Frontiers of 3D basin-scale modeling of natural gas hydrate systems

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Abstract

Numerical modeling of natural gas hydrate systems requires an innovative and complex approach. The variability of parameters present in natural geological settings and the lack of widespread high-quality 3D seismic data are the main factors limiting large-scale numerical simulations. Here, we present the outcome of a joint academic-industry project on testing the feasibility of a newly developed simulation-module included in the commercial software PetroMod™ for modeling the formation of natural gas hydrate deposits at two locations in the Gulf of Mexico. The project aimed at the scientific assessment of required input data quality and validity, choice of the computational methods, and calibration with the field data.

The first part of the study was to reconstruct the natural gas hydrate system at the well known GC (Green Canyon) 955 location. Combined 2D and 3D seismic interpretation and JIP-well information were used to build a full 3D basin-scale model of the Green Canyon area which comprises the thermal and depositional history, salt tectonics, complex migration pathways including fault development, generation and expulsion of hydrocarbons from various source rocks, and in-situ bio-methane generation. In total, 196 depth horizons with a vertical resolution between 1 and 10 m at targeted hydrate-bearing layers were created. The modeling results revealed gas hydrate saturations within Pleistocene sediments corresponding well with the field data. Prominent gas hydrate accumulations have been modeled to form at the base of the gas hydrate stability zone (GHSZ) (up to 80 vol. %) and within sand-rich intervals above the base of the GHSZ (5 – 8 vol. %). The majority of modeled gas hydrates have a biogenic origin; sparse thermogenic hydrate accumulations exist only in the direct vicinity of the GHSZ base. The mechanism described in the present study as 'methane recycling' is responsible for high porosity-blocking gas hydrate saturations forming in the deepest sections of the GHSZ base since about 0.4 Ma. Due to large sediment deposition during the Neogene, previously existing gas hydrates at the base of the GHSZ were buried outside the hydrate stability field. Methane formed by dissociating hydrates migrated upwards and re-charged the gas hydrate pool at the base of the newly equilibrated GHSZ resulting in high and wide-spread hydrate accumulations.

Overall, the GC955 model area covers about 448 km^2 and exhibits total gas hydrate accumulations of about 434 Mt of CH_4, or equivalently, 340 Mt of C (~0.75 Mt C/km^2 or 1.56 billion cubic meters (BCM)/km^2) which exceeds an average gas hydrate deposits at continental margins by a factor of forty (~0.02 Mt C/km^2). This finding is consistent with other published predictions obtained with a different method (transfer function integrating well and seismic data) and estimating the GC955 resource potential as ~1.8 BCM/km^2 (*Frye et al.*, 2012). A series of sensitivity analyzes were performed in order to investigate variability of the final results with respect to: reduction in the thickness and productivity potential of the Tithonian primary source rock, limited transmissibility of the deep-rooted faults, reduced biodegradation potential in the uppermost Pleistocene layers, higher variability in the bottom water temperature trends, and closed basin sides. The performed test runs revealed none or minor influence of Tithonian source rock properties on the present-day gas hydrate deposits which is consistent with the predictions assuming mostly biogenic origin of these deposits. A reduction in the total gas hydrate budget to ~425 Mt of CH_4 (-0.2 %) was calculated for the test scenario assuming impermeable large-scale faults which, in that case, did not contribute to facilitate both thermo- and biogenic methane migration from deeper sources. The reduction of the initial TOC content in the Pleistocene layers from 1 wt. % to 0.7 wt. % resulted in a decrease of the gas hydrate deposits to 371 Mt of CH_4, -14.5 % with respect to the reference run. By prescribing artificially impermeable basin sides, total gas hydrate accumulations summed up to 500 Mt of CH_4 (+ 15.2 %) assuming the same source rock productivity parameters and organic matter availability in the shallow sediment which clearly suggests the importance of horizontal migration pathways available to both fluid and gaseous components.

To evaluate the feasibility of using regionally-derived conclusions on sediment type and its behavior, source rock maturity and productivity, and to understand the driving forces of gas hydrate formation, a supplementary study was performed at location within the large Mississippi Delta fan area that lacks precise drill data and field observations. In summary, we could identify key modeling factors controlling hydrate formation and assessed uncertainty parameters which determine a potential economic relevance of a modeled region. In a contrary to the Green Canyon area, the model domain chosen at the Mississippi Delta fan does not contain important salt deposits and large-scale fault structures. Therefore, the main driving force of the methane migration was the Darcy flow based on the local pressure gradients. The geometry of the slope facilitated fluid and gas flow towards the upper slope of the northern Gulf of Mexico basin and resulted in abundant gas hydrate deposits at the base of the gas hydrate stability zone (50 – 60 vol. %) and within abundant highly permeable paleo-channel-levee systems (5 – 15 vol. %). Our findings from both study sites suggest the presence of lithologically-controlled mostly biogenic gas hydrate accumulations in both Gulf of Mexico regions as well as prominent gas hydrate saturations at the base of the GHSZ resulting from the methane re-cycling process. However, due to the lack of direct model calibration to the drill well data at the Mississippi Delta fan region (specifically porosity, permeability, TOC content, and sediment compaction properties), gas hydrate predictions are most likely less accurate in comparison to the Green Canyon study.