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Alaska North Slope 2018 Hydrate-01 Stratigraphic Test Well: Technical Results

Ray Boswell[1*], Timothy S. Collett[2], Kiyofumi Suzuki[3], Jun Yoneda[3], Seth S. Haines[2], Nori Okinaka[4], Machiko Tamaki[5], Stephen Crumley[6], David Itter[6], Robert Hunter[7]

[1]*The United States Department of Energy - National Energy Technology Laboratory (NETL), (Presenting Author)*
[2]*The United States Geological Survey (USGS)*
[3]*National Institute of Advanced Industrial Science and Technology (AIST, a member of MH21-S R&D consortium)*
[4]*Japan Oil, Gas and Metals National Corporation (JOGMEC, a member of MH21-S R&D consortium)*
[5]*Japan Oil Engineering Co., Ltd.*
[6]*BP Exploration Alaska, Inc.(BPXA)*
[7]*Petrotechnical Resources Alaska (PRA)*
*Corresponding Author: Email ray.boswell@netl.doe.gov

ABSTRACT

The Hydrate-01 Stratigraphic Test Well was drilled in December 2018 to confirm that a seismically-identified location within the western Prudhoe Bay Unit might be suitable for extended-duration scientific production testing. The well featured the acquisition of a full suite of logging-while-drilling data, collection of side-wall pressure cores, and installation of distributed temperature and distributed acoustic sensor (DTS, DAS) fiber-optic cables. Evaluation of the logging-while-drilling data confirms gas hydrate is present at high saturation in two target sands of high reservoir quality. Acquired logs and samples enable critical petrophysical information to be compiled for input into production models. The well tested two primary targets: the deeper Unit B is highly favorable due to optimal reservoir temperature and minimal observed risk for direct communication with permeable, hydrate-free water-bearing zones. The shallower Unit D provides a secondary target and opportunity to assess additional scientific and operational issues.

Keywords: *gas hydrates, logging-while-drilling, sidewall pressure coring, reservoir characterization.*

1. INTRODUCTION

The evaluation of gas hydrate as a future energy resource relies strongly on the ability to assess and simulate hydrate reservoir response under production conditions over extended production periods. This effort has been supported by wide-ranging laboratory and numerical simulation activities (Collett al., 2015) that are currently benefiting greatly from the ability to collect and analyze natural samples captured under in situ pressure conditions (Yamamoto et al., 2015; Boswell et al., 2019). However, most critical is the observation of reservoir response, which will only be obtained through a series of field experiments of increasing duration and complexity.

Field tests both onshore (Canada: Dallimore and Collett, 2005; Dallimore et al., 2012 and Alaska: Boswell et al., 2014), and offshore (Japan: Yamamoto et al., 2019; Konno et al., 2017, and China: Lei et al., 2018) have confirmed that reservoir depressurization is the most promising approach to achieve viable production rates from gas hydrate accumulations (Boswell et al., 2020). However, no tests to date have produced data that enables validation of long-term predictions due to insufficient test duration, an inability to isolate long-term production response from potential transient phenomena, and various operational challenges, (Yamamoto et al., 2020).

While it is likely that additional stimulation will be needed to maximize well performance and achieve the necessary commercial response, the highest priority at present is the observation of reservoir behavior over extended time periods in response to depressurization. At present, the most favorable location to conduct such a test is within the known gas hydrate accumulations that reside below the established oil and gas production infrastructure of the Greater Prudhoe Bay region on the Alaska North Slope. To be most viable, a location that isolates the scientific testing activities from ongoing industry operations is required. Therefore, in collaboration with the Alaska Department of Natural Resources (DNR) and the Prudhoe Bay Working Interest Owners (WIOs), the US Department of Energy's National Energy Technology Laboratory, Japan's MH21-S R&D consortium, and the US Geological Survey (Okinaka et al., 2020) have identified a location near a largely unused gravel pad (known as the "7-11-12" pad: **Figure 1**) where pre-existing log and seismic data were indicative of high-quality gas hydrate reservoirs.

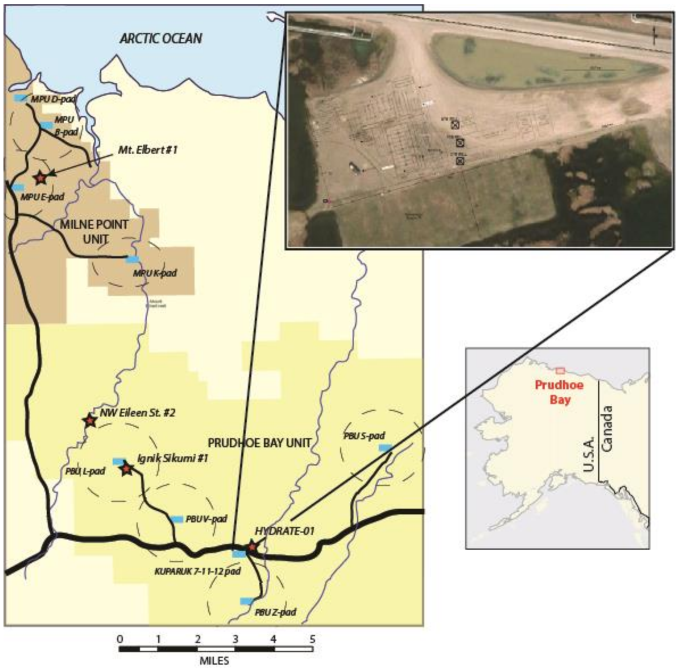

Figure 1: Location of the 7-11-12 site within the western Prudhoe Bay Unit on the Alaska North Slope. Also shown is the location of other wells with data used to study gas hydrates. Insert of the 7-11-12 pad shows the location of Hydrate-01 and other planned wells.

The 7-11-12 log data (of late 1970s vintage: **Figure 2**) show evidence of gas hydrate within two sands (an upper Unit D and a lower Unit B) that are commonly hydrate-bearing within the region (Collett et al., 2011). However, due to limited log quality, the occurrence of gas hydrate in the deeper (and thus warmer and more promising) "Unit B" remained uncertain. Therefore, as an initial step in the evaluation of the site, the project partners elected to drill a Stratigraphic Test Well (STW) to confirm gas hydrate occurrence and to provide necessary data to enable the planning of testing operations. Review of proprietary seismic data enabled by the Prudhoe Bay Unit Working Interest Owners and DNR allowed identification of an optimal STW bottom-hole-location.

In December 2018, the Hydrate-01 STW was drilled from the 7-11-12 gravel pad. The well was deviated ~800' to the east in order to penetrate the most promising location and to establish a test location offset from the existing 7-11-12 boreholes to minimize the risk that the presence of those wells within the dissociation radius of a future test would complicate operations or data interpretation. Data collection with the Hydrate-01 well included a full research-level suite of logging-while-drilling (LWD) tools (see Collett et al., 2020; Haines et al., 2020), sidewall pressure cores (see Yoneda et al., 2020); and fiber-optic distributed temperature (DTS) and acoustic (DAS) sensors. Subsequent to the drilling, the DAS cables were utilized for the collection of a large-scale DAS-3DVSP program and to collect temperature profile along the length of the Hydrate-01 well (see Lim, et al., 2020; Collett et al., 2020).

This report summarizes the general scientific findings from the 2018 drilling and subsequent data evaluation. The reader is referred to the referenced companion ICGH-10 papers, for greater detail. For information on Hydrate-01 operations, please see Collett et al., (2020).

2. SUMMARY OF SCIENTIFIC RESULTS

Both target sands were encountered in accordance with expectations. Careful attention to borehole mud temperatures were successful in limiting gas hydrate dissociation during drilling, resulting in a nearly in-gauge borehole and high quality LWD data (**Figure 3**).

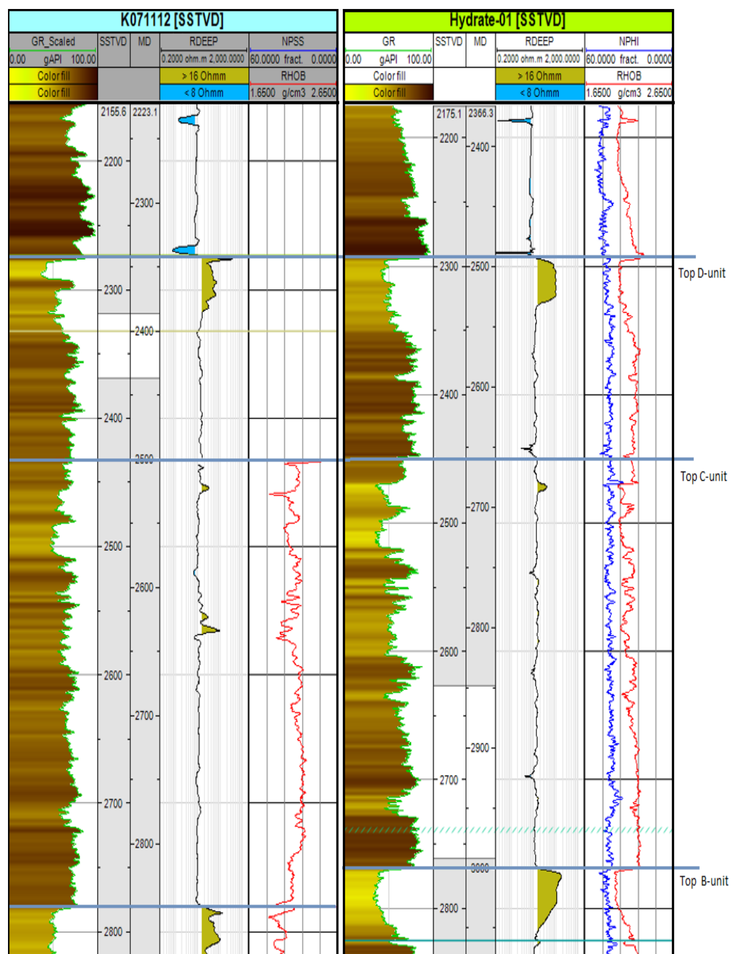

Figure 2: Wireline gamma-ray, resistivity, and porosity data for the 1970 Kuparuk State 7-11-12 exploration well (left) and the 2018 Hydrate-01 well (right).

Both of the targeted sands occur within the Tertiary Sagavanirktok Formation. These reservoirs were the subject of prior investigation in gas hydrate programs at the Mt Elbert site in the Milne Point Unit (see Hunter et al., 2011; Collett et al., 2011; Rose et al., 2011 and other papers within that special volume) and at the Ignik Sikumi site within the Prudhoe Bay Unit (see Boswell et al., 2016). At all of these locations, Unit B and Unit D exhibit the pronounced cleaning-upwards reservoir quality that is typical of progradational marginal-marine sands.

2.1 Observed Reservoir Condition

Unit D was encountered at 2,493' MD consists of two zones. The upper 37' of the unit (to 2,531' MD) is relatively massive, with density porosities averaging ~37%. Resistivity is consistent at 100 ohm-m and shows no significant separation between the various measured resistivity logs. Comparison of density porosity and NMR porosity indicate gas hydrate saturation throughout the upper part of Unit D is ~70%. Initial interpretation of NMR T2 data indicates that the 30% water content is roughly defined as 88% bound- and 12% free-water. The lower 24' of the Unit D (to 2,555'MD) exhibits a gradual decrease in porosity and increase in gamma ray with depth. However, despite the generally gradual change in reservoir quality, NMR and resistivity data show a sharp transition (~2,531' MD) from highly-saturated, gas hydrate-bearing saturation to gas-hydrate free with high percentage of the water (~80%) being mobile. Prior studies have shown similar features (i.e., apparent gas hydrate/water contacts within a given reservoir), and it remains uncertain whether these interfaces are due to partial reservoir charge (insufficient gas supply), a manifestation of the conversion of free gas accumulations to gas hydrate, or a result of subtle petrophysical controls on hydrate occurrence. Regardless, Unit D exhibits a large

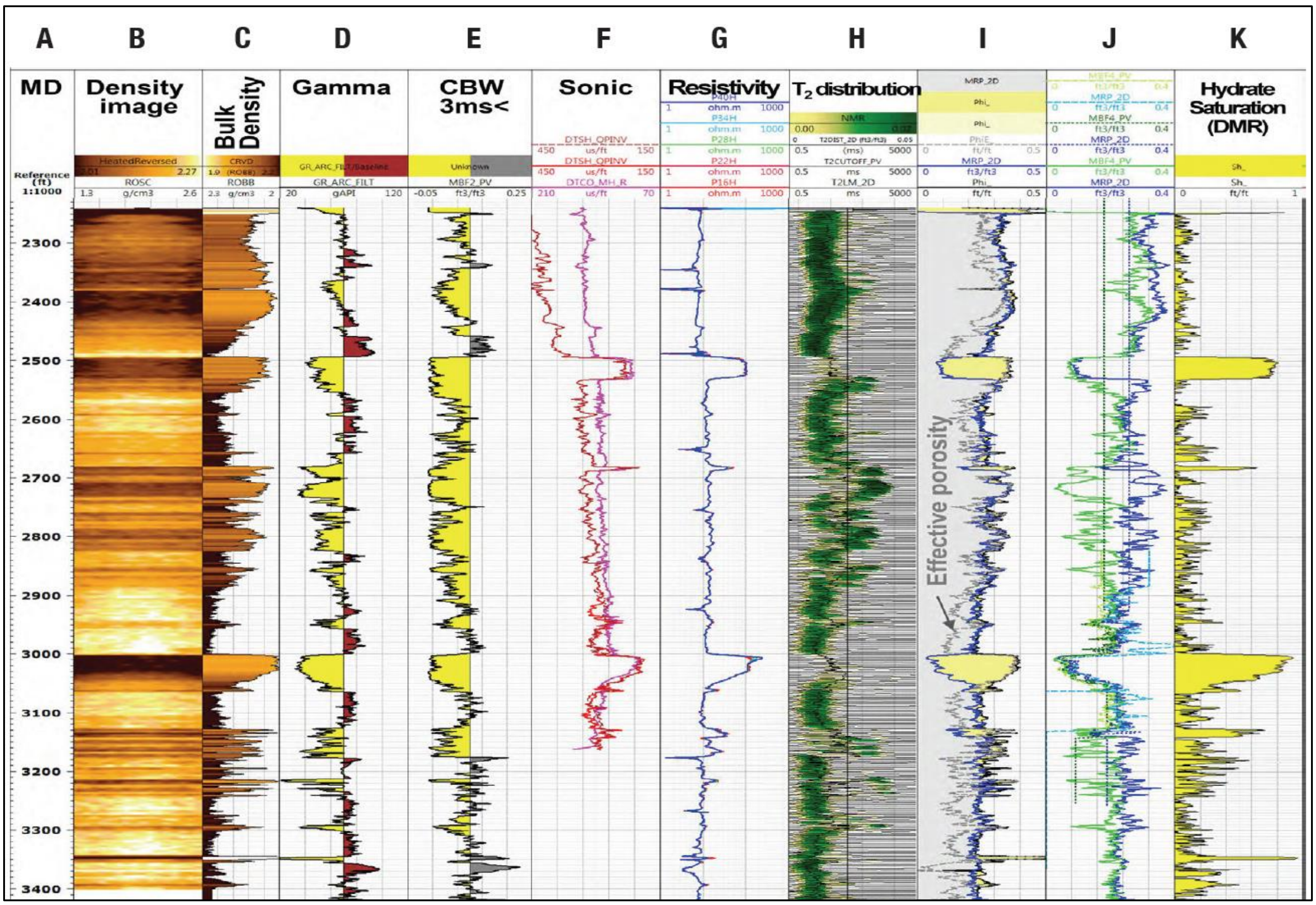

Figure 3: Summary of logging-while-drilling (LWD) and interpretations for the Hydrate-01 well, western Prudhoe Bay Unit, Alaska North Slope. Columns are as follows: (A)Measured depth, (B) Density image, (C) Bulk density, (D) Gamma-ray, € Clay bound water, (F) Acoustic slowness, (G) Resistivity, (H) nuclear magnetic resonance (NMR) transverse relation times (T2), (I) Density Porosity and others, (J) NMR volume fractions, (K) Gas-Hydrate saturation calculated by DMR method. (Suzuki et al. 2019).

source of mobile water in very close association with the hydrate reservoir, which is assumed to be in full communication with the hydrate-bearing zone.

Unit B was encountered at 3,001'MD. The reservoir appears massive and homogeneous to a depth of 3031'MD. This upper section of Unit D has density porosity of ~40%. Resistivity consistently averages ~100 ohm-m, but with the upper five feet showing slightly higher readings (up to 250 ohm-m) in those tools with greater depth of investigation. The lower 36' of the unit shows a gradual decrease in reservoir quality that is matched by a similar decrease in inferred gas hydrate saturation. This indicates that the reservoir is fully-charged with gas hydrate from top to base, with the degree of gas hydrate saturation being controlled by the petrophysical properties of the reservoir. NMR data from Unit B show no evidence of any substantial free-water zones. Assuming typical gas and water chemistries that are typical of the ANS (Collett et al., 2011), the base of gas hydrate stability is likely to occur from 50' to 100' below the base of Unit B.

The drilled interval contains numerous sands and silts of varying reservoir quality, particularly within the intermediate Unit C. Sediments directly overlying both Unit B and Unit D are among the lowest porosity and permeability sections observed (**Figure 4**).

The DTS cables indicate that reservoir temperature at the top of the D sand is ~40ºF (4.4ºC) and at the top of the B-sand is ~51ºF (10.5ºC).

Comparison of the true vertical depth (TVD) GR data between the Hydrate-01 and 7-11-12 data suggest missing section consistent with normal faults within the Hydrate-01 well in two locations (**Figure 4**). A minor fault (< 10' offset) may occur within Unit C coincident with a resistivity spike at 2,651'MD. A second and larger fault (~20-25') occurs in the fine-grained section directly overlying Unit B at ~ 2,990'MD. The orientation of the lower fault is interpreted to be down-to-the-east, which places the STW reservoir penetration on the upthrown block at the depth of the B-unit.

2.2 Petrophysics

Planning for subsequent test wells (particularly the design of sand control systems) necessitated the collection of grain size data within Hydrate-01. Given the unconsolidated nature of the units and the inevitable loss of sample with dissociation upon retrieval, the acquisition of pressure-cores was necessary to assure recovery of physical samples. To gather the samples, Halliburton's CoreVault™ system was deployed, collecting samples from both the reservoirs and the bounding units associated with Units B and D (Collett et al., 2020).

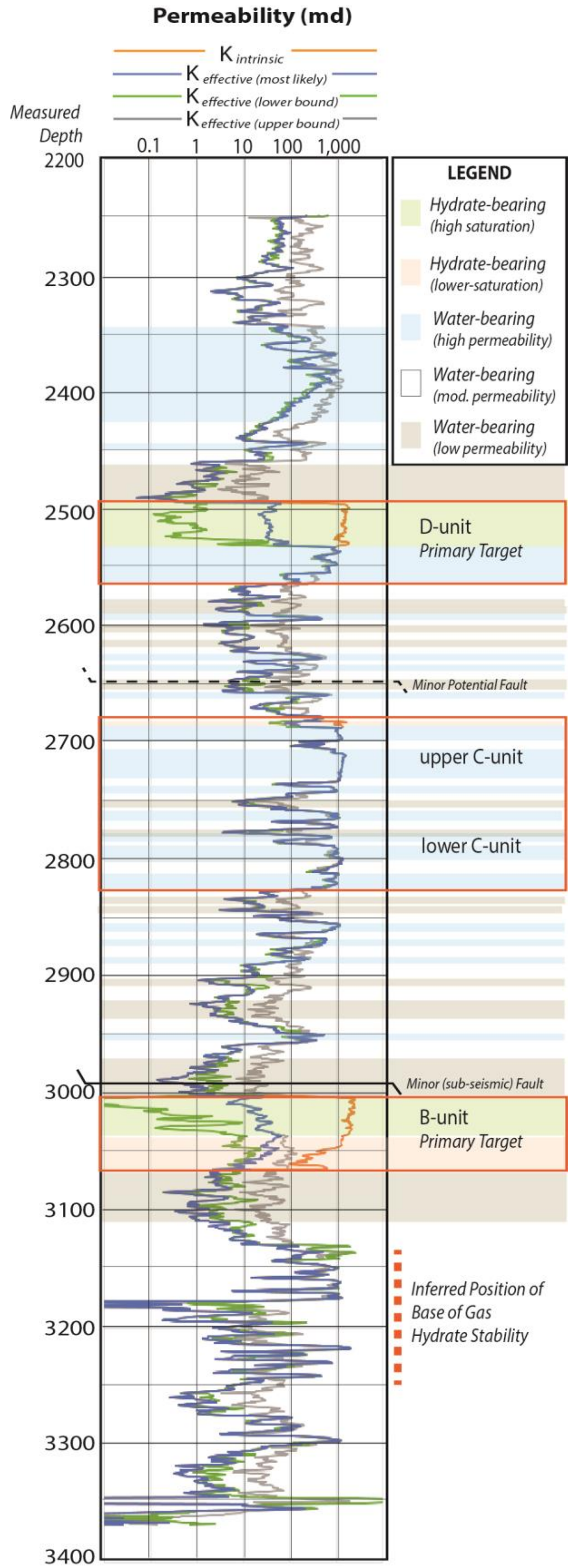

Figure 4: Summary of gas hydrate occurrence, faulting, and LWD-based and side-wall core calibrated permeabilities within the Hydrate-01 well.

Mineralogical and grain size studies (Yoneda et al., 2020) indicate the reservoirs are well sorted and quartz—rich. Grain size is very fine sand to coarse silt.

Expert handling of sidewall cores resulted in outstanding sample preservation, allowing a range of petrophysical measurements to be taken of both in situ (in the presence of hydrate) and intrinsic (in the absence of hydrate) sediment properties. Notably, in situ effective permeabilities measured in both Units B and D indicate values on the order of 10 md, (Yoneda et al., 2020), which is consistent with similar measurements obtained from hydrate reservoir samples acquired both offshore Japan (Konno et al., 2015) and India (Yoneda et al., 2019). Such values are several orders of magnitude greater than those inferred from modular dynamic tester data previously acquired in Alaska and the Mackenzie Delta of Canada (Anderson et al., 2011). Initial geomechanical studies of the samples indicate that reservoir compressibility under likely pressure drawdowns associated with production testing at the site should be anticipated, but is likely to be modest.

Evaluation of LWD NMR data allow a second interpretation of in situ effective permeabilities within the gas hydrate reservoirs. Standard methods of NMR analyses suggest low values (on the order of 0.1 md) associated with high bound water fractions. However, re-evaluation of the data indicates that higher permeability values consistent with those obtained from pressure cores, is reconcilable with the NMR data. Notably, within the fully-charged Unit B, effective permeability is observed to increase with depth in association with decreasing intrinsic permeability and decreasing gas hydrate saturation.

Given the uncertainty regarding effective in situ permeability, geologic models constructed for reservoir simulations represent an integration of measurements: a conservative (low-permeability) case is built using standard NMR methods; a core-calibrated (higher permeability) case uses reflects the side-wall core data (available only from the reservoir sections); a third "most likely" case uses the initial NMR-based values in the non-hydrate bearing sections and the relevant core-calibrated values within the reservoirs (**Figure 4**).

2.3 Site conditions

The MH21-S, DOE/NETL, and USGS team continues to develop plans for future testing at the site. Geologic models based on integration of LWD and side-wall samples are being evaluated through comprehensive collaborative numerical simulations focused on thermodynamic and hydraulic response (Myshakin et al., 2020) as well as assessment of geomechanical complications associated with sand mobilization (Uchida et al., 2020). Critical to this effort is the evaluation of potential reservoir conditions in three dimensions. To support that assessment, the program acquired and evaluated a DAS 3DVSP dataset (Lim et al., 2020) in March 2019. Mapping of local and bounding faults and interpretation of any major lateral changes in reservoir character in the area will inform the final selected location for subsequent wells in the planned testing program.

3. CONCLUSIONS

The data acquired at the Hydrate-01 site indicate the occurrence of two zones that meet the project requirements for scientific testing (**Figure 5**). The Unit B is exceptionally suited for testing, given its proximity to the base of gas hydrate stability, its warmer temperature, and the lack of associated free-water bearing zones. The Unit D also provides a good reservoir for testing designed to investigate production sensitivity to temperature as well as the ability to achieve and maintain the hydraulic isolation needed to enable effective depressurization.

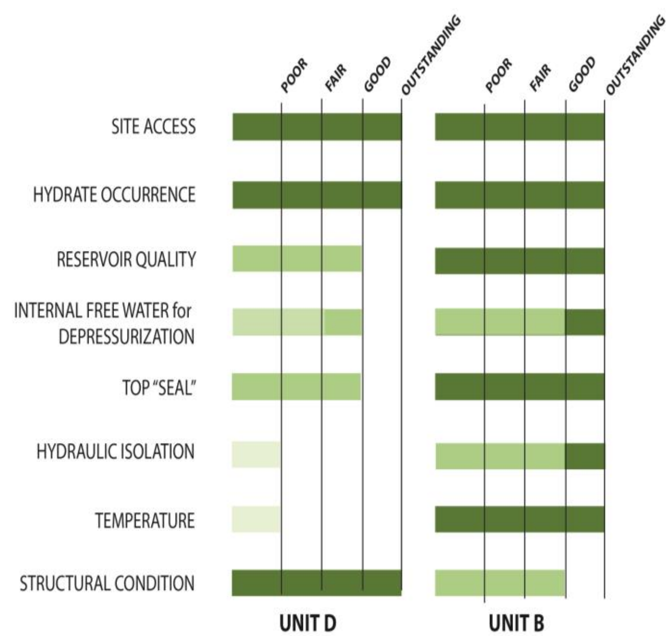

Figure 5. Summary of assessed conditions at the two gas-hydrate bearing reservoir units and their qualitative suitability for long-term reservoir response testing.

4. ACKNOWLEDGEMENTS

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