

Interactive comment on “An X-ray micro-tomographic study of the pore space, permeability and percolation threshold of young sea ice” by Sönke Maus et al.

Anonymous Referee #1

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1 Summary

This paper presents a new experimental characterization of the pore space and permeability of natural sea ice. The techniques are advanced and novel for natural sea ice. These measurements have a wide importance to those studying the evolution of sea ice, since many processes are very sensitive to permeability. The experimental technique is well described and careful. The results are presented clearly and provide strong evidence in contrast to widely-cited previous studies showing a percolation threshold at 5% porosity. The limitations of the study are discussed very well, although there are three significant areas in which I think limitations need more discussion. The

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writing quality is excellent. Overall, I think the paper is excellent and should be *accepted subject to minor revisions*.

2 General comments

- 1. Experimental procedure and the texture of sea-ice:** There is insufficient discussion of how the procedure followed might have affected the texture of the sea ice, such that the images collected are not necessarily representative of natural sea ice. Several aspects of the description of the procedure raised questions about this matter. For example, L65 describes an equilibration over 1–3 days. L71 describes a loss of brine during storage. I would expect the storage period to result in change in texture or pore space geometry. Loss of brine will generally increase the solid fraction and reduce the permeability. L83–89 suggests that it might have been worthwhile varying the centrifuging procedure to demonstrate more clearly that results don't depend too sensitively on it.
- 2. Porosity threshold ϕ_c :** The experimental evidence provides very strong evidence that sea ice is permeable beneath the often-cited threshold of $\phi_c = 0.05$. However, the evidence in support of $\phi_c = 0.024$ is very much weaker. As an example, figure 6 and the text that discusses shows several samples beneath this critical threshold (to the left of the dashed red line). I'm not convinced it makes sense to extend the dashed red line outside of the data range, especially in panel b). I think the text should be altered to discuss this threshold more tentatively, perhaps arguing instead that any threshold must be smaller than about 0.024 (see also final point).
- 3. Texture and the porosity threshold:** I think it remains an outstanding physical question whether a porosity threshold should be expected at all. I am more familiar with this discussion in the context of partially molten mantle rocks. For a

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period in the 1990s, the dominant view was that there was a porosity threshold (e.g. Faul, 1997, JGR). But the general view today (partly as a result of experimental improvements) is that there is no such threshold. If the sample is at textural equilibrium, then the texture is controlled by the ratio of surface energy, often expressed as a dihedral angle. If this angle is beneath 60° , the melt network remains connected to arbitrarily small porosities (Rudge, 2018, Proc. Roy. Soc., building on, e.g. von Bargen & Waff, 1986, JGR). The present study pushes the porosity threshold smaller than that suggested by previous studies, but perhaps rather close to the imaging threshold (see Table 3). Therefore, I would suggest that the conclusions/abstract should be more tentative. I would also expand section 4.5 to discuss the relationship further the relationship between texture and a threshold, building on the good discussion suggesting that the microstructure is controlled by morphological instabilities during ice growth rather than surface energy (in section 4.3). It would be good to see a bit more evidence for this claim and to consider whether the validity of this statement might evolve over time?

3 Specific comments and technical corrections

4. **L38–46:** This paragraph made me wonder whether it would be worth comparing this approach to laboratory permeameter measurements in future?
5. **L52:** 'not shown' is a typo?
6. **L58:** given the effort made to transport the samples rapidly, was any estimate made of the temperature change the samples might have experienced during the time
7. **L60:** consider noting that if samples were collected at a colder period, there would be a substantial *in situ* temperature gradient even across a 3.5 cm sample.

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This procedure would need adapting for a colder collection period.

8. **L63:** I didn't have a clear sense as to why the samples were collected in an usually warm period? This should be explained at some point (perhaps it was not by design?) Does it limit the relevance of the results?
9. **L81:** I would make it clearer that the stated accuracy is an analytical or measurement accuracy. The sample treatment errors might be larger.
10. **L96:** What is ϕ_b ?
11. **L108 (footnote):** Do these approaches agree?
12. **L145:** I think this part should be explained more clearly. Ordinarily, the term 'hydrostatic pressure' refers to the part of the pressure that does not drive fluid flow.
13. **L155–156:** sentence structure could be clearer (perhaps missing a comma or split into two sentences).
14. **L187:** I think this makes sense, but perhaps explain the rationale for neglecting solid salts.
15. **L213:** typo/referencing issue.
16. **L226:** another occasion when the unusually temperature could be mentioned.
17. **Fig 4(b):** figure quality is very poor (hard to read).
18. **Fig 7 (and 9 and 10):** I found the legend confusing (e.g. what does (5) mean?)
19. **Fig 11:** Consider explaining what 'upward' and 'downward' mean in the figure caption (or refer readers to the main text).

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20. **L298:** Perhaps clearer to say a factor of 100? Or 'two orders of magnitude'?
21. **L371:** Consider adding a reference for the 5% here.
22. **L414:** inconsistent italicisation of *D* and *L*.
23. **L424:** missing space
24. **L505:** Consider adding a citation of Wettlaufer, J.S., Worster, M.G. & Huppert, H.E. 1997; The phase evolution of young sea ice; Geophysical Research Letters
25. **L577:** I'm not sure of the practicalities but it would be good to make the data available as soon as possible. https://wiki.pangaea.de/wiki/Data_submission seems to suggest that you could have 20 files each up to 100 MB here which might be suitable?

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