Diagenetic Flow and Transport Modeling to Predict Reservoir Quality in Carbonate Formations*

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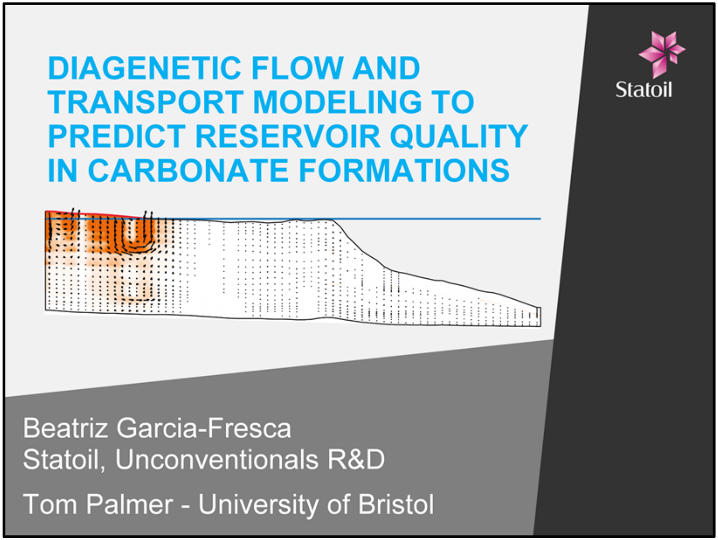
Abstract

Diagenetic modifications remain a challenge for predicting reservoir quality in carbonate reservoirs. Conventional study approaches (petrography, geochemistry, etc.) describe products of diagenesis, their paragenesis, the chemical and physical environment in which they formed, and define the types of diagenetic modification to expect in a reservoir but not its spatial distribution. Subsurface data offers a spotty view on the spatial distribution of petrophysical properties but no way to discern whether they are the result of depositional or diagenetic processes, or both. Numerical simulations of physical and chemical interactions between rocks and diagenetic fluids along flowpaths allows us to unravel the mechanisms controlling diagenesis and to model the size, shape and connectivity of diagenetic bodies and trends. We illustrate such process-based approach by a numerical model of reflux dolomitization based on outcrops of the Permian San Andres Formation in west Texas. Transient simulations of flow and solute transport during the accumulation of this carbonate platform are accompanied of a magnesium mass-balance to evaluate the growth and evolution of dolomite bodies in time and space. A parallel reactive transport modeling study evaluates transient changes in mineralogy, porosity and permeability.

Our work shows that the location of active dolomitization changes over the accumulation of the platform, as do the mechanisms of growth and development of dolomite bodies. The principal controls of this variations are (1) expansion and shrinking of brine source, controlled by sea level, accumulation rates, shifting environments of deposition, and other environmental factors, (2) flow paths and rates controlled by permeability pathways, also linked to environments of deposition and their stacking patterns, (3) presence of dolomite bodies that act as substrate for further dolomite precipitation, (4) kinetics of dissolution and precipitation of carbonate minerals, and (5) feedbacks with evolving permeability field. In this manner, we observe dolomite bodies that develop near the surface and the brine source. Other bodies grow in the subsurface, following propitious permeability settings and/or precursor dolomite bodies. Additionally, dolomite bodies can continue to grow during times of no flow, by a process known as "latent reflux". This approach can be applied to other diagenetic systems in carbonate and siliciclastic, conventional and unconventional reservoirs.

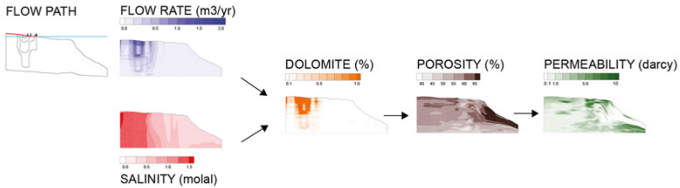


Presenter's notes:

- Now we are going to switch gears and look at paleoflow and the resulting diagenetic modification in a carbonate platform.
- A range of techniques and tools are necessary to build forward diagenetic models.
- Finally we will illustrate the workflow with an example of reflux dolomitization of the San Andres Fm based on outcrop data.

The goal

- Transient paleoflow through carbonates → delineate diagenetic trends → predict spatial distribution of RQ



Presenter's notes: We are going to illustrate how we can use fluid flow and transport models to predict reservoir quality.

DATA INTEGRATION	
Petrography	• Describe diagenetic products and understand paragenesis • Rock properties
Geochemistry	• Fluid-rock reactions • Describe diagenetic products and understand paragenesis
Stratigraphy, sedimentology and depositional systems	• Type of diagenetic modification and paragenesis • Boundary conditions • Initial conditions • Understand physical/chemical processes
Petrophysics	• Distribution and upscaling of rock properties
Hydrodynamics	• Describe paleoflow of diagenetic fluids
Numerical models	- Stratigraphic - Fluid flow - Solute transport - Reactive transport

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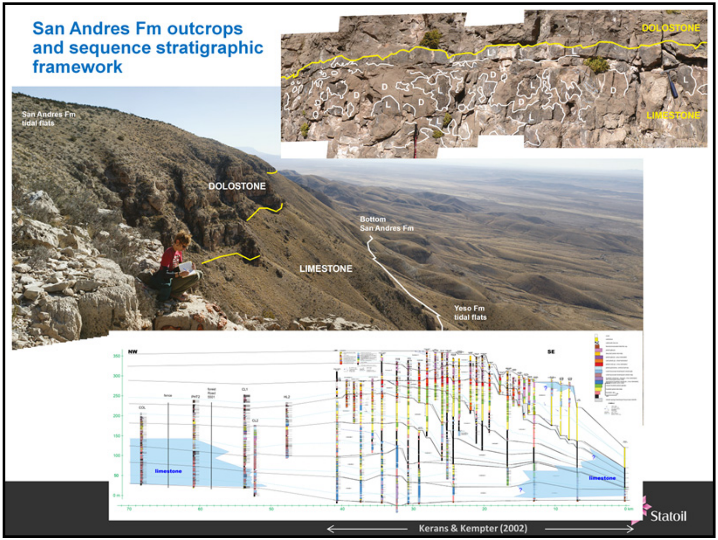
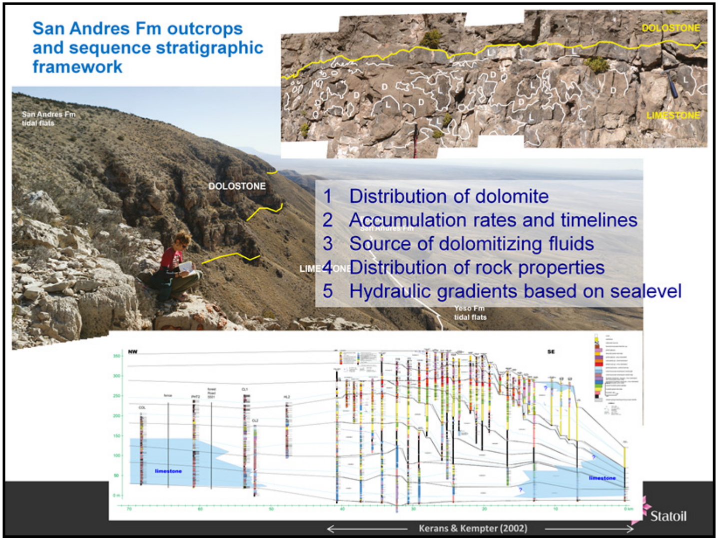


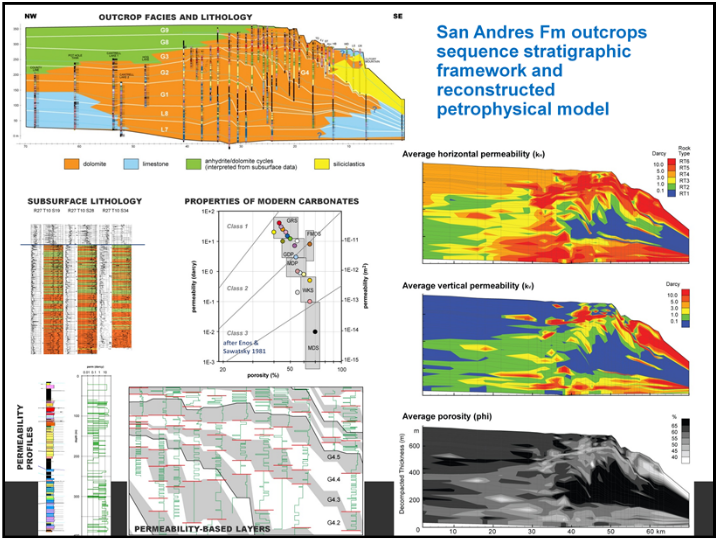
Presenter's notes:

- Permian San Andres Formation, west Texas and New Mexico.
- Platform-scale model was built based on the following outcrop data.



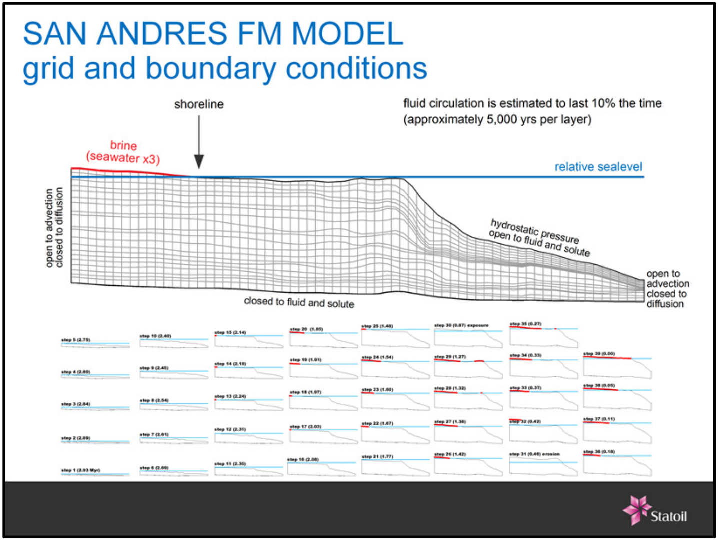
Presenter's notes: Outcrop data allows us to define the parameters for the flow models.

- Distribution of the diagenetic modification – in this example we traced the location and characterized the nature of the diagenetic fronts.
- Sequence stratigraphic framework help us establish the boundary conditions.
    - Timing: accumulation rates and model timelines
    - Depositional environments and location of diagenetic fluid sources
    - Distribution of facies and rock properties
    - Hydraulic gradients based on the relative position of sea level based on the occurrence of shoreline facies



Presenter’s notes:

- The upper diagram represents the basic lithologies present in outcrop.
- We used subsurface data to reconstruct missing parts of the outcrop – in this case it also represents the depositional environments that sourced the dolomitizing fluids.
- We used modern carbonate sediment measurements to represent the petrophysical properties of recently deposited carbonates.
- Then we upscaled these properties based on vertical permeability profiles following Lucia’s approach for carbonate reservoir modeling.
- Finally we came up with the upscaled distribution of permeability and porosity to input in the model.

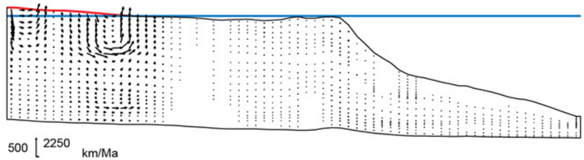


Presenter's notes: Then we build the grid, divided in 40 steps, each step represents a stage of platform accumulation.

In each step the position of the shoreline changes according to sea level oscillations and defines the extent of restricted environments where reflux fluids were sourced.

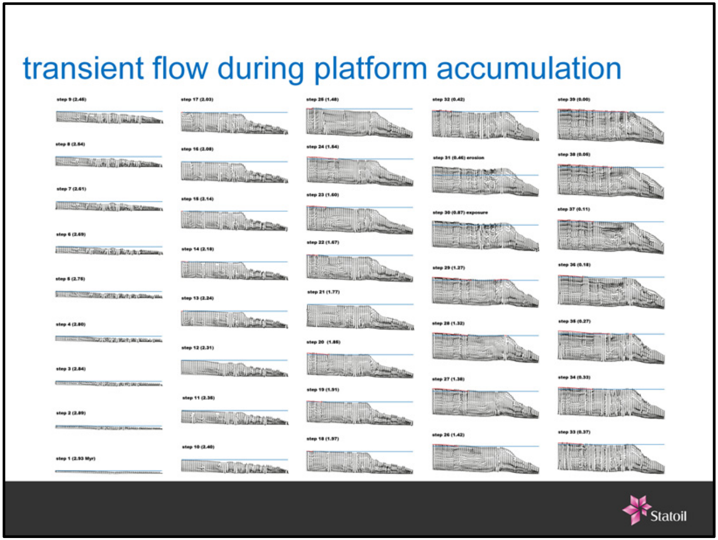
As the platform accumulates and sea level goes up and down, the restricted environment is wider or narrower or not present.

SAN ANDRES FM MODEL
flow and transport simulations

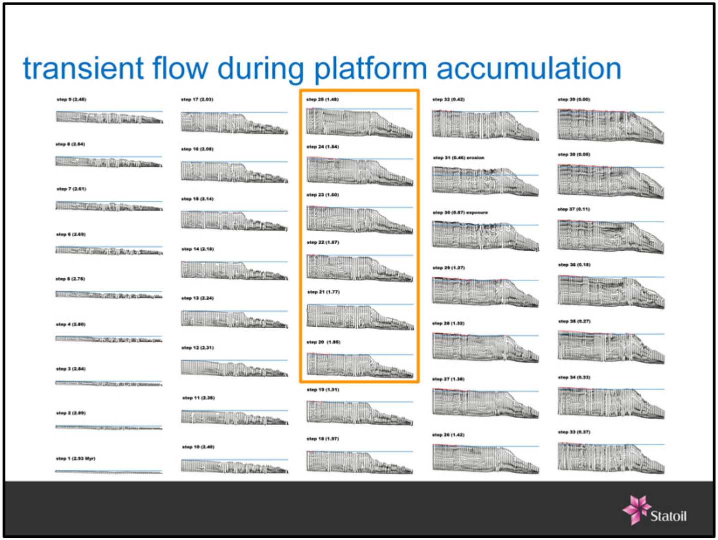


Statoil

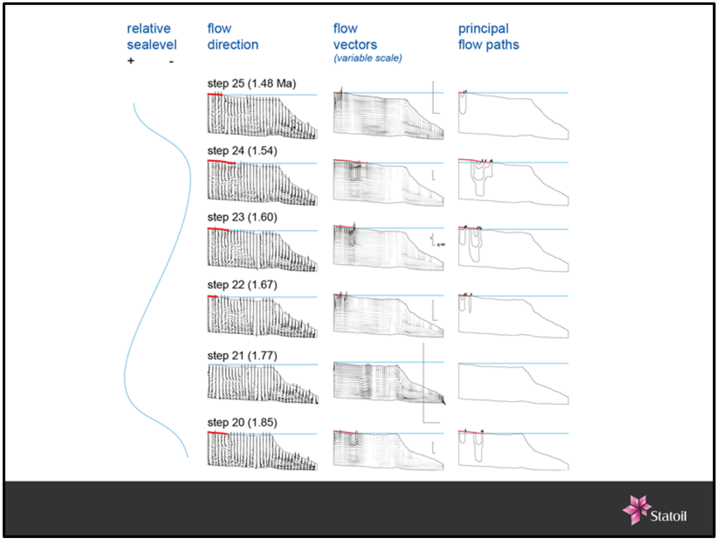
Presenter's notes: Next we will look at the flow patterns that develop though the simulation.
In general, we observe brines circulating downward and discharging near the shoreline.
Most significant brine flow is in the order of several meters per year.



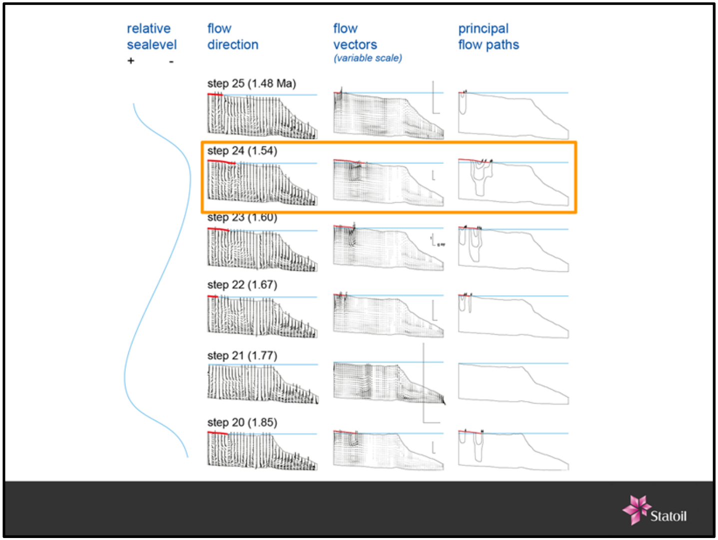
Presenter’s notes: Circulation patterns change according to sea level and the extent of the restricted environment sourcing reflux fluids.



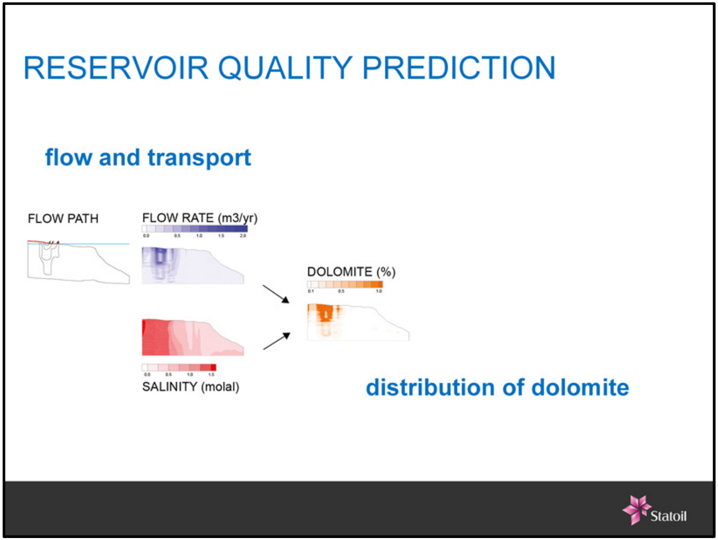
Presenter's notes: We will focus on a few steps for a better view of what is happening through a cycle of relative sea level rise and fall.



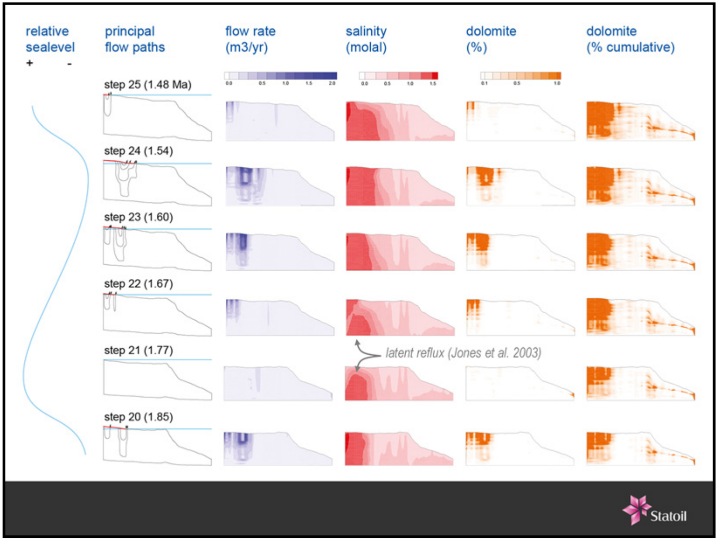
Presenter's notes: Relative sea level is rising then falling through a 3/4 order cycle.
We can see how the boundary conditions are changing.
The first column illustrates flow direction but not its magnitude.
The second column shows flow vectors indicating the magnitude of fluid flow; unfortunately the scale is not consistent in these plots.
The last column shows diagrams of the principal circulation patterns.
We see that the location and magnitude of flow is changing in each time step.
At times when the platform is submerged there is no reflux circulation.
Circulation patterns are best developed during relative sea level fall and maximum brine source extent.



Presenter’s notes: We will now focus on what happens during one of these steps.



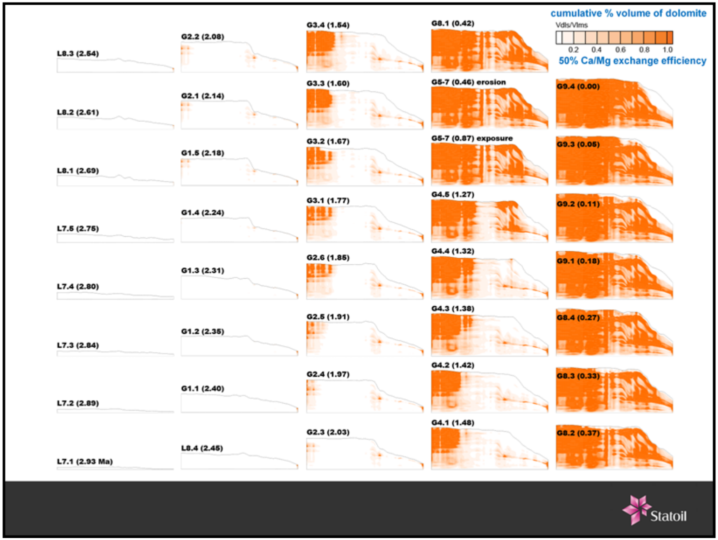
Presenter's notes: The simulations allow us to calculate flow rates as well as the distribution of brine in the platform.
Then we can estimate the amount of dolomite formed by a mass balance between the precursor limestone and magesium in the fluid.
We see that the location of dolomite formation coincides with locations where we find high flow rates and high salinity.



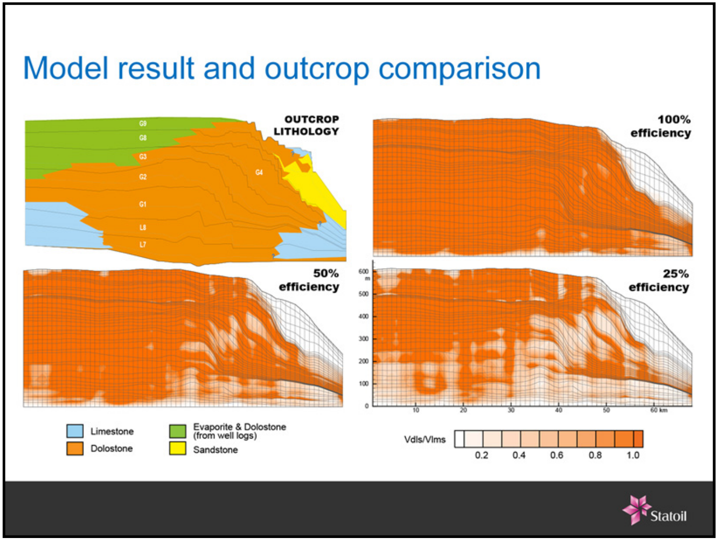
Presenter's notes:

- Most dolomite forms near the surface and the brine source.
- However, we must accumulate the amounts of dolomite formed in each step.
- Thus we see that dolomite bodies can grow in the subsurface, following propitious permeability settings and/or precursor dolomite bodies.
- Additionally, dolomite bodies can continue to grow during times of no flow because bines can continue to exist during times of now flow, a process known as "latent reflux".

The location of active dolomitization changes over the accumulation of the platform, as do the mechanisms of growth and development of dolomite bodies. The principal controls of this variations are: (1) expansion and shrinking of brine source, controlled by sea level, accumulation rates, shifting environments of deposition, and other environmental factors, (2) flow paths and rates controlled by permeability pathways, also linked to environments of deposition and their stacking patterns, (3) presence of dolomite bodies that act as substrate for further dolomite precipitation, (4) kinetics of dissolution and precipitation of carbonate minerals, and (5) feedbacks with evolving permeability field.



Presenter's notes: Transient approach shows that cummulative effect of short-lived flow events can lead to pervasive dolomitization of a carbonate platform over time.



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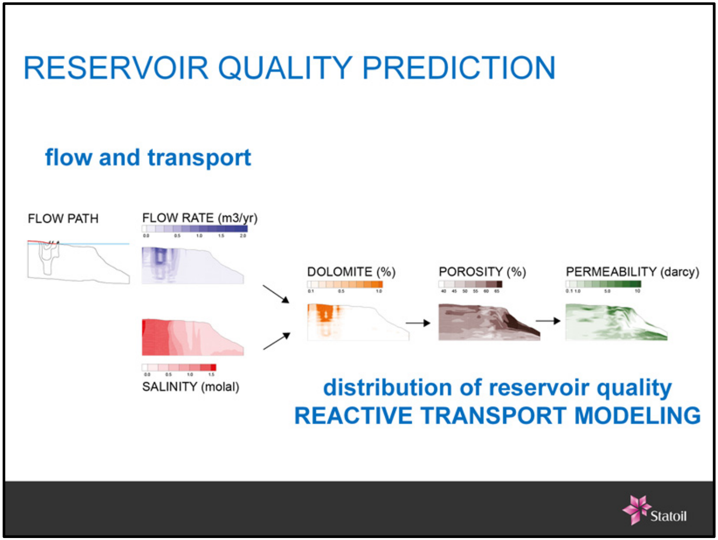
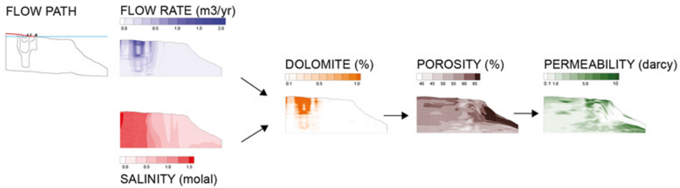


Presenter's notes: On these simulations, porosity changes by compaction of the precursor limestone, as a function of depth.
This model did not account for reactions and concomintat porosity changes related to dissolution and precipitation of minerals.
Tom Palmer will present reactive transport implementation on this transient model and porosity and permeability changes related to calcite dissolution and dolomite precipitation.

Take home message

- Transient paleoflow through carbonates → delineate diagenetic trends → predict spatial distribution of RQ



- This approach should work for other diagenetic systems and formation types