Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-373-AC1, 2016

Hydrology and Earth System Sciences
Discussions
Open Access
HESSD
Interactive comment

Interactive comment on "Modelling 3D permeability distribution in alluvial fans using facies architecture and geophysical acquisitions" *by* Lin Zhu et al.

Lin Zhu et al.

hi-zhulin@163.com

Received and published: 8 October 2016

Comment 1: The authors call this an "alluvial fan", which in the current sedimentology/geomorphology literature this may not be strictly considered an alluvial fan. Since it is longer than 30 km, this would be called a 'fluvial megafan' (e.g., Leier et al., 2005, Geology, v. 33, p. 289-292) or a "large distributive fluvial system (DFS)" (Hartley et al. 2010, Journal of Sedimentary Research, v. 80, p.167-183).

Response: We agree with this comment. The huge alluvial fan we dealt with is really a "large distributive fluvial system" or "megafan". In our revised text, we changed the term "alluvial fan" to "alluvia megafan" when describing our site model; when discussing about general alluvial fans, we still used the general term. We also cited these two papers the reviewer provided as: 1. Leier, A.L., P. G. DeCelles, J. D. Pelletier, Mountains, monsoons, and megafans, Geology, v. 33, p. 289-292, 2005. 2. Hartley, A.J., Weissmann, G.S., Nichols, G.J., and Warwick, G.L., Distributive fluvial systems: characteristics, distribution, and controls on development: Journal of Sedimentary Research, v. 79, p. 167-183, 2010.

Comment 2: In using the borehole geophysical tools (resistivity), the authors report resistivity values measured across the units. Were these logs calibrated? Are these values accurate given the calibration? If they were not calibrated, the relative values between muds and sands would be important but the actual values are not significant. If the logs were calibrated, some discussion of calibration procedures is important. Also, these values are strongly influenced by the fluid conductivity. Some discussion of fluid resistivity should be included. The depth of water table is also important to note unless all data come from below the water table (resistivity properties in the vadose zone are different). Line 161, where resistivity values are used in Archie's Law, makes it important that the logs were calibrated. If the logs are not calibrated, Archie's Law is not appropriate to use. Clarify this point.

Response: In this study, we assumed that clay fraction is negligible in the faces of gravel (G), medium-coarse sand (MS), and fine sand (FS) (new Line179-180). To calibrate the resistivity loggings data, we used the resistivity located in the middle of the facies block, where the resistivity is approximately the real resistivity. For VES data, we compared the inversed resistivity with the observed stratigraphic information (see Fig. 3 and new Fig. 4). Calibration is obtained by comparing the VES outcome with direct investigation, e,g. well stratigraphies and the inversed resistivity can reflect the difference of facies: the thick gravel layer has larger resistivity while the fine sand and clay layers have relatively smaller resistivity. The fluid conductivity was estimated by using total dissolved solids (TDS) and temperature data. Because of the relatively limited dataset and the observed small variability, in this paper the TDS variations in the vertical direction were neglected (Line147-148). That is, there is one TDS value at one logging position (vertically). We focused on the resistivity data below water table. The inverted resistivity from the VES data and the logging resistivity data were used in Archies' Law.

Comment 3: The use of zones for modeling the system is appropriate and interesting. However, progradation of fans often leads to these zones shifting position upward, where the coarser facies shown in Zone 1 overlie finer facies that you describe in Zone 2 (see Weissmann et al 2013, SEPM Special Publication 104, p. 131-147, for a discussion on this). Do you see this pattern in the logs? The abrupt boundary seen between zones 1 and 2 in Figure 7 probably does not exist. This sharp transition could have been softened by using the results from the zone 1 simulation as conditioning for the zone 2 simulation. Likewise, the zone 2 simulation results could have been used as conditioning for the zone 3 simulation.

Response: Yes, from the representative borehole data (5 logs in Zone 1) we see that the coarser facies in Zone 1 overlie finer facies (which has a small volumetric proportion and thickness). To smooth the abrupt boundary between Zone 1 and Zone 2, we used conditional facies data from boreholes (5 logs in Zone 1 and 15 logs in Zone 2) near the boundary to make the facies change gradually. But, since the volumetric proportions for sub-clay, clay and gravel change a lot from Zone 1 to Zone 2, we can still see that boundary. Next step we will follow this reviewer's suggestions to improve the simulated facies distributions near the zone boundaries by using some simulation results of Zone 1 at the boundary as conditional data for the simulation of Zone 2. Two references about indicator simulations in highly heterogeneous formations are cited in this section as: 1. Weissmann, G.S., Hartley, A.J., Scuderi, L.A., Nichols, G.J., Davidson, S.K., Owen, A., Atchley, S.C., Bhattacharyya, P., Chakraborty, T., Ghosh, P., Nordt, L.C., Michel, L., and Tabor, N.J. Prograding distributive fluvial systems–geomorphic models and ancient examples, in Driese, SG, and Nordt, LC (eds), New Frontiers in Paleopedology and Terrestrial Paleoclimatology, SEPM Special Publication No. 104, p. 131-147, 2013. 2. Maghrebi, M., Jankovic, I., Weissmann, G.S., Matott, L.S., Allen-

King, R.M., and Rabideau, A.J., Contaminant tailing in highly heterogeneous porous formations: Sensitivity on model selection and material properties. J. of Hydrol., 531, 149-160, 2015.

Comment 4: It isn't entirely clear how the lithofacies were placed into the variograms or modeled. Were lithofacies distributions modeled first, then variability added using variograms? Or, were K values assigned to the various lithofacies observed in well logs and lithologic logs, and then the variograms created from these K values? This must be clarified so others can apply your techniques. Looking at Figure 7, it appears as if you modeled lithofacies distributions first. . ..how did you do this?

Response: Yes, the lithofacies distribution was modeled first. Then, the distributions of log10(K) for three facies including G, MS, and FS were simulated, respectively, using SGSIM with the parameter determined from individual semivariograms. The 3D cells of the distributions of log10(K) is the same as that of the lithofacies indicator model. And then, since each cell is characterized by specific facies indicator and zone indices, its conductivity was assigned or mapped based on the corresponding facies, zone numbers and the 3D SGSIM simulated conductivity values. Finally, since sub-clay and clay are generally characterized by a low hydraulic conductivity value, a uniform conductivity value equal to 0.0001 m/d was set to all the C cells (new Line 244-247). The procedure flowchart is already provided in Figure 2.

Comment 5: Additionally, your horizontal variograms don't show very much character. The fit is somewhat arbitrary. This is very common since the spacing between wells is often greater than the average widths/lengths of lithofacies, especially since strictly horizontal measures from logs may not indicate the actual paleo horizontal. It's fine to show these models, but how sensitive were the results to these variograms (probably not very sensitive, but maybe).

Response: Yes, the horizontal variograms are fitted with some degree of arbitrary due to the sparse horizontal samplings or larger well distances. By using the variances estimated from the inversions of vertical variograms as prior information, the estimated variances and ranges of log10(K) in horizontal direction are reasonably constrained. We added a few sentences to discuss the uncertainty of the estimated horizontal ranges.

Comment 6: Figure 7 indicates that the facies were modeled with dip direction in one orientation, thus facies near the apex area will not include a radiating pattern that emanates from the fan apex. This should be noted somewhere. Also, the authors could note that a priori orientation information from surface mapping of the fans could be used to create a model with channel orientations aimed at the apex (See work by Carle et al., where they are able to put varying orientations into the resulting models). Response: In the description of Figure 7 (new Figure 8), we added a sentence to indicate that "since we simulate the dip direction along one orientation (along the main water flow direction), the simulated facies in the fan apex do not show a radiating pattern. More information about simulating the radiating pattern can be found from Carle and Fogg (1997) and Fogg et al. (1998)".

Fogg, G.E., C. D. Noyes, S. F. Carle, Geologically based model of heterogeneous hydraulic conductivity in an alluvial setting, Hydrogeol. J. , 6(1), 131-143, 1998.

Comment 7: It is unclear how the vertical electric soundings were used, or what these data look like or what they show. This should be clarified.

Response: We added Figure 4 to show the inverted resistivity from VES compared with the lithologic data.

Specific Comments:

1. Line 12: "heterogeneous" Heterogeneous in what? Hydraulic conductivity? Hydraulic properties?

Response: Changed. Here means heterogeneous in hydraulic properties.

2. Line 12, change "...which make difficult ..." to "which make it difficult..."

Response: Suggestion followed.

3. Line 23: Change "bad" to "poor"

Response: Changed.

4. Line 35: Change "Conductivity distributions..." to "Hydraulic conductivity distributions..."

Response: Done.

5. Line 36: Papers by Weissmann and Fogg (1999) and Weissmann et al (2002, 2004) also use conditional indicator geostatistical methods to model alluvial aquifers.

Response: The suggested references have been added in the Introduction section.

6. Line 90: Change "...exploration..." to "...exploitation..."

Response: Changed.

7. Line 100: remove the word "through"

Response: Changed.

8. Line 135: Change "...700 borehole lithostratigraphies were..." to "...700 borehole lithologic logs were..." My understanding is that these are the lithologic logs written by the drillers or well site geologists at time of drilling and are based on cuttings. Is that correct?

Response: Yes, you are right. The sentence was revised.

9. Line 141: "surrounding" Do you mean "in the area surrounding the sites of geophysical acquisitions."?

Response: Yes, the sentence was revised.

10. Line 156: What is the "representative" grain diameter"? D50? D10? How was this measured or estimated?

Response: The d(x,y,z) is the median grain diameter (D50) of the facies, which is determined on basis of the measurements of the lithologic samples. The sentence was changed.

11. Line 192: "...vertical and dip directions..." What was used in the strike direction (perpendicular to dip)? Expected length scales would be expected to be less than what is used in the dip direction.

Response: The semivariogram in strike direction is not calculated in this study. When simulating the distributions of log10(K), there is an assumption that the conductivity in dip/strike direction is the same with that in horizontal direction.

12. Line 248: Change "...bad..." to "...poor..." Grains are poorly sorted, not 'badly' sorted.

Response: Changed.

13. Line 254: Change "...have a good sorting." to "...are well sorted."

Response: Changed.

14. Line 260: Change "...alike..." to "...similar..."

Response: Changed.

15. Lines 265-268: This discussion of zone 2 does not make sense. All of the zones have multiple flooding events depositing the sediments. This medial zone does allow for greater preservation potential of finer sediments than the more proximal zone, where channel switching from the apex in the proximal zone tends to fill accommodation quickly and amalgamated channel belts are most likely preserved (see Weissmann et al. 2013, SEPM Special Publication 104, p. 131âĂŘ147 for more details on structure of megafans and development of this structure through time). A different explanation for the distributions of sediments and processes to develop these distributions is needed.

Response: We revised the discussions in former Lines 265-268 by taking account the complex structures of the megafan. We indicate that “Zone 2 extends from the fan apex area with much larger area which allows for greater preservation potential of finer sediments (such as medium-coarse sand (MS), fine sand (FS), and clay or sub clay (C)) than the more proximal Zone 1. Therefore, in Zone 2 the volumetric proportions for these three facies increase while that of gravel decreases. The estimated ranges of G and MS are increased, respectivelyïijĹrange of FS decreased. In Zone 3, the range difference among the three facies decreases gradually. The estimated range of FS is about 6.0 m, which is twice as much as that of MF. The spatial variation of the structure parameters of three facies causes the large changes of the correlation ranges from Zone 1 to Zone 3.

16. Line 293: Change “. . .our average K values is gently. . .” to “. . .our average K values are gently. . .”

Response: Changed.

17. Line 293: Change” . . .than these latter is likely. . .” to “. . .than these latter values are likely. . .”

Response: Changed.

18. Line 309: “lithostratigraphies” Do you mean “lithologic logs”?

Response: Changed.

19. Line 311: “. . .are builtâĂŘup. . .” Do you mean “. . .were constructed. . .”?

Response: Changed.

20. Line 320: Change “..a bad sediment sorting” to “ . . .a poor sediment sorting”

Response: Changed.

21. Line 321: Change “. . .relatively good sorted” to “. . .relatively well sorted.”

Response: Done.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-373/hess-2016-373-AC1-supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-373, 2016.

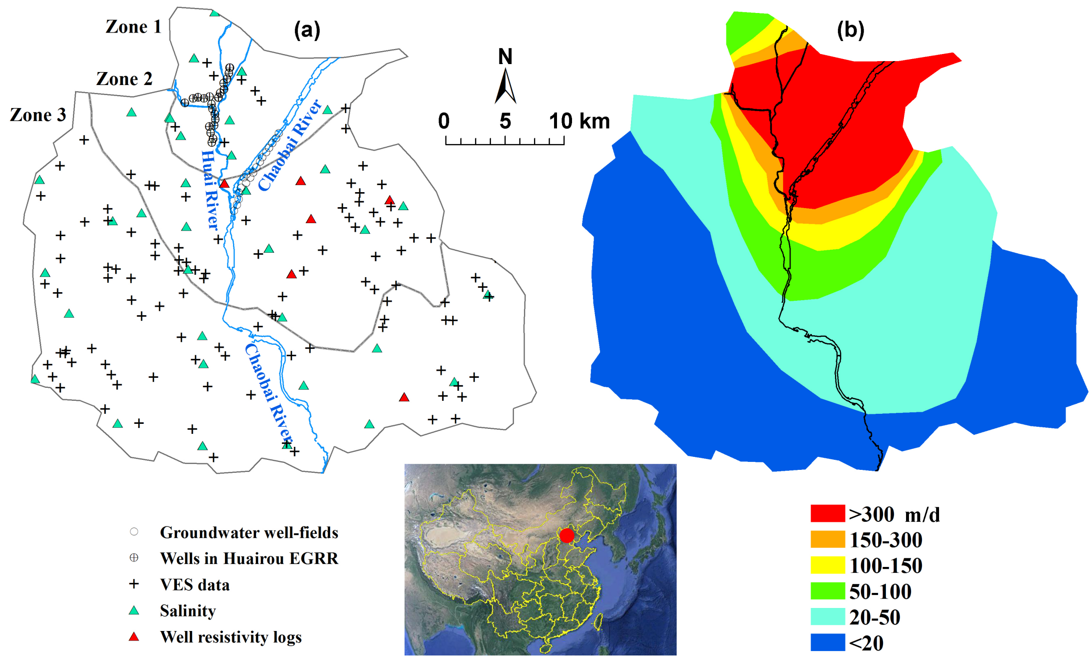
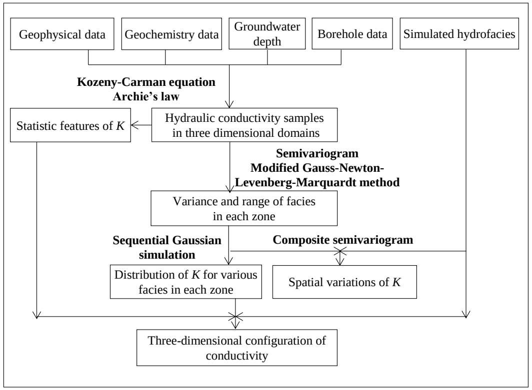


Fig. 1. Chaobai alluvial fan in the north of Beijing Plain.

Printer-friendly version

Discussion paper

Figure 2



1

Fig. 2. Flowchart of the geostatistical methodology

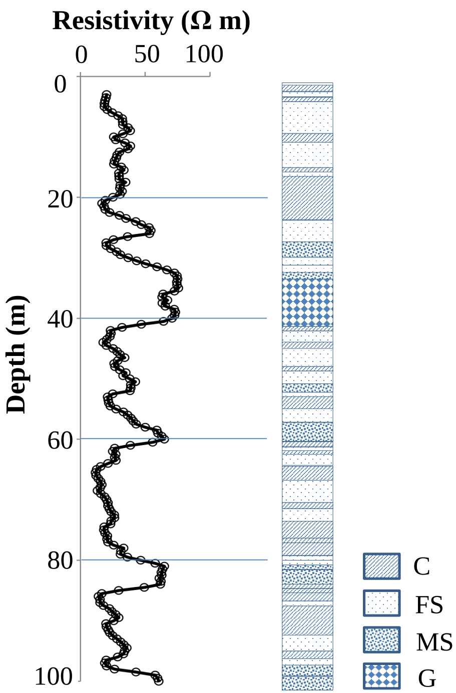


Fig. 3. Typical depth behaviors of resistivity and corresponding stratigraphy in the eastern part of Zone 2

Printer-friendly version

Discussion paper

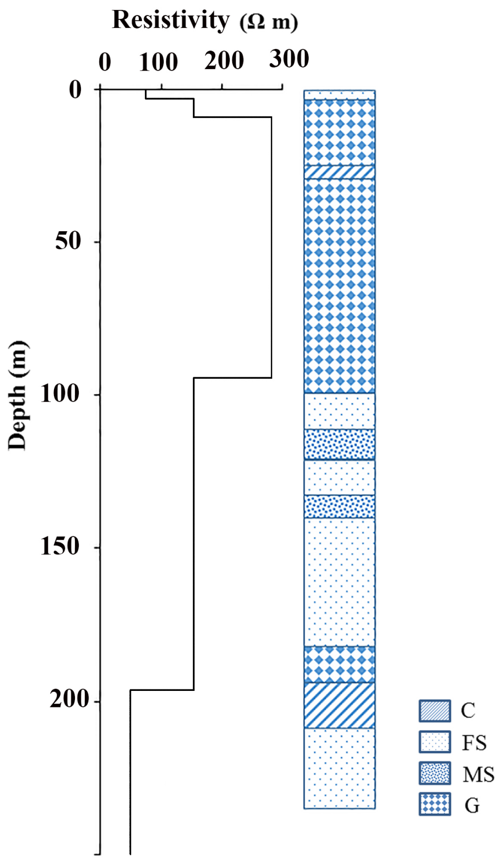


Fig. 4. Inversed resistivity and corresponding stratigraphy in Zone 1

Printer-friendly version

Discussion paper

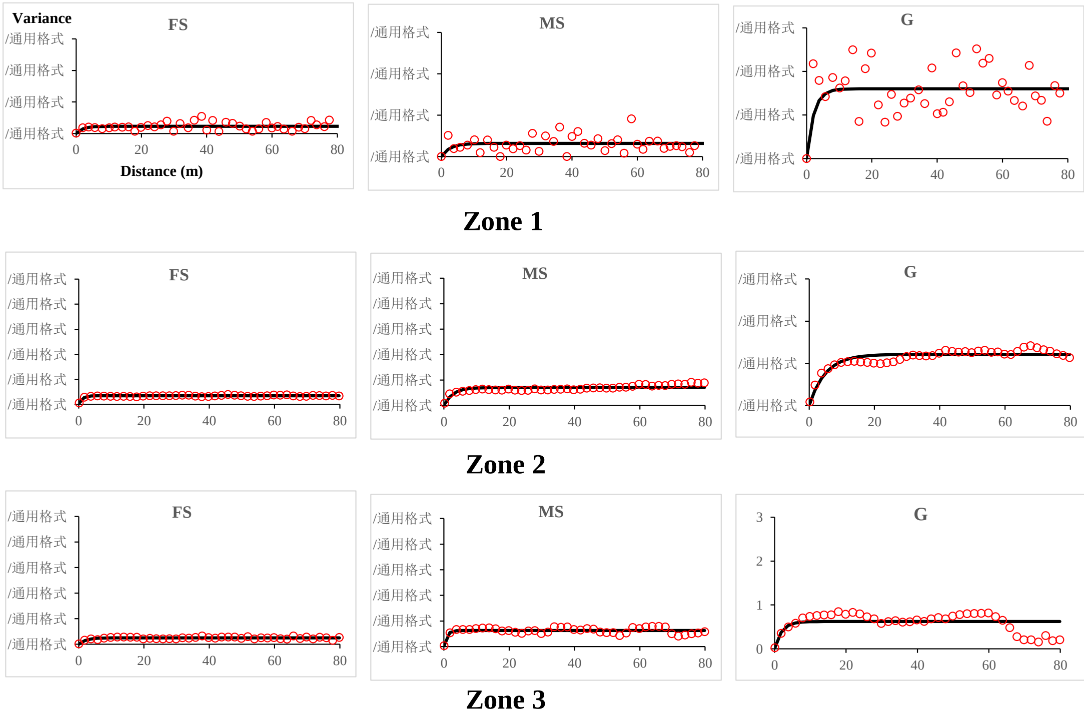


Fig. 5. Experimental (circle symbol) and model (solid line) semivariogram along the vertical direction for the various hydrofacies in the three zones. Notice that the range in the y-axis differs for sands and

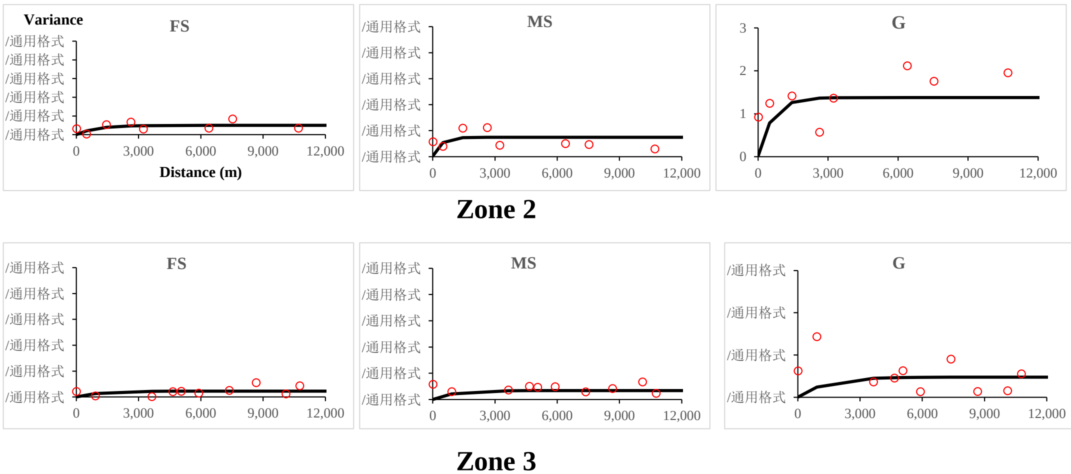
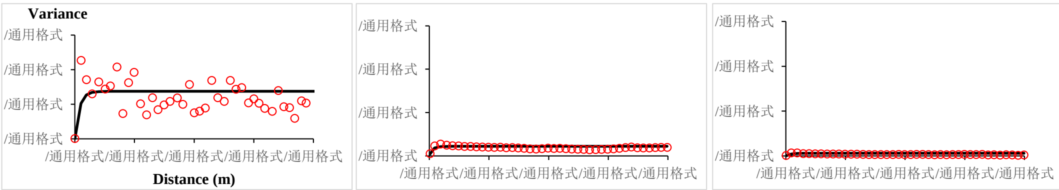


Fig. 6. Experimental (circle symbol) and model (solid line) semivariogram along the dip direction for the various hydrofacies in Zone 2 and Zone 3.

Printer-friendly version

Discussion paper



Zone 1 **Zone 2** **Zone 3**

Fig. 7. Experimental (circle symbol) and model (solid line) composited semivariogram along the vertical direction for the three zones.

Printer-friendly version

Discussion paper

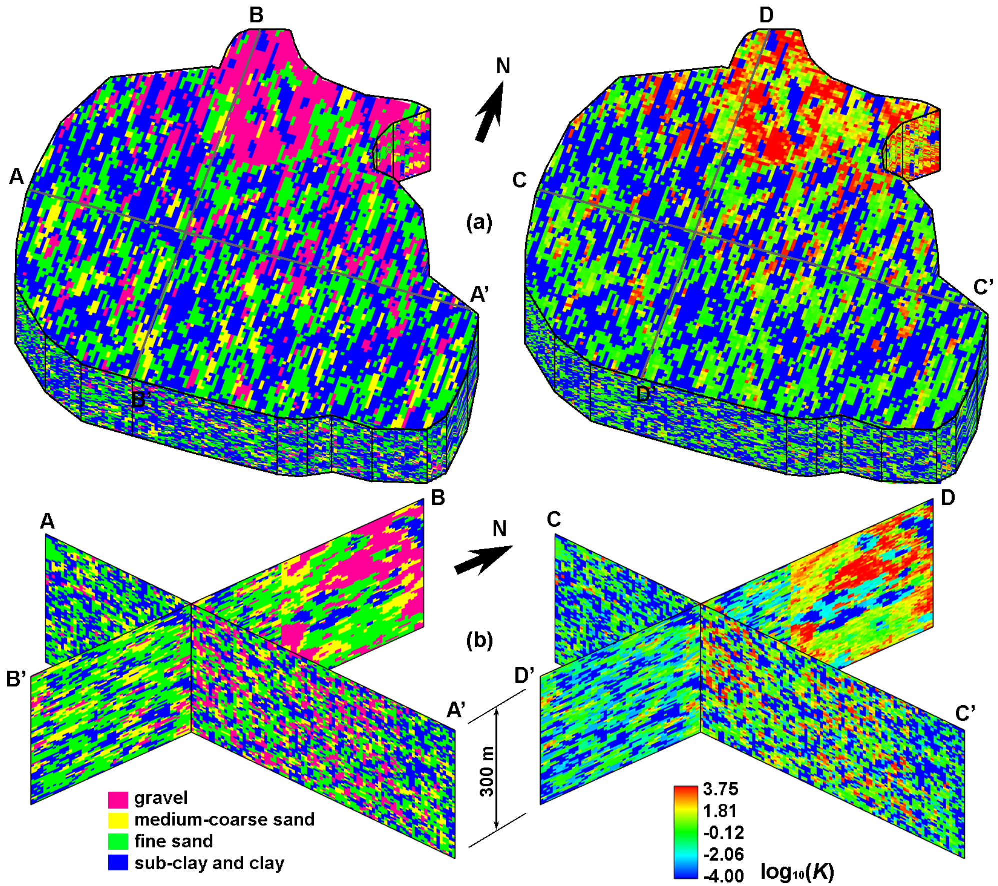


Fig. 8. Distribution of hydrofacies (after Zhu et al., 2015a) and log10(K) in the three-dimensional domain representing the Chaobai alluvial fan: (a) axonometric projection of the three-dimensional system and