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A new approach to understanding the occurrence and volume of natural gas hydrate in the northern Gulf of Mexico using petroleum industry well logs

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Abstract

The northern Gulf of Mexico has been the target for the petroleum industry for exploration of conventional energy resource for decades. We have used the rich existing petroleum industry well logs to find the occurrences of natural gas hydrate in the northern Gulf of Mexico. We have identified 798 wells with well log data within the gas hydrate stability zone. Out of those 798 wells, we have found evidence of gas hydrate in well logs in 124 wells (15% of wells). We have built a dataset of gas hydrate providing information such as location, interval of hydrate occurrence (if any) and the overall quality of probable gas hydrate. Our dataset provides a wide, new perspective on the overall distribution of gas hydrate in the northern Gulf of Mexico and will be the key to future gas hydrate research and prospecting in the area.

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Executive Summary

Natural gas hydrate are a solid combination of natural gas (usually methane) and H_20 that form primarily within marine sediments on continental margins. Because stability of gas hydrate is sensitive to temperature and pressure, sufficient warming or sea level change can cause dissociation or 'melting' of methane hydrate, which can affect both the local carbon cycling in the shallow marine system and may alter the earth's carbon cycle. Moreover, dissociation of marine gas hydrate can pose a threat as a submarine geohazard that could cause landslides or affect oil and natural gas production. Finally, because of the high concentration of methane in natural gas hydrate, hydrates could be a future unconventional natural gas resource. All of these facets of natural gas hydrate (carbon cycle, natural hazards, and energy) benefit from knowledge of the amount and distribution of natural gas hydrate in the marine sediment system.

In this work, we add significantly to our understanding of the occurrence and distribution of natural gas hydrate in the northern Gulf of Mexico by assessing publically available petroleum industry well logs throughout the interval where gas hydrate is stable, termed the hydrate stability zone (HSZ). In almost all cases, if well log data was available from industry wells within the HSZ, those logs were exclusively resistivity logs and a gamma ray log. Because natural gas hydrate is an electrical insulator, we can use the resistivity log to estimate the intervals where gas hydrate occurs. Further, we use the character of the resistivity log coupled with the gamma ray log to estimate the lithology of the reservoir and the type of hydrate morphology within the reservoir.

In our assessment, we have identified 798 wells with well log data within the HSZ, drilled between 1987 and 2014. Out of those 798 wells, we have found evidence of gas hydrate in well logs in 124 wells (15% of wells). Most of these 124 wells were not previously published or known to contain gas hydrate. As part of our assessment, we have built a dataset of all wells assessed, including information such as the location, total amount of well log data available and suspected hydrate intervals.

We have used the results in a comparison of hydrate occurrence on well logs and previously identified bottom-simulating reflections in the Gulf of Mexico. We found that hydrate appears to be more likely where bottom-simulating reflections (BSRs) occur, however, we also observed a large number of wells with evidence for gas hydrate that occur outside of areas with BSRs. As part of research, we also applied our results in a Monte Carlo volume estimate of gas hydrate over our study area in the northern Gulf of Mexico. We find a mean estimate of gas volume of 586 Tcf or $1.65*10^{13}$ m^3 at standard temperature and pressure. Further, our initial results were incorporated into a funded DOE NETL project to drill for gas hydrates in coarse-grained reservoirs in the northern Gulf of Mexico.

Our dataset provides a wide, new perspective on the overall distribution of gas hydrate in the northern Gulf of Mexico and we believe our results will be of interest to the broad hydrate community and the petroleum industry.

Background

Natural methane hydrate is considered a potential energy resource [*Boswell and Collett*, 2011], a dynamic component of the earth's carbon cycle [*Archer et al.*, 2009] and a marine geohazard [*Maslin et al.*, 2010]. Methane hydrate is composed of a solid H_2O lattice hosting guest methane (and sometimes heavier hydrocarbon) molecules that are stable under low temperature and high-pressure conditions commonly found in the shallow sediment column of deep marine environments [*Sloan and Koh*, 2007].

In the Gulf of Mexico, methane hydrate becomes stable within the sediments below the seafloor when water depths approach ~500 m [*Collett*, 1995; *Boswell et al.*, 2012; *Shedd et al.*, 2012]. The hydrate stability zone (HSZ) is the vertical interval starting at the seafloor and extending downward within which the pressure and temperature conditions are suitable for gas hydrate stability. As the water depth increases, the thickness of HSZ also generally increases, although the thickness can be highly variable depending on local geothermal gradient, pore-water salinity and gas composition [*Frye*, 2008].

The existence of methane hydrate in the northern Gulf of Mexico was first reported in the sediment samples in the 1980's [*Brooks et al.*, 1984; *Pflaum et al*., 1986]. It was soon established that the geologic and geochemical conditions prevailing in the Gulf of Mexico, along with the abundance of hydrocarbon makes the area a potential host of methane hydrate [Collett, 1995; Sassen et al., 2001]. Early estimates suggested the Gulf of Mexico contains somewhere on the order of 10^{13} [*Milkov and Sassen*, 2001] to 10^{15} m^3 [*Collett*, 1995] of methane in gas hydrate. In 2008, the Minerals Management Service (now the Bureau of Ocean Energy Management, or BOEM) gas hydrate assessment in the Gulf of Mexico was released [*Frye*, 2008]. Frye [*2008*] used a stochastic mass balance analysis to calculate the in-place gas hydrate in an area covering 450,000 km^2 in the Gulf of Mexico. The model depended on a large number of thermodynamic, biologic, petrophysical and spatial variables. *Frye* reported a mean estimate of $6.07 * 10^{14}$ m^3 of methane in gas hydrates in the Gulf of Mexico basin.

The first gas hydrate focused drilling project in the northern Gulf of Mexico was the Chevron led Gas Hydrate Joint Industry Project (JIP) Leg I in 2005. The JIP Leg I drilled at three sites in Atwater Valley 13, Atwater Valley 14 and Keathley Canyon 151, and was primarily focused on sediment and borehole stability at the gas hydrate sites [*Ruppel et al*., 2008]. This was followed by a Gas Hydrate JIP Leg II in 2009, which focused on LWD methods to detect gas hydrate occurrences in sand reservoirs [*Boswell et al.*, 2012]. Seven holes were drilled at three sites Alaminos Canyon 21, Green Canyon 955 and Walker Ridge 313, and high saturation gas hydrate was found at two locations [*Collett et al.*, 2012].

Motivation

While a wealth of information has been gained over the last several decades about gas hydrate in the northern Gulf of Mexico, there still are many unknown or unconstrained aspects. The two most common ways of identify gas hydrate geophysically are exploration seismic and geophysical well logs. While using exploration seismic data collected for the petroleum industry to assess and understand gas hydrate systems in the Gulf of Mexico has been increasing [e.g. *McConnell and Kendall*, 2002; *Boswell et al.*, 2009; *Frye et al.*, 2012; *Shedd et al.*, 2012] industry well logs have only been used at a few sites, such as Tiger Shark [*Boswell et al.*, 2009], or during pre drilling assessments by the JIP.   However, over 2700 industry well have been drilled and logged in water depths greater than ~500 m (Figure 1), suggesting that a wealth of information could be gleaned about natural gas hydrate from industry well logs.

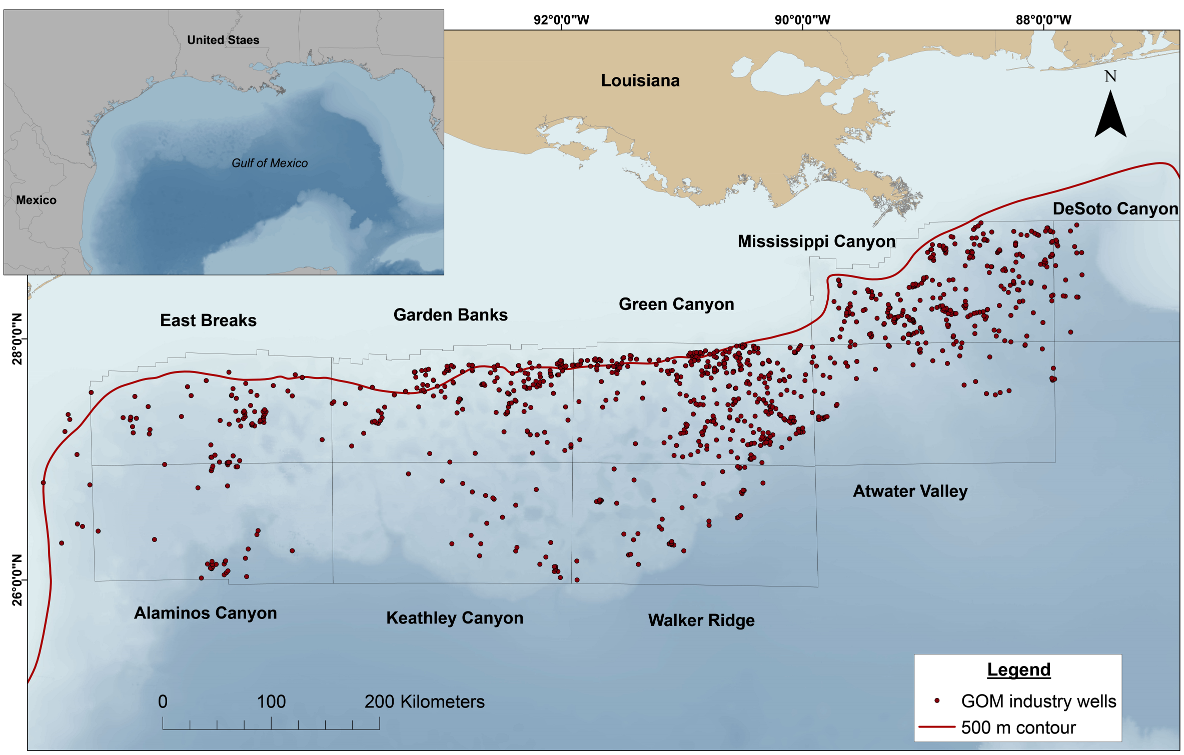

Figure 1: A plot of nearly 2700 industry wells located at within ~500m of water or deeper.

In this work, we filled a large gap in gas hydrate assessment in the northern Gulf of Mexico by undertaking a large, basin wide assessment of publically available petroleum industry well logs for natural gas hydrate.

Methods

Through collaboration with Matthew Frye of BOEM, we obtained the statistical estimate of Frye [2008] for the base of the hydrate stability zone (HSZ) in the northern Gulf of Mexico. The calculations contain percentile values from HSZ_10 (shallowest) to HSZ_90 (deepest) for the depth of the HSZ. For each of the 2700 industry wells, we began ordering pdf and tiff images of industry well logs as long as well log data occurred within HSZ_90 from the public database managed by the U.S. Bureau of Safety and Environmental Enforcement.

We began our initial assessments of well log orders for the western Gulf of Mexico in the spring of 2013. We completed our first round of assessments for Alaminos Canyon and East Breaks in the early fall of 2013, so that we could learn what was needed for the process of analysis and database building. We learned, for example, that when wells had the same surface latitude and longitude, and the same top of logged interval, the well logs within the HSZ were the same and so, in future orders, we ordered only one dataset. If there was any question that the data in the HSZ may not be the same, we ordered all datasets.

Well log analysis

Gas hydrate is electrical insulator and displaces the conductive pore fluid in marine sediments. The electrical resistivity is mainly controlled by the type and amount of fluid present in the sediment. The resistivity response will be higher if resistive gas hydrate or hydrocarbon is present compared to conductive porewater brine. Other than gas hydrate and hydrocarbons, the fluid in the shallow marine sediments is usually equivalent to seawater conductivity, or more conductive than seawater if a location is close to a salt deposit.

Typically, only resistivity logs are available and useful for gas hydrate assessment within the HSZ in an industry well. Also, a gamma ray log is generally available with the HSZ in the northern Gulf of Mexico. The gamma ray log measures the natural radiation of a formation and can qualitatively distinguish between clay rich and sand rich lithology, as clay sediments tend to have a higher natural radiation; when gamma ray is coupled with the resistivity log, it can be useful for identifying gas hydrate in high angle fractures. Other types of well log measurements, such as density, neutron porosity, caliper and compressional velocity, are usually only used much deeper than the base of the HSZ to appraise conventional oil and gas reservoirs.

In order to identify intervals in a well that likely contain gas hydrate, we identified a background resistivity in each well within the HSZ from the clay or sand intervals that appear to be water-saturated (Figure 2, 3 & 4). A common water-saturated background resistivity is 1 Ωm, though this value can vary, generally between 0.5 Ωm and 2 Ωm. Different types of resistivity measurements are collected in the Gulf of Mexico with a variety of tools from different manufacturers. For consistency, we choose to use the deepest penetrating resistivity log in each hole, as this measurement is most likely least affected by borehole rugosity and drilling mud invasion. We are considering an increase in deepest resistivity response compared to the background resistivity within the HSZ to be associated with the presence of gas hydrate.

We identified an increase in resistivity of at least 0.5 Ωm compared to the background resistivity within the HSZ as evidence for gas hydrate. Other factors, however, may cause small increases in resistivity relative to background resistivity similar to 0.5 Ωm, such as carbonate cementation or overcompaction of the sediments. We cannot rule out these cases from our results since our dataset lacks further data such as density and porosity logs or sediment cutting samples in the HSZ. We can, however, roughly quantify how frequently we would encounter a carbonate-cemented layer. Within our study area, carbonates (positive seafloor anomalies as mapped by BOEM geoscientists) occupy an area of 1424 km^2, which is 0.7% of the total study area. So, it is likely that only a few resistivity increases identified on the well logs are the result of carbonate. Furthermore, many of the low resistivity increases that we observe in our industry well dataset exhibit curve separation with a pattern indicative of natural gas hydrate in fractures in marine mud [*Cook et al.*, 2010]. Figure 3 shows a well with curve separation that are likely caused by near-vertical gas hydrate filled fractures, from ~7500 to 7900. A similar curve separation pattern would not be expected for overcompacted sediments or carbonate cementation.

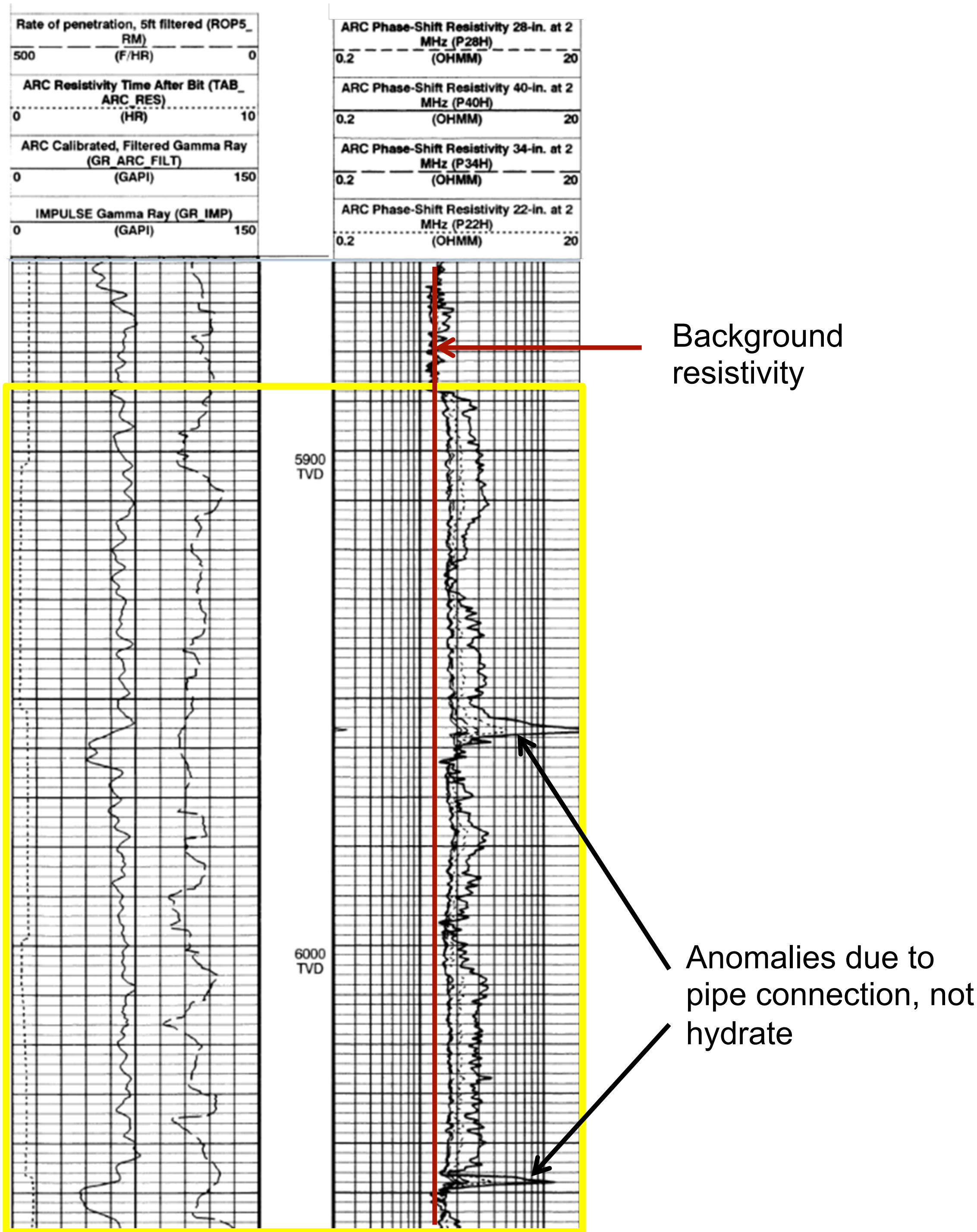

Figure 2: Analysis of a well from East Breaks Block 990, showing an interval within the hydrate stability zone (HSZ). We have selected a background resistivity of ~1.3 Ωm, as identified by the red line. The yellow box highlights the data more than 0.5 Ωm greater than background resistivity, which we consider to be evidence of natural gas hydrate. In this well, there are also connection anomalies – resistivity highs and drops in gamma ray that occur every 90 ft, the length of the drill pipe. These increases in resistivity are not due to hydrate. We classify this well as a Category B (Table 1).

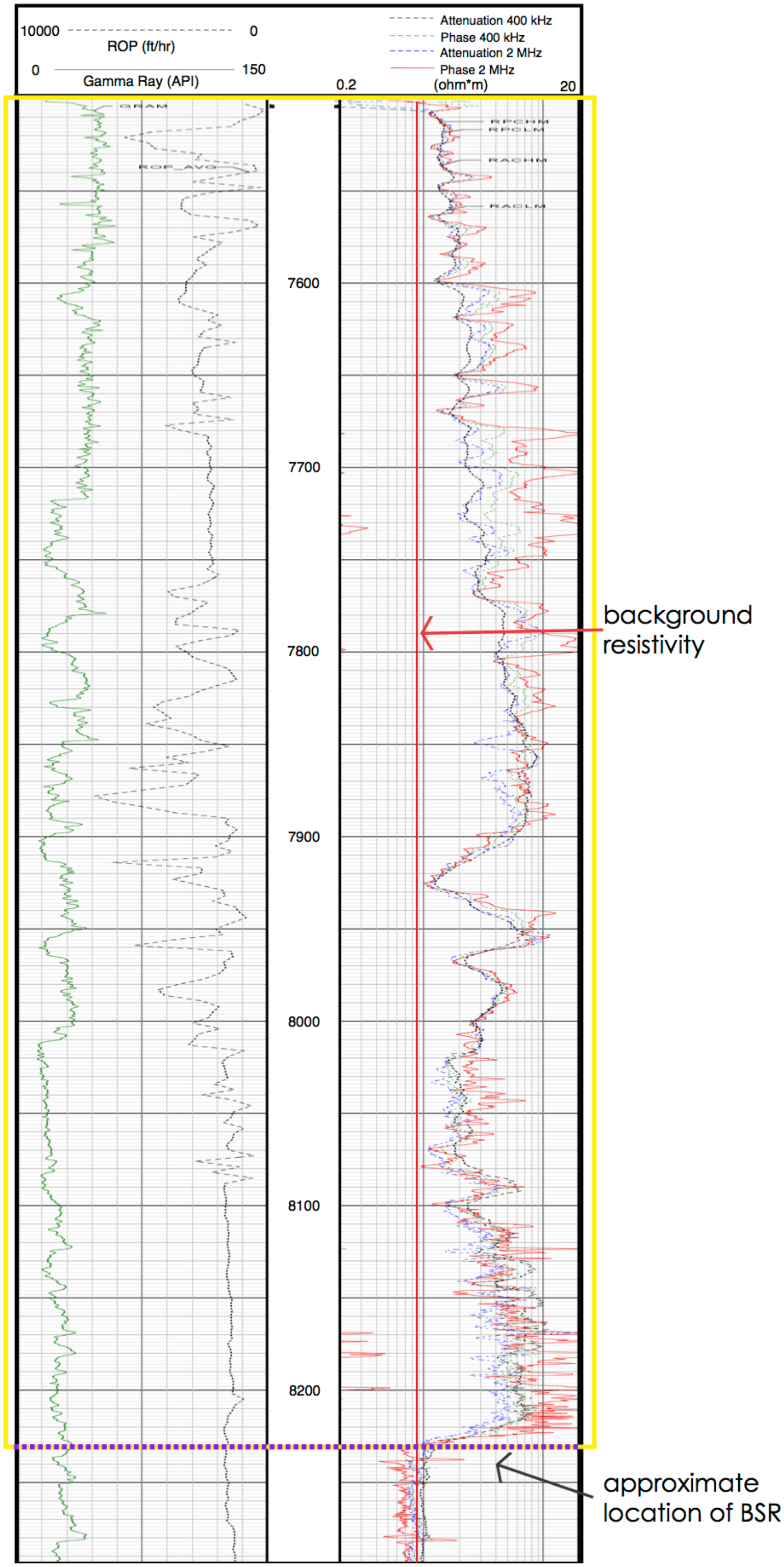

Figure 3: Analysis of a well from Alaminos Cayon 810 within the hydrate stability zone (HSZ). We have selected a background resistivity of ~0.8 Ωm, as identified by the red line. The yellow box highlights the data more than 0.5 Ωm greater than background resistivity, which we consider to be evidence of natural gas hydrate. From ~7500 to ~7900 there is separation in the resistivity curves with the Phase 2MHz measuring the highest resistivity, strongly suggesting that gas hydrate is occupying near-vertical fractures. At this site, a BSR was mapped intersecting this well. Using the depth migrated seismic, the depth of the BSR and the drop in resistivity coincides. We classify this well as a Category A (Table 1).

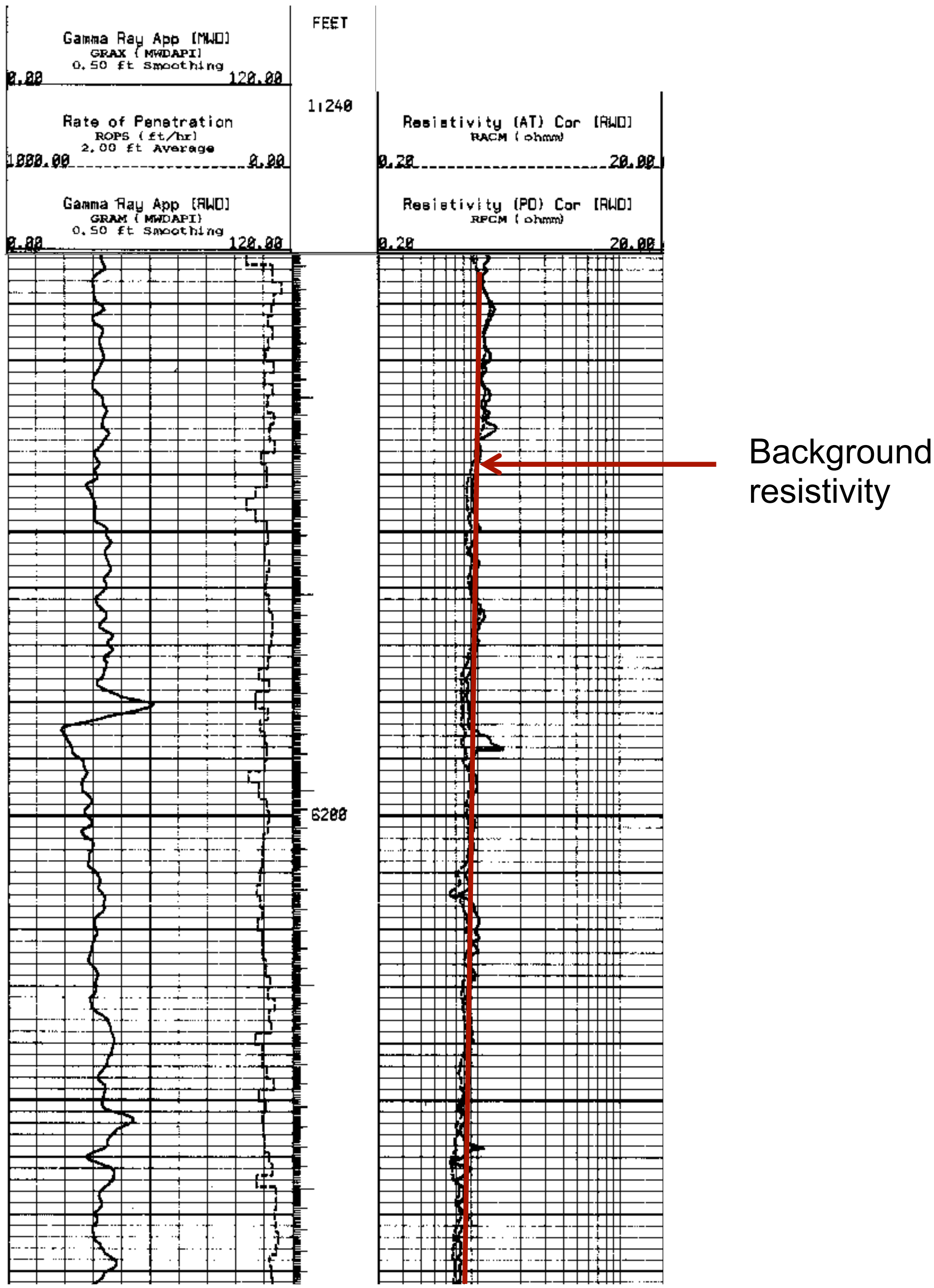

Figure 4: Analysis of a well from Alaminos Canyon Block 627 for a section of the well within the gas hydrate stability zone. Here, the background resistivity (red line) decreases through the HSZ as the depth increases due to the proximity of a salt body. None of the resistivity exceeds the background resistivity more than 0.5 Ωm, so this well does not meet the criteria required for a Category and does not contain evidence for gas hydrate (Table 1).

While miscatagorizing overcompaction or cementation as evidence of gas hydrate is a possibility, so is underestimating gas hydrate presence. By setting the 0.5 Ωm increase in resistivity above background as the cutoff for possible gas hydrate presence, we are perhaps excluding low concentration of gas hydrate from our study. For gas hydrate in sand sediment, this concentration can be as high as 15%, as calculated using Archie's equation [*Goldberg et al*., 2010]. In high angle fractures in clay, measured resistivity does not increase proportionally to saturation. In this case we are likely excluding very small saturations of gas hydrate, such as ~3% or less [*Cook et al*., 2010].

Not all the industry wells have resistivity well logs recorded within the HSZ. Some wells had resistivity log for the entire section of HSZ, while majority had no suitable well logs recorded within HSZ. This may be due to the placement of jet-in casing or merely that well logging did not occur with in the shallow section of the well that coincides with the HSZ. In our dataset, we have set a cutoff of 15 m (~50 ft) of resistivity log section to be considered for gas hydrate assessment. That is, we are considering only those wells that have at least 15 m of resistivity log data within the HSZ. On average, wells have 386 m of resistivity well log data within the HSZ. Using this criteria, we have assembled dataset consisting 798 existing wells from the Gulf of Mexico (Figure 1), out of which 788 are standard petroleum industry wells and 10 are the Chevron-led Gas Hydrate Joint Industry Project (JIP) Legs I and II wells [*Ruppel et al*., 2008; *Boswell et al.,* 2012].

In our dataset, the increase in resistivity above background resistivity varied from as low as 0.5 Ωm to greater than 100 Ωm. Some increases above background were spikes in the data less than 1 m in thickness, while other resistivity increases persisted for hundreds of meters. For these reasons we classify the gas hydrate accumulations into categories from A (highest quality) to D (lowest quality) based on the resistivity increase and the total thickness of the accumulations as shown in Table 1. Since the increase in resistivity above background is high in categories A and B, it is less likely that such increase is due to factors other than presence of gas hydrate, especially considering the shallow depths within HSZ where the thermodynamic conditions are suitable for gas hydrate stability. Our confidence about the presence of gas hydrate is higher in categories A and B, and in any well where resistivity curve separation [*Cook et al.*, 2010] is observed (Figures 2 and 3). In Figures 2, 3 and 4 we show our process of selecting background resistivity and identifying intervals that contain gas hydrate.

Throughout the project, we communicated closely with Bill Shedd and Matthew Frye and BOEM, who helped us understand some of the anomalies and avoid misclassification. For example, in some wells in AC 857, we had identified gas hydrate reservoirs, however, cores and cuttings had revealed that these resistivity anomalies were due to gas condensate and are likely not gas hydrate. These AC 857 wells were then recategorized.

Results, Discussion and Applications

Using our approach, we categorized 116 of the 788 industry wells (15%) within the northern Gulf of Mexico as having evidence of natural gas hydrate (Table 1, Figure 5). Considering that as recently as 2005, that it was suggested by *Smith et al.* [2005] that no gas hydrate had ever been documented in the northern Gulf of Mexico during industry drilling, this is a substantive and important result. Further, our results represent the largest assessment of gas hydrate ever undertaken anywhere in the world using well log data.

Category	Classification criteria	Number of industry wells	Number of JIP wells
A	5 Ωm or more increase in resistivity above background for at least 10 m	10	4
B	2 Ωm or more (but less than 5 Ωm) increase in resistivity above background for at least 10 m, *or* more than 5 Ωm increase above background resistivity but less than 10 m	5	0
C	0.5 Ωm to 2 Ωm increase in resistivity above background for at least 10 m	67	4
D	0.5 Ωm to 2 Ωm increase above background resistivity for less than 10 m	34	0
Wells with no resistivity increase		672	2
Total		788	10

Table 1: Well catagories and the number of industry wells and JIP wells in each category for our study.

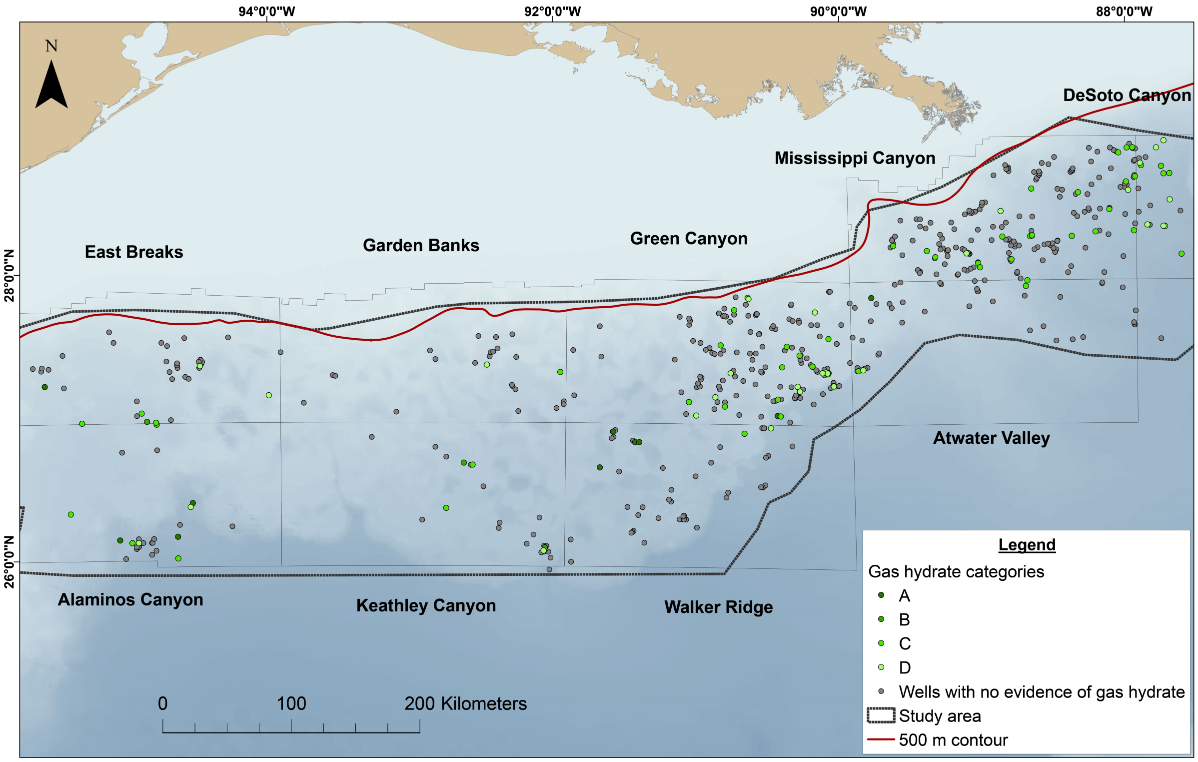

Figure 5: The 798 wells in the northern Gulf of Mexico plotted with the category from Table 1.

With the widely variable well density in each protraction area it is challenging to assess any regional trend of gas hydrate occurrence. The protraction areas with the largest number of wells is in the Mississippi Canyon (267 wells) and Green Canyon (250 wells); these areas contain 25 and 44 wells with evidence for gas hydrate, respectively, meaning that Mississippi Canyon has a lower than average hydrate occurrence at 9%, and Green Canyon has a slightly higher than average hydrate occurrence, at 18%. The protraction area with the largest percentage of hydrate wells is DeSoto Canyon where 12 of 16 wells have evidence of gas hydrate, though, well data was only available in a small western section of the protraction area (Figure 5). DeSoto Canyon is interesting, because *Frye* [2008] suggested that this area may have a higher hydrate volume, though *Frye* [2008] also found Mississippi Canyon to have a higher hydrate volume, which does not match with our observations.

In each of the 798 wells, we recorded information in our database including:

- Protraction area name
- Block number
- Wellhead latitude/longitude
- API number
- Water depth
- Corrected HSZ from seafloor (for HSZ_mean and HSZ_90)
- Year logged
- Operator
- MD (measured depth)/TVD (true vertical depth)
- Well inclination
- Available data interval
- Types of well logs available
- Rough lithology determination
- Background resistivity
- Depth intervals with elevated resistivity (likely gas hydrate)
- Gas hydrate category
- Additional information (such as BSR depth, or additional known information)

A manuscript on the dataset is currently in preparation, which will include data information described and the recorded dataset and that we plan to submit to *Geochemistry, Geophysics, Geosystems*, as they provide an option to publish a descriptive narrative about our dataset and the full dataset. Currently, you may contact PI Ann Cook (cook.1129@osu.edu) to access the data. After publication, a link to the dataset will be available on her website. We have also published initial results from our project in *Fire in the Ice* [*Majumdar et al.*, 2014a] and at the International Conference on Gas Hydrates meeting in Beijing [*Majumdar et al.*, 2014b].

Using our results and resistivity models developed as part of the project, we were also able to complete or initiate a number of subprojects. We detail the projects that we have undertaken or collaborated on at Ohio State using this data so far, below.

Resistivity models

To properly appraise the amount of gas hydrate in place, we proposed to develop resistivity models of both gas hydrate in pore-filling sand and gas hydrate in near-vertical fractures in marine mud. We used the JIP Leg 2 wells as test sites for the modeling.

For the sand models, we completed true resistivity models for the gas hydrate sand bearing intervals at JIP Leg 2 Hole WR313-H, WR313-G, and GC955-H using the UTAP-WeLS software from UT-Austin. These showed, similar to previous modeling, that the ring resistivity most closely represented the true resistivity of the formation [*Cook et al*., 2012]. For JIP Leg 2 AC-21A and AC-21-B sand reservoirs, we were curious if gas hydrate occurred at the site or not. We used resistivity models coupled with a synthetic seismogram to show it was possible that a decrease in porosity in the sand to 29% could produce a similar response as a low saturation of gas hydrate at the JIP Leg 2 wells in AC 21 [*Cook and Tost*, 2014].

For the gas hydrate filled fracture models, we completed an additional ten models using the software ANISBEDS with Barbara Anderson, as described in [*Cook et al*., 2010]. In these models, we used a background resistivity of 1 Ωm, which was frequently observed in our dataset. While these models are helpful for understanding curve separation magnitudes and potential hydrate volumes, we are not able to vary fracture thickness, spacing, or allow for fractures dipping at different angles within the model. In future work, we hope to address these knowledge gaps using models that allow for these variables.

Gas hydrate volume in the Gulf of Mexico

Using our well log dataset, we constructed a Monte Carlo model to determine possible hydrate volume in the northern Gulf of Mexico. This simulation includes variables unique to our dataset, such as the ratio of hydrate occurrence in industry wells, the fraction of the hydrate stability zone occupied by gas hydrate and the likely lithology acting as the gas hydrate reservoir.

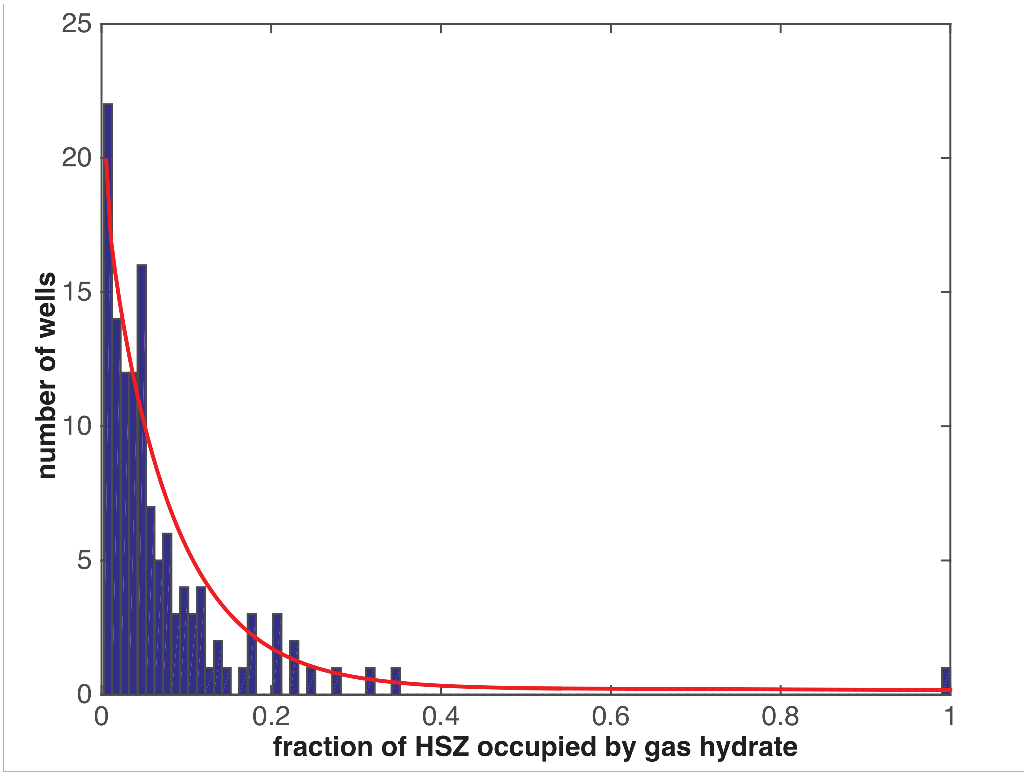

Figure 6: The fraction of the hydrate stability zone (HSZ) occupied by gas hydrate as defined by our dataset. In our Monte Carlo, the fraction of the HSZ is sampled from the distribution as defined by the red line.

Our model begins by selecting a HSZ for each grid cell, as defined by 1 km^2 within our 190,356 km^2 study area (Figure 5). Next, our model decides if the grid cell contains gas hydrate. We found 124 wells out of 798 total wells (industry + JIP, Table 1) contain gas hydrate and we use this data distribution directly in our model. If the model selects a hydrate well from the 798 wells, the fraction of the HSZ containing gas hydrate is randomly selected (Figure 6). This fraction ranges from 0.003 to 1 in our dataset, as shown by the histogram in Figure 6 and we sample from the distribution as defined by the red line.

Next, we select if the well is a sand reservoir or a clay reservoir. While we acknowledge that there is surely a wide range of reservoir types that include variations of sand, mud, silt, clay and ash in the Gulf of Mexico, we cannot completely describe those details from the few logging measurements available in the HSZ and have chosen to classify reservoirs as overall likely to be sand or clay. We have found, from analysis of the gamma ray log and the response of the available resistivity measurements that ~24% of the potential hydrate reservoirs we have analyzed appear to be in sand. Because we are now dealing with small numbers (about 30 wells), we have allowed a range of uncertainty for the ratio of sand reservoirs, as defined by Figure 7. We truncated the low end of the range at 18% sand, and allowed the higher end of the range to extend to 37%, as *Frye* [2008] suggested that sand ratios could be relatively high in the Gulf of Mexico.

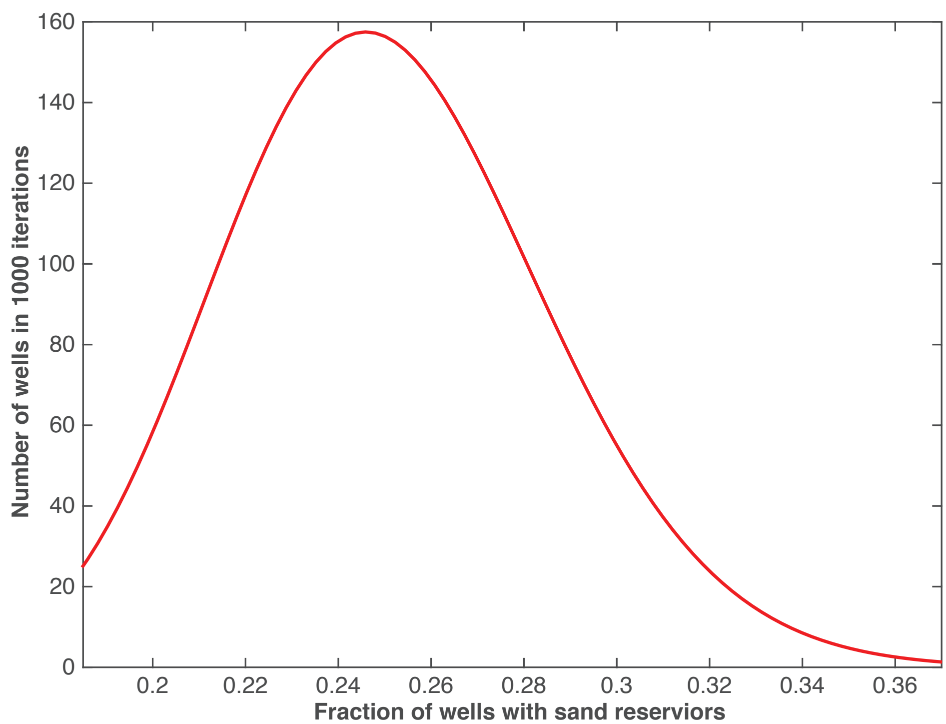

Figure 7: The fraction of sand reservoirs used in our model.

Following the lithology selection, we choose the saturation for each reservoir, which is defined by the reservoir type. For sand reservoirs, we select a gas hydrate from an evenly distributed range between 0.15 and 0.9. For clay reservoirs, these saturations are overall very low, as determined from the modeling described in *Resistivity Models* and from surveying results from the National Gas Hydrate Program Expedition 01 and the JIP [*Cook et al.*, 2014], and so we developed the distribution shown in Figure 8. Saturation is somewhat of a misnomer when gas hydrate occurs in fractures and not in the primary pore space, but keep the common convention here and report saturation.

The last two components are the porosity, which is selected from a range of 0.28 to 0.5, and the volumetric conversion factor, which is selected from a range between 150 and 190 [*Boswell & Collett*, 2011; *Frye* 2008] and converts gas hydrate to gas at standard temperature and pressure. All of the previously discussed components are all multiplied together for each cell and this process is continued through each 1 km^2 grid cell in our 190,356 km^2 study area. After 1000 iterations over the study area, we find a total gas volume of 586 Tcf (trillion cubic feet) or $1.65*10^{13}$ m^3, with approximately 320 Tcf in sand reservoirs and 266 Tcf in clay reservoirs (Table 2).

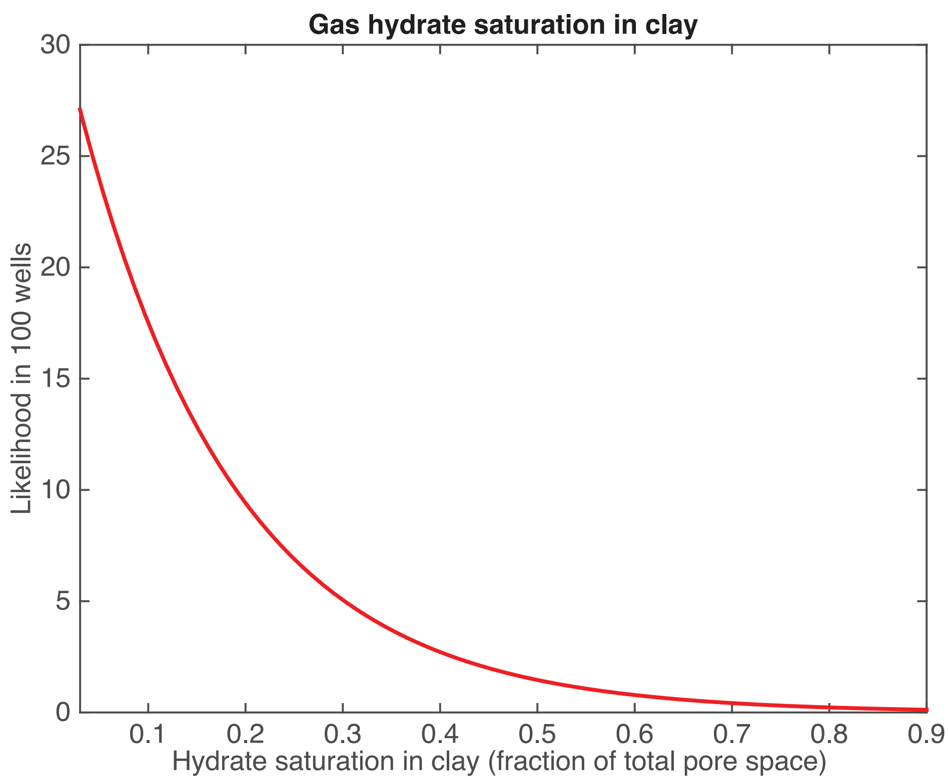

Figure 8: Estimated gas hydrate saturation distribution in clay reservoirs.

95%	**mean**	**5%**
528 Tcf $1.50*10^{13}$ m^3	586 Tcf $1.65*10^{13}$ m^3	644 Tcf $1.82*10^{13}$ m^3

Table 2: Gas hydrate resources at 95%, 50% and 5% probability at standard temperature and pressure as estimated from our model in both Tcf (trillion cubic feet) and m^3.

Our results come very close to the estimated values of *Milkov and Sassen* [2001], who proposed $2*10^8$ m^3/km^2, which, given the size of our study area, comes to 3.8 10^{13} m^3. *Milkov and Sassen* [2001] estimated gas hydrate volume with very little subseafloor information but did consider geologic effects such as structurally focused gas hydrate accumulations.

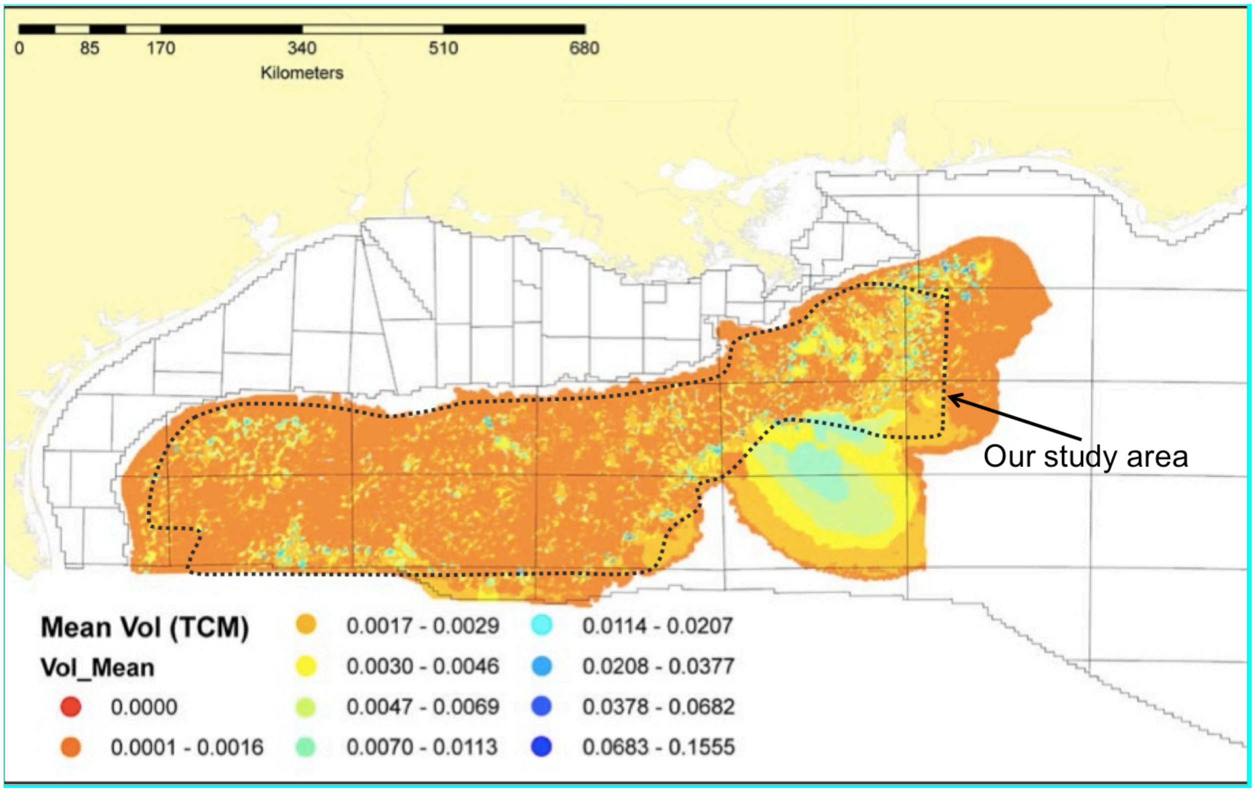

Figure 9: A result from *Frye* [2008] with our study area imposed on top. Note that a large volume predicted in the Atwater Valley and Lund protraction areas is not included in our study because wells were not available in those areas.

To compare our results directly to the study area of *Frye* [2008], which included large continental margin areas off of Florida, we multiply our result by 2.4, so that the overall area is the same. This results in an average of 1,406 Tcf from our model, an order of magnitude smaller than *Frye's* [2008] estimate of 21,444 Tcf. This order of magnitude difference could be caused by several factors. We think the most significant factor is the large number of wells (674, Table 1) where we found no evidence of natural gas hydrate. When a non-hydrate well is selected as representing our 1 km^2 gridded area in our model that cell is treated as having no gas hydrate. In *Frye* [2008] nearly all areas contain gas hydrate, though often in very small amounts. Our assessment does not detect very low saturations of gas hydrate, due the limits of our industry well data. If gas hydrate resides in near-vertical fractures, we can generally detect hydrate presence, to a saturation as low as ~0.03 (or 3%). For hydrate in sands, however, using the cutoff of 0.5 Ωm in our well assessment (Table 1) may mean that we could be ignoring up to ~0.15 hydrate (or 15%). We selected our cutoff of 0.5 Ωm above background resistivity to avoid overestimating the presence of hydrate, though it could be possible that we are underestimating the presence of hydrate. Lastly, another difference between our model and the *Frye* [2008] model is the geographic area, which could cause differences in variables such as overall sand percentage. For example, *Frye* [2008] suggests a high hydrate volume in the Atwater Valley and Lund protraction areas that were excluded from our study area because we lack any well control in that area (Figure 9). This area would certainly be interesting for future exploration.

This manuscript is still in progress and we plan to submit our results to a journal like *Marine and Petroleum Geology*.

BSRs and gas hydrate occurrence in the Gulf of Mexico

Bottom simulating reflectors (BSRs) on marine seismic data are commonly used to identify the presence of natural gas hydrate in marine sediments [e.g. *Wood et al*., 1994; *Saeki et al.*, 2008; *Mosher*, 2011; *Boswell et al.*, 2012], though the exact relationship between gas hydrate occurrence and BSRs is undefined. To clarify this relationship we used our dataset of probable hydrate occurrence as appraised from well logs from the 788 industry wells in the northern Gulf of Mexico. We combine the well log dataset with a dataset of BSR distribution in the same area identified from 3D seismic data, as documented by *Shedd et al* [2012]. We find that a BSR increases the chances of finding gas hydrate by 2.6 times as opposed to drilling outside a BSR, and that the wells within a BSR also contain thicker and higher resistivity hydrate accumulations. Even so, over half of the wells drilled through BSRs have no detectable gas hydrate accumulations, and gas hydrate occurrences and BSRs do not coincide in most cases. This paper was recently published in *Geophysical Research Letters* [*Majumdar et al.*, 2016]

GOM^2 (DE-FE0023919)

Ohio State is also collaborating with UT Austin on GOM^2 or DE-FE0023919. Two locations were identified via well logs through this project (and in collaboration with Bill Shedd and Matt Frye): Perdido (located in Alaminos Cayon 810) and Orca Basin (an area located in 9 blocks in the Walker Ridge area). After the award was granted to UT-Austin, seismic data was ordered through *DE-FE0023919*, further assessment was done at both the Perdido and Orca Basin sites by Ohio State. Currently, the Orca Basin site remains as primary location to be drilled in 2019, in part, due to the initial work on this project.

Conclusion

Our well log derived dataset provides a wide, new perspective on the overall distribution of gas hydrate in the northern Gulf of Mexico and we believe our results will be of interest to the broad hydrate community and the petroleum industry. We will continue to use the results that we have found on current and future projects and we are planning to archive the data set with a data publication.

If a company is interested in evaluating a shallow hydrate reservoir, we recommend collecting caliper, density and compressional velocity in addition to resistivity and gamma ray logs. These additional logs will provide a more detailed picture of the gas hydrate reservoir, and allow for more thorough analysis of gas hydrate in place.

New wells are always being drilled in the northern Gulf of Mexico. In a span of 5-10 years, it would likely be worthwhile to examine the new wells that were drilled to add to our current dataset.

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