Reply to the Interactive comments by P. Szymczak

We thank P. Szymczak for the time invested to give some important suggestions for improvement of the paper. We highly appreciate the overall positive comments that state the importance of our research on that topic.

We have considered all comments. The replies to comments are listed bellow. he changes can also be seen in a tracked version of revised manuscript, where those corresponding to the comments of Piotr Szymczak are highlighted green.

1. Relevance of the previous work and references:

We agree that there are important contributions of earlier work and we have therefore added into the text on page 3:

Wormhole formation has been in the focus of many researchers from different fields. There are other systems with similar competitive dynamics, where fingers grow. The longer ones screen the shorter ones, thus preventing their growth.

Side branches of 2-D dendrites growing by diffusion limited aggregation show a similar behavior (Couder et al, 2005) as we find it in this paper.(Budek et al, 2015) investigated growth of anisotropic viscous fingers in flow of immiscible fluids in a periodic, rectangular network of micro fluidic channels. Although the underlying physics is different in both cases and from that in our work the temporal evolution of viscous fingers is similar as we observe it in the basic case. see Fig. 3.

In 1997 a larger class of systems with competitive growth is described in the review article by J. Krug, 1997) dealing with solid state properties of materials generated by molecular beam epitaxy , a topic remote from our system.

Most of the cited work focuses on the mathematical properties of competitive growth. Therefore they are not perceived by the community of earth science. In this work we take a different empirical approach. From the results of model realizations we detect the underlying mechanisms of hydro dynamical flow in the fractures and its interaction with dissolution widening their apertures.

To this end we use the idea of Upadhyay et al., 2015, who has put seeds into the entrance region of the modeling domain consisting of areas with increased fracture aperture width with respect to the apertures widths in the net. This way the seed triggers wormhole growth from its region.

and after line 9, page 9:

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We have not cited the paper of Cabeza, Y et al: Controlling factors of wormhole growth in karst aquifers, in Hydrogeological and Environmental Investigations in Karst Systems, pp. 379–385 (2014) because it deals only with the evolution of one single wormhole to characterize its capture area and does not deal with competition of wormholes.

2. Applicability of the model to the real systems:

We have not claimed that all fractures show even dissolution fronts. Maybe this was not stated clearly. The first five fractures show wormholes. But we regarded this as not important. However the argument that the boundary conditions do not show constant head and constant concentrations at the entry of the single fractures is important. We have used our method to find out by increasing the hydraulic head and increasing Pe if we can find a condition where **all** elementary fractures show even compact dissolution until breakthrough of the corresponding 2-D net. The result is that for hydraulic heads larger than 27.5 m we observe even dissolution fronts in **all** fractures. For this case hydraulic heads are constant at the junctions of the fractures. Then we have recalculated the basic net with a head of 27.5 m and found similar behavior in the evolution of wormholes . This means as pointed out by Prof. Szymczak that *many features of flow focusing systems are rather generic and independent of the particular model.*

We have explained this in the text, lines 3-2, pages 29-30:

After about 1200 years in the first five 1-D fractures this even front breaks due to the instability and wormholes develop. Whereas in all the following 1-D fractures downstream, due to the increasing flow after the 2D- wormhole has arrived there the Peclet number rises sharply by about one order of magnitude within a few ten years. Therefore these 1-D fractures exhibit an even dissolution front. In our model we have assumed that in each junction of fractures lateral head differences are smoothed, such way that at the downstream input fractures constant head conditions can be applied. P. Szymczak in the interactive comment regarding this work has argued correctly that this assumption is dubious "as the pressure will be highly non uniform there, with the maximum along the developing wormhole" at the output of the fracture. Due to the computational limitations, however, we have no choice in our approximation. A better approximation might have been to limit the width of the fractures to about one tenth of the width we use to account for the wormhole formation in the first fractures. The basic behavior of the wormhole formation under these conditions will be similar qualitatively to our findings.

*On the other hand under initial boundary conditions of higher head at the input of our 2-D model **all** fractures may show even compact dissolution fronts due to higher flow through the system. Therefore we have repeated the procedure described above for higher heads imposed onto the 2-dimensional net. For heads higher than 27.5 m we find even compact dissolution fronts in **all** fractures including the entrance one. We have also repeated the calculation for the basic case (see Fig.3) with the elevated head of 27.5 m instead of 15 m and found qualitatively similar behavior as for a head of 15 m. From this one may conclude that wormholing in the 1-D fractures does not change the general behavior of the nets because as pointed out by P. Szymczak in his interactive comment "many features of flow focusing systems are rather generic and independent of the particular model".*
We agree that our model has no quantitative predictive power (in terms of breakthrough time in years etc). We have added this to the text on page 30

Of course our approximation cannot be applied to predict breakthrough times in real systems. The target of our work is to get insight into the processes active during the formations of wormholes.

3. Minor comments.

There is a typo 3 must read 6. See Dreybrodt, 1988. We have added this citation.

Eq.7. There is a typo, 3 must read 6 close to the value as used by Szymczak See Dreybrodt, 1988. We have added this citation.
p. 17., line 4: We have changed the text to:

With increasing length, the inflow into the faster growing wormhole increases, whereas, that of the delayed one rises only slightly until it declines. This is reasonable because its outflow is inhibited by the faster growing wormhole. If, however, the distance down flow between their tips exceeds some limit, the flow through the shorter wormhole decreases.

What is plotted in Fig. 22?
There is a typo in the text A_0 must read a_0. We have corrected this.

Technical comments:
We have made the small lettering because of space limitations. As the paper is electronic, the magnification allows to see details. Therefore, we prefer to leave as it stands.