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SITE SELECTION FOR DOE/JIP GAS HYDRATE DRILLING IN THE NORTHERN GULF OF MEXICO

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ABSTRACT

In the late spring of 2008, the Chevron-led Gulf of Mexico Gas Hydrate Joint Industry Project (JIP) expects to conduct an exploratory drilling and logging campaign to better understand gas hydrate-bearing sands in the deepwater Gulf of Mexico. The JIP Site Selection team selected three areas to test alternative geological models and geophysical interpretations supporting the existence of potential high gas hydrate saturations in reservoir-quality sands. The three sites are near existing drill holes which provide geological and geophysical constraints in Alaminos Canyon (AC) lease block 818, Green Canyon (GC) 955, and Walker Ridge (WR) 313. At the AC818 site, gas hydrate is interpreted to occur within the Oligocene Frio volcaniclastic sand at the crest of a fold that is shallow enough to be in the hydrate stability zone. Drilling at GC955 will sample a faulted, buried Pleistocene channel-levee system in an area characterized by seafloor fluid expulsion features, structural closure associated with uplifted salt, and abundant seismic evidence for upward migration of fluids and gas into the sand-rich parts of the sedimentary section. Drilling at WR313 targets ponded sheet sands and associated channel/levee deposits within a minibasin, making this a non-structural play. The potential for gas hydrate occurrence at WR313 is supported by shingled phase reversals consistent with the transition from gas-charged sand to overlying gas-hydrate saturated sand. Drilling locations have been selected at each site to 1) test geological methods and models used to infer the occurrence of gas hydrate in sand reservoirs in different settings in the northern Gulf of Mexico; 2) calibrate geophysical models used to detect gas hydrate sands, map reservoir thicknesses, and estimate the degree of gas hydrate saturation; and 3) delineate potential locations for subsequent JIP drilling and coring operations that will collect samples for comprehensive physical property, geochemical and other analyses.

Keywords: gas hydrates, Gulf of Mexico, ocean drilling, hydrate-bearing sand, resource, geohazard, bottom simulating reflector

INTRODUCTION

For decades, the northern Gulf of Mexico has been intensely drilled by commercial interests seeking conventional oil and gas. With the most recent shift of some operations from shallow water to deeper water (>500 m water depth) targets, the private sector is increasingly encountering sediments within the pressure-temperature regime for gas hydrate stability. Nonetheless, relatively little information has been collected about the gas hydrate systems during these deep drilling activities or during geotechnical surveys conducted in advance of drilling. At the same time, academic studies sampling gas hydrate, with the exception of DSDP Leg 96 [1], have largely focused on seafloor gas hydrate deposits [2-7] or near-seafloor sediments (upper tens of meters) that provide only some clues about the deeper gas hydrate system (e.g., [8, 9]). Addressing the lack of knowledge about gas hydrate occurrences to depths of several hundreds of meters below the seafloor has been a major goal of the Chevron-led Joint Industry Project (JIP) on methane hydrates.

The JIP, a consortium of industry participants and government agencies in partnership with the U.S. Department of Energy, was formed in 2001 to (a) study hazards associated with drilling the types of hydrate-bearing sediments common in the Gulf of Mexico; (b) assess the capacity of geological and geophysical tools to predict gas hydrate distributions and concentrations; and (c) sample reservoir units with high concentrations of gas hydrate to obtain physical data on hydrate-bearing sediments as a first step in the analysis of marine resource and production issues associated with these unconventional gas sources. In 2005, drilling, coring, and downhole logging was conducted to assess hydrate-related hazards in fine-grained sediments with low concentrations of gas hydrate (e.g., [10, 11]). During the current phase of JIP research, hazards assessment is being extended to coarser-grained sediments with much higher inferred gas hydrate saturations. In addition, the current phase of JIP work provides an opportunity to validate methods devised to estimate gas hydrate distributions and concentrations as well as to analyze the resource potential of these hydrate-bearing sediments. This paper describes the geologic and geophysical setting of three sites in the northern Gulf of Mexico interpreted to contain hydrate-bearing reservoir sands that will be drilled in late spring, 2008.

GOALS AND OBJECTIVES OF DRILLING

The primary goal of the 2008-2010 JIP project is to test geologic and geophysical approaches for identifying gas hydrate occurrences in sand-rich units in the northern Gulf of Mexico. The site selection process has utilized both geologic perspectives and quantitative geophysical analyses of existing seismic and downhole logging data. At the same time, identification of individual drilling holes has utilized a petroleum systems context, which recognizes the importance of an identifiable source of free gas, enhanced permeability pathways (faults, high permeability lithologies) that may permit migration into the hydrate stability field and/or structural traps for the free gas-gas hydrate system, and a reservoir unit (coarser-grained material) that both has access to free gas and lies within the hydrate stability field.

GEOLOGIC FRAMEWORK

The continental margin of the northern Gulf of Mexico, although passive in a plate tectonic context, is actively deforming due to the complex interplay of salt tectonism and sedimentary loading [12]. Middle Jurassic Louann Salt deposited during the opening of the ocean basin underlies much of the northern Gulf of Mexico [13]. Beginning in Miocene time, enormous volumes of sediment were supplied to this margin by river systems as the ancestral Mississippi, and eventually delivered many of the denudation products of North American Pleistocene glaciations to the Gulf of Mexico. The complex seafloor morphology (Figure 1) of ovoid minibasins surrounded by rims is due to this sediment loading, which caused the salt to buoyantly rise to form the uplifted edges of the basins while withdrawing from beneath the basins.

Salt has also spread laterally on the lower slope to form the Sigsbee Escarpment, one of the most prominent features of the margin. Minibasins in the shelf and upper slope are generally filled while those in the lower slope are still filling [14]. Numerous canyons have also incised the margin. The youngest of these is the Mississippi Canyon, which provided a pathway for sediments to move from the Mississippi River onto the Mississippi Fan. The pathways associated with some of the older canyons (e.g., Alaminos, Bryant, Keathley, and Green Canyons) are obscured by younger salt movement, deposition, and tectonism (e.g., [15]). Detachment faults soling into salt are common in the Gulf, and have created large gravity-driven, generally buried, salt-cored foldbelts in sediments near the Sigsbee Escarpment, such as the Perdido Foldbelt in the western Gulf and the Mississippi Fan Foldbelt in the east [16, 17].

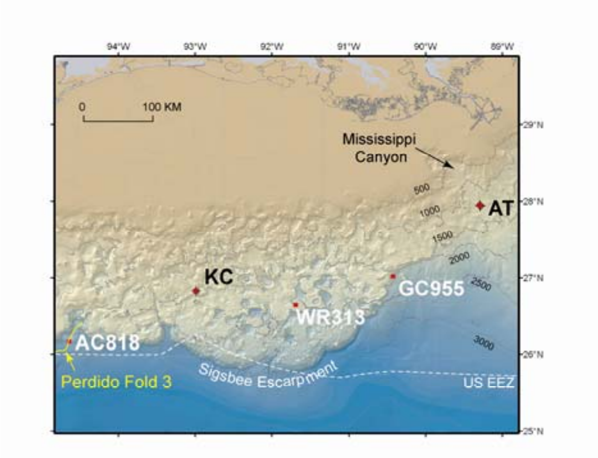

Figure 1: Bathymetric map of the northern Gulf of Mexico showing three sites recommended for 2008 JIP gas hydrate drilling program (AC818, GC955, and WR313) together with the location of holes drilled in 2005 (KC and AT). The axis of fold 3 of the Perdido Foldbelt is labeled in yellow where it crosses the AC818 site.

Superimposed on this complex morphology is a near-seafloor hydrate stability zone that increases from zero thickness at the pressure-temperature conditions on the upper slope to an estimated 1,150 m thickness at mid-slope water depths [18]. Stratigraphic and structural disturbances are common in the shallow section, with faults, mass wasting, gas chimneys, and overpressured zones being typical of the variability [19, 20]. Thermal anomalies from 3 to 10 times background values can also occur locally near seep sites and mud volcanoes [9, 21, 22]. The hydrate stability zone, therefore, includes sedimentary, chemical, thermal, and tectonic processes that occur and continue to occur at multiple spatial and temporal scales.

SITES

In this paper, "site" is used to define an area of interest for drilling, generally described in terms of one of the lease blocks that includes well information and is near the structural or stratigraphic features of interest. Multiple drilling locations exist at each site. Sites have been identified as potentially having gas hydrate in reservoir units through the application of geologic and geophysical models and approaches. Drilling locations are chosen to implement a sampling strategy designed to maximize specific information to be obtained by drilling at a site.

During the JIP site selection process, several approaches were adopted for identifying sites and locating drilling targets. Industry-standard 3D multichannel seismic data were used for stratigraphic mapping, seismic facies analyses, structural interpretations, and identification of features associated with free gas. Geophysical approaches used during the site selection process have included qualitative analyses of peak-trough relationships in seismic traces to infer occurrences of free gas, gas hydrate, and water-saturated lithologies. Quantitative well-log analyses have also been essential, with gamma ray logs used to infer lithologic variations. When available, sonic and resistivity logs were used to constrain potential gas hydrate saturations. A centerpiece of the geophysical analyses has been the inversion of the 3D seismic data, coupled with lithologic information from well-logs to estimate gas hydrate saturations [23-26]. Results of these inversions are described below. Details of the site selection process and information about sites not chosen for further analysis are given elsewhere [27].

After much consideration, the JIP site selection team identified Alaminos Canyon 818, Green Canyon 955, and Walker Ridge 313 as having characteristics consistent with the goals of sampling gas hydrate in coarse-grained sediments in a variety of structural or stratigraphic plays in the deepwater northern Gulf of Mexico. Table 1 provides basic information at the three sites derived from the well analyses in each of these lease blocks.

Lease Block No.	AC818	GC955	WR313
Well Name	AC818#1	GC955#1	WR313#1
Water Depth (m)	2744	2026	1917
Base of gas hydrate stability (m)	3197	2499	2758
Seafloor to base of gas hydrate stability (m)	453	473	841
Thermal gradient (mK/m)	~44	~32	~19
Target Facies sampled at the well	Frio volcaniclastic Oligocene sand	Pleistocene levee sands	Sheet sands within a minibasin

Table 1. Well information for three recommended drilling sites.

For these three sites, specialized processing was undertaken on 3D multichannel seismic cubes at the approximate dimension of a lease block (4.3 x 4.3 km) in order to preserve impedance contrasts and maximize gas hydrate information [26]. The processing included amplitude preservation, prestack time migration, full waveform inversion, rock modeling, hydrate quantification, and comprehensive evaluation at each step. Nearby well information was used to calibrate impedance contrasts (and hence amplitudes and sediment lithologies). Because the well information is not used to calibrate hydrate saturation, the resulting hydrate saturation estimates should be roughly comparable among the three areas, although there are uncertainties in how the rock physics models perform when applied to partially consolidated sediments found at the Alaminos Canyon site versus unconsolidated sediments in the other two sites. Both the Green Canyon and Walker Ridge seismic data are Q-data, in which measurements are made at each hydrophone and can be combined into optimal geometries. The final step in analysis and interpretation was to integrate estimated gas-hydrate saturations with lithologic and geologic mapping for selecting recommended drilling locations.

Although multiple drilling locations are recommended within each site, only 3 holes per site are likely to be drilled. Final drilling order and locations will be established after shallow-hazards assessments and permitting are completed. Finally, drilling will use a riserless system, meaning that high-amplitude anomalies associated with possible free gas were avoided in the site-selection process.

Site AC818

Lying just north of the U.S.-Mexico border in the deepwater Gulf of Mexico, site AC818 is about 10 km seaward of the Sigsbee Escarpment at ~2,700 m water depth (Figure 2a). Chemosynthetic communities, which are often associated with methane seeps and gas hydrate occurrences in the Gulf of Mexico, occur in the lease block and have been sampled during submersible dives [28]. The Perdido Foldbelt, a large salt-cored detachment foldbelt, underlies the area [17, 29], with fold 3 immediately underlying AC818 and vicinity. The top of fold 3 extends into the estimated hydrate stability zone, and provides the closure, the reservoir lithology, and drilling targets at AC818 (Figures 2b and 2c). Conventional hydrocarbons are well known within this part of the Gulf of Mexico; the AC818#1 ("Tigershark") well discovered oil in deeper Eocene Wilcox sands, and subsequent wells in the Perdido foldbelt confirmed hydrocarbons extending as high as the Oligocene section as well (e.g., [30]).

Of all existing Gulf of Mexico wells considered in the JIP site selection process, the AC818#1 well provides the most compelling evidence for the possible existence of gas hydrates. The Oligocene Frio sandstone, lying in a structural trap at the crest of Perdido fold 3, is a coarse volcaniclastic sand that has elevated sonic velocities and high formation resistivities (> 40 Ωm) interpreted to be caused by high saturations of gas hydrate [31]. The base of the hydrate stability zone at the AC818#1 well is estimated to be at a depth of 3197 m, corresponding to a thermal gradient of ~44 mK/m for pure methane gas as the hydrate former, seawater as the pore water, and an average seafloor temperature of 3ºC. The inferred thermal gradient is consistent with known thermal gradient measurements in this part of the northern Gulf of Mexico [32]. Gas flow was observed during drilling at a depth of 3,184 m, which is within the

Frio sand just above the base of the high-resistivity section [31]. The Frio at the crest of the fold is unconformably overlain and potentially sealed by younger fine-grained Plio-Pleistocene deposits associated with the Alaminos Fan [33].

In addition to the gas flow in the AC818#1 well, pervasive seismic indicators of gas around Perdido fold 3 take the form of bright spots that indicate gas charging of units and attenuation of higher frequency energy beneath and west of the crest of the fold, consistent with the presence of small amounts of free gas (Figure 2). These indicators do not extend further east of the approximate crest of the fold. Numerous faults are evident in the seismic data, indicating pathways for gas-rich fluids to move into the Frio formation where it occurs within the hydrate stability zone. Faulting that both disrupts the Frio unit and cuts through the presumptive free gas-gas hydrate boundary implies potential compartmentalization of the accumulation. Based on the seismic inversion, both the thickest inferred occurrences and highest estimated gas hydrate saturations in the Frio unit occur across faults to the north and southeast of the AC818#1 well.

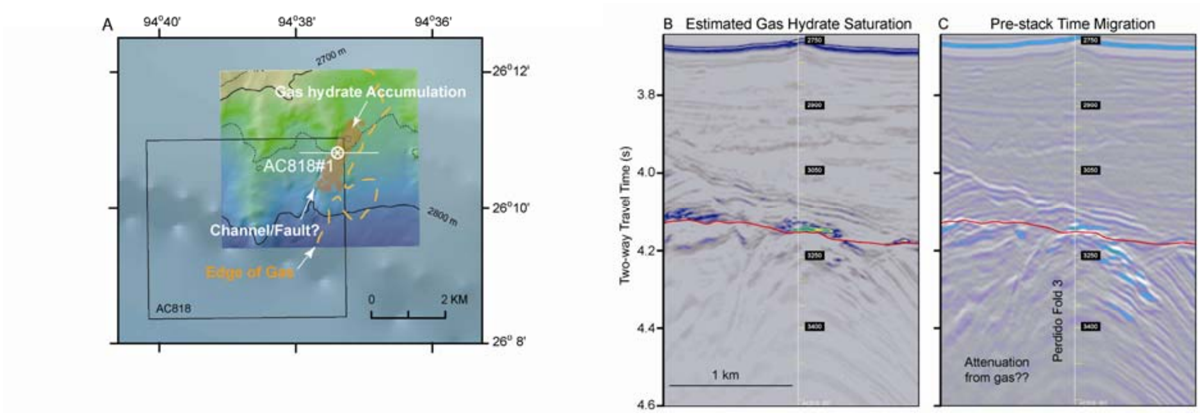

Figure 2: A. Map of the area of the AC818 site showing the locations of the AC818#1 well, inferred gas hydrate accumulation at the crest of the fold 3 of the Perdido Foldbelt, and the boundary marking the approximate eastern limit of gas indicators near the base of the gas hydrate stability zone. Bathymetry from the 3D seismic cube has shaded relief and is colored and contoured separately from the regional bathymetric data. White line shows the location of the seismic section shown in B and C. B. Inverted seismic data across the AC818#1 well showing the base of gas hydrate stability zone (red line) and elevated gas hydrate saturations at the crest of Perdido Fold 3 just above the base of the gas hydrate stability zone. Location shown in fig. 2a. C. Reprocessed seismic section through the AC818#1. Base of gas hydrate stability zone (red line) passes through the top of the Frio sand in the crest of Perdido Fold #3. Change in seismic character in the lower left quadrant of the seismic section in interpreted as attenuation from small amounts of gas present in the strata.

Estimates of gas hydrate saturation within the Frio interval at the AC818 well have been performed using three independent methodologies and are in good agreement. Gas-hydrate saturations estimates from using resistitivities with Archie's equation are in excess of 70% and reach maximum values in excess of 80% (Lee, personal communication). Estimates using sonic velocities and the Biot-Gassmann theory [34, 35] reach about 80% (Lee, personal communication). Methodology using the seismic inversion results [26], yield an estimated gas-hydrate saturation of about 77%.

Throughout the mapped area of the Frio gas hydrate accumulation, estimates of the thickness of the gas-hydrate-bearing zone range from less than 12 m to about 40 m. Inversion based gas-hydrate saturations range from ~35% to as much as 95%, but an inherent challenge is that these estimates may be affected by such complications as thinning of the Frio sand, faulting, and other phenomena. Our working assumption is that the gas hydrate saturation in the Frio unit ranges from 70% to 80% where it occurs within the gas hydrate stability zone and that saturations likely vary with subtle changes in reservoir quality. One primary purpose of the drilling at AC818 is to test this assumption and improve the ability to accurately estimate gas hydrate saturations in sand lithologies with the potential for concentrated gas hydrate accumulations.

At the AC818 site, 10 drilling locations have been recommended. While it is unlikely that more than 3 of these drilling targets will be drilled in 2008, the specific targets that are being permitted for potential drilling include highest saturations of gas hydrate (two targets), thickest occurrences of the Frio sand within the stability zone (two targets), intermediate saturation anomalies within the general accumulation (two targets), low saturation anomalies at the edges of Frio occurrence (two targets) and reference sites to recover Frio sand where it occurs beneath the hydrate stability zone (two targets).

Site GC955

Like the AC818 site, the Green Canyon site is also seaward of the Sigsbee Escarpment, although GC955 lies right along the escarpment at the mouth of Green Canyon (Figure 3a) where sediments can debouch onto the deep seafloor of the Gulf of Mexico. A small surface channel crosses the study area towards Green Knoll. Seismic data acquired at GC955 show that channels similar to this surface channel occur at approximately the same location in several of the deeper Pleistocene horizons that were mapped (Figure 3b), indicating that channelization is a long-lived process in this area [19, 36]. The existing GC955#1 well provides lithologic control, having penetrated 26 m of permeable sand at a depth of ~366 m below the seafloor [36]. At GC955#1, the depth to the top of gas, interpreted to be the base of the gas hydrate stability zone, is estimated to be at 473 m. This corresponds to a thermal gradient of 32 mK/m, assuming pure methane as the hydrate former, seawater as the pore water, and a bottom water temperature of 4ºC. This thermal gradient places these permeable sandy units within the hydrate stability zone.

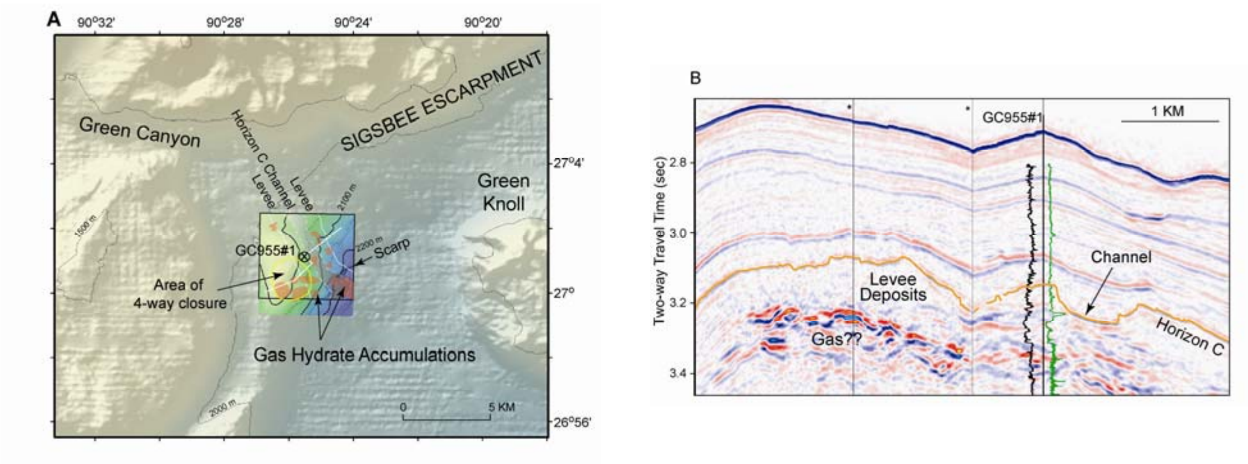

Figure 3: A. Map of the Green Canyon 955 region showing the major morphologic features around the site and the position of the GC955#1 well. Bathymetry from the 3D seismic cube is colored and contoured separately from the regional bathymetric data. The area of 4-way closure (yellow outline) coincides with an uplifted mound. Gas hydrate accumulations are shown in brown and the location of the buried channel mapped on horizon C is shown in gray. Seismic line illustrated in B is shown by a solid white line from the southwest to northeast. B. Randomly-oriented seismic section through the GC955#1 well showing gamma ray (black) and resistivity measurements (green) at the position of the borehole. Bends in the line are indicated by *. Location of the line is shown in A. "Channel" indicates the channel on horizon C that is shown in A. Bright reflections beneath horizon C are consistent with the occurrences of gas and gas hydrate.

An uplifted area with more than 60 m relief forms a four-way closure on the west side of the study area. The uplift, cored by allochthonous salt, deforms the overlying fine-grained sediments [36], including the deeper channels. In the seismic data, the deepest channel mapped, identified as the horizon C channel (Figure 3a), now slopes towards the north. When this channel originally transported material out of Green Canyon though, it sloped south. A young slump scarp with 91 m of headwall relief occurs on the east side of the uplift [36]. The headwall and the uplift are associated with faults, and many of the faults have associated gas chimneys inferred to be conduits for gas migration from the deep to shallow section [19]. A small mud volcano in the southern part of GC955 provides additional evidence of fluid expulsion in this young system.

Taken together, these data indicate the components of a petroleum system are present. The well log and seismic data suggest a high potential for sand reservoirs in the channel levees. A trap is provided by uplift from a rising salt body that forms a four-way closure in the southwest corner of the block. The apparent seal for the reservoir sand package is a regional shale layer (Horizon C) that occurs above the interpreted sandy levees. The system contains numerous migration pathways along abundant faults. Gas chimneys, numerous seismic indicators of gas (particularly within the structural closure), and seafloor features consistent with fluid expulsion (e.g., mud volcano, slump scarp) provide evidence for migrating gas. The geographic coincidence of the gas chimneys with the faults indicates active gas migration into the shallow sedimentary section. Hence, there is good confidence in the geologic interpretation for this site.

The presence of gas hydrate is less certain from existing data. A small resistivity anomaly of 4.3 Ωm within the sand penetrated by GC955#1 well could be an indicator of low-saturation gas hydrates. Numerous bright reflectors in the seismic data beneath the levee sand are interpreted to be gas below the base of hydrate stability, but the chaotic geometry of these deeper reflections makes determination of a clear base of hydrate stability using seismic data ambiguous. Three pieces of evidence support the existence of gas hydrate. First is the presence of an elevated interval velocity anomaly within the overall channel-levee complex. This velocity anomaly is up to 600 m/s above the background velocity of 1.54 km/s and is difficult to explain in these kinds of unconsolidated sediments without invoking a mechanism such as the presence of gas hydrate. Second is the inversion result showing high saturation of gas hydrate along discrete reflections just above the depths estimated for the base of hydrate stability, within the region of elevated velocities. These saturations range from ~50% to 80% and coincide with patchy occurrences above trough reflections, i.e., not with reverse-polarity amplitudes expected from low-velocity gas at the base of hydrate stability. Third is the observation that gas hydrate saturations inferred within the deposits filling the bottom of the north-dipping horizon C channel increase toward the position where the channel intersects the base of hydrate stability. Deposits within the channel are interpreted to be a coarse lag which contains progressively higher amounts of gas hydrate as the channel approaches the source of and intersects with deeper gas-filled units. While containing uncertainties, these reasons are the motivation for drilling the GC955 location.

At the GC955 site, the drilling locations coincide with permeable levee-sand facies within the closure structure (1 target), and similar levee-sands on the flanks of the structure (4 targets). Drilling at these targets can test several alternative geologic models, including 1) presence of a relatively thin zone of high gas hydrate saturation within the sands that directly overlay the base of gas hydrate stability and may form a trap for free gas below; 2) the potential persistence of lower levels (seismically undetectable) of pore-filling gas hydrate throughout the sandy facies, perhaps extending to the level of the regional potential seal; and 3) the potential occurrence of zones of massive gas hydrate concentrated in near-vertical faults and fractures extending an unknown distance above the base of gas hydrate stability. An additional target is the potential channel lag deposit of a shale filled channel as it nears the base of gas hydrate stability (1 target).

Site WR313

In contrast to the two previous sites, the Walker Ridge site WR313 is within the tabular salt minibasin province on the lower slope of the northern Gulf of Mexico margin (Figure 1). A previous study has identified the presence of a bottom simulating reflection in areas near this site [37]. WR313 is in a semi-enclosed portion of the Terrebonne basin at ~2,000 m water depth (Figure 4a). A salt wall forms the southern rim of the basin, and thrust faults within this semi-enclosed basin are evidence of uplift and compression, probably from salt flowing from north to south [38]. Uplift and extension also occur at the position of a north-south-trending salt diapir attached to the northeast end of the salt wall. Giant seafloor gas mounds marking focused fluid expulsion sites [38] have formed at the north end of the diapir. Like many minibasins in the Gulf of Mexico, the seismic stratigraphic interpretation relies on areally extensive continuous and semicontinuous reflection packages that are consistent with deep-water sedimentation cycles. Sediments entering the semi-enclosed subbasin are trapped because there is no exit point, although sediments within the Terrebonne basin proper can flow out of the basin southeast of the salt diapir.

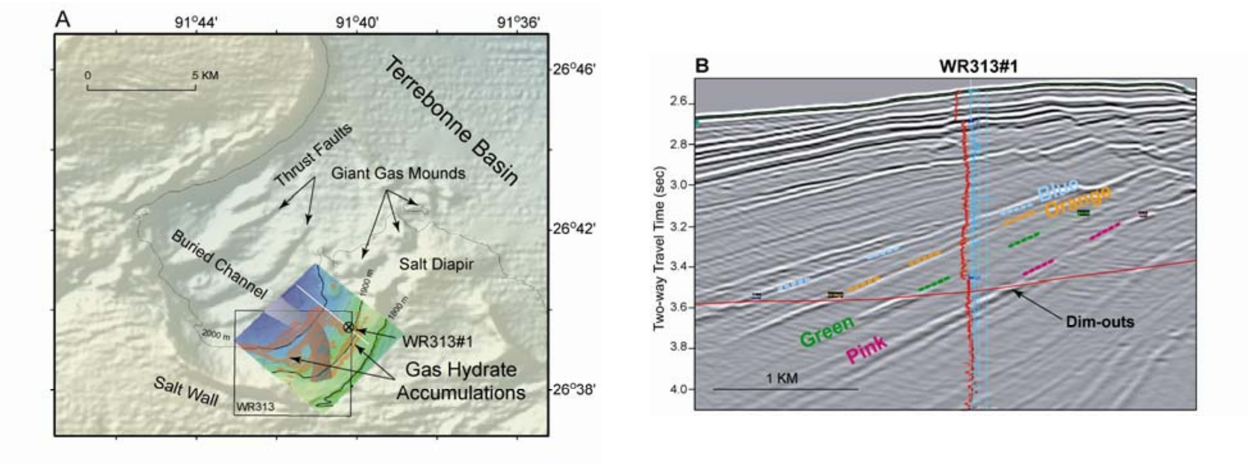

Figure 4: A. Map of the Walker Ridge 313 area showing the major morphologic features (salt wall, salt diapir, gas mounds, and thrust faults) as well as the position of the WR313#1 well. The linear aspect of gas hydrate accumulations (brown areas) is related to the dipping stratigraphy and its intersection with the base of gas hydrate stability. The location of an inferred buried channel along the orange horizon is shown in gray. Bathymetry from the 3D seismic cube has is colored and contoured separately from the regional bathymetric data. Location of the seismic data in B is shown by the white line trending northwest to southeast. B. Seismc traverse through the WR313#1 well showing the youngest (blue) to olderst (pink) horizons where they cross the base of gas hydrate stability (red line marking positions of dimouts). Gamma ray log at the well is shown in red. Location of the seismic line is shown in A.

The WR313#1 well provides the evidence for permeable sands within this sub-basin. For the site survey analysis, four sand sheets, designated pink (oldest), green, orange, and blue (youngest, Figure 4b), were mapped from the WR313#1 well across the study area. At the well, the pink-to-blue section is 257 m thick and dips westward as it thickens into the basin. Gamma ray data indicate that these sands are interspersed with shales, as would be expected in a deep-water depositional environment that includes debris flows, turbidites, and hemipelagic clays. Mapping also shows the existence of at least one buried channel and associated levee system on the orange horizon. The integrated interpretation of this basin setting is that coarse-grained permeable sands entered this subbasin through channels (like the one imaged on the orange horizon), and spread outwards as sandy fans or sheets that covered much of the basin floor. The pink-to-blue horizons provide markers for the reservoir section containing potential gas hydrate deposits.

The base of gas hydrate stability has been mapped at WR313 by connecting the tops of amplitude dim-outs along six continuous, subparallel seismic reflections [38]. These dim-outs were formed by deeper bright spots interpreted as gas that terminated abruptly upwards. Together, the dim-outs define the base of gas hydrate stability although they generally do not form a single cross-cutting reflection event like a classic bottom simulating reflector. Comparing the depths of the dim-outs with the theoretical gas hydrate stability curve yields an estimated thermal gradient of ~19 mK/m [38]. While this is lower than the gradients at the other sites selected for drilling by the JIP, this part of Gulf of Mexico is known to be significantly cooler than the western part and indeed the inferred base of gas hydrate stablity is deeper (841 mbsf) at this site. Gas hydrate at the updip position of the dim-outs is interpreted from impedance analysis of seismic sections and mapped horizons [39] and the gas hydrate is interpreted to form the trap for the gas bright spots [38]. The six horizons mapped by those authors include the pink-to-blue sequence mapped for this drilling study, although the exact correlations between numbered and colored horizons have not been completed. The pink-to-blue horizons also show distinctive dim-outs, and the inferred distribution of the dim-out features extends across a region larger than the area of reprocessed seismic data used in the site-survey analysis.

Although there is good evidence at the WR313 site for permeable reservoir sands (pink-to-blue horizons) and gas in the form of seafloor seeps (giant gas mounds) and bright spots at the base of the hydrates stability zone, migration pathways are less certain. Faults are not common within the mapped area except along the areas of most active salt movement (e.g., the salt wall), suggesting that the gas within the basin is primarily migrating along stratigraphic horizons either from in-situ or deeper sources. Large faults outside of the study area may also be charging the system, although considerable migration along stratigraphic horizons would be required if this were happening.

The seismic inversion yields maximum estimates of 35% to 60% for gas hydrate saturations at WR313. These values are generally lower than those at the GC955 and AC818 sites. One of the quandaries associated with recommending drilling sites at WR313 is that inversion results identify the horizons that mark the tops of gas hydrate-saturated units (e.g., pink to blue horizons), but not the bottom of these units. Drilling should test whether these horizons are associated with a tuning thickness in the data or whether the intervening low-amplitude intervals are shales or thin-bedded gas-hydrate saturated sands.

All of the saturation anomalies at WR313 are strongest near the inferred base of hydrate stability and weaken as traced up-dip, consistent with the interpretation that the source of gas is migrating upwards along stratigraphic horizons and is therefore most highly concentrated near the base of hydrate stability. The stratigraphic horizons interpreted to contain gas hydrate can be mapped updip to the WR313#1 well, in which gas hydrate is inferred to be absent. Primary risk at the site would appear to be degree of saturation related to charge issues.

Drilling targets in the Walker Ridge site afford the opportunity to penetrate similar horizons at multiple depths and inferred saturations relative to the base of gas hydrate stability. Of the 7 drilling locations, three were recommended to penetrate inferred variable gas hydrate saturations in the orange and blue horizons. One target is for saturations interpreted in the green-to-orange interval near the base of gas hydrate stability. Two prospective drilling locations are in the channel imaged along the orange horizon. The final drilling location is in an areally extensive, moderate-to-high saturation gas-hydrate anomaly of the blue horizon at the western end of the study area where the stratigraphic units dip most steeply.

SUMMARY

The three sites chosen for the next Gulf of Mexico JIP drilling program offer an excellent variety of settings and systems for testing the occurrence of high-saturation gas hydrate. Each site satisfies many elements of a petroleum systems model, including the presence of a good reservoir unit, an identifiable gas source, and possible migration pathways. The Alaminos Canyon 818 site involves an Oligocene volcaniclastic sand (Frio Formation) at the crest of a fold within the Perdido Foldbelt that is shallow enough to be in the hydrate stability zone. This site has the largest gas-hydrate saturations and provides the greatest confidence in finding gas hydrate. The Green Canyon 955 site involves a Pleistocene channel-levee system with structural closures and abundant faulting. Estimates of gas-hydrates saturations are slightly lower than in Alaminos Canyon, but the reservoir sand body is considerably thicker. The Walker Ridge 313 site involves dipping Pleistocene strata common throughout much of the slope of the northern Gulf in which, for this basin, the coarse-grained sands spread as sheets across the basin floor in the absence of an exit. Migrating gas along stratigraphic horizons at the base of the hydrate stability zone is the source of the hydrate which has maximum concentrations near the base of hydrate stability. Overall saturations at the Walker Ridge site are less than at the other two sites and present the deepest targets because of the lowest estimated thermal gradients. Together, these sites provide the opportunity to test a variety of potential geological models for gas hydrate occurrence and to calibrate geophysical models for interpretation of gas hydrate response.

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