3D DETERMINISTIC MODELLING OF TURBIDITES

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During the last 20 years, geology has been revolutionised by the development of sequence stratigraphy. In the same time, more and more oil fields have been discovered in deep offshore environments. However, the deep offshore environment remains the most complex geological environment, with an important play of tectonics, erosion and sedimentation.

Aim of stratigraphic model

We have developed a 3D stratigraphic model, Dionisos (Granjeon, 1997, Granjeon and Joseph, 1999). The aim of this numerical model is to reconstruct the evolution through time of a basin paleo-geography, using macro-scale sediment transport laws, in order to obtain a 3D quantification of the basin stratigraphy. This physical approach gives geologists new keys to study a basin, and to test different geological correlation schemes. Furthermore, this stratigraphic simulation provides quantified information about possible reservoir locations and characteristics (geometry, facies, petrophysics, ...), which can help geologists to better define possible prospect, and to optimise oil recovery.

Principles of stratigraphic model

A stratigraphic simulation is performed in a sequence of time step, from the past up to the present. After the definition of the initial topography of the basin (fig. 1), three main actions are performed at each time step to reconstruct progressively the basin paleo-geography evolution.

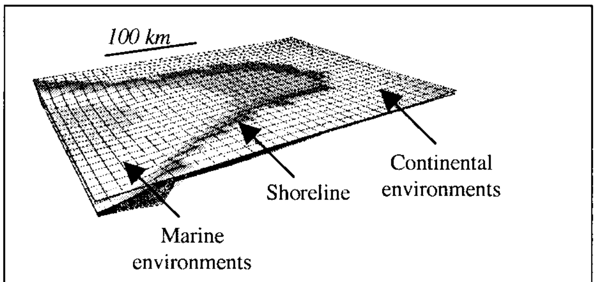

Fig.1 - Definition of the initial topography of the basin

1. definition of accommodation (fig. 2), which is the available space created in the basin by subsidence (or uplift) and by sea level variation,

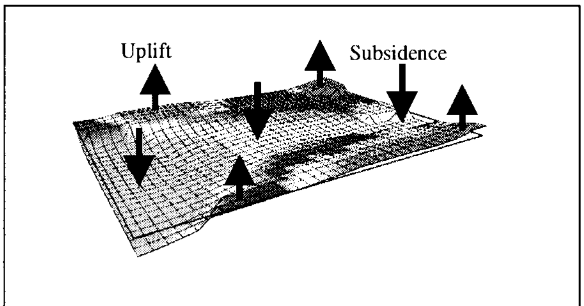

Fig.2 - Definition of subsidence and uplift

2. definition of sediment in-flow (for example, amount of sediment introduced in the basin by rivers) and production (for example, marine carbonate production) (fig. 3),

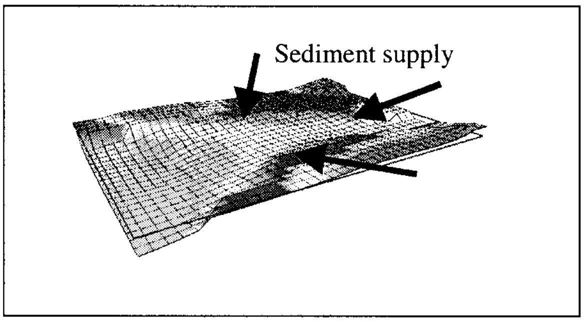

Fig.3 - Definition of sediment supply

3. deterministic simulation of sediment transport.

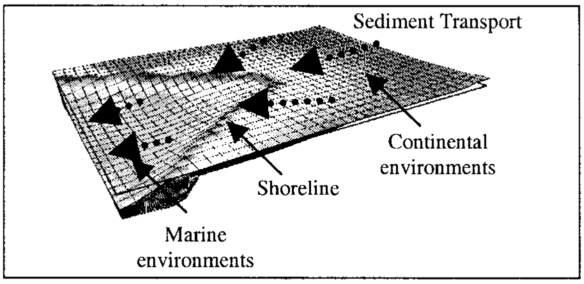

Fig.4 - Simulation of sediment transport and quantification of the new topography of the basin

Numerous studies have been undertaken to define empirical sediment transport laws, both in fluvial and in deep-offshore environments. However, these laws are usually only applicable on micro-scale (some hours to some years), to simulate a river erosion, or a harbour sandy filling, or catastrophic deep-offshore landslide. Direct application of these micro-scale deterministic laws on geological scale (some tens to some hundreds of thousands of years) leads to a "perfect" simulation of depositional environments, but also to a chaotic behaviour of the simulated paleo-geography.

We chose to upscale these micro-scale deterministic laws to obtain some macro-scale laws, applicable only on geological scale. Three main agents responsible for sediment transport were differentiated: rivers, wave and gravity.

Fluvial transport is simulated both in continental and in marine environments, in order to take into account deltaic flume which can carry a non-negligible amount of sediment. The fluvial transport is assumed to be proportional to the ground slope and to the water discharge, using a 3D water-improved diffusion equation (Granjeon, 1997). As a first-order approximation, waves are only considered to slow down (in the case of sandy lithologies for example), or to speed up (in the case of shaly lithologies for example) the fluvial and gravity transport.

Definition of macro-scale gravity laws is a challenge, due to the catastrophic nature of gravity flow. 3D micro-scale steady and unsteady gravity flow models (fig. 5) have been developed at IFP to simulate and better understand these flows, and to define the macro-scale laws. Three main equations are used to quantify: (1) water incorporation, linked to turbidity flow velocity and to the balance between friction and gravity forces, (2) energy expenditure due to internal turbulence and to external friction, and (3) sedimentation or erosion rate.

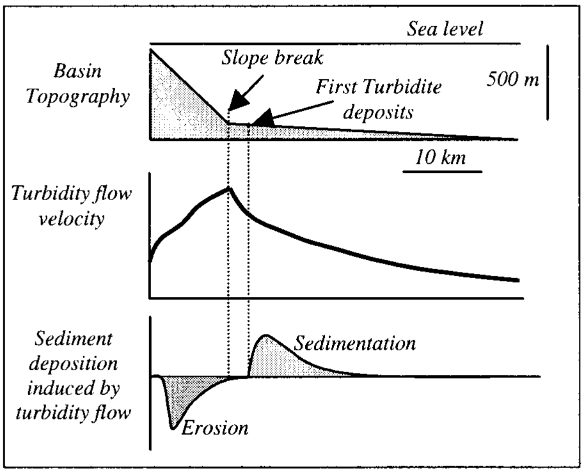

Fig 5 - Micro-scale simulation of turbidity flow
Quantification of turbidity flow velocity, and of turbidites erosion and sedimentation rate

Validation on the Eocene Formation, Santos Basin; Brazil.

The macro-scale sediment transport laws have been defined not only by an upscaling of micro-scale laws, but also by a calibration on real case studies in different geological setting (Brent Fm. in North Sea, Natih Fm. in Oman, Miocene carbonate platform in Turkey, ...).

A special focus will be put on the Eocene Formation of the Santos basin, localised on the passive Brazilian margin, near Rio de Janeiro, Brazil. Analysis of 3D seismic data allowed us to reconstruct the evolution of this margin.

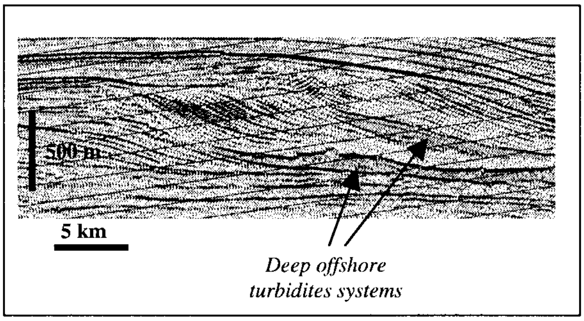

Fig 7- Seismic profile of the Brazilian Margin

Due to the uplift and erosion of the Serra do Mar, an important sediment supply fed the Santos Basin during the Eocene. The basin morphology progressively evolved from a ramp setting towards an offlap-break setting. Two important turbidite depositional systems were identified. On the ramp setting, turbidites were deposited far into the basin, and a very extended bypass zone was developed, while on the shelf-break setting, debris-flows occurred and turbidites were trapped near the slope break.

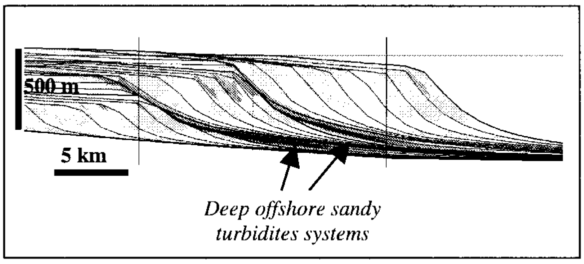

Fig 8 - Macro-scale simulation of turbidite systems

Application of our macro-scale gravity flow equations on this detailed geological database led to a validation and calibration of our 3D stratigraphic model in deep-offshore environments, and also to a better understanding of the timing, geometry and facies of turbidites on two extreme basin physiographies.

Conclusion

Dionisos, a stratigraphic model has been developed to reconstruct in 3D the stratigraphy of a basin, on prospect scale (several kilometres) and on basin scale (several hundreds of kilometres), and on fluvial to deep-offshore environments. Such simulation can provide geologists new keys to understand geological basin history better, to test different correlation schemes, and to localise and characterise possible oil reservoirs.

References

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