Solid Earth Discussions

Solid Earth Discuss., author comment AC2
https://doi.org/10.5194/se-2021-140-AC2, 2022

Reply on RC1

Ernest Rutter et al.

Author comment on "Matrix gas flow through “impermeable” rocks – shales and tight sandstone" by Ernest Rutter et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-140-AC2, 2022

Anonymous referee RC1 : posted 4 January 2022

General Comments

The paper presents interesting study of permeability of tight rocks with comparable porosities over a wide range of pressure conditions. The authors explain the pressure dependence of permeability using a model that capillary tubes with eccentric cross sections. However, the model fails to explain the permeability evolution in Bowland shale which is interpreted to be a result of the heterogeneity of the pore size and tortuosity. Overall, I found the study well supported by the amount of data and nicely discussed.

Specific Comments

- In line 88-89, it is not clear what the author means by ’bedding horizontal’. Please clarify.

- The author mentioned conducting permeability measurements using both pulse-decay and oscillation method. But it is hard in the later plots to distinguish measurements from different method. Could the author elaborate on how much difference would it make using different method for permeability measurements in this study.
- In line 221-225, as described by the author, the samples were exposed to higher effective pressure before the application of pore pressure. Would this contribute partly to the later observed difference in the ‘m’ and ‘n’ variation in the effective pressure law.
- In line 344-349, would the bioturbation in the Haynesville shale be partly the reason for the higher permeability and lower pressure sensitivity in the normal to bedding flow?
- The authors attributed the different pressure sensitivity of permeability in the Bowland shale to the pore structure complexities (heterogeneity of the pore size and tortuosity). Is there any direct microstructural evidence comparing the Bowland shale to the other two rock types?
- The use of pore pressure parameter 'n' and the pore pressure coefficient 'm' in the discussion of the effective pressure can be confusing. It might help the reader if this is introduced and discussed earlier in the paper (line 258-260 might be a good place for a clarification).

Technical Corrections

- In section 2, it might be more reader friendly and easier to compare if the author could put the composition proportions, density and porosity data in a table.

Authors' responses:

The referee is thanked for complimentary general comments and specific comments of a constructive nature. The latter are addressed as follows, in order of the six numbered points:

- The bedding trace in the images of Pennant sandstone microstructure are 'horizontal' with respect to the page orientation. To avoid confusion, in the text we now say that the bedding trace is parallel to the long axis of the images.
- We have previously reported (McKernan et al. 2017) excellent agreement between the results of pulse transient decay and oscillating pore pressure methods for permeability measurements on the same material at the same conditions, and we have now made it clear in the text.
- Concerning the sequence of application of confining and pore pressures, in a sequence of measurements the aim is initially to apply an effective pressure equal to the maximum the rock will experience in that sequence of tests, to 'pre-condition' the rock, otherwise the sample will not display recoverable elastic behaviour in successive pressure cycles. Obtaining reproducible response to repeated pressure cycling was essential to obtain meaningful permeability/pressure relations. This is not thought to contribute to differences in the pore pressure coefficients m and n, which describe physically different behavioural responses.
- The different permeabilities and pressure sensitivities of Haynesville shale according to orientation must be reflections of the compressibilities and pressure sensitivities of connected pore spaces, and ultimately this must be relatable to microstructural anisotropy. It seems quite likely that differences like these could relate to factors like bioturbation, but unfortunately we do not have any data on this beyond reasonable speculation.
- There is a substantial amount of microstructural data available on the Haynesville shale, on samples taken from the same cores and close to those used in this study. The study of Ma et al. (2018, op.cit.), using a range of different imaging techniques over a range of scales, shows that the conductive pore dimensions are of the same order of size as calculated from the simple modelling used in this paper. Dowey and Taylor (2020, op.cit.) provide details of the range of diagenetic features represented in this shale. Ma et al. (2019, Energy, 18, 1285-1297) provide further detail on microstructures. The Bowland shale is mineralogically and microstructurally highly heterogeneous over short distances, and there have been detailed studies of such variability reported (Fauchille et al. 2017, Marine and Petroleum Geology, 86, 1374-1390, and Fauchille et al. 2018, Marine and Petroleum Geology, 92, 109-127) but unfortunately not from the particular phyllosilicate-rich, carbonate-poor core-section studied here. Thus we cannot say more about the source of the differences between these rocks other than attributing differences to generalized mineralogical and microstructural contrasts. This issue is commented upon in the discussion (sections 5.4 and 5.5).
- We have included a clarification of the different significance of the two pore pressure coefficients at the line suggested and also at line 316.

Technical point 1: Table 1 already contains for each rock type the mineralogic composition, and elastic moduli data. Because other data for different rock types is reported in slightly different ways, we considered including it in the paragraphs describing the characteristics of each rock type might be clearer.