PS Reaction Transport Modelling: Simulation of Reflux and Convection Dolomitization Models in an Isolated Carbonate Platform*

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Abstract

The dolomitization in a carbonate platform can occur at different times and in different diagenetic environments from synsedimentary to deep burial settings (Machel, 2004). A well constrained diagenetic interpretation allows assumptions to be made about the distribution of the dolomitized bodies (Whitaker, 2004). This is particularly important in the oil industry because the dolomitized bodies frequently have the best petrophysical properties, particularly ion the Paleozoic sequences (Lucia, 2004).

The results of diagenetic analyses do not always point to an unequivocal conceptual model. In this situation, a numerical modelling exercise may help to select the model that best honours the mass balance, kinetic and thermodynamic constrains. Moreover, the effects of the diagenetic processes on reservoir properties may be estimated (Xiao and Jones, 2006).

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Reaction Transport Modeling:
simulation of reflux and convection dolomitisation models in an isolated carbonate platform

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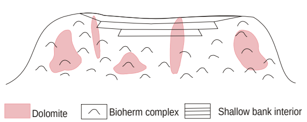
Replacive dolomitisation of a carbonate platform may occur in different diagenetic environments, from near-surface to deep burial settings. The rock observation and paragenetic interpretation commonly lead to the choice of a conceptual model for dolomitisation, involving some hypotheses on the environment, fluids chemistry and circulation patterns. **A realistic conceptual model allows to make assumptions on the geometry and distribution of dolomite bodies**, that are of particular interest in the oil industry, as dolomite bodies are frequently associated with better reservoir quality.

The rock observations and diagenetic analyses in some cases do not point to a unique interpretation, and can be explained by different conceptual models. In such situation an exercise of **numerical modeling may help to select the model** that best honours the mass balance, kinetic and thermodynamic constraints acting in the different models and, moreover, it allows an **estimate of the reservoir properties** resulted from diagenetic modifications.

The subject of this study is an application of the TOUGHREACT code (Xu et al., 2004) to a case history in which two different dolomitization models could explain the data: thermal convection and mesohaline brine reflux. The water/rock interactions and the porosity evolution are estimated by means of simulations of brine flux in a porous medium, coupled with the reactive solute transport and the mineral/fluid reactions. **The test** allowed to define and quantify the main constraints involved in the two models, and in the end **produced a more realistic geological interpretation.**

GEOLOGICAL MODEL

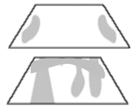


The object of the simulation is an **isolated carbonate bank**, about 25x12 km wide and 750 m thick. The model geometry, the geological constraints and assumptions, are inspired to a Paleozoic subsurface example. In the bank architecture two phases are detectable: a **biohermal complex in the lower part**, capped by **shallow bank interior deposits in the upper part**, that pass laterally to bank margin bioherms.
The bank consists mainly of limestone, with a **complex distribution of dolostone bodies**, that occur in general toward the bank margin. Some time-transgressive, dolomite bodies occur also in the inner part of the bank, following areas interpreted as syndepositional fracture zones.

Petrographical analyses document several types of dolomite: the most abundant is finally crystalline, replacive, with stable isotope signature (positive Carbon and Oxygen) suggesting **sea-water** as the probable **parent fluid**. The genetic relationship with burial stylolites supports a **shallow burial replacement**.
The occurrence of dolomite is associated with secondary intercrystalline and moldic porosity; the dolomitisation improved the reservoir quality of the biohermal limestone deposits.

TESTED CONCEPTUAL MODELS

The simulation reproduces two mechanisms of fluid flow able to generate circulation of sea-water into the carbonate bank: **thermal convection ('Kohout' convection)** and **density-driven brine reflux**, that produce dolomite bodies with different geometry (Whitaker et al., 2004).
The bank architecture suggested to test the two models in subsequent times: the thermal convection is the dominant mechanism occurring in the first phase, while in the second phase a moderate evaporation in the inner bank lagoon, allowed a brine reflux.
Two zones with enhanced permeability simulate the fracture zones.

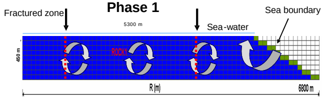


Phase 1
Thermal convection

Phase 2
Density-driven brine reflux

GEOMETRICAL MODEL AND INPUT PARAMETERS

Phase 1

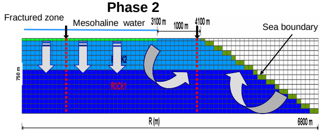


Biohermal complex: thermal convection

Surface
T° 30°C

Sea Bottom
T° 12°C

Phase 2

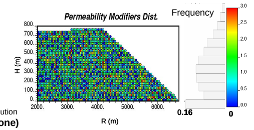


Evaporation in the bank interior: density- driven brine reflux

Lagoon salinity gradually increasing from 3.5 to 5.5% (NaCl)

2D Radial Grid Geometry
Porosity:
matrix = 25%
fracture zone = 35%

Permeability (matrix)*
K horizontal = 300mD
K vertical = 100mD
* with a random gaussian distribution
Permeability (fracture zone)
K horizontal = 1D
K vertical = 5D



		Dolomite Dissol.	Dolomite Precip.	Calcite Prec. and diss.
Kinetic Constant at 25 °C	mol/m2/s	1E-12 (3)	4.577E-19 (1)	1.5E-6 (4)
Activation Energy	kJ/mol	95.3 (4)	133.5 (1)	23.5 (4)
Specific surface	cm2/g	10 (5)	1000 (2)	10 (5)

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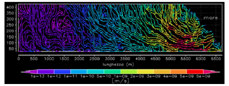
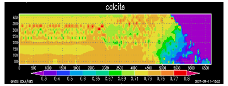
SIMULATION PHASE 1: THERMAL CONVECTION

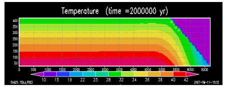
HOMOGENEOUS BANK after 2 My



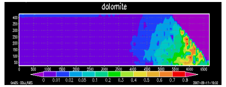
A large convective cell is established with sea water flowing into the platform at the bank margin; minor convective cells occur in the inner part.



Calcite dissolution occurs mainly at the bank margin, in the zone of sea water influx.

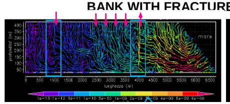


The convective cell is due to the temperature difference between the ocean and the bank interior.

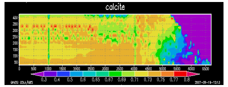


A dolomite body is produced in the bank margin, where calcite is replaced.

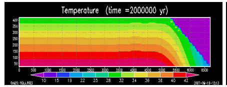
BANK WITH FRACTURED ZONES after 2 My



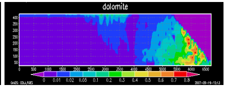
New influx of sea water from the bank top in correspondence with the fracture zones.



Calcite dissolution occurs where sea - water enters the bank: at the margin and from the bank top in correspondence with the fracture zones.



The temperature field is not modified by the flow in the fractured zones.



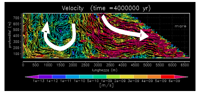
In addition to the bank margin body, minor dolomite precipitates due to the influx from the bank top.

CONCLUSIONS OF PHASE 1

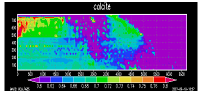
- The higher temperature within the bank with respect to the ocean allows the establishment of a thermal convection flow.
- The bank margin deposits are in part dolomitised in 2My. The geometry of the dolomitised body depends on the permeability, and particularly on the Kvert/Khoriz ratio.
- The high permeability conduit (fracture zone) in the inner part of the bank focuses the influx of sea water, producing local dissolution of calcite.
- The fracture zone located near the bank margin modifies the shape of the main convection cell, producing both calcite dissolution and dolomite precipitation.

SIMULATION PHASE 2: DENSITY - DRIVEN BRINE REFLUX

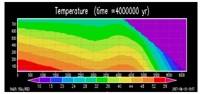
HOMOGENEOUS BANK after 4 My



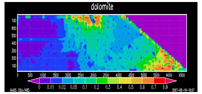
When lagoon salinity reaches 4.5%, after 2.5 My the density -driven reflux replaces the convective flow.



Calcite dissolution occurs in the area of downward brine reflux.

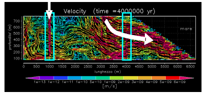


The temperature distribution is modified by the density-driven reflux.

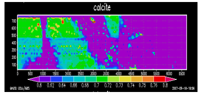


Dolomite replacement occurs in the area of downward brine reflux.

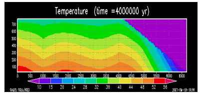
BANK WITH FRACTURED ZONES after 4 My



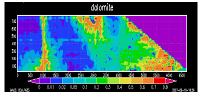
The inner fracture zone produces additional, focused influx of lagoon brine.



The occurrence of high permeability zones enhances the calcite dissolution.



The temperature distribution is modified by the fluid flow.



The occurrence of high permeability zones increases the volume of dolomite precipitated.

CONCLUSIONS OF PHASE 2

- The new geometry of the bank top allows evaporation in the inner bank, the lagoon salinity is gradually increased up to 5%.
- The denser, mesohaline brine flows downward and gradually interacts with the thermal convection flow, modifying the shape of convective cells.
- The thermal convection cell is finally cancelled when salinity reaches about 4.8%, with differences depending on the distribution of permeability.
- Calcite dissolution and dolomite precipitation occur in the reflux area.
- Fracture zones enhance the efficiency of the processes and produce local dolomitisation in the inner bank.

CONCLUSIONS

The tests highlight that different factors control the development of dolomitisation, depending on the specific conceptual model tested. An important limiting factor for thermal convection is the duration of the process, while the reflux is more influenced by the salinity of the lagoon brine; however, in both cases the most effective control on final geometry and actual volume of dolomite precipitated is represented by the permeability and its distribution. This exercise has been successful in explaining the complex dolomite distribution of the actual case under study and validated the diagenetic interpretation.

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