# PS Geothermal Convection at Tengiz: Reactive Transport Models of Predictive Diagenesis and Evidence from the Rocks*

By

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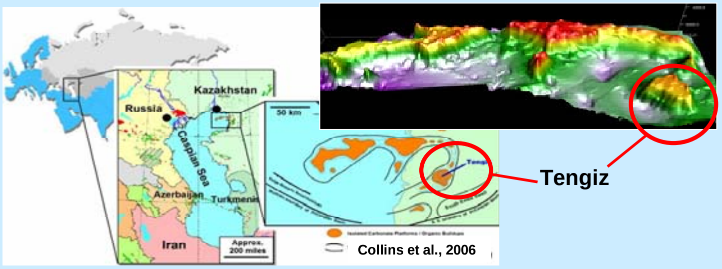
## Abstract

Reactive Transport Models that couple fluid flow and chemical reactions were used to test the viability of pre and post burial geothermal convection in the Tengiz carbonate platform reservoir. Simulations demonstrate that geothermal convection can drive diagenetic reactions capable of modifying reservoir quality. Specific model predictions include: 1) Concurrent dissolution and cementation in a mixed-convective system prior to burial in the platform rim, 2) Dissolution by forced convection prior to burial towards the platform center, 3) Perpetuation of early diagenetic patterns, but at lower rates after burial, 4) Dissolution beneath salt-withdrawal basins and cementation in the platform interior due to free convective flow modified by halokinetics and 5) Minor to no dolomite.

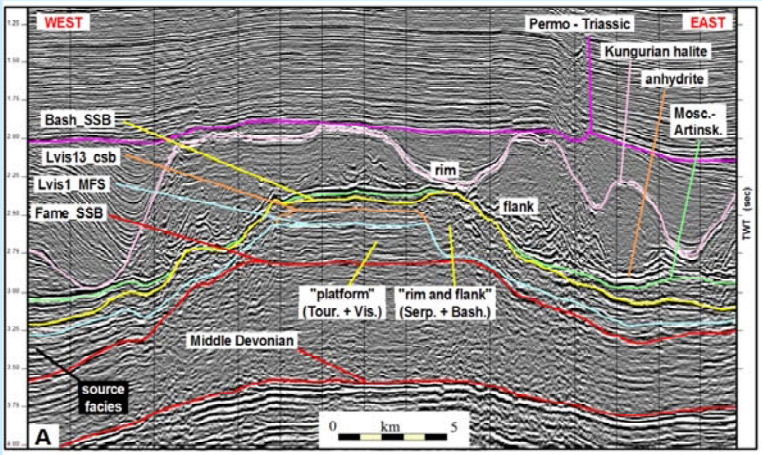
Ongoing Tengiz reservoir characterization studies were used to evaluate model predictions. Core and petrographic data support or at least do not rule out model predictions 2), 3) and 5). Enhanced porosity that is stratigraphically discordant, vertically oriented and platform-centric supports model predictions 2) and 3). Dolomite is present in the Carboniferous section but is generally volumetrically insignificant supporting prediction 5). Model prediction 1) is possible, but has been overprinted by later cementation and dissolution. A zone of enhanced porosity beneath a salt dome and not the adjacent withdrawal basin suggests model prediction 4) is either invalid or has been overprinted by later diagenesis.

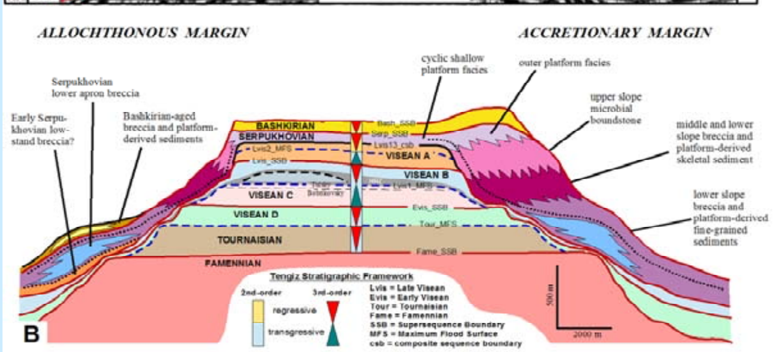
This case study demonstrates the potential of Reactive Transport Models to develop viable and testable hypotheses that if integrated with observations from the rock record results in improved process-based predictions of carbonate reservoir quality.

# Tengiz Geologic Setting




- Tengiz is a world class “super giant” oil field located in Kazakhstan
- Reservoir is a Devonian to Carboniferous age isolated carbonate platform
- Sediments are predominantly grainy in the platform interior
- The rim and flank (highest rate wells) is composed of fractured microbial boundstones
- The seal is provided by a thin shale and a thick salt section

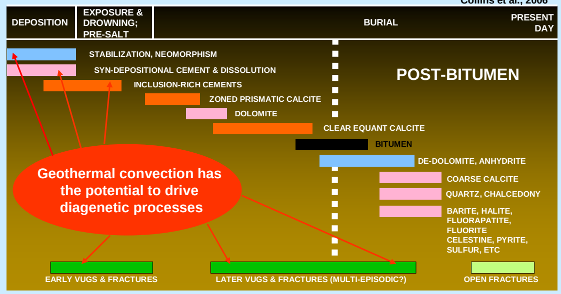


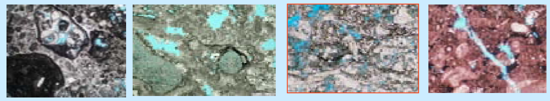




Collins et al., 2006

# Tengiz Diagenesis

Collins et al., 2006



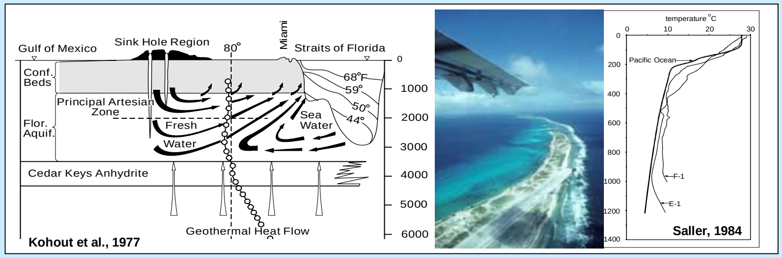



- Diagenesis at Tengiz is complex spanning pre to post burial environments
- Reservoir quality modification by diagenesis is more significant than previous studies suggest

# Geothermal Convection in Nature

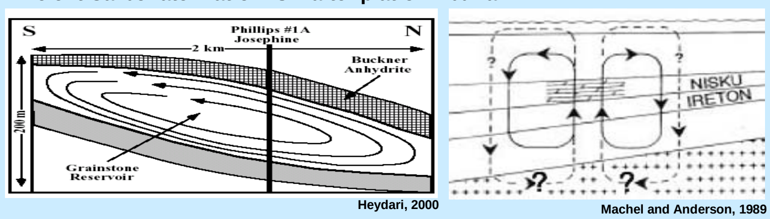
*‘Geothermal convection describes groundwater flow in response to temperature derived variations in fluid density’*

## Modern Carbonate Platforms – prior to platform burial

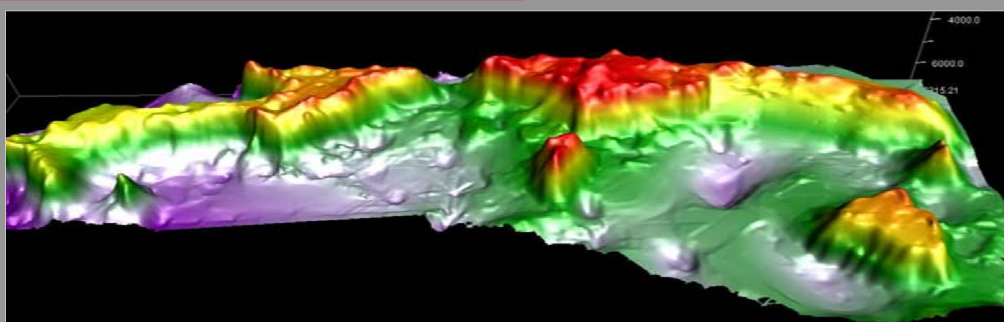



- Commonly observed in rimmed shelf carbonate platform margins (e.g. Florida; Enewetak Atoll)
- Invoked to explain calcite cementation and seawater dolomitization

## Ancient Carbonate Platforms - after platform burial




- Never directly observed in nature and conflicting conclusions on diagenetic potential
- Invoked to explain calcite cementation (Jurassic Smackover Fm) and dolomitization (Nisku Fm)



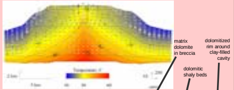
# Geothermal Convection at Tengiz
# Reactive Transport Models of Predictive Diagenesis and Evidence from the Rocks

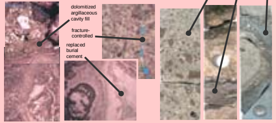
G. D. Jones, J.F. Collins, Y. Xiao, J.A.M. Kenter, P. M. Harris & G. Kuanysheva

## Executive Summary


- Reactive Transport Models (that couple groundwater flow and chemical reactions) support the hypotheses that geothermal convection can drive groundwater flow in Tengiz, both before and after burial
- The associated spatial distribution of diagenesis is a derivative of this evolving flow system
- Results show 5 specific predictive diagenetic concepts
  - Limited potential for seawater dolomitization
  - Limited burial diagenetic modification of Units 2&3
  - Burial dissolution in the central platform
  - Dissolution associated with salt withdrawal basins
  - Vertical dissolution and cementation in boundstone slope
- Evidence from the rocks supports several of the model predictions

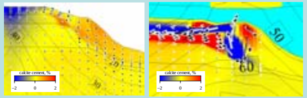

## Predictive Concept #1
## Limited potential for seawater dolomite

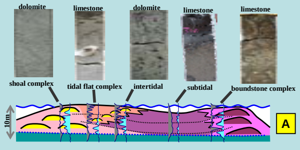


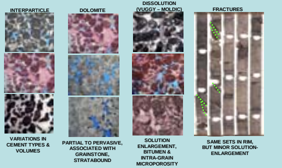




RTM models predict a lack of dolomitization from seawater in general, based on low temperatures (< 60 °C). Dolomite occurrences in Unit 1 are more prevalent in the rim and flank, but probably do not originate from seawater. Replacement dolomite is found along fractures and associated with burial cements, including some saddle dolomite. Other dolomite occurrences (possibly earlier) are associated with fine-grained and clay-rich facies in the rim / flank. Overall however, dolomite is volumetrically minor, and probably has multiple origins. In the Unit 2, minor stratabound dolomite is associated with grainy tidal flat facies at the tops of some parasequences (see Predictive Concept #2).

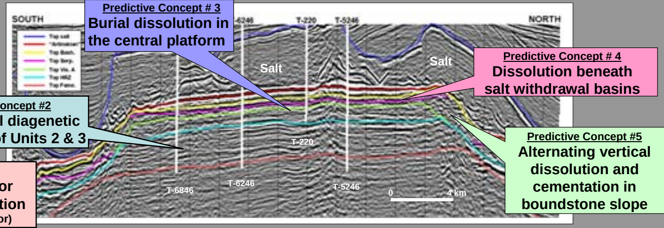
## Predictive Concept #2
## Limited burial diagenetic modification of Units 2 & 3

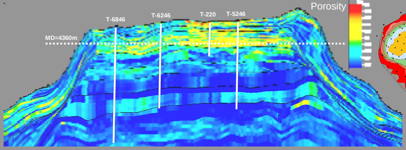


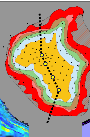



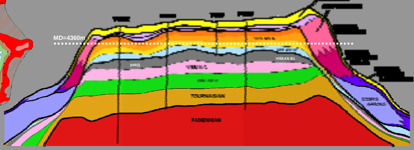




RTM models predict a low impact of convection-driven diagenesis on Units 2 and 3, based on reduced platform interior permeability. In particular, highstand platforms of Units 2 /3 (latest Famennian, upper Tournaisian and Visean D) are characterized by grainy margins and muddy platform interiors (A). Geologic studies of Units 2 & 3 are preliminary and specific geochemical studies have yet to be undertaken, but in general, grainy margins appear to show mainly early diagenetic variability. Dissolution styles, particularly later diagenetic and burial dissolution events similar to those observed in Unit 1, are not present to the same degree in Units 2 & 3. Fractures are present, but solution-enlarged fractures are less common compared to the Unit 1 margin.

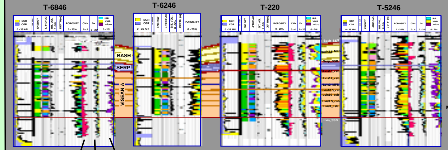


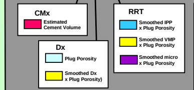






Models predicts vertical dissolution / cementation variations arising from geothermal convection cells developed in a high-permeability fracture network at various times during burial. Matrix porosity (from perm plug data) shows greater geographic variability compared to facies (A), indicating that a diagenetic overprint controls reservoir quality. Thin-section counts reveal significant lateral variability in open fractures and vugs (B), although these formed multiple times (C). Much of the dissolution responsible for ultimate porosity distribution appears to have occurred after bitumen cementation (D), but may partly reflect a distribution inherited from prior patterns of dissolution and cementation.

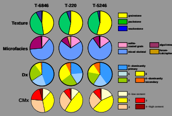


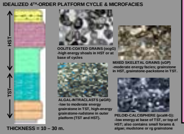




**DIAGENESIS DATA:**
Thin-section data from core plugs were used to test RTM models. Curves for dissolution factor (Dx), cement volume (CMx), and reservoir rock type (RRT) were derived from visual estimates of plug thin-sections. **Dx indicates the relative contribution of secondary pore-types to total porosity observed in thin-section. CMx indicates the total volume of calcite cement present.** The scale used for Dx and CMx varies from 0 (very low or none) to 4 (high). **RRT "values" in the curves (also scaled from 0-4) respresent estimates of the relative contributions of interparticle pores (IPP), vuggy-moldic pores (VMP), and microporosity (micro) to total reservoir porosity**. Curves were smoothed using a sliding window average over 3 samples. The Dx and RRT curves were then scaled to total porosity measured in the plugs (scale = 0 – 20%).

**PLATFORM-CENTRIC HIGH POROSITY:** Wells from the central northern platform region (T-220 and T-5246) exhibit higher porosity in most Visean A and Bashkirian 4th-order cycles, despite complex inter-well vertical and lateral variability in textures and lithofacies, compared to wells from the peripheral and southern platform regions (T-6246 and T-6846). Thin section data indicates elevated cement volumes toward the top (Bashkirian) and bottom (Visean B and lower Visean A) of the reservoir interval. Detailed evaluation of thin section data also indicates that higher overall porosity is associated with an increase in dissolution and secondary pore-types throughout the reservoir, in all components of a typical 4th-order cycle (right, and Predictive Concept #3)

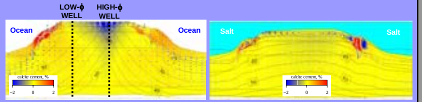
Dx and CMx factors from thin-sections were compared against texture, microfacies, and stratigraphy for T-6846, T-5246 and T-220. All 3 wells are texturally and compositionally similar, on average, over most of Unit 1. The main difference is an increase in secondary pore-types observed in wells (T-220 and T-5246) from the high-porosity platform regions.

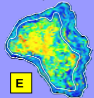


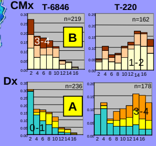



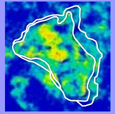

## Predictive Concept #3
## Burial dissolution in the central platform

Porosity: slice at 4360m MD

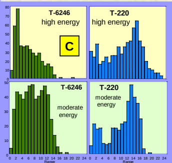


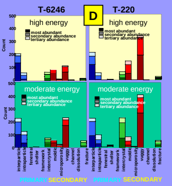



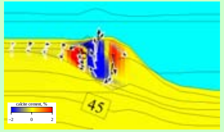
Porosity: Lvis13-Lvis12

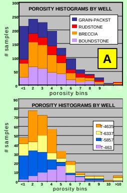


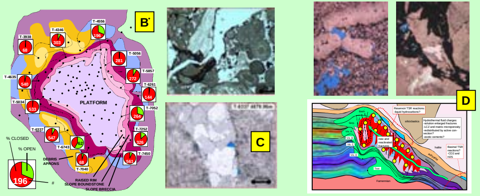




The model predicts dissolution throughout the reservoir in high-porosity areas, with a slight increase in cementation throughout in low-porosity areas, but with greater emphasis on reduced dissolution. Comparison of CMx and Dx values in a high-porosity (T-220) and a low-porosity well (T-6846) clearly shows the effect of increased dissolution on high porosity in T-220 (A). The data also shows a slight increase in cement volume in low-porosity plugs from T-6846 (B). A comparison of T-220 (high-porosity well) with T-6246 (low-porosity well) shows increased porosity in both high and low energy facies (C), suggesting that depositional environment is only a secondary control on porosity distribution. A comparison of dominant pore-types (D) shows an increase in vuggy and other secondary pore types in all facies at T-220, indicating that dissolution is a dominant process involved in elevated porosity. The interpreted diagenetic sequence (Poster 1) shows that both cyclic eogenetic dissolution and dissolution post-dating early meteoric diagenesis are present in the platform interior. The platform-centric high–porosity pattern (E) is consistent with forced (or free) convection, although it does not rule out that dissolution from platform-centered, cyclic exposure as an important mechanism.

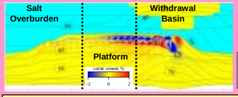
## Predictive Concept #5
## Alternating vertical dissolution and cementation in boundstone slope

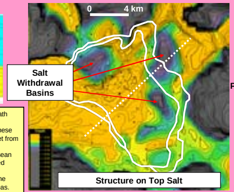


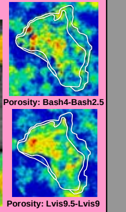




## Predictive Concept # 4 Dissolution associated with salt withdrawal basins

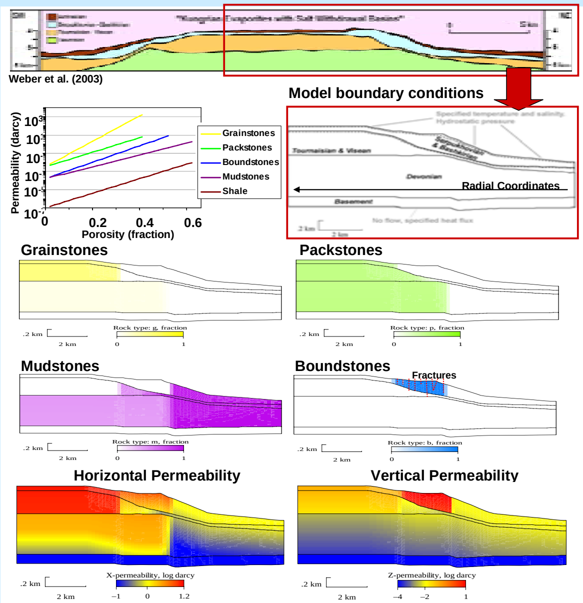


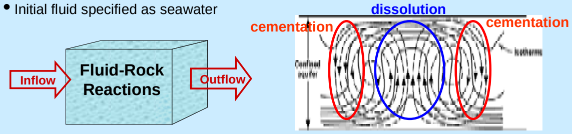

Models predict dissolution by ascending and laterally migrating fluids beneath and adjacent to salt withdrawal basins. Model results also predict an upper interval of dissolution and a lower interval of cementation associated with these fluids. Platform-centric high porosity could be interpreted as a result of offset from several salt withdrawal basins above the platform, but cement volumes are actually higher in the upper section (Bashkirian) compared to the lower (Visean A) in high-porosity wells. This appears to be partly associated with increased early (marine) cementation, so elevated porosity could arise from a burial overprint. However, increased cement volumes to the extent predicted by the models near the base of Unit 1 have not been confirmed in low porosity areas.

# Model Design and Hydrostratigraphy

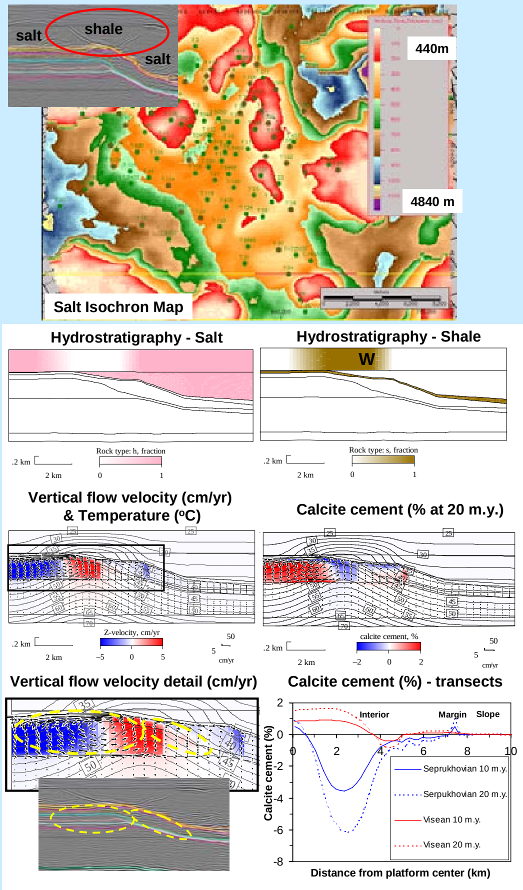



# Reactive Transport Models (RTM's)

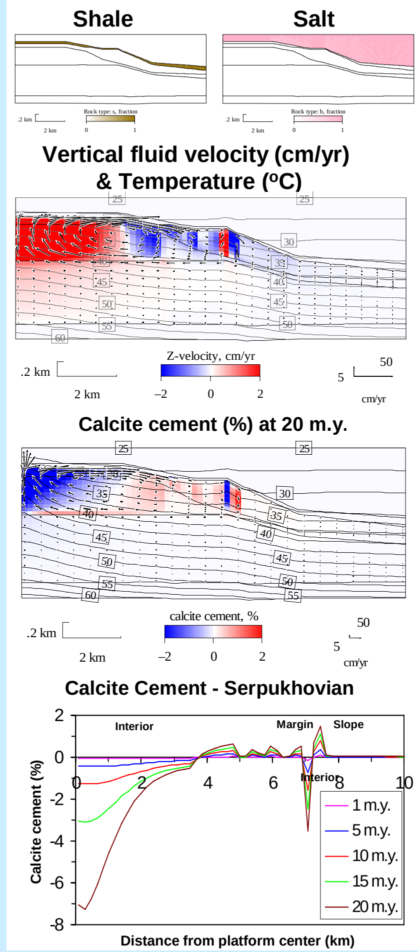
- Simulate groundwater flow, heat and solute transport (use Basin2 code)
- Track calcite mineral reactions (cementation/dissolution)
- Incorporate porosity/permeability feedbacks due to porosity evolution
- Calcite maintains local equilibrium with flow along pressure & temperature gradients
- Reaction kinetics were not simulated
- Calcite has retrograde solubility (warming=cementation; cooling=dissolution)
- Initial fluid specified as seawater



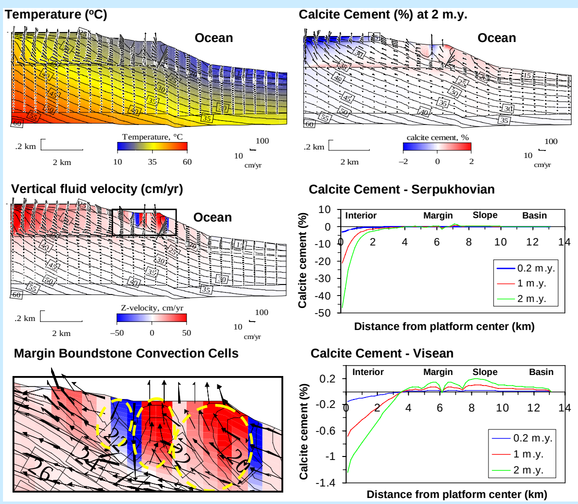

# Effect of Shale-Filled Salt Withdrawal Basins




# Geothermal Convection Post Burial




# Geothermal Convection Prior to Burial

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