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GAS HYDRATE RESOURCE ASSESSMENT ON THE UNITED STATES OUTER CONTINENTAL SHELF: A MASS BALANCE MODEL

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ABSTRACT

The Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE; formerly the Minerals Management Service) is a U. S. Department of the Interior bureau charged with managing the nation's natural gas, oil, and other mineral resources on 1.7 billion acres of the U.S. Outer Continental Shelf (OCS). Over the past five years, BOEMRE has worked to develop an assessment methodology to evaluate the resource potential of natural gas hydrate across the entire OCS, including the Alaskan, Atlantic, Gulf of Mexico, and Pacific margins. Preliminary assessment results were published for the Gulf of Mexico OCS in 2008, reporting a mean in-place volume of 606.87 trillion cubic meters *[1]*. The assessment model structure has been modified in many ways over the past three years. In this paper, we report on major model changes that allow for the adaptation of the Gulf of Mexico model to other U.S. OCS areas, including the integration of Bottom Simulating Reflectors, stochastic prediction of reservoir facies, and migration model modifications.

Keywords: gas hydrate, mass balance, resource assessment, BSR, model

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INTRODUCTION

The Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) is a U. S. Department of the Interior bureau charged with managing the nation's natural gas, oil, and other mineral resources on 1.7 billion acres of the U.S. Outer Continental Shelf (OCS)(Figure 1). Over the past several years, BOEMRE has led an effort to provide a comprehensive assessment of undiscovered gas hydrate resources across the U.S. OCS, including the Alaskan, Atlantic, Gulf of Mexico (GOM), and Pacific margins. The ongoing project was developed with a goal of delivering, in succession, an estimate of in-place, technically-recoverable, and economically-recoverable gas hydrate resources.

Figure 1. U.S. Outer Continental Shelf margins.

The model framework and methodology for an in-place analysis were first developed for the U.S. GOM, where preliminary assessment results indicate a mean in-place volume of 607 x 10^{12} m^3 (trillion cubic meters; TCM)*[1]*. This original modeling approach was built upon a Monte Carlo mass balance progression that utilized a combination of spatially-resolved geologic inputs and empirically-defined probability distributions. A comprehensive description of the geologic inputs, model structure and components, and inherent uncertainties for this initial effort are described in OCS Report MMS 2008-004 *[1]*.

The current resource assessment effort builds upon the initial release of model results in the GOM and involves the adaptation of the original mass balance model to other deepwater areas of the OCS. In this paper we discuss how the mass balance model components - comprising a charge module, a container module, a concentration module, and an integration module - have been developed and modified since 2008 to reflect our current approach and understanding of the GOM, Atlantic, and Pacific deepwater OCS areas[1,2].

DEEPWATER MASS BALANCE MODEL

Methodology

Unlike BOEMRE assessments of undiscovered *conventional* oil and gas resources on the OCS, which are performed using a geologic play-based approach, the principle BOEMRE gas hydrate assessment model was developed using a mass balance approach. The mass balance analysis is applied to each model cell, providing a level of spatial resolution that supports detailed mapping. While other possible methodologies exist, mass balance has two important advantages: it is transparent and it allows extreme variable disaggregation. Therefore, as new or improved information becomes available for the various input parameters, the system can be easily updated.

The deepwater assessment areas of the Atlantic, Pacific, and Gulf of Mexico are each divided into grid model cells that cover those areas from 300 m water depth to the 200 nautical mile (nm) U.S. exclusive economic zone (EEZ), where supporting data are available. The grid cell size varies between each of the regions. Cell size was selected to optimize the spatial resolution of the results with respect to the density of the input parameters, while providing an acceptable level computational speed and a manageable results database. The size of individual model cells can be modified for any geographic area of interest.

In an effort to capture the many uncertainties associated with the geologic framework and the petroleum systems analysis of the offshore regions, and their collective affect on the location and volume of undiscovered resources, a stochastic modeling approach was adopted.

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[1] At the time of this paper, quantitative assessment results of this effort have not been released by the U.S. Government and can not be included in this paper; regional model inputs and sub-module outputs are described.

[2] Custom model changes and input files for the Alaskan deepwater areas (Beaufort Sea, Bering Sea, Aleutian Trench, and Gulf of Alaska) have not yet been developed.

Specifically, uncertainties include the presence and quality of source rocks, reservoir rocks, and traps; the timing of hydrocarbon generation, migration, and entrapment; the thickness of the gross and net gas hydrate stability zone (GSHZ); and the location, number, and size of potential accumulations. In this particular assessment, many of these uncertainties typically associated with conventional oil and gas resources are magnified when applied to an unconventional, poorly understood gas hydrate resource base. When necessary and feasible, each of these factors – including the volume of gas hydrate derived from them – is expressed as a range of values with an associated probability of occurrence.

A fundamental advantage of this approach is that the model can use Monte Carlo sampling to generate empirical distributions of key output variables. As the number of Monte Carlo trials increases, the distribution of each output variable converges to a probability distribution logically coincident with the model's structure and initial conditions assigned to input variables. Probability distributions assigned to input variables and to model parameters are, in some cases, derived exclusively from statistical analysis of data, and in other cases, from expert judgment, or from a combination of both.

Input Parameters

Inputs for the model are generally derived from one of the three following categories: spatial, empirical, or calculated.

Spatial - Spatially-referenced inputs are available when the data coverage allows for a unique value (or range of values) to be attributed to each model cell. Spatial data coverage includes 2-D and 3-D seismic, seafloor renderings and interpretations, morphologic feature expressions, and wellbore data. With few exceptions, spatial inputs provide the most accurate representation of the physical environment into the model structure. Examples of spatial inputs include bathymetry, depth to basement, vertical sand component, bottom simulating reflector (BSR) occurrence, and location of surficial seismic anomalies[3]. These five fundamental datasets provide the underlying structural fabric that is evident in all by-products and end-products of a model run, and are briefly described below.

Bathymetry is derived from interpreted 2- and 3-D seismic surveys and from public datasets (Figure 2). Bathymetric variations influence the thickness of the GHSZ through the associated changes in temperature and pressure conditions. Also, in order to accurately predict the methanogenic rates that drive gas generation, initial seafloor temperature is combined with a geothermal gradient to provide an estimate of sediment temperature at a given depth. In addition, the bathymetry interpretation is used foundationally to derive two other input parameters: depth to basement and distribution of surficial seismic anomalies.

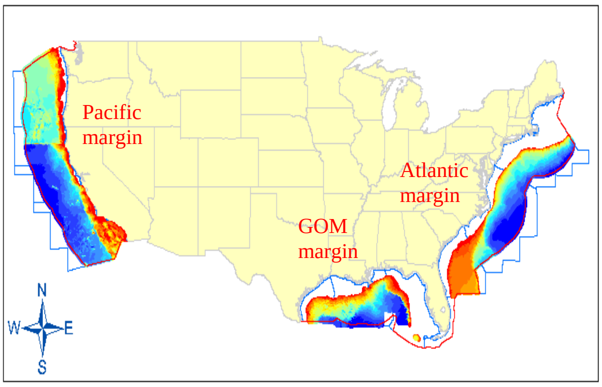

Figure 2. Color shaded bathymetry from Pacific, GOM, and Atlantic OCS deepwater margins.

The *depth to basement* represents the isopach thickness from the seafloor the base of the relevant sedimentary section. In the GOM (Figure 3), this thickness is interpreted to the top of salt north of the Sigsbee Escarpment and to the base of the Mesozoic section in several areas south and east of the Sigsbee Escarpment, where depositional and allochthonous salt bodies are limited. In the Atlantic, the thickness is measured to the base of the Tertiary stratigraphic section. Interpretations are derived from a combination of 2-D and 3-D seismic data, wellbore data, and published thickness models.

In all three of the deepwater regions, the thickness of the sedimentary section in each cell represents a significant input parameter in the biogenic methane generation model. Due to the overwhelming impact of salt on the gas hydrate

[3] Surficial seismic anomalies are used exclusively in the GOM model.

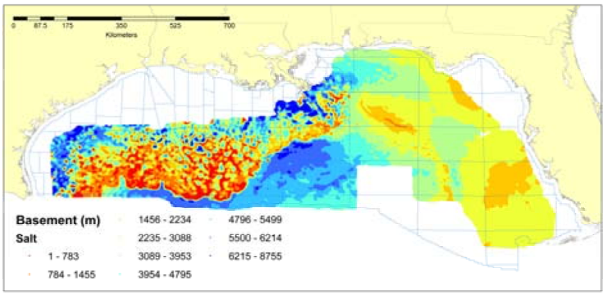

Figure 3. Depth to basement spatial input for the GOM. Thickness values are in meters.

petroleum system in the GOM, this interpreted surface has two additional uses here. First, the true vertical depth of the basement is used as a surface for estimating the relative dip of strata for the gas migration model. Second, the depth to basement is used to calculate the distance to salt, which affects the thickness of the gross HSZ through its influence on both connate water salinity and temperature in the sedimentary section.

The *vertical sand component* input provides a measure of the two end member lithologies ("sand" and "shale") considered across each of the study areas. In the GOM, the distribution of sand is modeled through a two-phase analysis. First, the sand body thicknesses in over 800 shallow well logs (upper 610 meters) were summed and then divided by the total log thickness evaluated, generating a percent-sand value in the shallow section. These values were gridded as a first approximation of the areal distribution of sand-rich facies. Interpretive data points were added to enhance the grid where sediment isopach maps and seismic stratigraphic analysis indicated sand-prone facies, often in established sand fairways, the centers of minibasins, and those areas just downdip of the Pleistocene shelf edge deltas. In the Atlantic, we employed a simplified version of the GOM workflow by considering the available well and 2-D seismic data (Figure 4).

In the Pacific, we adopted an approach that utilizes a depofacies classification scheme derived from local data sources (Figure 5). Each of the five depofacies is assigned an uncertain distribution of sand content that is reflective of those particular environments.

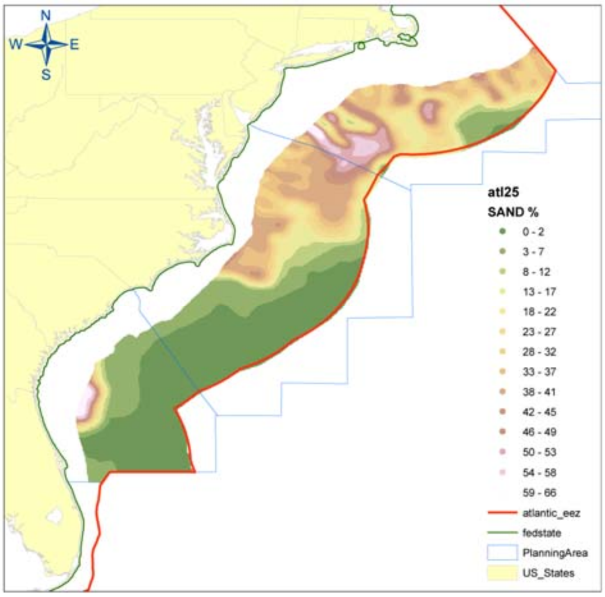

Figure 4. Spatial sand distribution input for the Atlantic OCS margin, expressed as a percent of the shallow section.

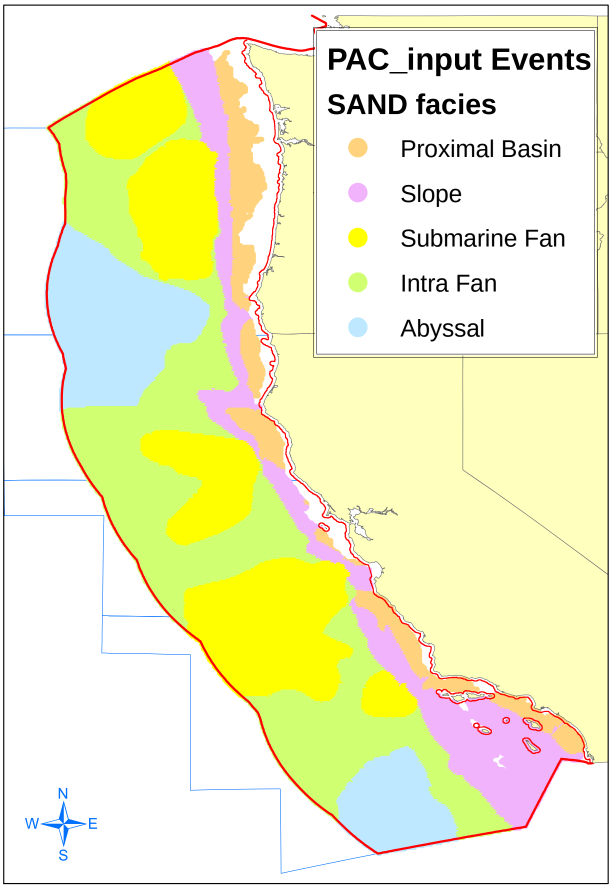

Figure 5. Depofacies approach to spatial sand distribution in the Pacific margin.

The sand component is used in the analysis for two purposes. First, the sand and shale content of the HSZ is used to define the distribution of porosity and the saturation of available pore space in the concentration module. Second, in the charge module, the relationship between water flux in the source rock and methanogenic productivity is presumed to be direct. We invoke the end member physical properties of sands and shales to model water flux (using permeability as a variable) and apply them through the candidate section using the sand/shale ratio defined here.

The *distribution of BSRs* is recorded in the input file for each of the OCS regions and noted as either a "high confidence" or "moderate confidence" feature (Figure 6). The presence (or absence) of one of these features in a model cell will impact the trapping and migration efficiency applied to the gas charge in the cell.

Surficial seismic anomalies in the GOM[4] were identified by extracting the seismic amplitude response of the seafloor from the 3-D derived bathymetry data. Anomalies are typically found where the seafloor substrate comprises something other than the typical soft mud and silt found across the majority of the GOM. The anomalies often coincide with active or paleo-vents of methane to the seafloor, which themselves tend to be coincident with basin margins and shallow fault systems. The areal extent of the mapped anomalies was extended with a concentric 762 meter buffer to more accurately reflect the area where venting occurred or is occurring. Over 10,000 unique anomalies were identified.

We assume that the surficial seismic anomalies, and the associated high flux of gas interpreted to accompany them, indicate the presence of a thermogenic gas component in the shallow subsurface. As such, two modifications were made in model cells that fall within the bounds of a surficial anomaly that have a direct affect on in-place hydrate volume. First, the gas composition used to determine HSZ thickness is drawn from a distribution with a lower methane component, typically resulting in a thicker gross HSZ. Second, in model cells within the bounds of an anomaly where the modeled charge does not fill the available void space in the HSZ, the remaining space is filled manually with additional gas.

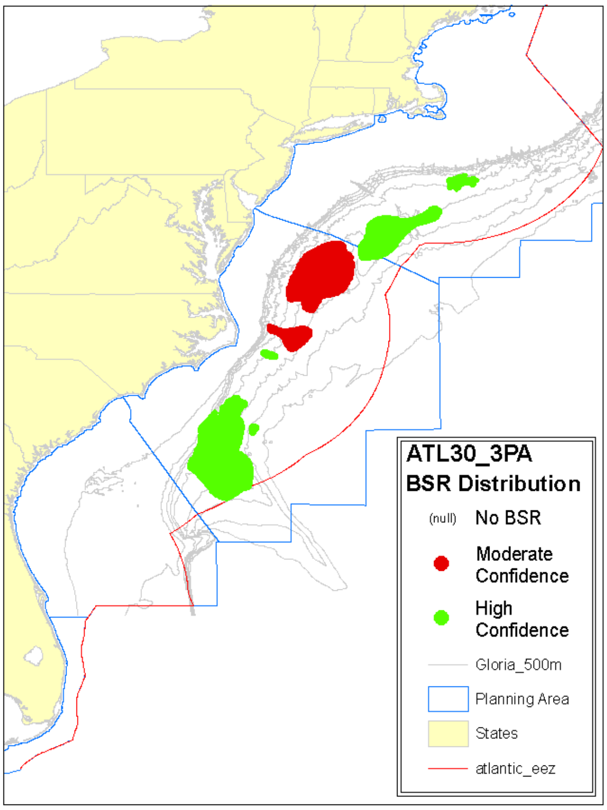

Figure 6. Distribution of BSRs on the Atlantic margin. Green = high confidence; Red = moderate confidence; White = no BSR present.

Empirical - Empirically-derived model inputs are drawn from a distribution of data points that come from various geographic locations, but are assumed to represent a likely state of nature for any cell in the study areas. For instance, total organic carbon (TOC) is input into the model as a draw from a curve fit to a distribution of regionally-derived samples (Figure 7). Other examples include organic carbon conversion efficiency, geothermal gradient, gas chemistry, and hydrate saturation.

Calculated - Calculated model inputs are founded in physical observations and relationships that can be applied across the study areas, such as water bottom temperature as a function of bathymetry, or sediment porosity as a function of burial depth. Many of these parameter inputs will vary between OCS regions.

[4] The GOM is the only region where seafloor anomalies are identified. This is partially a data-driven issue (near-complete coverage by 3-D data) and partially a conducive local geology issue.

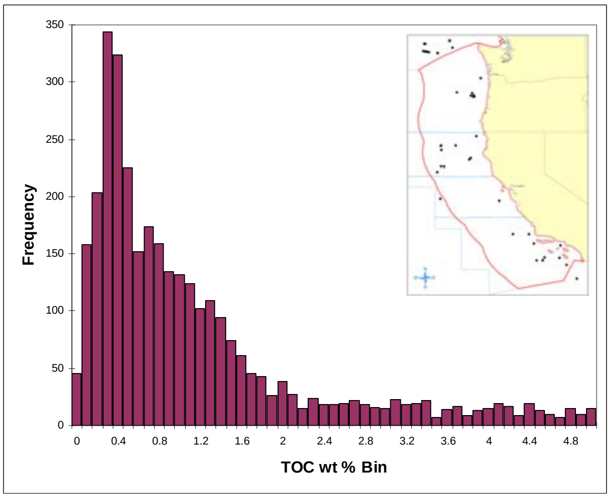

Figure 7. Histogram of TOC weight % from the Pacific margin (n=3373). Map view of sample locations (black dots) included in upper right.

Model Structure

The software application through which the analysis is performed comprises four modules (Figure 8). Within each of the modules, there are models and sub-models that represent biological, chemical, or physical processes.

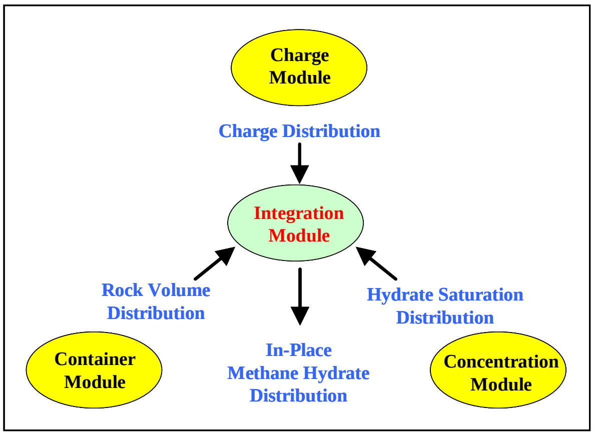

Figure 8. Mass balance model structure.

Charge Module - The charge module contains a generation model and a migration model. A single Monte Carlo trial of the generation model produces the amount of biogenic methane produced in each cell at that trial. The migration model then distributes a gas charge to the HSZ in each model cell. Migration can be vertical, where all gas remains in the cell of origin (Atlantic, Pacific, and part of GOM), or lateral (GOM only), where gas is partially redistributed in hydrodynamic catchment areas.

In the *Generation Model*, a mass of organic carbon is provided to a production function that determines the efficiency of its transformation to biogenic methane, and provides an estimate of the output mass (Figure 9). While the structure of the generation model is the same for all three OCS regions, many of the locally-derived empirical datasets vary. The components of Figure 9 are described below.

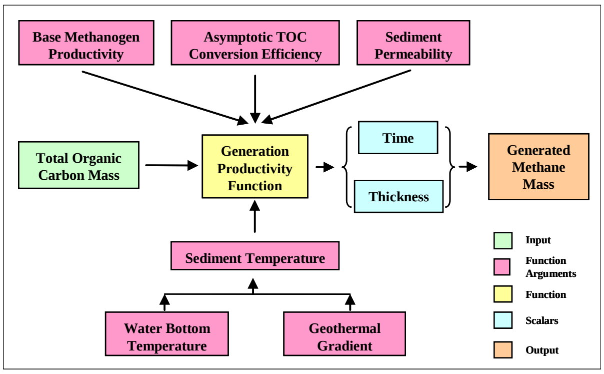

Figure 9. Schematic diagram of the Generation Model.

The TOC mass is drawn from a distribution fitted to measurements from core data specific to each OCS region. The Pacific OCS contains the TOC dataset with the most comprehensive spatial variation (Figure 7), while the Atlantic and GOM distributions are based on data of a more limited coverage. Data from core subjected to the procedure hydrous pyrolysis (better known as *Rock Eval*), from which the limiting value of organic carbon to hydrocarbon transformation is calculated as conversion efficiency, are also assembled into a region-specific distribution. The generation model draws a value for conversion efficiency from a curve fit to this data.

The productivity[5], or rate at which methanogenic archaea convert organic carbon to methane in a given environment, is assumed to be a function of ambient temperature in that environment. Sediment temperature for a given depth interval of any model cell is found using a derived water

[5] For a complete mathematical description of methanogenic productivity, including the influence of sediment permeability, the reader is referred to the full report *[1]* that accompanied the initial release of the GOM results.

bottom temperature (dependant on water depth) and a geothermal gradient drawn from an empirical probability distribution function. As temperature increases above its minimum, methane productivity increases monotonically over a finite temperature interval. This is the domain of Arrhenius' Law, an exponential growth law where the rate of a chemical reaction doubles for every 10°C increase in temperature. Additional heat ultimately slows the rate of productivity after a peak at a temperature of 35°C. As temperature continues to increase above peak productivity temperature, the rate of productivity rapidly declines. Finally, as with any biologic organism, there is a temperature limit beyond which organisms can no longer survive, taken here to be 70°C; biologic metabolism of organic carbon ceases—and so does biogenic methanogenesis.

The total thickness of the stratigraphic column in each cell in the study area (*depth to basement* spatial input; e.g. Figure 10) is supplied to the generation model as a series of discreet chronostratigraphic units. The duration and the thickness of each chronostratigraphic unit are calculated uniquely in each of the OCS regions.

In the GOM model we recognize five geologic units: the Lower Miocene, Middle Miocene, Upper Miocene, Pliocene, and Pleistocene *[1]*. In lieu of mapping each of these units across the GOM, an unpublished data set comprising average sediment accumulation rates was used to create a distribution of the relative thickness of each of the five stratigraphic units over the study area. The base of each of the five units and the time duration was taken from Berggren et al. *[2]*. A set of 100 locations was randomly generated within the study area, where the thickness of the five geologic units was determined by multiplying the sediment accumulation rates by the length of time. For each of the five time/rock units, the distribution of sediment thickness of that unit, as a fraction of total sediment thickness, is calculated. Multiplication of relative proportions of the cell's total column thickness produces five individual unit thicknesses.

In the Atlantic region, two chronostratigraphic horizons were interpreted on the 2-D seismic dataset: the base of the Pleistocene and the base of the Tertiary. The absence of any definitive sedimentation rate data or finer well control requires that the Pliocene through Tertiary section be equally divided into the following chronostratigraphic units: Pliocene, Miocene, Oligocene, Eocene, and Paleocene.

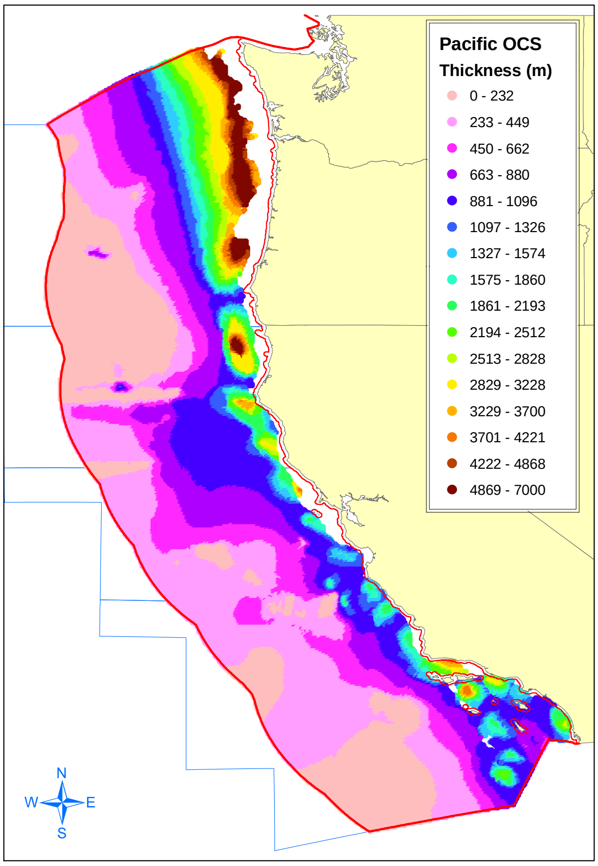

Figure 10. Sediment thickness input for the Pacific margin. Total thickness (shown here in meters) is divided equally into five stratigraphic units. (Figure modified after Collett, 1995 *[3]*).

The absence of an extensive seismic dataset across the Pacific OCS requires that an even broader classification be employed. Here, while no mapped horizons were carried across the study area, many of the wells that provide paleontological age control suggest that the oldest sedimentary units are of Miocene age. For these reasons, we equally divide the entire stratigraphic thickness into the same five units used in the GOM (Pleisto-, Plio-, and Upper, Middle, and Lower Miocene).

Calculation of the mass of methane produced, given a mass of organic carbon input, is done by looping through each of the stratigraphic units that cover the sedimentary column of each cell.

Starting with the original deposition of organic carbon in any one of those units, the productivity function is integrated over a temperature interval corresponding to top and bottom depths of the unit to determine the amount converted to methane at a period in geologic time. At each time period, the cumulative amount of organic carbon converted to methane is calculated. The mass of organic carbon already converted is subtracted from the mass available for conversion in the next geologic time step. However, if the cumulative amount converted at any time step exceeds the estimated asymptotic conversion efficiency, production of methane ends, and no more is generated in the model for the remaining periods of geologic time.

In the *Migration Model*, a fraction of the gas generated in each cell is directed to the HSZ as a gas charge. In the GOM, gas migration is modeled using a combination of lateral movement and vertical movement. In the Pacific and Atlantic, gas migration is modeled using only a vertical component[6]. All gas migration is subject to a trapping/migration efficiency reduction that accounts for gas that is not entrapped in the HSZ, such as those gasses improperly expelled from deep sources, gas retained as deeper conventional accumulations, and gas expelled at the seafloor.

The vertical migration submodel directs all gas generated in a model cell to remain in that cell and be made available to charge the HSZ in the cell (subject to the application of the trapping/migration efficiency). This submodel is most appropriately applied in abyssal areas where the sedimentary section comprises a mostly flat, structureless environment. Vertical migration is also employed in areas where available data does not allow for detailed mapping of subsurface features, including areas of moderate deformation.

The lateral migration submodel is founded on the notion that gas will migrate laterally within discreet, continuous basins, where the directions and magnitudes of gas transport are largely controlled by a function of stratal dip. The workflow to define these flow paths and magnitudes is based on several products consecutively derived from GIS-based procedures.

In the simplest model of dip-driven migration, all generated gas is evacuated from structural lows and redistributed to the structurally highest points in the study area. The magnitude of charge in the cells on the structural highs would be a function of the hydrodynamic catchment areas surrounding them and the volume of generation within the catchment.

Our model builds on this basic idea, with a modification based on empirical data on the spatial distribution of hydrates and hydrate-indicator variables observed on and near the seafloor of the GOM. In adopting this approach, the dip of the surface of the basement is the basis for estimation of the dip of sediments in the section that control migration[7], and the geometry of this surface is used to determine the catchment areas across the study area. A catchment basin comprises the union of all contiguous cells across which gas can move laterally without reversing dip (i.e., moving downdip). As the catchments are deemed hydrodynamically isolated systems, the redistribution of gas in the dip-driven migration submodel is conducted by catchment, where the value of total generation in each cell is summed by catchment and redistributed across the cells in that catchment.

The trapping/migration efficiency submodel is the final step in the Charge Module. Here, we reduce the gas charge to be delivered to a model cell by selecting a fractional value (less than one) from one of three uncertain distributions. The three distributions are positively correlated to the presence or absence of a BSR in the model cell, where higher migration efficiencies are associated with model cells with high confidence BSRs. Figure 11 is an example of the mean values output from the Charge Module.

[6] The change in modeling approach is a result of both data availability and assumed underlying geologic controls.

[7] In most cases, the salt-floored basement of the GOM stratigraphic column is a dramatic and regionally dominant factor in determining stratal dip throughout the sedimentary column.

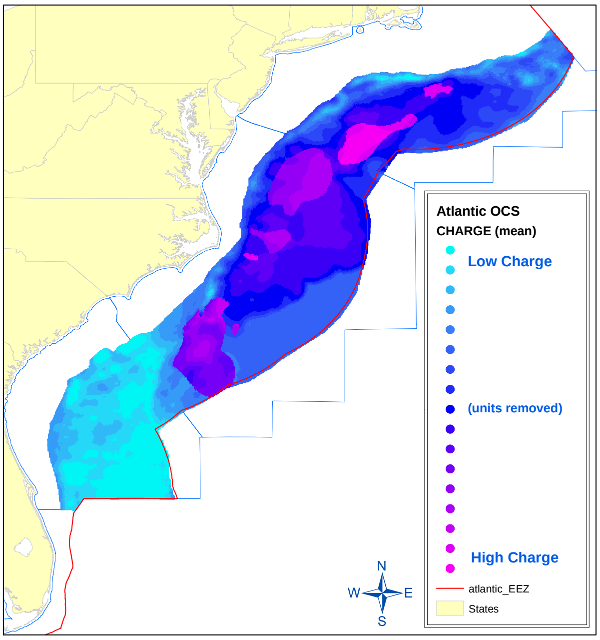

Figure 11. Mean charge in the Atlantic OCS.

Container Module - The container module employs a two step process to provide an estimate of the study area's rock volume that is a candidate for formation of natural gas hydrates. First, we model the gross HSZ, which covers that volume of rock in which pressure, temperature and salinity conditions permit the formation of hydrates, if available pore space and sufficient hydrocarbon charge are present. Second, we remove a layer of the HSZ, starting at the seafloor and extending downward, where the saturation of gas in ambient waters is presumed to be below 100 percent. Here we call a layer in which this condition is present the "undersaturated zone" (UZ). In the GOM, the thickness of the UZ is inversely related to the charge allocated to each cell, where a high gas charge equals a thin UZ (minimum 0 m), and a low charge a thick UZ (maximum 250 m). In the Pacific and Atlantic, where we observe far less focused flow as compared to the GOM, the UZ thickness is drawn from an uncertain distribution (mean=200m; std dev=141.4m). The gross HSZ, minus the UZ, yields the net HSZ.

Estimation of the gross HSZ is based on a phase stability equation described by Milkov and Sassen *[4]*[8]. Their fundamental equation is an implicit function in which two relationships are set equal to each other to establish a phase boundary in temperature and pressure. The equation is solved for a value of C, the depth below the seafloor at which ambient temperature and pressure are equal to the value of the phase stability expression. This depth marks the bottom of the gross hydrate stability zone and thereby defines its gross thickness. If pressure is too low and/or temperature to high in any cell, the thickness of the gross HSZ will equal zero, and no gas hydrate is expected.

In this study, the basic analytic expression provided by Milkov and Sassen *[4]* is modified in several important ways. First, we have adopted a stochastic approach where some parameters regarded as uncertain quantities have been assigned probability distributions. Second, we have replaced the water bottom temperature and geothermal gradient expressions with equations that draw from a different empirical dataset. Finally, in the GOM, we have incorporated the modeled influence of local salt on sediment temperatures and on pore water salinity.

Influence of local salt - In the GOM, particularly across the upper slope, salt plays a major role in tectonics and the distribution of sediments on a large scale. On a local scale, the presence of salt impacts pore water chemistry and local sediment temperature. This chemical impact arises through the dissolution of salt at the face of the salt body and its transport away from the salt body by diffusion and through fluid flow. For all points in the section below the seafloor, where salinity exceeds ocean salinity, the phase stability boundary for hydrates shifts. When this happens, the quantity of salt in pore waters above ocean salinity reduces the temperature at which hydrates will form (for a given pressure), making the gross HSZ thinner than it would be otherwise. We calculate the reduction in phase stability temperature by solving for the change in salinity above ambient at some measured distance from the salt.

Local salt also raises local sediment temperatures. Compared to surrounding sandstone and shale, salt is a differentially effective conductor of heat. The temperature field at the top of the salt body is warped by the increase in heat conducted into surrounding sediments. Following O'Brien and

[8] Refer to OCS Report MMS 2008-004 for a complete description of this calculation.

Lerche *[5]*, the decrease in sediment temperature is taken as a function of increasing distance from salt. We assume that the increase in geothermal gradient (over ambient) at the salt face is uncertain and assign to it a normal distribution.

The mean values of the gross HSZ output for the Atlantic OCS are shown in Figure 12. Note that in the absence of any significant shallow salt bodies or anomalous thermal features, the gross HSZ output is driven mostly by the bathymetry input feature.

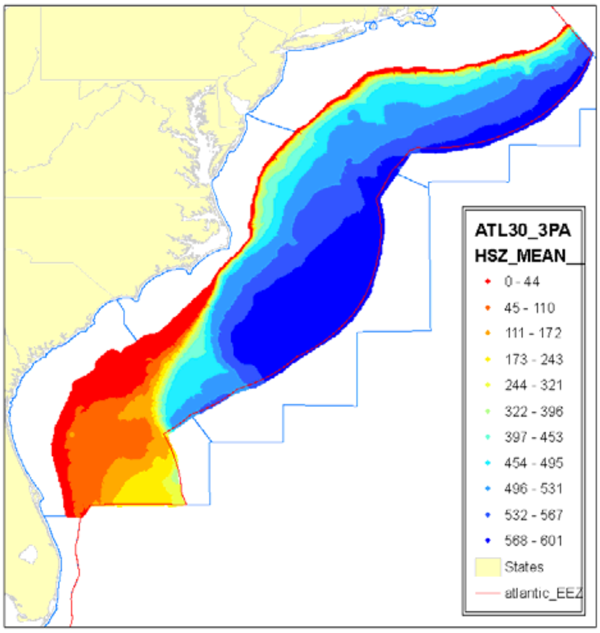

Figure 12. Gross HSZ thickness(m), Atlantic OCS.

Concentration Module - The concentration module provides a probability distribution of volume of hydrates per unit of bulk rock volume in the net HSZ, conditional on it being charged with methane. It includes models of rock porosity, based on depth and lithology, and of the fraction of void space that can be saturated by methane hydrates.

The gross matrix porosity of the net HSZ is estimated separately for sand and shale. Because of the paucity of empirical data for the GOM fine grain sediments, the shale depth-porosity relationship is taken from Hamilton *[6]*. Sand depth-porosity is modeled from several shallow core observations in the GOM. Sand and shale porosities in a cell are then weighted relative to the sand/shale ratio in that cell. For both sand and shale, porosity is evaluated at the depth below seafloor of the midpoint depth of the net HSZ. For each trial and each cell, the realization of the depth of midpoint thickness of the net HSZ is passed from the container module.

The steps above result in, for each trial and cell, a percent of bulk rock volume of the net HSZ that is occupied by void space. The void space is saturated for each lithologic end member by drawing a gas hydrate saturation value from a distribution that includes values from all major global drilling projects.

Integration Module - At each Monte Carlo trial, the charge module's output and the volume of candidate saturateable void space generated by the container and concentration modules are compared. The smaller of the two volumes is retained, as the volume of in-place methane hydrates in a cell cannot exceed the accommodation space available. Executing the model over 1,000 trials yields a distribution of in-place methane hydrates in each cell. For all cells, if the thickness of the net HSZ on a trial is equal to zero, a zero hydrate volume is assigned to the cell for that trial.

In the GOM, cells covered by surficial seismic anomalies are treated differently from those cells which are not covered by anomalies. We assume that if the volume of the charge is or has been enough to vent methane to the seafloor surface (resulting in a seafloor anomaly), than there is enough charge volume to fill the available effective void space to its calculated capacity. In instances where the modeled charge does not fill the HSZ, the available void space is manually filled to capacity.

In-place volumes are calculated under reservoir temperature and pressure conditions. These volumes are converted to standard temperature and pressure using a conversion factor drawn from a subjective probability distribution with a mean of 164.

Results

At this time, final volumetric results from our recent model runs have not been publicly released by BOEMRE. In general terms - and in concert with the initial release of results for the GOM [1] - the areal distribution of the in-place volume is heavily influenced by the geometry of the input data sets. Also, model routines have been calibrated such that assessed volumes coincide with observed and published resource estimates from several sites, including the Blake Ridge *[7]*, GOM Joint Industry Project locations *[8]*, and Hydrate Ridge *[9]*. The example results in Figure 13 highlight the many factors in our model that we believe drive gas hydrate accumulations: bathymetry, source thickness, lithology, and direct hydrocarbon indicators.

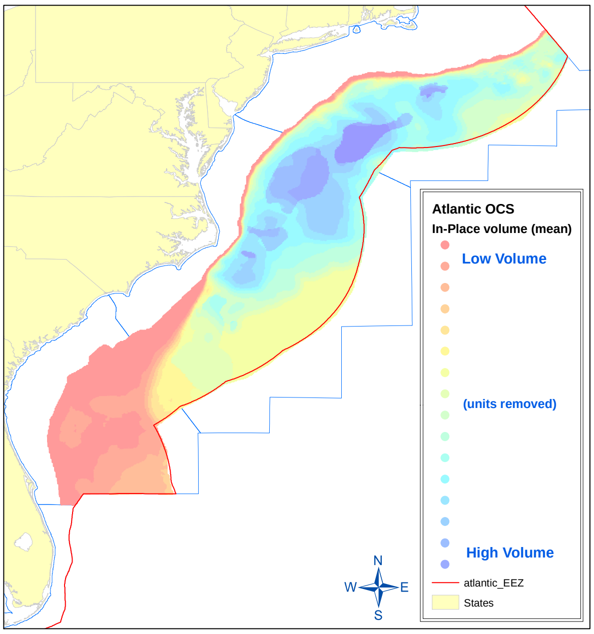

Figure 13. Relative in-place gas hydrate volume distribution on the Atlantic OCS. Specific values not available for release at this time.

The larger in-place results volume will ultimately be further reduced to include only those resources hosted in sand reservoirs, with the assumption that this is a necessary first step on the road to a full technically-recoverable analysis. Recent successful short term gas hydrate production tests at the Milne Point Unit in northern Alaska *[10]* and from the Mallik Field in the Mackenzie Delta, Northwest Territories, Canada *[11]* have helped demonstrate that porous and permeable sandstone reservoirs have the capacity to produce gas from hydrate using existing technologies.

CONCLUSIONS

The U.S. BOEMRE has developed a stochastic mass balance model for the purpose of assessing undiscovered gas hydrate resources on the U.S. Outer Continental Shelf. Following the release of preliminary assessment results for the GOM in 2008 *[1]*, efforts to modify the model structure and adopt it to other U.S. deepwater margins are underway. Many significant changes have been incorporated into the model, including the evaluation of bottom simulating reflectors, the expansion of the lithologic analysis to include depositional facies, and the allocation of vertical gas migration methods.

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