Integrated Structural and Charge Modeling in Compressional Areas – Application in the Monagas Fold and Thrust Belt (Venezuela) and Decompaction Uncertainty*

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Abstract

Conventional basin and petroleum system modeling (BPSM) uses the vertical backstripping approach to describe the structural evolution of a basin. In structurally complex regions, this is not sufficient. Wherever lateral rock movement and faulting must be incorporated in the models, BPSM should be performed on structurally restored models. Following this approach, pressure evolution and compaction can be modeled in a decoupled way: the overall geometry is taken from the structural restoration, pressure and compaction are modeled, and porosity is derived from the calculated effective stress. On this basis, other geologic processes, such as temperature evolution, source rock maturity, hydrocarbon migration and accumulation can be modeled.

We demonstrate the strength of this approach in a case study from the Monagas Fold and Thrust Belt (Eastern Venezuela Basin). The different petroleum systems have been fully evaluated through geologic time within a calibrated pressure and temperature framework. Particular emphasis has been given to investigating the structural dependencies such as the relationship between thrusting and hydrocarbon generation, dynamic structure-related migration pathways, and the general impact of deformation on the petroleum systems.

We describe the uncertainty, which is introduced by replacing backstripped paleogeometry by structural restoration, and discuss decompaction "adequacy". We have built two end member scenarios: structural restoration assuming hydrostatic decompaction and one that neglects decompaction. We have quantified the impact through geologic time of both scenarios by analyzing important parameters such as rock matrix mass balance, depth, temperature and transformation ratio (TR). For the case study presented, hydrostatic decompaction seems to be the most appropriate methodology.

Introduction

The backstripping approach used in conventional BPSM models has limitations for complex basin geometries, especially in areas with thrusting and salt movement. In these geologic settings, structural restoration, which accounts for lateral rock movement along faults, should be applied to describe the geometric evolution of a basin. Structural restoration is also possible using geomechanics where elasticity replaces conventional geometric rules and where displacement, strain and stress are a result of the simulation (Maerten and Maerten, 2006). The structurally restored paleogeometries (basin structural geometry at a given moment in the geologic past) can then be used in BPSM, replacing the conventional backstripping method. We demonstrate this workflow and discuss specific aspects related to the quantification of uncertainties using a 2D case study of the western Monagas Fold and Thrust Belt of Venezuela.

Application in the Monagas Fold and Thrust Belt

We present a 2D BPSM analysis of the western Monagas Fold and Thrust Belt (Gallango and Parnaud, 1995; Parnaud et al., 1995; Roure et al., 2003; Schneider, 2003; Parra et al., 2011) This analysis integrates geomechanical-based structural restoration (Figure 1 a-d) and BPSM forward modeling (Figure 1e) and describes the evolution of the petroleum systems through geologic time and their relationship with the structural evolution and deformation. The dynamics of the different petroleum systems are in most places directly controlled by the structural evolution. There is a clear correlation between the local onset of thrusting and the critical moment in the footwalls resulting from rapid tectonic burial. Hydrocarbon migration and accumulation take place in a constantly evolving structure with complex fill-and-spill and remigration processes. Petroleum systems and associated plays must be laterally segmented by structural aspects because they do not share a common structural history.

Decompaction Uncertainty

General input and workflow uncertainties linked to the integration of structurally restored paleogeometries are discussed. Automated decompaction optimization as applied in the backstripping approach cannot be performed, so we focused on decompaction adequacy. Figure 2 shows a quantification of two end member decompaction scenarios (hydrostatically decompacted versus non-decompacted structural restoration) and its influence on important parameters.

For source rocks, the conservation of the rock matrix mass balance through geological time is very important; matrix mass directly governs reactive kerogen mass through total organic carbon content and the hydrogen index. Backstripping results by principle a constant rock matrix mass so that the balance is always 100%. As seen in Figure 2a, conservation of rock matrix mass is not given for non-decompacted paleogeometries,: this is because, for constant cell volume and ongoing compaction during forward modeling, the rock matrix mass increases through geologic time towards the present day mass (100 %). However, decompaction assuming hydrostatic pressure gives much better results in this particular cell.

Both decompaction scenarios result in different paleo depths (Figure 2b). This difference can probably be neglected during the passive margin phase (less than 100 m vertical burial depth), but from early Miocene on, when thrusting started, this difference becomes important (more than

1,000 m). The depth difference gives rise to a significant difference in calculated temperatures (Figure 2c), which is as much as 23°C. Because temperature is the main driver for transformation of source rock kerogen to hydrocarbon, the difference between the decompaction scenarios is also reflected in the TR (Figure 2c). Hydrocarbon generation and the derived critical moment are "delayed" in the non-decompacted scenario, and differences of more than 20% TR exist for the same timestep.

Summary

Our work suggests that rock matrix mass balance is a good indicator for decompaction adequacy. In the model presented here, the rock matrix mass balance percentage varies for both end member scenarios. Extreme values are about 50% difference between present day matrix mass and past matrix mass for the non-decompacted paleogeometries.

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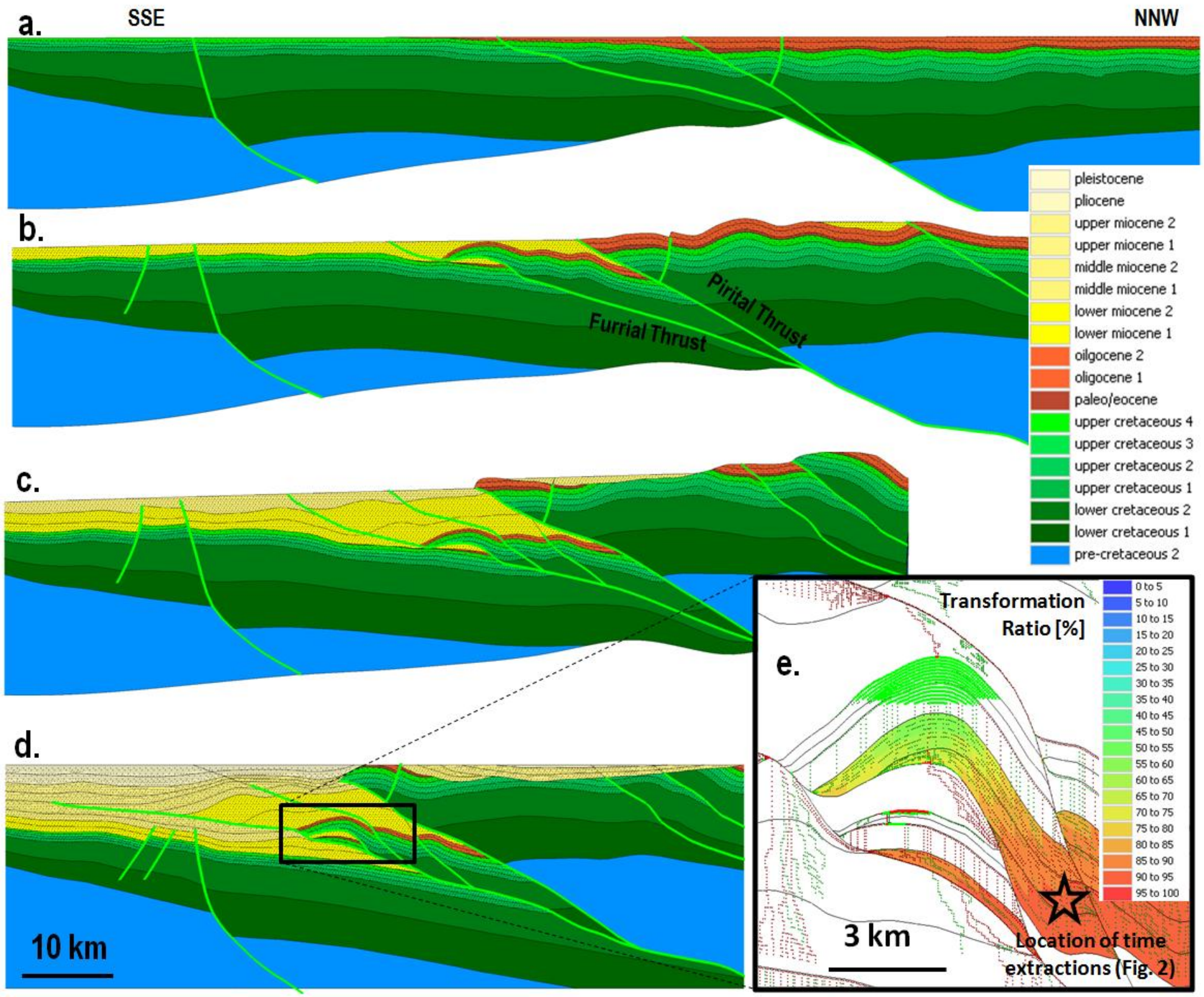

Figure 1. Structural restoration of the Monagas Fold and Thrust Belt, Venezuela. Timesteps from undeformed passive margin stage (Oligocene; a.) via compressional phase (Miocene; b. and c.) to present day (d.). Active petroleum system within in the Furrial Trend (e.) with TR for the Upper Cretaceous Querecual and San Antonio source rocks. Green and red dots show respectively simulated liquid and vapor phase hydrocarbon migration (small pixels) and accumulations (bigger pixels).

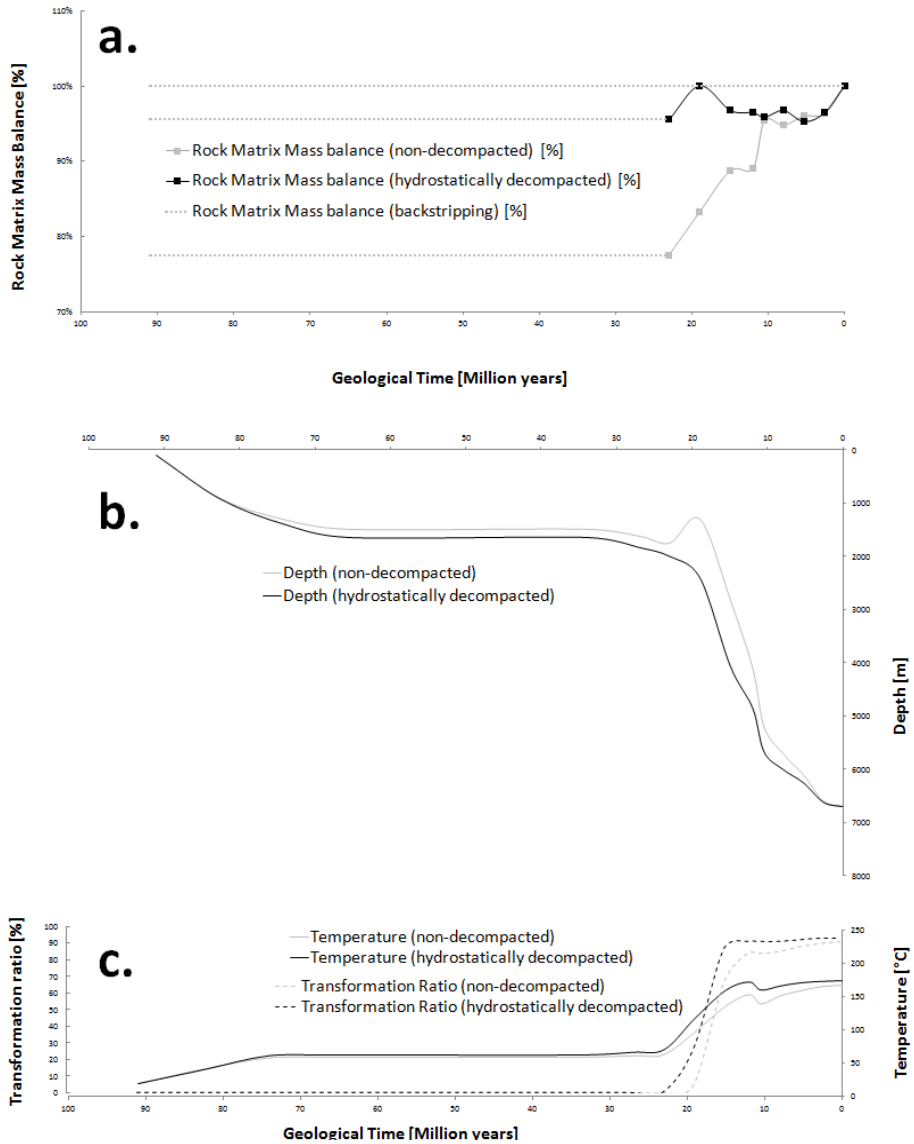

Figure 2. Quantification through geological time of two end-member decompaction scenarios for one source rock cell (location see Figure 1). All other parameters (e.g., thermal boundary conditions) are identical. a) Rock matrix mass balance (rock matrix mass for a given timestep divided by present day rock matrix mass). Points are timesteps for structurally restored paleogeometries, dotted lines represent backstripping. b) Depth; and c) Temperature and TR.