Designing the DEM of the Base of the Swiss Plateau Quaternary Sediments

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Abstract

The bed rock surface, i.e. the base of the Quaternary loose rock is of great practical and scientific interest. Unfortunately, its position is known from punctual and often disperse borehole and pit data only. Since some thirty years, several local and regional attempts have been made to outline the trend of the bedrock by isoline sketches. Starting in 2005, an important attempt was made to collect all available information on the bedrock surface and to integrate them in a Digital Elevation Model (DEM) of the Base of Quaternary of the Swiss Plateau and of northern Switzerland. Beside older studies and isoline maps, data of approximately 13,000 boreholes and all available geological maps have been consulted. These data were compiled in isolines and stream lines designed in a GIS framework by experts. The actual bedrock surface is rather complex as it was carved by a great number of different fluvial and glacial erosion events separated by times of loose rock accumulation and partly filling of the antecedent created depressions. Consequently the interpolation of rock surface data asks for a great knowledge of erosion processes, landscape development and ice age history in connection with spatial sense and decisiveness.

The 25 m x 25 m resolution DEM, calculated on the base of the isolines and stream lines, covers loose rock areas as well as areas with no or only few Quaternary sediments. It is consistent in spatial reference and grid size to the land surface model of Switzerland (DHM25). Thus, it can be used for 2D (map) and 3D visualisations, and raster calculations including comparisons between bedrock and actual land surface.

1. Introduction

Precise knowledge about the position of the rock surface and the thickness of its loose rock cover are of primordial interest in many geomorphologic, Quaternary and geotechnical studies. Specifically, geophysical and geothermal prospections as well as planning of underground constructions can profit from detailed information about loose rock cover thickness. This need for a continuous model of the basis of Quaternary cover was the starting point for the creation of a Digital Elevation Model (DEM) including all possible information about Quaternary sediment thickness. The aim of this work is to propose a consistent model of the bedrock surface and its loose rock cover of the Swiss Plateau and the adjacent regions including the Alpine Foreland.

The bedrock surface is identical to the land surface at places with no or only a thin loose rock cover („outcrop area"). In the domain of thick loose rock cover, the position of the bedrock surface is known from pit, trench, tunnel, and borehole data only. The scatter of these data is very erratic with clusters in urban areas and along road or tunnel projects, and nearly no information in rural areas.

It is important to note, that the actual bedrock surface does not represent a surface that was, in its whole, the land surface at specific date. It was rather carved, within the last about one million years, by a great number of different fluvial and glacial erosion events each of them reaching and eroding the rock surface at different places. These erosion events have been separated by times of loose rock accumulation and (partly) filling of the antecedent created depressions.

2. Material

In a first step, earlier work on rock surface position was compiled (Fig. 1). As a basic principle, these interpretations were taken for authentic, if there was no conflict with more recent data or other interpretations. All available 1:25,000 scale sheets of the Geological Atlas of Switzerland, and regional geological maps in the scale 1:50,000 (Hantke 1967, Schläfli 1999) or 1:100,000 (Müller et al. 1984) were used to delineate the contact outcrop between loose rock and bedrock. Valuable information concerning the bedrock surface can also be found in regional hydrogeological studies (e.g., AfU Thurgau, 2003; AfU Zug, 2007; DÖB Zürich, 1986; all available sheets of the 1:100,000 scale hydrogeological Atlas of Switzerland).

The most important source of raw data was the borehole database of the Swiss National Cooperative for the Disposal of Radioactive Waste / NAGRA, the most comprehensive database of the region. In addition several local to regional published and unpublished databases were consulted (Jordan 2004, Jordan & Schuler 2007, Jordan et al. 2008). Some of them also comprise pit and tunnel information. Boreholes and pit bottoms not reaching the bedrock surface were used as minimum value for the construction of the

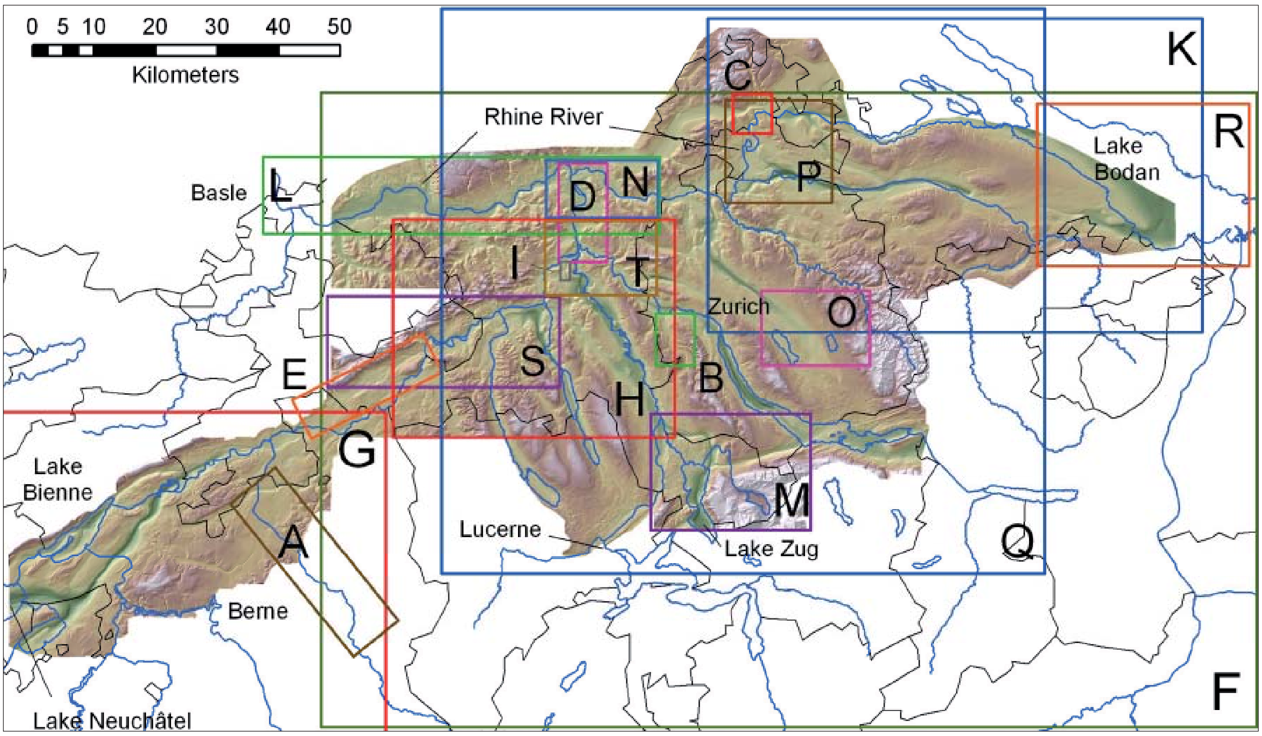

Fig. 1: Actual extent of the DEM and pre-existent isoline maps used for its compilation: A: Werner + Partner AG & Petraqua (1975 and 1976), Werner + Partner AG & Wanner (1981); B: Wyssling (1983); C: Schindler (1982); D: Haldimann et al. (1984); E: Pasquier (1986); F: Wildi (1984); G: Pugin (1986); H: Geol. Inst. Uni Bern (1996); I: Wyssling AG (1996); K: Keller & Krayss (1999); L: Wagner et al. (2001); M: AfU Zug (2007); N: Matousek et. al. (2000); O: Wyssling (2007); P: Frank (2005); Q: Naef (2004); R: Zaugg & Vogel (2005); Jordan (2004).

DEM. In total, 12,600 point informations were taken in count. The manipulation of this quantity of data pointed out some limitations and some care to take before using the information: The consistency of the database has to be checked in a very early stage in order to recognize and correct input mistakes. Typing mistakes are very common and sometimes difficult to identify in this early stage. Therefore, while digitizing isolines, every data had to be critically considered.

Comprehensive information on hydrological and geomorphological landscape evolution was predominantly available for the Northwest of Switzerland (Hofmann 1977, Keller 1994, Müller et al. 2002, Graf 2003, Hantke et al. 2003). Villinger (1998) gives a general image of the knowledge of the bedrock surface position at an over-regional scale.

3. Method

The workflow to reach the bedrock surface DEM comprises four steps:

1. Compilation of data (see Section 2)
2. Interactive design of isolines and valley axes on screen
3. Interpolation of DEM
4. Quality control, going back to step 2 if quality objectives were not achieved.

3.1. Interactive design of isolines and valley axes

The hand design of isolines and valley axes was done by expert on screen using all GIS-facilities but no interpolation code (Fig. 2). All available information has been digitized (if not already done) or scanned and georeferenced. Due to the complexity of the bedrock surface (as a result of its intricate genesis) and the diversity of data type and their respective precision and reliability, it is impossible to expect a statistic surface interpolation algorithm to provide a realistic image of the bedrock surface. The design of rock surface data rather asks for a great knowledge of erosion processes, landscape development and ice age history in connection with spatial sense and decisiveness. In some way, designing bedrock surface has some affinities to forensic plastic surgery, but in a reversed way, i.e., from skin (actual land surface) to skull (bedrock surface). The borehole and outcrop information corresponds to the pin points. And how to interpolate muscles or bedrock, respectively, between these pin points is expert knowledge.

The isolines with an equidistance of 10 or 12.5 m are the backbone of the model. In some regions of higher density of information, and especially in areas with an extremely flat or agitated bedrock surface, equidistance was reduced to 5 m, 2 m or even 1 m (Fig. 2 and 3). The isolines are designed on the following information and priorities:

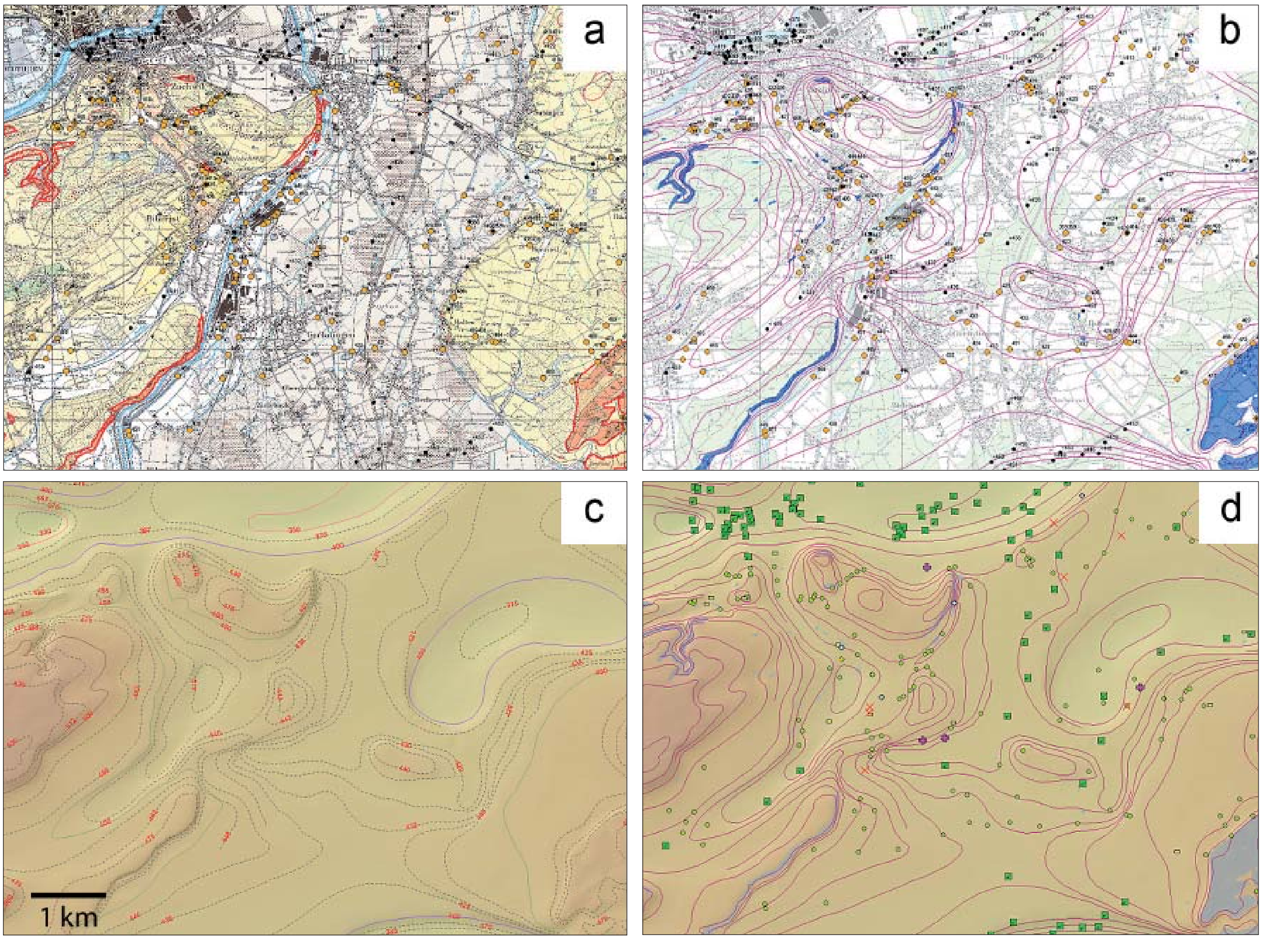

Fig. 2: The four main steps of DEM building: a) compilation of raw data (yellow dots: boreholes; red: outcrop area); b) design of isolines (blue: outcrop area); c) calculation of DEM; d) quality control (green dots and squares: concordance between DEM and borehole data; plus and minus signs: DEM higher or lower than borehole data; crosses bottom of borehole that has not reached bedrock is deeper than DEM; grey: outcrop area calculated by intersection of DEM and DHM25).

1. boreholes and underground construction reports
2. outcrop information about bedrock surface
3. the spatial distribution of outcrops referred to the geological maps
4. the bottom of boreholes that did not reach the bedrock surface
5. regional interpretation of the bedrock surface found in older references
6. bedrock surface in interpreted cross sections
7. migrated seismic profiles or their interpretation when available
8. regional works about landscape evolution (e.g. paleo river networks)
9. general hydrological and glaciological concepts.

Another important element for the modeling of the bedrock surface are the valley axes (Fig. 3). They describe the interpreted paleo flow paths of rivers. They were defined for first and second order rivers as well as important side valleys and gorges. For large glacial valleys, the flow paths were defined in the simplest way. In more complex situations, were valley axes cross, a hierarchy was defined in order to reach a higher detail level.

3.2. Raster interpolation

The range of methods for interpolation of punctual data comprises Nearest Neighbour, bilinear interpolation Inverse Distance Weighting (IDW), Kriging, etc. These methods provide contrasting results in modelling topography. Schmidt and Bill (2000) describe the application of different methods to the specificity of DEMs; it appears that very few methods are able to interpolate between the lines without degenerating them in a succession of points. Spline interpolation (Mitasova et al. 1993) is a powerful method when using isolines. For the particular purpose of a dataset including also valley axes there was a need to include the different types of data without losing their specific geometry. The ANUDEM algorithm (Hutchinson 1988, 2000) was chosen for its ability in doing so (Fig. 2 and 3). This method is particularly indicated as it was specifically developed for hydrologically correct DEMs. These algorithms are integrated in the „topo-to-raster" function of ArcGIS Spatial Analyst (ESRI, 2007). Borehole data were not directly integrated in the calculation but were used for quality control after each interpolation (Fig. 4). Additional isolines were added after each intermediary interpolation step in order to eliminate artificial smoothing of the surface due to high isoline spacing.

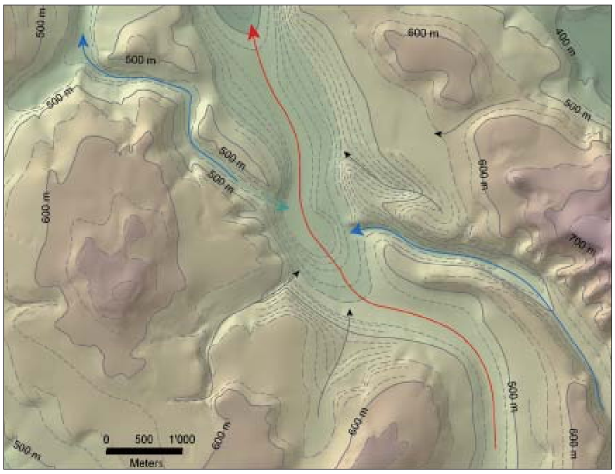

Fig. 3: Valley axes in an area of crossing valleys near Zurich: the older glacial valley (red) was filled by gravel before it was crossed by a younger fluvial valley (blue). At the beginning of the lower section of the fluvial valley with a valley axis higher than the axis of the glacial valley, a reverse axis (turquoise) has to be introduced, to get a good result. Black: secondary valley axes.

3.3. Quality control

The quality control was a continuous process of the production of the DEM and was applied all along the workflow. High quality objectives were set before the data compilation phase started. Primarily the best coherence between the borehole database and the outcrop information from geological maps had to be reached. With the later integration of various data which sometimes deviated far from the primary data set, a revision and refining of the tolerance was applied (Fig. 2 and 4):

- for boreholes that reached the bedrock: maximum deviation 5 m, in some complex areas a tolerance of 10 m was allowed.
- for borehole not reaching the bedrock: the modelled surface should be deeper the bottom of the bore-hole (tolerance: 1m).
- outcrop areas have to be within the 5 m tolerance limit: For example: in areas where the model shows no Quaternary cover, the Quaternary thickness should not exceed 5 m.
- borehole data falling far from the accepted model were excluded and returned to the owner for verification.

4. Result and conclusions

The result product is a raster elevation model with a grid size of 25 meters. The present state of the DEM stretches from Lake Neuchâtel in the West to Lake Constance in the East and from the Rhine River in the North to the Lake Zug in the South (Fig. 1). It is expected that the spatial extent will be expanded thank to further fruitful collaborations. Within its actual limits, the dataset is subject to continuous improvement and densification depending on the new raw data findings especially from boreholes.

In a first conclusion, the attempt to bring all informations on bed rock surface within a specific area to a comprehensive DEM was successful. Beyond controversy, the DEM comprises, despite all objectivity in the workflow, many subjective interpretations by the DEM editors or inherited from older interpretations. However, the DEM is a good base for further discussions on plausible alternatives.

The DEM allows direct comparison with datasets of similar resolution, e.g. from the Swiss Federal Office of Topography. Classic DEM derivates can be calculated out of the Bas_Quat model, the most interesting being the hill shade in 2D and perspective views and block diagrams in 3D. The DEM allows a detailed examination and the visualization of many significant and interesting structures. The most spectacular comprise abandoned valleys, some of them crossing actual hill ranges, over deepened valleys that follow mostly the actual axes, but being much deeper than the recent valleys, or isolated sheepback shaped hills reaching nearly the surface of valleys now filled by thick loose rock sediments (Fig. 3 and 5). To be honest, it has to be noted, that many of these structures have been already described in the literature. But the present work is not in the first instance a research

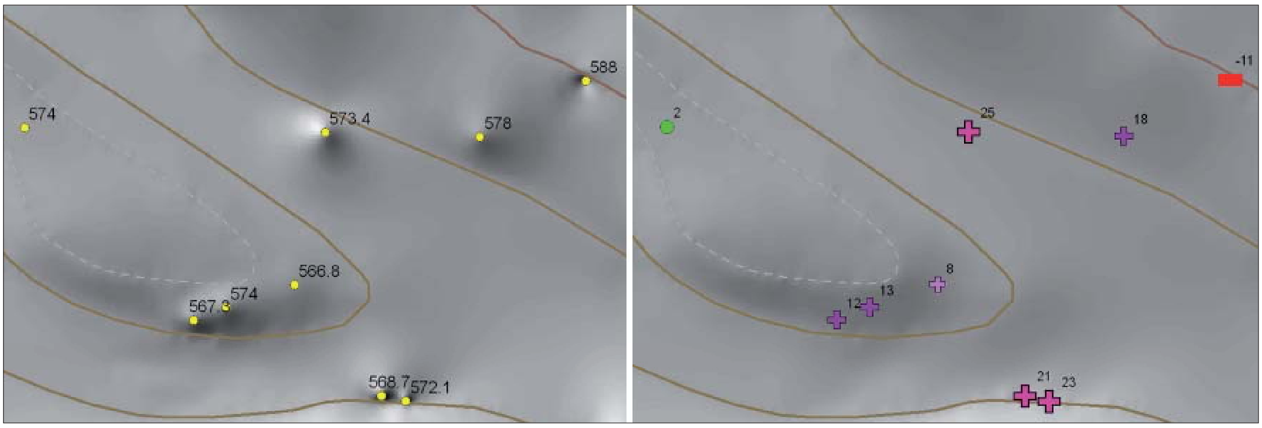

Fig. 4: Considering borehole information. Left: point information is directly integrated in the interpolation along with isolines. It creates spots and funnels on the surface. The value is the altitude (in meter) of the modeled surface corresponding exactly to borehole data. Right: point information is initially used for the drawing of isolines and in a further step as control points. The value is the deviation (in meter) from the model to the borehole data. This helps for corrections of the isoline model.

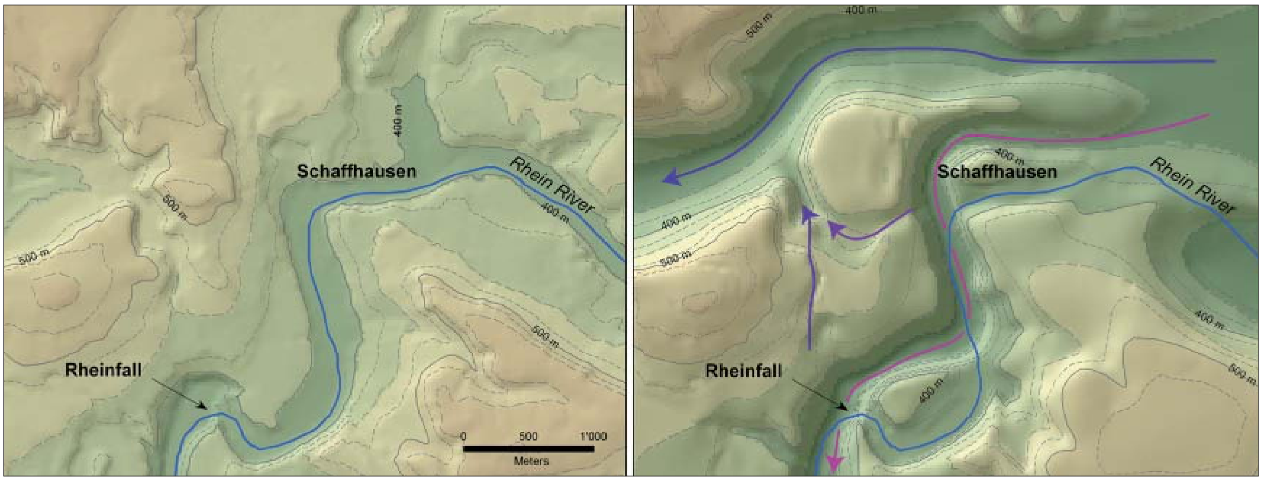

Fig. 5: Recent and former valleys in the vicinity of Schaffhausen: left: actual topography; right bedrock surface showing the traces of older courses of the Rhine river and its tributaries (arrow lines going in age from blue-purple to red-purple). At the Rhine Falls waterfalls, the actual Rhine river drops in one of his antecedent valleys.

work ob Swiss Plateau bedrock surface, but an attempt to bring all available information in a coherent DEM.

In a second conclusion, the DEM of the basis of Quaternary cover is an important instrument for the visualization, the control and the further evolution of hydrological, geomorphological and geological concepts. Furthermore, it is a valuable instrument for small to middle scale geotechnical and civil engineering tasks.

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