The Cryosphere Discussions

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Comment on tc-2021-226

Scott Dallimore (Referee)

Referee comment on "Review Article: Permafrost Trapped Natural Gas in Svalbard, Norway" by Thomas Birchall et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-226-RC3, 2021

The paper by Birchall et al presents observations of natural gas occurring beneath permafrost in the Svalbard area. The paper advances the premise that permeability reduction in ice bearing permafrost can effectively act as a seal to the migration of both biogenic and thermogenic gas from depth. This topic is of interest to permafrost scientists and has relevance to possible atmospheric release of gas as permafrost warms in response to ongoing climate change. The authors have compiled/synthesized a significant body of work including the results of geothermal modeling of regional permafrost occurrence and information/interpretations from hydrocarbon and scientific research wells. As a reviewer I appreciate the considerable efforts taken by the authors to assemble a rather disparate body of knowledge.

Unfortunately, as a permafrost scientist I was disappointed that the available data presented in the paper to demonstrate permafrost occurrence, ice bonding and associated permeability reduction is in my view rather weak and not adequate for publicatiion as submitted. I have studied well log interpretations of permafrost occurrence in hydrocarbon wells in the North Slope of Alaska, the Mackenzie Delta and the Beaufort Sea. As described in the paper there are many published studies from these settings using industry data to delineate well-defined occurrences of permafrost based using mainly well log resistivity and seismic velocity anomalies as well as in situ temperature measurements. Many of these wells have additional well log data and core samples that reveal that the permafrost occurs in mainly unconsolidated high porosity sediments, rather than in cemented bedrock. Based on the presentations in the Birchall et al paper it seems that the shallow sections of the hydrocarbon wells and scientific wells from Svalbard were not fully characterized by industry with the same rigor that we see in some other settings. This deficit in hard data is a challenge for the authors to overcome if they wish to present convincing and strong arguments in support of their conclusions. Indeed in the various well log sections presented in the paper, I did not see any examples that in my opinion yielded a high confidence assessment of ice bonded permafrost occurrence with multiple lines of evidence such as documented in other settings. Without well log indicators, the authors rely heavily on assumed variations in permeability expected from ice bonded permafrost to non-ice bonded sediments resulting in water influx into well bores or simply the occurrence of free gas. This association in itself is not an unreasonable

expectation, however the authors have not given the reader the basic information they need to appraise these indicators. While there are some vague statements suggesting that the study wells penetrate low porosity bedrock rather than unconsolidated sediments, no data is presented on the petrophysics of bedrock occurrence in terms of porosity and permeability and only a few examples of pore water geochemistry. All of these factors are critical for the assessment of the manifestation of ice within the porosity of the bedrock setting or occurrence of ice in fractures limiting fracture permeability. I have not rejected the paper as it is my hope that the authors in a revision of the paper can provide an expanded assessment of the petrophysics of the setting they are studying. Hopefully bedrock mappers or industry scientists have appraised the porosity, permeability and fracture characteristics of bedrock occurrences. If these observations are available they should be described for the reader and interpreted within the context of the goals of the paper. In addition, it is important to understand if there are any observations of ground ice form and occurrence that have been complied by surface mapping or in laboratory studies on core samples. Another concern is the confidence in assessment of the base of permafrost. No in situ ground temperature data are presented on permafrost occurrence and for the most part the authors have had to rely mainly on permafrost modeling by others or very weak estimates based on drill mud temperatures. I note that on Figure 3 for instance that the authors acknowledge considerable uncertainty in their estimates of base of permafrost. Gas and water anomalies in many wells are considerable distance below their high confidence estimates (see my notes on the pdf copy of the manuscript). This does not lend confidence to the assertions made in the paper as it may be that the indicators are not related to variation in ice bonding. Concerns related to the geothermal setting, pore fluid chemistry and petrophysics also in my view render the gas hydrate discussion in the paper as even more speculative than the permafrost discussion. Indeed in several places in the text the authors suggest that if gas occurred in hydrate form the volume of stored gas could be much larger than if the gas was free gas. This suggestion is in my view unsupported, leading to my suggestion that reference to gas hydrate occurrence in the paper be significantly scaled back.

I close with a note of encouragement to the authors - the topic they are studying is important and certianly of interest to the readers of the journall, thus I hope that they can continue their study and advance this paper to publication. I have made some minor comments on the attached PDF that I hope will help point out to the authors my concerns with the present manuscript. These include a need for considerable effort to improve nearly all of the figures and the captions for the figures and tables. I have not dwelled on the writing however there is also a need to stream line the writing (perhaps by simplifying some of the extended discusison on the petroleum setting) and improve the consistency in terminologies referring to permafrost terminology. Finally, I recommend that the authors more carefully assess references from the Mackenzie Delta. This could be done simply by using Googlescholar with a search for 'permafrost occurrence Mackenzie Delta'. In particular perhaps the Geochemistry paper by Collett and Dallimore and Geology paper by Dallimore and Collett would be helpful as they provide some insights and observations of gas within and below ice bonded permafrost

Please also note the supplement to this comment:
https://tc.copernicus.org/preprints/tc-2021-226/tc-2021-226-RC3-supplement.pdf