Reply to comments by reviewer 2 on "Palaeo-modeling of coastal salt water intrusion during the Holocene: an application to the Netherlands" by J. R. Delsman et al.

We thank reviewer 2 for his/her kind words and helpful suggestions. Questions raised by the reviewer are in bold face, our answers in regular face.
On behalf of all coauthors,

Joost Delsman

General comment

The manuscript " Palaeo - modeling of coastal salt water intrusion during the Holocene: an application to the Netherlands" is an interesting study which shows that the existing groundwater salinity in a coastal aquifer is not only the result of the current state of the system, but can be significantly influenced by its recent geological history. Besides showing an interesting case, supported by extensive data, manuscript is well illustrated by what it is, overall, a very attractive paper; however, it has aspects that must be corrected or treated further before publication. Therefore, I would recommend this paper for publication in HESS but only after major changes to manuscript.

We thank reviewer 2 again for his/her kind words and helpful suggestions and will do our best to improve our paper accordingly.

1. Treats many issues of the same subject (evolution of salinity during the Holocene in a coastal aquifer in Netherland) which, in some cases, are not sufficiently clear because the information provided by the authors is insufficient for reader understanding. For example, there is insufficient information in the following sections: description of the study area, parameters and boundary conditions of the mathematical model, hydrochemical conditions selected for the hydrochemical analysis...

We added the requested information to the manuscript; details are provided in our answers to the specific reviewer comments regarding these issues.

2. The structure of the manuscript is deficient: the description and the geological setting of the study area are included in the methodology chapter, the sensitivity analysis of the model should be located before model validation ... Within the sections also there are mixture of different themes. For example, section 3.2 is repetitive and treats in a mixed way the evolution of groundwater salinity and the total amount of salt present in the model, both of which should be treated separately to facilitate the reader understanding.

We re-structured the indicated parts of the manuscript, further details are provided in our answers to the specific reviewer comments regarding these issues.

3. The author is too meticulous in some sections which might be simplified to improve of the reader understanding. For example, Figures 2 and 6 should be more simplified and the Holocene palaeo - geographic development and the evolution of groundwater salinity chapters.

We shortened and simplified Figs 2 and 6, and the chapter on the evolution of groundwater salinity. Again, details are provided in our answers to the specific reviewer comments regarding these issues.

Another aspect that the author should address deeper is the eastern side boundary condition of the study area. The mathematical model has been made with a closed boundary throughout the period studied. Ie, through that limit has not been produced freshwater input in the 8500 years modeled. This is critical in the evolution of salt washing that has occurred since the 6500 BC transgression. The authors consider a limit of no flow due to the existence of a groundwater divide whose regional character is not sufficiently justified. Just as it has remained unchanged throughout the period considered. If through this limit occurs or has occurred freshwater input, the paper conclusions would not be valid.

The elevated position of the ice-pushed ridge within its low-relief surroundings (on both its western and eastern side) ensures the role of the ice-pushed ridge as a groundwater divide over the entire profile depth. Results of the nation-wide groundwater model of the Netherlands (De Lange et al., 2014) indicate a negligible flux crossing the ice-pushed ridge and support this choice of boundary condition. The important landscape features that define the large scale flow patterns all predate the model period, they have been in place since the Saalien (150 ky BP). We better motivated our choice of boundary condition in the manuscript.

Specific comments

Abstract

The abstract is too general. The sentences of generic character should be reduced and concrete results obtained in this paper should be added.

We pretty much completely revised the abstract and included more specific results.

Methods

Paragraph "Study area and Holocene palaeo-geographical development" should not be included in Methods, but should be a separate chapter of description of the study area.

We moved the description of the study area and its palaeo-geographical development to a separate chapter.

The authors considered a dividing of regional flow in the eastern side due to the recharge that occurs in the ice - pushed ridge. However, given the depth of the aquifer in this area is greater than 200 m and the existence of levels of low hydraulic conductivity about 50 m b.s.l., I do not find it difficult to believe the existence of a shallow local flow with a divide in this position and a deeper regional flow with a general EW component. Has this situation changed over time? This subject would have great impact on the salt washing that has occurred over time.

See response under General comment 3.

This section (description of the study area) should include any information about Maassluis formation due its significance in the evolution of the groundwater salinity of the aquifer.

We included more specific information on the Maassluis formation: “The Maassluis formation comprises the oldest Pleistocene deposits and includes sandy and clayey sediments of marine origin, limited dated samples indicate remaining connate marine groundwater (Post et al., 2003).”

Further explanation would be necessary about the infiltration scheme used since 1957 in the study area.

We added a line to the manuscript explaining the infiltration scheme used since 1957.

Palaeo - hydrogeological modelling

Please, consider adding a figure to represent the conceptual model used in mathematical modeling with the different boundary conditions considered.

We added a conceptual figure containing the boundary conditions and, whenever possible, parameter values used.

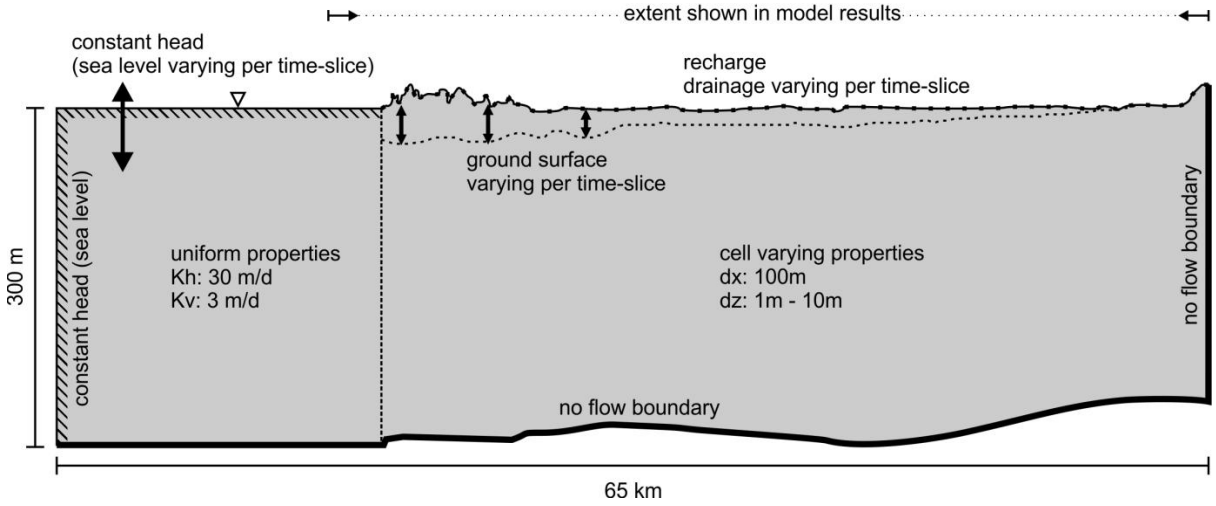

Figure 3. Conceptual model representation.

As I said earlier, the eastern side boundary condition should be addressed in more depth by the authors.

See response under General comment 3.

What section has been modeled, the transect AB or the A' - B?

We modeled the entire transect AB, we clarified this in the manuscript.

From sentence found on lines 18 and 19 of page 13713, is understood that the Maassluis formation occupies the entire edge.

For the landward part of the transect (A’-B), the Maassluis formation indeed spans the entire bottom edge. On the seaward side of the transect, however, geohydrological information is scarce. We therefore modeled the seaward side as one homogeneous aquifer. We clarified this in the manuscript.

K and S values used in modeling should be provided.

We used cell-specific K values in our modeling, based on the national geohydrological databases of the Netherlands (REGIS and GEOTOP), we clarified this in the manuscript. It was therefore impossible to provide the used K values in the manuscript. Given the long time scales considered, we modeled flow as steady state and therefore did not use storativities.

Why authors speak of time slices and not of stress periods?

The term time slice denotes a period with a distinct (palaeo-) geographical signature. Stresses (and therefore stress periods) can vary within a time slice. The rapidly rising sea level in the first two time slices necessitated the use of several stress periods in modeling. We added a line to the manuscript noting that time slices 1 and 2 contain several stress periods, all others contain just one.

Hydrochemical facies analysis

Authors should describe in more detail the characteristics of different hydrochemical zones considered in the study. In this sense, it would be interesting to complete the table I with more hydrochemical information.

We extended the section on the Hydrochemical Facies Analysis with more detail regarding the geochemical parameters used.

What is the difference between recharge and surface water in Table I?

The origin tracer Recharge enters the model as recharge (RCH package), Surface water as infiltrating surface water (losing streams, RIV package) (see Table 1).

Model validation

It is desirable that the authors indicate the number of points used for model validation and also add their location in Figure 1.

We added the number of validation points and their locations to Fig 1.

RMSE values (head and concentration) should be given in% for knowing the degree of mathematical model validity without having to check the range of variation of these parameters in the study area.

We reported normalized RMSE values in the manuscript.

Evolution of groundwater salinity

This section is very confusing and, in some cases, repetitive. Authors should simplify and structure more. Speaking, first, about the evolution of the salinity based on Figure 6, that should contain less phases and should coincide with the different phases seen in Figure 2 (it should also be simplified), then of the Total SP based on Figure 7 and, finally, of the evolution of water types considered. Authors should not intermix the different topics.

We reduced the number of phases shown in Figs 2, 6 and 8, moved the description of all time slices to a new table, and re-structured the Results section to separate the different topics and improve overall clarity.

From reading the text is deducted the river Vecht is a gaining stream and this should be made clearer.

The reviewer is correct; we clarified this in the manuscript.

Sensitivity runs

This section should come before the section on model validation.

We moved the section on the sensitivity runs to precede model validation.

Figure 1

Please, in the legend include the age of the materials.

To include more information on the age of the deposits, we added the Holocene / Pleistocene delineation in Fig 1 and added 'Tertiary' to indicate the age of the aquiclude.

The different frames of the legend are not easily distinguished. It would be better to use different colors.

We followed the reviewer's suggestion and colored Fig 1.

What kind of rock is "heterogenous"?

'Heterogeneous' in Fig 1 denotes not further lithologically differentiated formation members of the geological classification used by the Geological Survey of the Netherlands, due to a lack of borehole information. Hydraulic parameters are however assigned to these formations by the Netherlands Geological Survey (Van der Meulen et al., 2013; Vernes and Van Doorn, 2005; Weerts et al., 2005). We changed the label from 'heterogeneous' to 'undifferentiated' in Fig 1b to avoid confusion.

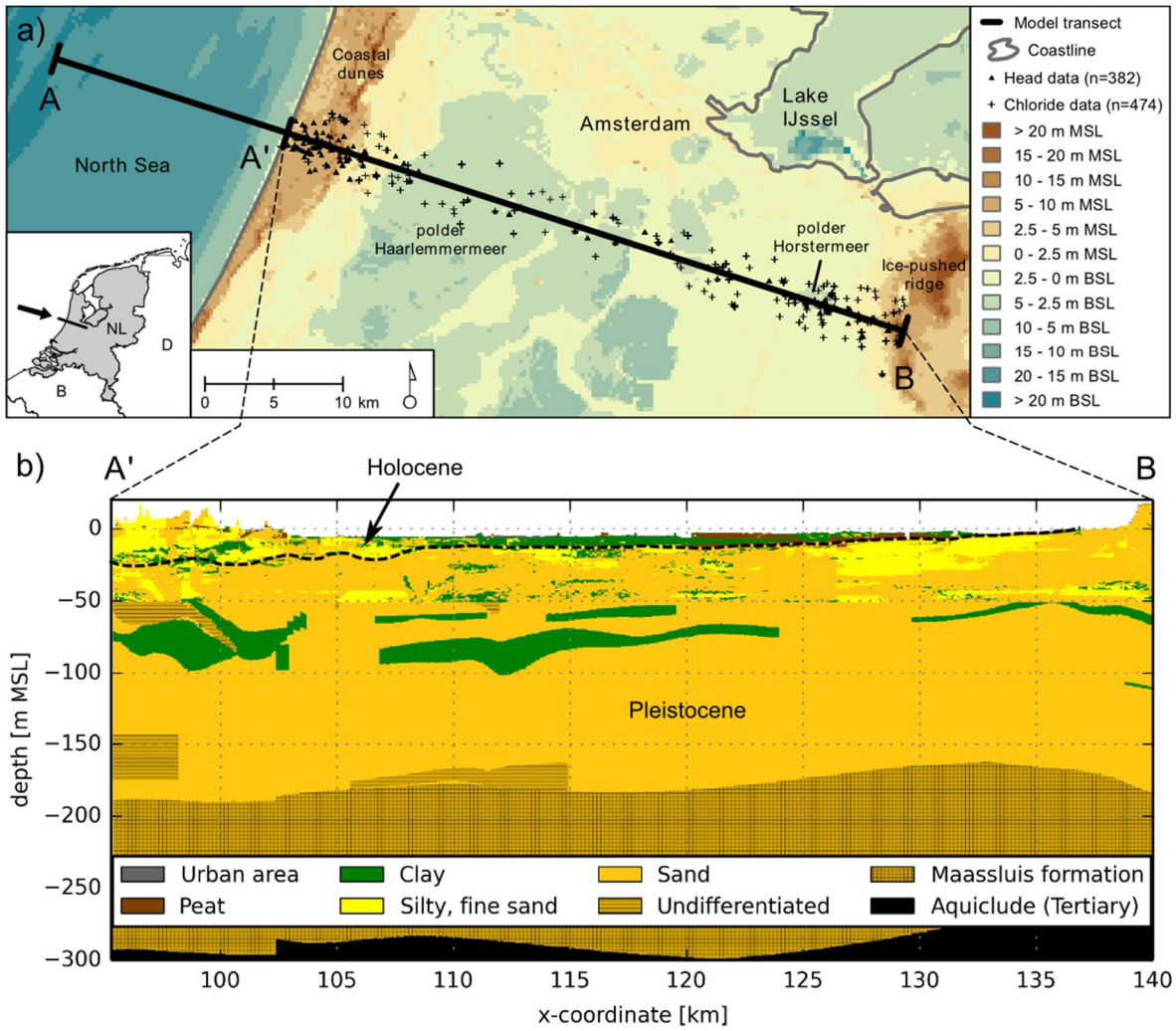

Figure 1. Location of studied transect (A – B), elevation and main topographical features (a), and lithological cross-section along the transect (A' – B) (b), dashed line in (b) demarcates Pleistocene and Holocene deposits.

Figure 2

I recommend simplifying the text shown in the different stages, leaving an explanatory chart by stage considered.

We revised Fig 2 to include one less period, moved the time slice description to a separate (new) table, and included information on sea level rise.

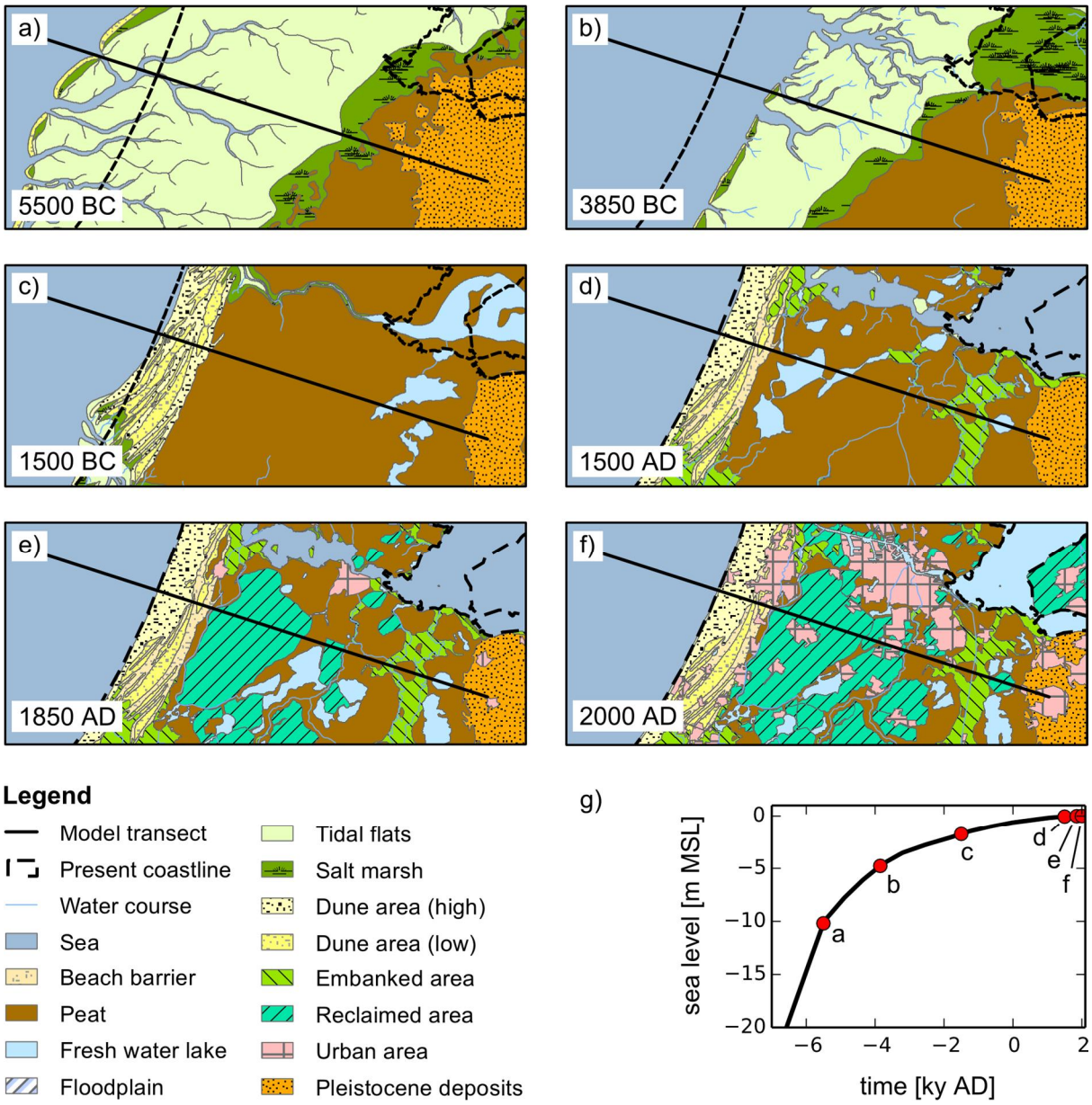

Figure 2. Overview of Holocene palaeo-geographical development (a-f) and sea level rise (g, adapted from Plassche (1982)). Red dots and letters in g) refer to corresponding palaeo-geographical maps a-f. For reference, note that the extent of the palaeo-geographical maps equals the extent of Figure 1a.

Figure 6

Please, add the x axis in the right column. It would be interesting that graphs coincide with moments shown in Figure 2. Please, locate in the graphs the position of the coastline in each of the moments. Please, locate in the graphs areas with pumping, river and lakes

We simplified Fig 6 (and 8) to include only those moments coinciding with the palaeo-geographical maps in Fig 2 and added explanatory information.

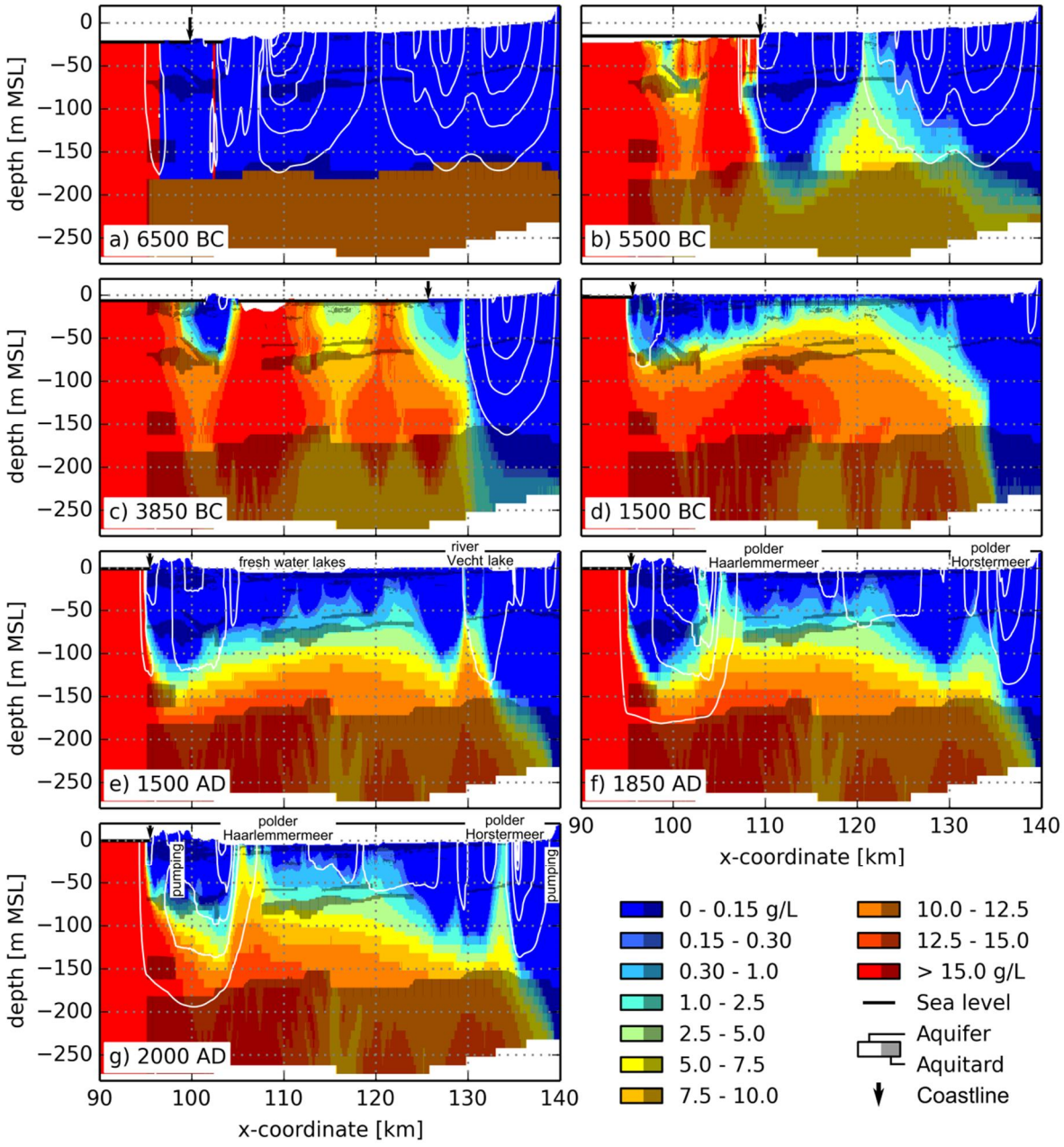

Figure 7. Modeled evolution of groundwater chloride concentration (a – g). White lines are contours of the stream function, contour intervals are equal for all time slices. Except for a) (starting concentration), transect times correspond to palaeo-geographical maps in Figure 2.

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