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Interactive comment on “A Multi-phasic Approach for Estimating the Biot Coefficient for Grimsel Granite” by Patrick Selvadurai et al.

Anonymous Referee #2
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Reviewer’s Comments:

General comments

The measurement of the poroelastic properties of low permeability rocks is not an easy task due to saturation issues and pore pressure artifacts. This paper presents a mixed approach for estimating Biot’s coefficient based on direct measurements of the bulk modulus of the porous skeleton and estimations of the bulk modulus of the solid matrix from the sample mineral content and the bulk moduli of the constitutive minerals.

The paper is interesting and well-written. The authors first summarize the measures of the elastic constants of Grimsel granite available in the literature and discuss their consistency. The transversely isotropic measurements are used to compute an equivalent isotropic skeletal bulk modulus. The multiphasic approach used to assess the bulk modulus of the solid matrix (Ks) is then detailed and upper and lower bounds are C1 computed. The obtained bounds are then used to compute upper and lower limits for Grimsel Granite Biot’s coefficient. The consistency of the obtained variation ranges is finally discussed and a set of realistic estimates is provided.

Authors’ Reply

The authors are grateful to the reviewer for the constructive and supportive comments. The recommendations of the reviewer will be taken into consideration in the revision of the manuscript.

Specific comments

Reviewer Comment 2.1 Measurement of Biot’s coefficient

Additional information on the test system and the followed loading path associated to the "conventional" measurement of K_S considered by the authors would make it easier to follow the reasoning. Is this an unjacketed test? If not, the flow through the cylindrical sample would be linked to its length or half-length according to the applied hydraulic conditions at the sample ends and not to its diameter. Is the sample initially saturated at a given small confining pressure and then both the confining pressure and the pore pressure are simultaneously increased at the same rate? Or is the sample saturated at a higher confining pressure which is then kept constant as the pore pressure is gradually increased? The later approach would allow the checking of the pore pressure equilibrium at each pore pressure increment (see for example Bemer E., Longuemare P., Vincké O., 2004, Poroelastic parameters of Meuse/Haute Marne argillites: Effect of loading and saturation states, Applied Clay Science, 26, 359-356).

Authors’ Reply to 2.1

The ideal arrangement for the measurement of the Ks would involve an unjacketed specimen where the saturating fluid is identical to the pressurizing fluid. In situations where the saturating fluid is water and the pressurizing fluid is oil (needed to attain high pressures without compressibility issues), the sample needs to be jacketed. The sample can be subjected to a constant high confining pressure and the pore fluid pressure increased to attain equilibrium. This appears to be the preferred mode of estimation of the solid material compressibility. Other variations on this procedure are possible depending on the permeability of the rock under investigation. With very low permeability rocks there are issues that need to be recognized in the excessive time for attainment of equalization. The multiphasic approach advocated in the paper stems from this fact. The reference relating to the measurement of poroelastic parameters for the Meuse/Haute Marne argillites is valuable and will be included in the revised version of the paper. If ever there is a criticism in the use of oedometric compression tests for estimating the Biot coefficient, this relates to the radial stress developed in the sample, which is a function of the skeletal Poisson’s ratio, which adds a level of uncertainty in the interpretation of the solid material compressibility. In the opinion of the authors, the most appropriate technique is the use of isotropic compression of a jacketed sample. Also, the Meuse/Haute Marne argillite is a clay rock, which will have irreversible deformations in terms of the stress history and the interpretation of the skeletal elasticity properties should reflect stress history. In the case of the Grimsel granite, such effects are not expected to be significant.

Reviewer Comment 2.2 Transversely isotropic material

Equations (1) correspond to the behavior of a transversely isotropic dry porous skeleton. The description of the poromechanical behavior of this porous medium would require the introduction of two different Biot's coefficients (Coussy O., 2004, Poromechanics, John Wiley and Sons, USA).

Authors' Reply to 2.2

The issue of requiring two different Biot coefficient to describe a single pore pressure variation is not a rational approach. The same applies to formulations that assign a tensorial structure define the Biot coefficient, which would imply that the pore pressure is not a scalar. This is possible only if the fluid pressure at a point is allowed to have different directional values. The extension of Biot's definition to incorporate anisotropy of the fabric is most conveniently done by evaluating the volume change in an anisotropic fabric under isotropic compression.

Reviewer Comment 2.3

Equations (1) are used to define a bulk modulus for the transversely isotropic porous skeleton through Equation (4). The computed "TI" bulk modulus is then used to compute an isotropic Biot's coefficient through the expression $\alpha=1-(K_D/K_S)$. The transversely isotropic nature of Grimsel granite is thus not fully considered here. This point should be rapidly discussed in the paper. Measurement of the elastic properties of Grimsel granite As a general comment on the literature data on the elastic properties of Grimsel granite, the issue of the saturation state of the tested samples should be more thoroughly discussed. The considered elastic properties should be representative of the skeleton behavior (drained or "dry" properties). The skeletal bulk modulus values deduced from measurements performed on "wet" samples could notably be overestimated. The applied confining level would also be a key parameter as the presence of cracks could lead to underestimated skeletal bulk moduli at low confining pressures. The saturation state issue is all the more pregnant for dynamic measurements as dispersion effects could be high for cracked samples and lead to overestimated skeletal bulk moduli. Multiphasic approach for computing Ks. The void fraction is said to be neglected in the calculations. As the aim of the computation is to derive the bulk modulus of the solid material, the only relevant void fraction should correspond to occluded porosity. It should be clearly specified in the text. Anyway as it is neglected, it should be removed from Equation (7).

Authors' Reply to 2.3

The approach adopted in the paper is to consider a transversely isotropic dry Grimsel rock, whose transversely isotropic elastic constants have been determined through separate tests. *Once these parameters are available, a hypothetical sample of the dry Grimsel granite can be subjected to an isotropic state of stress and this will result in the development of normal strains in the sample without distortion. The principal strains can be calculated and if infinitesimal strains are considered, the volumetric strain is the first invariant of the infinitesimal strain tensor. The reviewer is correct in outlining other issues related to the testing of "wet samples" and "testing at high confining stresses" that could induce crack closure/crack opening, which can influence the estimation of elasticity parameters and subsequently the estimation of* K_D. *While these issues can be addressed in relation to the experiments performed by the authors, the task of determining the exact test conditions that other researchers followed is not so straightforward. The authors can therefore only adopt the values reported in the literature. The concluding remarks in the paper emphasizes the need to be vigilant about test procedures, particularly when reporting values for the elasticity properties.*

Reviewer Comment 2.4 Technical corrections

(a) Lines 27-29: Terzaghi's effective stress corresponds to a Biot's coefficient tending towards unity and thus to a case where the bulk modulus of the solid material is small and not large in comparison to the skeletal bulk modulus. Please correct the misprint.
Figure 1: (b) the legend and details of the figure are too small.
Line 81: One extra bracket
Figure 2: Please specify the sample size and its orientation. White lines oriented at 45_ seem to be visible on the sample lateral surface.
Line 136: The maximum and minimum values associated to the medium-grained granite are missing in the text.
C3
Line 185: There is a misprint in the unity of Poisson's ratio estimates.
Line 234: Only the Hashin-Shtrikman reference is given in the text, while the keywords include Hashin-Rosen estimates. "Shtrikman" is misprinted line 237.
Equations (13) and (14): The lower (L) estimates are higher than the upper (U) estimates?

Line 242: "skeletal" is misprinted.

Authors' Reply to 2.4

The authors greatly appreciate the Technical Comments made by the reviewer and, where relevant, these will be corrected/implemented in the revised version of the paper.