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Interactive comment on "Structural geology and geophysics as a key to build a hydrogeologic model of granite rock to support a mine" *by* L. Martinez Landa et al.

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SE-2016-27-RC2-Reply: Replies (in colors for clarify) have been added as a suplementary pdf file.

This paper nicely illustrates a methodology to characterize and model groundwater flow in a fractured granitic rock. The overall approach is to characterize the hydraulically important structural features (such as faults, dykes, etc.) in the "near" or "inner" region (for example, in the vicinity of a mine) using a combination of geology, geophysical, geochemical and hydrologic methods. These features are explicitly built into a numerical model of the groundwater flow system. For the "far" or "outer" region, equivalent hydraulic properties are used to include structural features that are unknown or not characterized. This is certainly a reasonable approach, and this paper shows that the approach can work quite well. This paper is suitable for publication in Solid Earth after minor revisions.

Comments:

1. I am confused by the column headings "transmissivity" and "storativity" in Table 1. I assume these terms apply only to 2D features. For 3D features, these terms should be "hydraulic conductivity" and "specific storage". For 1D features, there are no standard terminologies in groundwater hydrology. It would be helpful to show the flow law that is being used in the model. Also, the meaning of the storativity of a 1D feature (borehole) is unclear to me. Yes, the column headings have not been a right choice. We have tried to clarify it with the dimensionality and with the table-foot note. We modify the table caption as follows: Table 1: Parameters obtained after calibrating the South cross-hole test. Units are meters and seconds, 1D feature are defined in terms of hydraulic conductivity and specific storativity by assigning them a 1 m2 cross sectional area. Hydraulic conductivity values of matrix and fractured belts change with depth: the first value holds for the upper 250 m (constant parameter), the second value applies to the bottom of the domain –both for the matrix and the fractured belts. The storativity of the "fractured belts lehm" is negligible in the model (1.0Âů10-30), to prevent the artifact that water might be withdrawn from that zone. Standard deviations of the decimal logarithms of estimated parameters (not shown for parameters held constant during calibration) are also presented as a measure of uncertainty.

We modify the table as follows (we include also the standard deviation, as requested in the following column): (see suplementary pdf file)

Does this have to do with simulating the effect of wellbore storage during hydraulic test? Actually, not only wellbore storage, but also the connectivity caused by the wellbores. We have added a statement to clarify this issue: Note that fully penetrating boreholes are explicitly included in the model to represent that they connect fractures.

2. Please provide some measure of uncertainty for the parameters in Table 1. These could be in the form of linearized confidence intervals that are usually calculated by optimization programs. Also, were some of the parameter values assumed a priori and held fixed (not changed) during the calibration? We have changed Table 1 adding values of Standard Deviation in two columns (one for Transmissivity and hydraulic conductivity parameters and the other one for Storativities parameters). Fixed parameters has been boreholes K and Ss, mined dykes T and S, fractures S and the permeability of altered unit, the last has been calibrated during the calibration process but has been fixed at the end with a coherent parameter. In fact, the parameters whose standard deviation is not shown remained fixed during calibration. The modified caption and table were shown in response to the previous comment.

3. I would like to see a bit more information about the model set-up for the blind prediction. On page 10, the text noted that fractures not affected by any tests were assigned the hydraulic properties of fractures of the same family in the calibrated model. Which are these "uncalibrated fractures"? All the structures shown in table 1 are affected by the XÂůhole tests (calibrated model) and has been calibrated. The fracture 474 has not been calibrated at this model, as Fr4, Fr1, North Fault and a parallel dyke located at the right side of the 27 dyke (crossing 474, 285 and south faults). Some of these structures have been tested individually during characterization phase, as North Fault, and we had used the value obtained from the test interpretation. We have identified which fracture family belong these fractures and assign the calibrated value obtained for them. Thus fractures 474 and Fr4 has the values obtained for fracture 285, and dyke those obtained for 27 not-mined dyke. We have added an explanation in the text:

Fractures not affected by any test were assigned the transmissivities that had been obtained during calibration for fractures belonging to the same family, according to the geophysical and structural analysis. Specifically, fractures 474, 474', 478 and Fr4 were assigned the values obtained for fracture 285, and the SR3 dyke was assigned the T obtained for the not-mined portion of the 27 dyke.

The fractures shown in Figure 11 (blind prediction) appear to be the same as the features shown in Figure 9 (calibration). It has been an error in the Fig 9. We modify the Figure 9 as follows:

How would the predictions be affected if the "uncalibrated fractures" were given different hydraulic properties? The question is fair. We have decided not to include such prediction to keep the paper short. Not including such fractures should not have been a problem on short term response for intervals located in the XÂůhole test calibrated model area, because the new pumping point is well connected with this zone without the need for structures other than the existing on the calibrated model. Main fractures, as North Fault, have been tested before on the hydraulic characterization phase, so we have reasonable parameter values. The main differences would have been on boreholes SR2-1, SR2-2, SR2-3, as well as SR3-1, SR3-2, and SR3-3. These wells would have displayed a much more deayed response than observed and modelled (perhaps similar to the response observed in SR4-3 or SR3-3). Perhaps more important, the slope of the late time drawdown in semi-log is quite accurate, which suggest that the overall parameters are OK. To address this comment, we have added a short paragraph at the end of the section stating: It is worth pointing at the good quality of the responses obtained at intervals, SR2-1, SR2-2, SR3-1, and SR3-2, which would have displayed a much more delayed response than observed and modelled (perhaps similar to the response observed in SR4-3 or SR3-3) if the untested (and only observed through geophysics) fractures had not been included. Perhaps more important, the slope of the late time drawdown in semi-log is quite accurate in most observation points, which suggest that the overall parameters are adequate for this test, even though it lasted some 100 times longer than the calibration tests.

Also, how are the hydraulic properties of the "external matrix" determined? We have added a statement in section 3, when we explain the subdivision of the domain, about the external matrix hydraulic conductivity: Its value was assigned by approximately evaluating the effective hydraulic conductivity (matrix plus fractures) of the area that was characterized in detail.

4. I find the discussion of the scale effect (section 4) rather confusing. Looking at Figure 10, one might ask why there are no higher K values (for example, 1E-5 m/s) measured by pulse tests? The answer likely lies in the fact that the pulse would decay so quickly in a high K test interval that the pressure data would be impossible to analyze. Conversely, why are there no low K values (for example, 1E-11 m/s) measured by constant head tests? The answer likely lies in the fact that the flow rate would be too low to measure. Thus, I think Figure 10 can readily be explained as illustrating the limitation that the testing equipment and resources impose on the range of K that can be practically measured. To call this a "scale effect" seems to obfuscate rather than clarify.

The problem here was that not all borehole intervals were tested at short time scale (pulse, slugs). Boreholes were drilled during an unusually rainy season. As the experimental site (around boreholes SR1 and SR4 especially) is located at a discharge place (from the mine and river), some of them became flowing wells. It was not be possible to characterize correctly the entire length of the boreholes. From this place come the more permeable structures as S10-Fr, SR1-3-Fr, and South-Fr. The 285-Fr is far away from the borehole intervals to obtain a response from a short test. And the Lehm is too shallow to test it from the borehole intervals using a short time test (pulse or slug). We did not perform constant head test at every borehole intervals because we did have problems with the instrumentations making us very difficult maintaining the head constant.

Still, the reviewer is right in the issues he raised about the confusing nature of Figure 10 (although the above response is much more prosaic than he hinted, in hindsight, we suspect that he may be right, at least about the absence of high T values from short term tests):

The most surprising feature of Figure 10 is the absence of high conductivity values for small scale tests. Even if effective permeability increases with scale, some high permeability values should have been identified by the small scale tests coinciding with the intersection of the fractures that dominate the large scale behavior of the site (see e.g., Martinez-Landa and Carrera, 2005b). We attribute this absence to the fact that characterization tests were performed during an unusually rainy season. The most permeable zones are located at the discharge zone of the mine, which caused some of the boreholes become flowing wells making it impracticable to perform a short scale test for the highest permeable part. As a consequence, the highest values are not available for the short scale tests.

Also, to avoid confusing unsuspecting readers, we have added the following statement to the caption of Figure 10:

See the text regarding the surprising lack of high K observation during small scale tests.

We thank the reviewer for the detailed and constructive nature of his comments, which we acknowledge in the revised version of the paper.

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Please also note the supplement to this comment:
http://www.solid-earth-discuss.net/se-2016-27/se-2016-27-AC2-supplement.pdf

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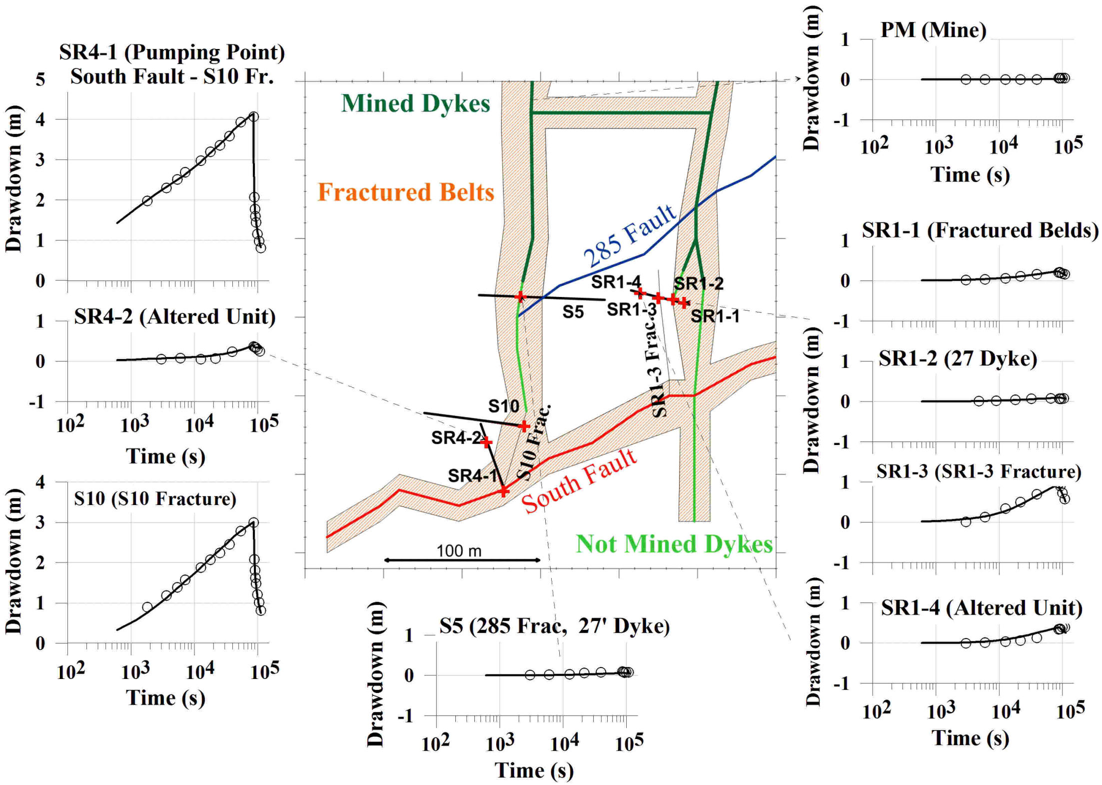

Fig. 1. Figure 9: Results obtained after calibrating the SR4-1 cross-hole test are indicated by a black line, observed data are indicated with circles using a 3D model. All graphs maintain the vertical scale

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Discussion paper