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Research paper

Semi-quantitative gas hydrate assessment from petroleum industry well logs in the northern Gulf of Mexico

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ABSTRACT

The northern Gulf of Mexico has been a major location for exploration of oil and natural gas resources for decades. We have used the rich data of existing, publicly available petroleum industry well logs to identify potential occurrences of natural gas hydrate in the northern Gulf of Mexico. Our data set contains 798 wells with resistivity and gamma ray well log data in the gas hydrate stability zone - 788 wells from the petroleum industry and 10 wells with data collected for the purposes of scientific drilling. Based on an increase in resistivity of 0.5 Ωm or greater relative to the interpreted resistivity of brine-saturated sediment, we found evidence consistent with gas hydrate occurrences in 124 wells. We have built a data set of the analyzed wells that includes information such as the well surface location, depth intervals and resistivity of potential gas hydrate accumulations. Moreover, we have categorized the overall quality of the potential gas hydrate accumulations, based on thickness of the accumulation and the resistivity log increase. Our data set provides a wide perspective on the potential spatial distribution of gas hydrate. For example, we find subsurface gas hydrate of higher quality five to eight times more frequently along the rims of mini-basins and over salt ridges than inside mini-basins in the northern Gulf of Mexico. We provide the included data set as a resource for future gas hydrate research and prospecting in the area.

1. Introduction

1.1. Background

Gas hydrates comprise lattice structures consisting of gas molecules (predominantly methane) trapped in H_2O cages that are stable under moderate pressure and low temperature conditions (Sloan and Koh, 2007). The pressure and temperature conditions that sustain gas hydrate existence occur in the marine sediments of continental slopes and the sediments of permafrost.

Because stability of gas hydrate is sensitive to temperature, modeling results surmise that sufficient warming or cooling of the earth might alter the role of gas hydrate in the earth's carbon cycle (Dickens, 2003; Archer et al., 2009) by the release or storage of the greenhouse gas, methane. The dissociation of marine gas hydrate can also be a geohazard by causing destabilization of shallow marine sediment (Maslin et al., 2010). Moreover, natural gas hydrate could be a future unconventional natural gas resource (Boswell and Collett, 2011) with developments in technical and economic recoverability. Various countries throughout the world such as Japan, Korea, India, China, Canada and the U.S. are working to identify and drill gas hydrate (Takahashi et al., 2005; Ryu et al., 2009; Collett et al., 2014; Fujii et al., 2015; Hui et al., 2016).

The northern Gulf of Mexico is an active world-class petroleum province in terms of the large area and exploration activities (Weimer et al., 1998; Pettingill and Weimer, 2002). Abundant proprietary and publicly available subsurface seismic data and geophysical well logs exist over the northern Gulf of Mexico shelf and slope. For mapping and oil/gas leasing purposes, the Bureau of Ocean Energy Management (BOEM) has divided the Gulf of Mexico offshore continental shelf in polygonal areas called the protraction areas (e.g. Alaminos Canyon, East Breaks, Garden Banks, Keathley Canyon, Walker Ridege, Green Canyon, Atwater Valley, Mississippi

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Canyon and Desoto Canyon) (Fig. 1). Oil and gas production in the Gulf of Mexico region started in the late 1940s (Managi et al., 2005), and since 1987, over 2700 industry wells have been drilled in the deeper waters (>500 m of water) of northern Gulf of Mexico continental slope. We use this industry well log data to assess potential gas hydrate occurrences, and provide a data set presenting our results and other well information.

1.2. Geologic setting and history

The Gulf of Mexico basin started developing in the Late Triassic-Early Jurassic when the North American plate began drifting away from the African and South American plates (Salvador, 1987). The Middle-Jurassic was dominated by the deposition of Louann Salt in the northern Gulf of Mexico. This thick sequence of salt was mobilized and deformed as a result of basin tectonics and continuous sediment loading from the North American continent from Jurassic to Neogene periods. The result was the formation of many large salt domes and ridges, separated by deep salt-withdrawal mini-basins on the continental slope (Bryant et al., 1990; McBride et al., 1998; Milkov and Sassen, 2001), which enhance the Gulf of Mexico petroleum system by creating excellent hydrocarbon migration pathways through numerous faults and structurally focusing hydrocarbon accumulation in dipping strata. As such, the area has been heavily explored by the petroleum industry for decades to exploit conventional oil and gas resources (Managi et al., 2005). Due to the industry activity in the Gulf of Mexico, extensive geologic and geophysical information, including geophysical well logs, are available for review and form the foundation of this study.

The existence of gas hydrate in the Gulf of Mexico was suspected from a very early time, based on the presence of bottom-simulating reflectors (BSR) and sediment gas chemistry (Shipley et al., 1979). Gas hydrate was first identified in the surface sediment samples at the Green Canyon Block 185 (Brooks et al., 1984) and the Deep Sea Drilling Project (DSDP) Leg 96 Site 618 in the Orca Basin (Pflaum et al., 1986) (Fig. 1). This was followed by a considerable advancement in identification and research on sea floor and shallow sub-seafloor gas hydrate in the Gulf of Mexico based on hydrate mounds, hydrocarbon seeps and gas geochemistry. A detailed review of these early phases of investigation of gas hydrate is available from Hutchinson et al., (2011). Seafloor amplitude mapping by the Bureau of Ocean Energy Management (BOEM, formerly Minerals Management Service) geoscientists and the observation of the venting of free gas also led to the discovery of the gas hydrate in Mississippi Canyon Block 118 in 2002 on a BOEM funded cruise utilizing the Johnson Sea Link submersible (Sassen et al., 2006). Here, gas hydrate was observed at the sea floor, in lens-like fractures in mud, rapidly crystallizing from the venting free gas. Simultaneously with these early phases of hydrate investigations, it was established that the geologic and geochemical conditions prevailing in the Gulf of Mexico make the sediments on the continental slope a potential host of significant gas hydrate accumulations (Collett, 1995; Milkov and Sassen, 2000).

Apart from the early identification of subsurface gas hydrate in the Orca Basin (Pflaum et al., 1986), the distribution and amount of the sub-surface gas hydrate remained enigmatic due to the lack of prominent traditional BSR in the region (Hutchinson et al., 2011). BSRs are anomalous seismic reflectors of negative impedance that are caused by the presence of free gas below water-saturated or hydrate-saturated sediments (Holbrook et al., 1996) or the presence of hydrate above water-saturated sediments (Miller et al., 1991; Hyndman et al., 1992; Shedd et al., 2012). In most cases, such non-diagentic BSR coincides with the thermodynamic base of hydrate stability (Hein et al., 1978; Shipley et al., 1979; Hyndman et al., 1992; Petersen et al., 2007). BSR can also arise at diagenetic

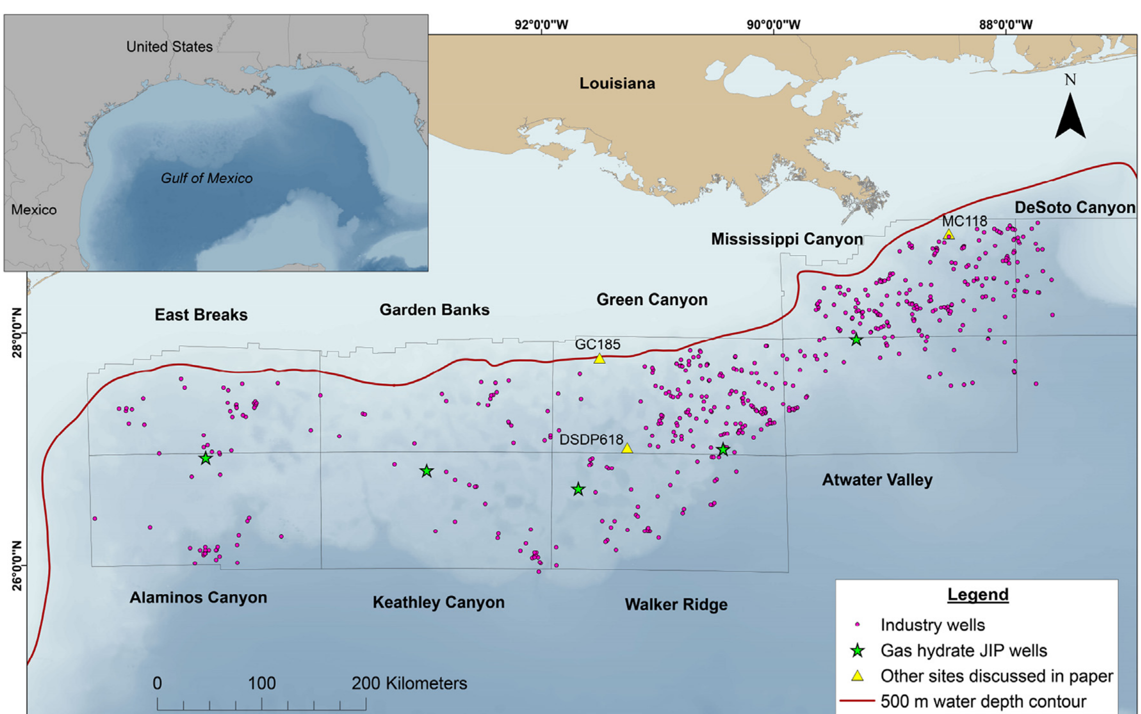

Fig. 1. The 798 existing wells in the northern Gulf of Mexico region, USA. The 788 petroleum industry wells drilled from 1987 to 2014, that contained at least 15 m (~50 ft) of resistivity log data within the HSZ, are shown as purple dots and the ten Gas Hydrate JIP wells are shown as green stars. Individual wells may not be fully resolved on map due to the close proximity of wells. Additional gas hydrate sites discussed in text are marked as yellow triangles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)