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Early Fracture Network Prediction in Carbonate Systems through Process-based Forward Modelling

Winterleitner, G. [1*], Maerz, S. [1], Meier, N. [1], Niederau, J. [1] and Bruhn, D. [1]

[1] Fraunhofer IEG, Fraunhofer Research Institution for Energy Infrastructures and Geotechnologies, IEG, Germany

* Corresponding Author: gerd.winterleitner@ieg.fraunhofer.de

SYN-DEPOSITIONAL FRACTURES IN CARBONATES

The formation of early fractures in carbonates is an important feature, as these fractures may constitute long-lasting fluid flow conduits. Yet, these fractures are frequently overlooked in carbonate reservoir characterization due to lack of suitable workflows and methodologies to predict these fracture networks. However, syn-depositional fracture networks significantly affect reservoir quality and performance due to (1) providing an early and effective fluid flow network, (2) are prone to reactivation during later tectonic events and (3) are pathways for early dolomitising fluids.

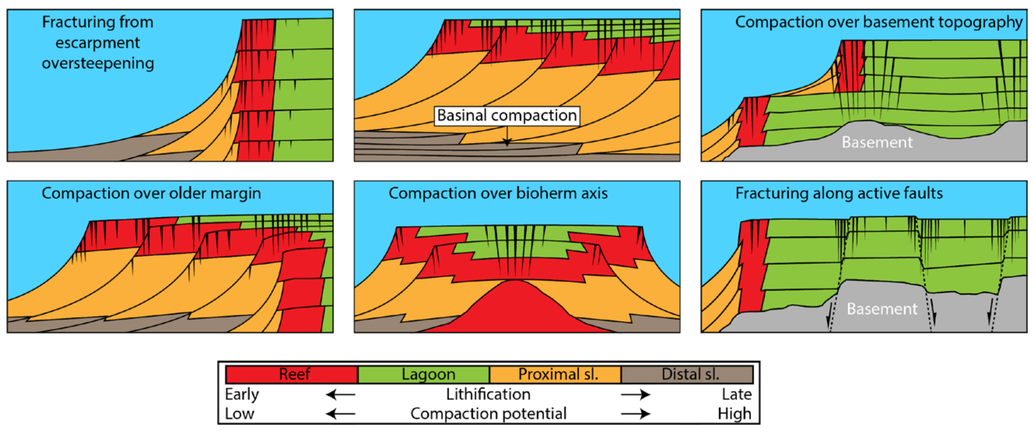


Figure 1: Sketch illustrating fracture zones in carbonate platforms due to differential compaction and early lithification. Modified after Frost and Kerans (2010).

DEFORMATION ZONES AS A FUNCTION OF PLATFORM EVOLUTION

An understanding of the spatial and temporal evolution of these syn-depositional features is thus essential to accurately predict geothermal reservoir performance in carbonate systems. The challenge, however, is to model and characterize these early fracture patterns because they form in absence of a tectonic driver. Syn-depositional fracture formation is contributed mainly to the effects of intrinsic stresses related to the internal geometry of the carbonate sequence (e.g.: overstepping of steep platform margins over slope sediments (Figure 2).

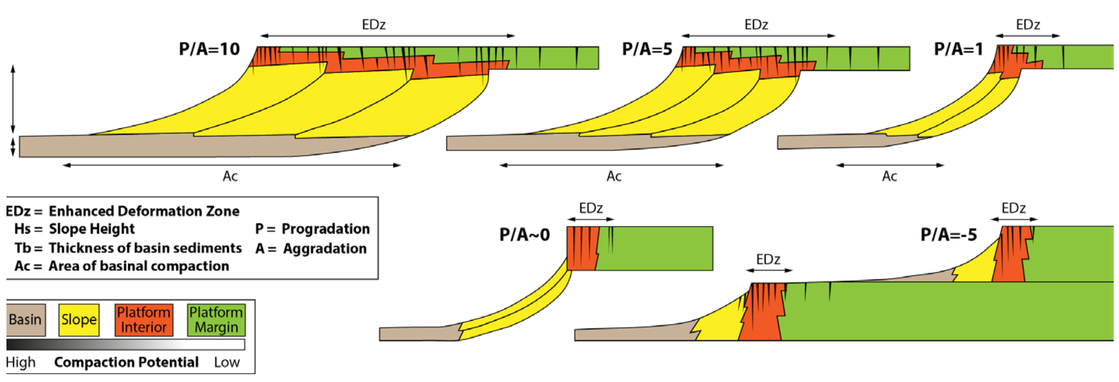


Figure 2: Deformation zones as a function of platform aggradation and progradation cycles. Modified after Nolting et al., (2020).

The early lithification of carbonates enables the syn-depositional fracture formation due to internal weakness of the rigid framework, rapid progradation of strata over unconsolidated sediments or the effects of antecedent topography (e.g.: new reef grows over an older one). Platform internal fracture patterns are characterised by the absence of a predominant orientation, vary over short distances and may crosscut the entire sequence (Figure 3). Traditional Discrete Fracture Network (DFN) generators are not suited to accurately predict these fracture networks since the main driver of fracture formation is not the regional stress field but complex internal geometries, which cannot easily be translated to DFN input parameters.

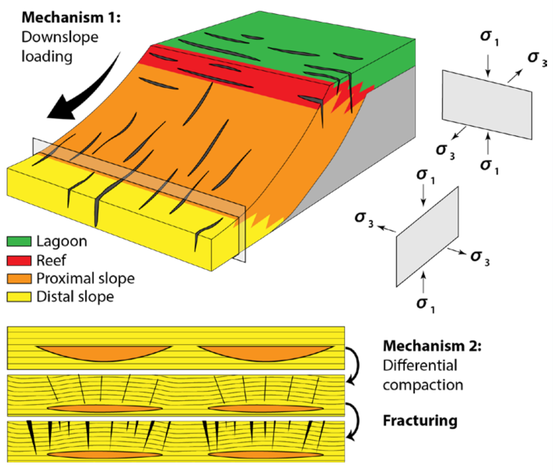


Figure 3: Deformation zones as a function of platform aggradation and progradation cycles. Modified after Nooitgedacht et al., (2018).

FRACTURE ZONES FROM STRATIGRAPHIC FORWARD MODELLING

Our research in process-based modelling showed that the internal geometry of complex carbonate systems can be modelled in detail. Thereby differentiating between the main lithofacies zones. This enables us to model the complex alternating patterns of progradation (P) and aggradation (A) through time (Figure 4). That is of particular interest since the P/A ratio is linked to syn-depositional fracture intensity and spacing (compare Figure 1). Additionally, the evolution of the platform margin and reef crest trajectory are modelled throughout the evolution of the platform.

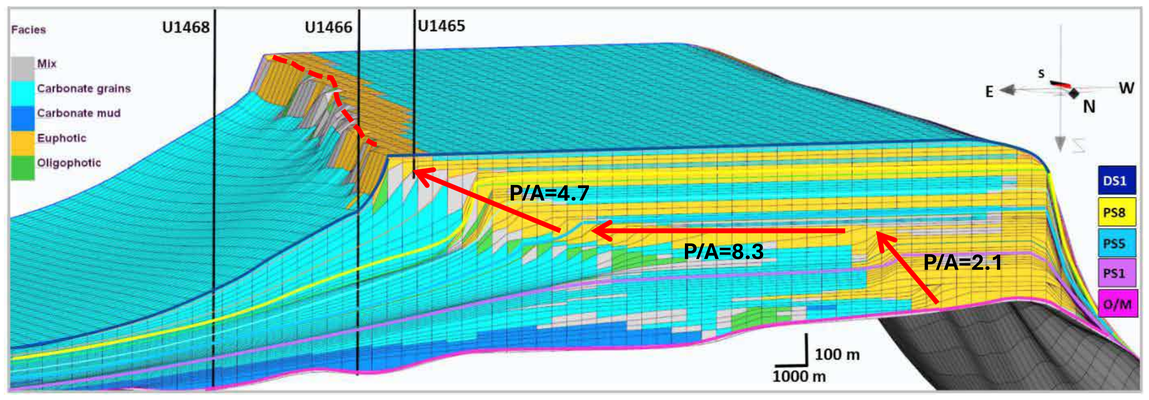


Figure 4: Stratigraphic forward model of the Maldives illustrating progradation vs. aggradation cycles and platform trajectory (red arrows). Red dashed line shows reef crest trajectory.

FRESERVOIR MODELLING WORKFLOW

In reef-rimmed platforms, fracture orientation is preferentially perpendicular and normal to the platform trajectory, respectively. Subsequently, fracture zones within the platform can be identified and syn-depositional fractures can be modelled using the P/A ratios to define spacing, length and intensity whereas reef-trajectories provide fracture orientation and variation throughout the platform. The result of the workflow is a reservoir model with detailed facies distribution and early fracture networks and deformation zones to guide fracture modelling (Figure 5).

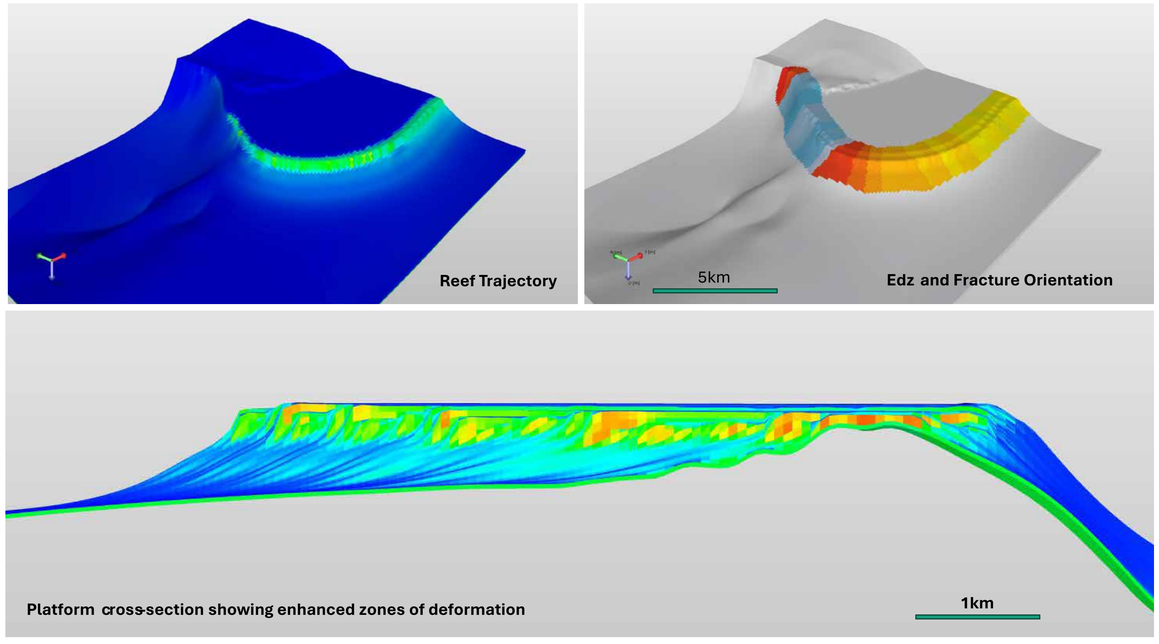


Figure 5: Reservoir model of the Miocene Llucmajor Platform based on SFM modelling. (a) Reef crest trajectory, (b) Edz and fracture orientation for one P/A cycle and (c) platform cross section illustrating high variability of fracture zones (warm colours represent high fracture intensity and narrow spacing).

GO-Forward - Geothermal Exploration and Optimization through Forward Modelling and Resource Development

GO-Forward aims to develop a novel methodological approach to make more accurate pre-drilling predictions of geothermal reservoir properties and thus reduce the mining risk. The key to the GO-Forward approach is to simulate geological processes for pre-drill assessment of reservoir structure and properties, calibrated to geological or geophysical data, rather than extrapolating the properties from those data with geostatistical methods.

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