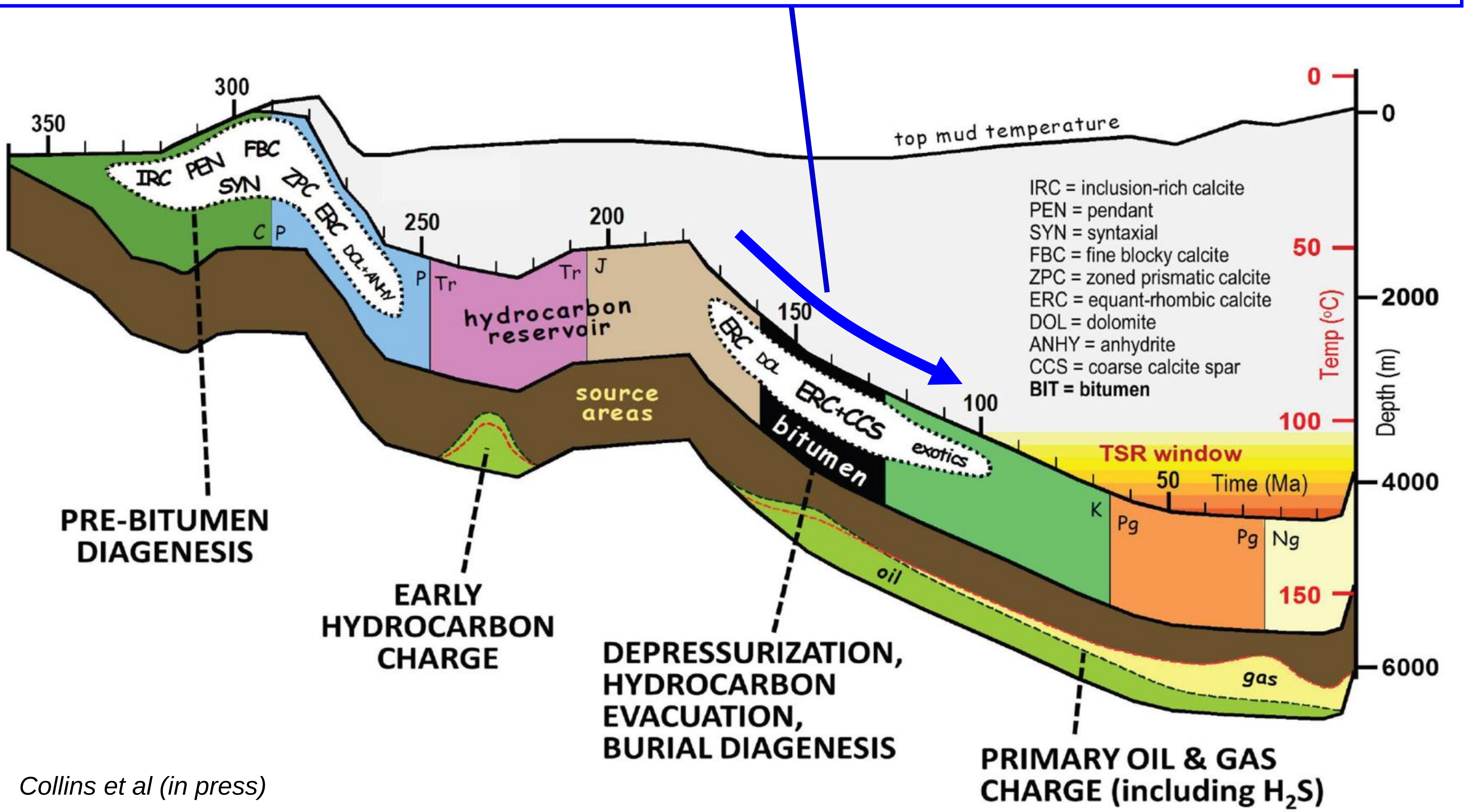
-hydrothermal temperatures up to 226°C
-enriched fluids probably not in equilibrium with reservoir
-no indication of organic carbon source (large –ve $\delta^{13}C$)
-basin derived fluid or modified groundwater?



Presenter's notes: The 600m depth difference between the roof and slope calcites implies a minimum temperature gradient greater than geothermal (the slope breccia average temperature excludes the 226°C vein), suggesting at least hydrothermal circulation. The 226°C vein would have to have originated below the reservoir if it was precipitated at the time of the depressurization event (or deeper if some cooling occurred).

SEQUENCE OF EVENTS SUMMARY

HYDROTHERMAL EVENT CAUSED BY SEAL BREACH \ PRESSURE TRANSIENTS?
- seal breach caused by addition of primary charge to reservoir (overpressure)
- compaction, stylolites, and burial fractures
- some early fractures reactivated
- fractures dissolved by organic acids (pressure, hydrocarbon + groundwater flux)
- hotter and deeper fluids involved as fracture permeability increased



Collins et al (in press)

CONCLUSIONS

1. EARLY CLUMPED ISOTOPES RESULTS INDICATE HYDROTHERMAL ACTIVITY INVOLVED IN BURIAL DIAGENESIS

2. SUGGESTS RESERVOIR PRESSURE FLUCTUATIONS and FRACTURE PERMEABILITY AS DRIVERS FOR LARGE-SCALE FLUID FLOW LIMITED TO THE MARGIN OF TENGIZ FIELD

ALMATY, KAZAKHSTAN