

## ***Interactive comment on “Influence of initial heterogeneities and recharge limitations on the evolution of aperture distributions in carbonate aquifers” by B. Hubinger and S. Birk***

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This paper deals with the evolution of a simple karst aquifer with constant head difference between the input and the output boundaries.

Two issues are discussed: 1) The influence of the heterogeneity of the initial distribution of conduit diameters, which are is simulated by lognormal distributions and 2) the evolution of such aquifers, which first evolve under constant head conditions until at some stage of their evolution the boundary condition is switched to constant recharge (limited recharge) at all input nodes. The results are presented by showing the dis-

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tribution of the hydraulic effective conduit diameters as they evolve in time. For each scenario 30 statistical realisations are provided.

The results are impressive, but their discussion and interpretation is extremely difficult to read because the physical processes causing them are not sufficiently revealed. It is possible, however, to interpret the results from a few well-known facts about the evolution of such simple standard karst aquifers.

For the scenario with lognormal distribution with  $\sigma/\mu_0 = 0.1$  one finds breakthrough times ranging between 2.5 ka and 5 ka whereas for distributions with  $\sigma/\mu_0 = 1$  times range between 5 ka to 30 ka. The reason for this is not explained (page 5641, lines15-25). Inspecting the initial distributions for the high and low heterogeneity scenarios reveals that the high heterogeneity distribution, HHD, ( $\sigma/\mu_0 = 1$ ) contains 50% of tubes with diameters below 0.3mm.

Since their hydraulic resistance is related to the fourth power of the diameter, their resistance is higher at least by a factor of 10 compared to the remaining tubes with diameters above 0.5 mm. In contrast to the net with low heterogeneity distribution, LHD, ( $\sigma/\mu_0 = 0.1$ ) where 50% of the tubes exhibit diameters above 0.5 mm the HHD contain high resistance pathways, which increase breakthrough times, BT, and cause also large variations. It may be interesting to plot the distribution of BT for both cases. Animation 2 shows, how the distribution of diameters changes in time. For times below TB there is a slight widening and the distribution stays one-modal for all realisations. Immediately after breakthrough some pathways connecting the input and output boundaries attract all the water (animation 1) and widen quickly creating a second peak in the distribution of diameters, whereas almost all tubes outside these pathways stop widening. As can be seen in animation 2 flow rates after breakthrough are higher than  $10^{-7}$  m<sup>3</sup>/s. If flow is restricted to some value  $Q_{max} > 10^{-7}$  m<sup>3</sup>/s breakthrough happens and the diameters of the tubes involved widen under first order kinetics linearly in time.

The figure attached presents the flow rate through the aquifer as function of time. For

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all points A above a critical flow rate  $Q_{\max} \approx Q(TB)$  one finds a bimodal distribution of tube diameters.

For points B with  $Q_{\max} < Q(TB)$  the situation changes. Because the penetration lengths  $L_1$  for first order kinetics and that for higher order kinetics  $L_n$  are related linearly to the flow rate  $Q$  further penetration of breakthrough pathways is stopped once  $Q_{\max}$  is reached, because the feedback of increasing  $L_1$  with increasing  $Q$  is switched off. For points B with  $Q_{\max}$  well below  $TB$  only the entrance tubes will experience widening by first order kinetics, because  $L_1 \ll L$ , the length of the tube. For all the other tubes higher order dissolution kinetics is active. Because  $L_n$  increases with  $(1-c(x)/c)^{1-n}$  after some distance  $x_s$  in the net  $L_n$  will be much larger than the length of the aquifer and dissolutional widening will be slow and almost even in all the tubes beyond  $x_s$ . Therefore one expects few wide tubes at the entrance causing something like surface denudation, whereas the diameters of the remaining tubes widen slowly from  $5 \times 10^{-4}$  m to  $5 \times 10^{-2}$  m in 3Ma. This is an entirely different mode of karstification without any preferred pathways of flow. The local distribution of the tube diameters in the net should be shown by a figure.

Animation 5 for  $Q_{\max} < 10^{-8}$  m<sup>3</sup>/s shows nicely a one-modal distribution shifting to higher diameters in time and with increasing half width. The entrance tubes show up as a little peak at about 0.02 m, see Fig. 5.

In between the two extreme cases of  $Q_{\max} > Q(TB)$  with breakthrough and conduit evolution and  $Q_{\max} < Q(TB)$  with even widening of all tubes without evolution of large conduits from the input to the output boundary intermediate cases must be considered. If  $Q_{\max} < Q(TB)$  is very close to  $Q(TB)$ , point B in the attached figure, some breakthrough channels have already invaded deeply into the aquifer but have not yet reached the output boundary, see animation 1 at 16.2 ky. Pathways originating at such a channel exhibit higher dissolution rates in comparison of most of the other tubes and will grow slowly towards the output. This may be the case for the scenario with  $Q_{\max} = 10^{-7}$  m<sup>3</sup>/s. After 3Ma it shows a bimodal distribution of tube diameters with a maximum

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at 0.05 m. In contrast to the extreme breakthrough case the distribution is continuous. From animation 5 one finds that after 1.5 Ma dissolution is active only in tubes with diameters larger than 0.01 m.

The authors should also address this intermediate case by presenting a figure of the spatial distribution of the tube diameters in the net. If the authors revise the paper using the ideas outlined above as a frame to discuss and interpret their results the paper should be acceptable for publication. It has potential and presents an impressive set of data. The interpretation of the results, however, is entirely descriptive and incomplete. Furthermore the paper is too long, especially the introduction. I had to read it several times until I found out, how to understand the results. As it stands the paper is not acceptable for publication. But I am convinced that using my suggestions the authors will be able to revise the paper successfully.

Wolfgang Dreybrodt

Please also note the supplement to this comment:

<http://www.hydrol-earth-syst-sci-discuss.net/8/C3312/2011/hessd-8-C3312-2011-supplement.pdf>

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