

GAS HYDRATE DYNAMICS AT THE GREEN CANYON SITE, GULF OF MEXICO – RECOVERY PROSPECTS BASED ON NEW 3-D MODELING STUDY

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ABSTRACT

Due to their favorable P-T conditions and organic-rich deposits, sub-seafloor sediments in the northern Gulf of Mexico are known to have a large potential for gas hydrate accumulations. The presence of gas hydrates within sediments of the Green Canyon block has been proven by various methods, incl. seismic imaging, geochemical analysis, and drilling conducted mainly as a part of Joint Industry Project (JIP) Phase II. Gas hydrates reported therein usually occur as tens up to hundreds of meters thick sections with moderate to high concentrations within a range of 50 – 70 vol. % of pore space, and hence, seem to offer a considerable natural deposit of methane gas.

The main focus of this study was to explore the complex effects of a set of control- parameters responsible for hydrocarbon migration and storage within the Gas Hydrate Stability Zone (GHSZ) on the accumulation of gas hydrates. To investigate the processes of basin formation and its subsidence history, source rock maturation, hydrocarbon migration and expulsion, and to quantify the gas hydrate accumulation potential, 3-D numerical study has been conducted using PetroMod. The area of interest extends over ~14 km x 33 km and covers the edge of the Sigsbee Escarpment representing the main salt mobility front in the region. The simulation contains full depositional

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history of the Green Canyon block, incl. salt deposition and re-mobilization as well as its further implications for temperature field, fluids migration and sedimentary layers distribution. Methane generation has been resolved by in-situ POC degradation and deep thermogenic mobilization from two distinct hydrocarbon sources. As a result, we present a number of likely scenarios of gas hydrate formation and accumulation in the study area that have been calibrated against available data.

Keywords: gas hydrates, numerical modeling, salt tectonics, Gulf of Mexico

NOMENCLATURE

GHSZ – Gas Hydrate Stability Zone [m]

INTRODUCTION

Green Canyon site, Gulf of Mexico is a well-studied gas hydrate-bearing marine province where gas hydrate presence has been reported from over 50 drill sites. Milkov and Sassen estimated the total amount of gas trapped within gas hydrate structure at $10 - 14 \times 10^{12} \text{ m}^3$ only at the northwestern Gulf of Mexico [1]. Due to the mostly thermogenic origin of the Gulf of Mexico hydrates, structural and combined-stratigraphic/structural traps associated with faults and salt withdrawal mini-basins show a good potential of storing gas hydrate deposits formed from upraising thermogenic hydrocarbon fluxes. Biogenic gas hydrate accumulations are somewhat rare and clearly dominated by their thermogenic equivalents [2]. Salt tectonics and high sedimentation rates are the major forces shaping the present-day geology of the north- and northwestern Gulf of Mexico. Thus, it is essential to incorporate them into numerical simulation that aims on estimating gas hydrate resources on a basin scale. According to [2], fault structures are capable of accumulating large amounts of gas hydrates all the way from the bottom of the Gas Hydrate Stability Zone (GHSZ) up to the seafloor (sometimes even up to 1000 m) which makes them economically interesting and feasible for further industrial exploration.

MODEL DESCRIPTION

3D numerical model has been designed using PetroMod software platform delivered by Schlumberger, Aachen. It covers an area of about 14 km by 33 km lying within the Green Canyon protraction area, Gulf of Mexico. Water depth ranges roughly from about 1500 m up to 3500 m. Bottom water temperatures and heat flow values have been prescribed separately for each geological epoch according to available data. The model contains 40 defined horizons, 32 of which

have been interpreted directly from seismic data (see Fig. 1). Each sedimentary layer has its unique lithology (incl. compaction scale, horizontal and vertical permeability etc.) and ability to store gas hydrate deposits.

Several fault structures and salt edges have been incorporated into the model with prescribed high-permeability values and high potential for fluid and gas migration enhancement. Salt is present in the model as discontinuous horizon emplaced into sedimentary layers on a later stage of basin development (salt injection according to the regional history of the basin). Salt layer represents the allochthonous deposit with no connection to the original Louann Middle Jurassic salt layer.

Methane generation is based on both biogenic and thermogenic processes. Three source rock layers are identified and prescribed by appropriate hydrocarbon generation kinetics which allow to form sufficient amounts of hydrocarbons migrating along the high-permeability pathways. Migration method has been prescribed as a Darcy flow coupled with the Flowpath numerical approach.

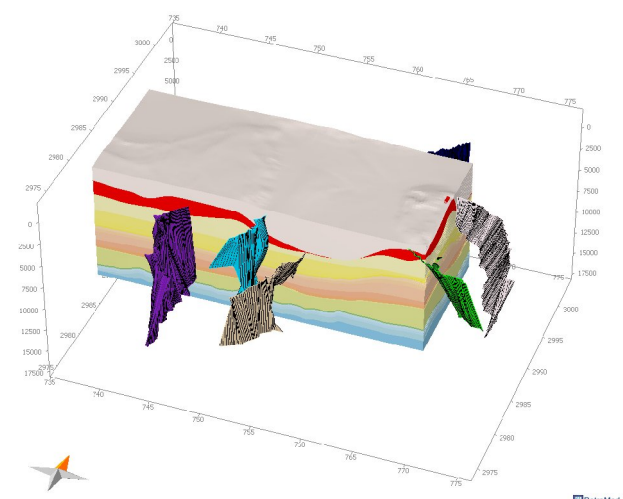


Figure 1: 3D modeling domain, Green Canyon site, Gulf of Mexico. Figure shows sedimentary layers and faulting structures implemented into the model.

CONTROLS ON PHASE MIGRATION

Gulf of Mexico region is known for its high rates of sedimentation throughout the history of the basin, active salt tectonism, and highly productive source rocks which, eventually, cause high-rate venting fluxes of hydrocarbon gases through the seafloor [3, 4]. This hydrocarbon venting sites represent practically all stages of development which suggests that the venting process has been taking place on a much larger scale of the basin history. Therefore, numerical modeling of the Gulf of Mexico system requires precise data on major potential migration pathways which, on one hand, deliver hydrocarbons to the reservoir layers, and on the other hand, form structural and structural/stratigraphic traps for potential hydrocarbon storage. Two kinds of structures were considered while setting up the model: associated with salt tectonics faults, and salt edges.

Fault structures

Present and continuous venting of hydrocarbon gases occurs at the Gulf of Mexico seafloor. Spatial location of these thermogenic seeps is almost always associated with faults and fault-like structures present in the underlying sedimentary layers. It was also reported that the rims of salt withdrawal mini-basins strongly enhance the presence of active venting sites [3]. To correctly represent all features of modeling area, four continuous fault structures were interpreted from seismic data and implemented into the model as numerically meshed geo-bodies. These fault structures are directly related to the salt tectonics (see Fig. 2, central part of the modeling domain) and provide perfect migration pathways for hydrocarbon gases rising up along the high-permeability fields.

Salt edges

Allochthonous salt deposits are represented in the numerical model as discontinuous salt layer which acts like an efficient sealing horizon, blocking the upward flow of fluid and gas phases into the upper reservoir layers. This feature is known for its large impact on forming structural and combined-stratigraphic/structural traps for hydrocarbons. As it is known, hydrocarbon gas migration is a key parameter to investigate the potential large-scale gas hydrate accumulations. Thus, implementing clearly defined edges of the present salt bodies helps to achieve more precise and probable migration pathways of methane and higher hydrocarbon gases. Presence of faults and fault-

like structures associated with local tectonics and salt diapirism has been confirmed by seismic observations, direct drilling, and geochemical data analysis.

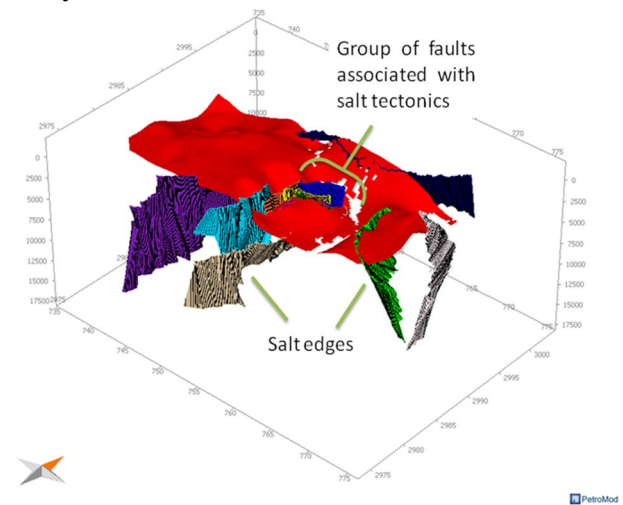


Figure 2: Presence of salt layer (in red) and fault-like structures strongly influences the migration of fluid and gas phases. Migration pathways formed along salt edges (outer part of the model) and faults (central part of the model) provide an efficient high-permeability background for fluid and gas phase transportation.

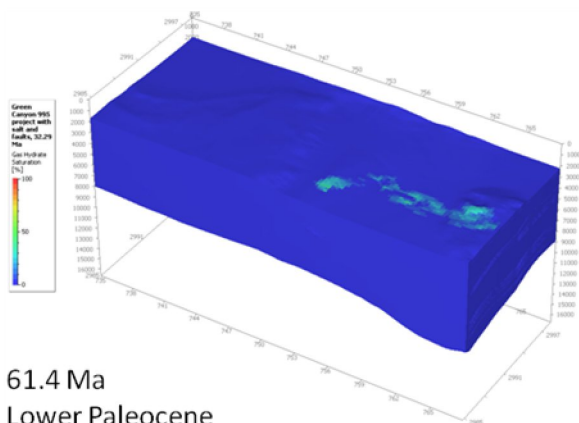
PRESENT AND PALEO- GAS HYDRATE ACCUMULATIONS

Gulf of Mexico, especially northern part of it, acts like a large flow-through system where hydrocarbon components being generated at great depth travel upwards finally reaching the seafloor. The evidence of this process comes from abundant venting sites, natural cold seeps etc. reported from all over the northern Gulf of Mexico region.

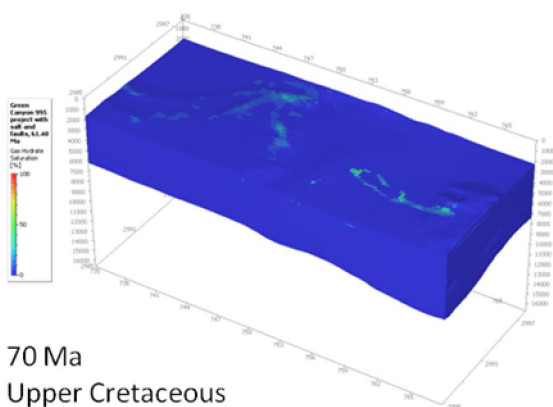
According to the model of Cathles, over 180 billions of tons of petroleum have been generated from the source rocks of 120 km x 200 km area lying in the northern Gulf of Mexico [5]. Accordingly, over 130 billions of tons of petroleum previously generated have been vented out through the seafloor throughout the basin history (~5.5 Mt/km²) which confirms the flow-through behavior of the system [5]. As the migrating gas phase is the key parameter required for gas hydrate crystallization, it is not surprising that the gas hydrate accumulation history can be also characterized by very high (up to 95 vol. %) periodic hydrate saturations followed by low and very-low hydrate saturation periods.

Additionally, it has been concluded that the shape of the present petroleum, as well as gas hydrate reservoirs, has been finally formed in relatively recent history of the basin due to the formation of salt- withdrawal mini- basins and recent high accumulation rates of sediments [5]. This finding is also supported by the results of our 3D model which confirm the dynamic formation and dissolution of gas hydrates amongst past geological decades (see Fig. 3).

32.3 Ma
Lower Oligocene



61.4 Ma
Lower Paleocene



70 Ma
Upper Cretaceous

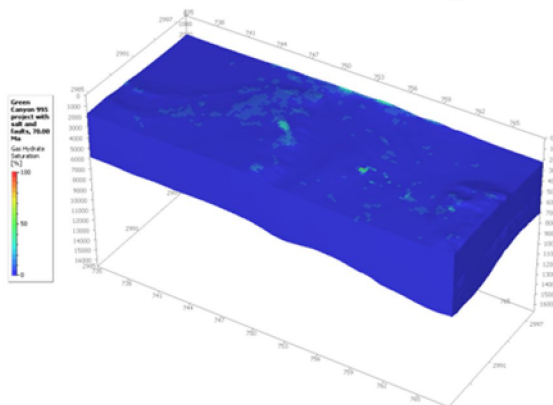


Figure 3: 3D modeling results presenting paleo-gas hydrate accumulations at the chosen age of 70Ma, 61.4 Ma, and 32.3 Ma, respectively.

Highest gas hydrate saturations (up to 95 vol. %, not shown on the picture) can be commonly found throughout Upper Oligocene layers while moderate to high gas hydrate concentrations (50 – 65 vol. %) occur broadly in Upper Cretaceous, Paleocene, Oligocene and, partially, Miocene layers.

CONCLUSIONS

During all modeling scenarios, fault systems are completely saturated with fluid and gas phases and provide an important and efficient migration pathway which delivers hydrocarbons on a high flux rate to the upper parts of sedimentary column. If possible, faults and fault- like structures (e.g. salt edges) should be considered as valuable part in constructing numerical large- scale models. Due to the complex history of the basin, it is crucial to estimate the right timing of hydrocarbon generation, expulsion, migration, and retention in order to predict the potential hydrocarbon reservoirs and gas hydrate accumulations in present. Across the whole history of the modeled northern Gulf of Mexico domain, we have concluded that major part of generated petroleum components (incl. gas phase essential for gas hydrate formation) has been removed from the basin top and dissolved in the ocean. We estimate this number to be $\sim 12 \text{ Mt/km}^2$ of petroleum (oil and gas) which corresponds well to the value published by Cathles [5]. Finally, presence of such events imply that large amount of gas hydrate deposits decomposed and released the gas stored within their structure into the ocean on a scale of many geological epochs.

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