3D-visualisation of Vienna's subsurface

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1 SUMMARY

For the planning of major construction projects such as subway tunnels or building foundations, knowledge of the structure and material properties of the subsurface is essential. We have developed a three-dimensional, geo-referenced model of Vienna's subsurface using the information from over 40.000 boreholes as described in a database at the Vienna City Administration (Municipal Department MA29 - Foundation Engineering) and analysed geologically over the last 3 years. This model shows the geometry of geological layers including the depth and morphology of layer boundaries and the thickness of geological sediments. Combined with knowledge of the genetic origin of sediments, material properties of the subsoil can be estimated.

A Java-3D-viewer, developed at the Netherlands Institute of Applied Geoscience, is used to visualise the model and to construct cross-sections (clip planes) at any location and orientation (horizontal, vertical or inclined). The interactive viewer provides immediate access to available data on Vienna's subsurface and represents an innovative IT-tool for urban geologists, engineers and city planners concerned with mayor construction projects. The fast and accurate presentation of underground structure constitutes an economical means for the communication of information among spatial planners and urban developers.

2 INTRODUCTION

City planners as well as engineers, legislators and public workers all depend to some degree on geological and geotechnical information on the subsurface of urban areas. The characterization of construction sites, the evaluation and protection of urban ground waters, the environmental review of contaminated ground water, surface water or substrates, the management of urban waste all require detailed knowledge of the geological characteristics of city areas. These characteristics include the structure (geometry) of geological layers as well as their respective material properties. While the structure of layer boundaries and the thickness of geological sediments is described by a three-dimensional model, the nature of sediments is expressed by hydraulic, chemical and engineering parameters such as permeability, adsorption capacity, grain size or water content to name but a few. Filling a geometric model with values for these parameters results in a complete account of the subsurface. Put into an information system and combined with the geological expertise of urban geologists, this provides all information necessary for decision making.

The Geological Survey of Austria together with the Vienna City Administration (MA29) are developing such an information system for the city of Vienna built on geological maps, borehole logs collected in over 40.000 boreholes, and on data derived from standard material testing. At present, the geological analysis and evaluation of borehole logs and the construction of the geometric model are completed (Hofmann & Pfleiderer, 2003) whereas the connection to material data is still ongoing. However, with knowledge of the genetic origin and sedimentary history of geological layers some parameter values can be estimated.

2.1 Geological background

The geological situation of the city area of Vienna is described by Brix (1972). The western part of Vienna is dominated by flysch (sandstones, claystones and marls; brittle material with poor conductivity for groundwater), while the central and eastern parts constitute the Vienna basin which is filled with loose sediments. At the western edge of this basin, along a narrow N-S-trending band, clay and silt occur at the surface (impermeable, fine-grained layers with occasional sandy units). In the central and eastern part of the basin, these clay and silt layers are overlain by gravel (coarse-grained layers with high conductivity for groundwater). Occasionally, gravels are covered by a thin layer of fine-grained material (loess and loam). The structure and tectonic evolution of the Vienna basin are explained by Decker (1996).

2.2 Borehole data

In the course of the last 100 years, the subsurface of Vienna has been probed by over 40.000 boreholes, reaching mostly to depths of 5-20 m below surface, exceptionally down to 400-600 m below surface. The logs of these boreholes are collected by the Vienna City Administration (MA29). The data include the location of drilling, the material description of geological units (thickness, grain size, packing density, consistency, water content) and references to the depths where samples were taken for material testing. Analysis and evaluation of all borehole logs with respect to their geological information has been performed by the Geological Survey of Austria over the last three years (Hofmann & Pfleiderer, 2003).

3 MODEL CONSTRUCTION

Geological maps represent 2D-models of the regional distribution of geological units at the surface whereas borehole logs denote the distribution of geological units from the surface down along a vertical line (1D). By combining geological maps with borehole logs, a three-dimensional model of the subsurface can be constructed in three steps. First, the boundaries of geological layers are marked in borehole logs and the markers are correlated to build 2D-surfaces (interpolation). Then, these surfaces are stacked upon each other like a series of "flying carpets". Finally, the volumes between the surfaces are filled to construct a layer model of the subsurface. While the first two of these steps are carried out within a geographic information system (ArcGIS) the layer model is built using a geo-viewer.

The following surfaces (ordered from top to bottom) were imported into the layer model (Fig. 1):

- The topmost surface (A) represents a digital elevation model (DEM) of the city of Vienna. This surface was created using geodetic points measured by the Urban Survey Department (Municipal Department MA41), and including some additional information on altitude and surface morphology.
- The second surface (B) represents the bottom of the fine-grained cover overlying the gravel unit. It occurs as isolated patches mainly in the eastern half of the city area and lies on average 2 m, at most 23 m below ground. Almost all boreholes penetrate this surface.
- The third surface (C) corresponds to the bottom of the gravel unit, covers the central and eastern part of the Vienna basin continuously and lies 10-30 m below ground. Approximately one third of the boreholes reach down to this level. Therefore, the surface is less exactly defined as the previous one.
- Next, an intermediate (stratigraphic) surface (D) within the unit of clay and silt was constructed from maps published in the literature (Unterwelz, 1993) to demonstrate the tectonic structure at greater depths (100 m below ground in central Vienna, descending in a step-wise fashion to 1100 m below ground in the southeast).
- Finally, the bottom of the clay and silt unit (E) was also constructed from maps published in the literature (Wessely, 1993). It reaches down to 5000 m and more below ground. The material underlying this surface constitutes flysch material in the north-western part and includes limestones and dolomites (carbonates) in the south-eastern part of the city area.

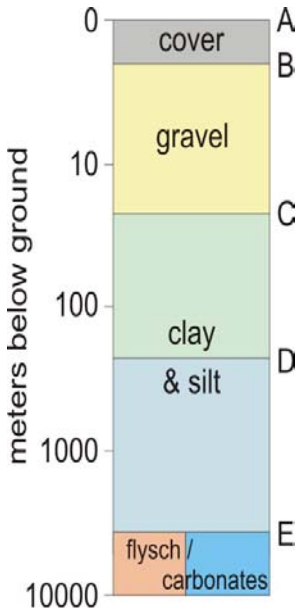

Fig. 1: Schematic sequence of modelled layers

For most purposes, the lowest two surfaces (D and E) are of little importance, as construction activities in urban areas are usually limited to the uppermost 40-50 m below ground (Rogers & Horseman, 1999).

4 GEO-VIEWER

The viewer used to visualize the layer model was developed at the Netherlands Institute of Applied Geoscience (TNO-NITG; http://dinoloket.nitg.tno.nl). It makes use of Java 3D technology to display three-dimensional data sets such as raster surfaces, 3D-polylines and scattered 3D-points imported from SURFER, ZYCOR or ARCINFO. The program performs 3D-rendering, offers free customization of colour display, illumination and shading and includes a wide range of user-friendly interactive features such as mouse-driven real-time rotation, vertical scaling, contouring and clipping (TNO-NITG, 2003). A public version of the viewer is available free of charge at the above mentioned website.

Figure 2 displays the surfaces modelled by interpolating geodetic points (surface A) and correlation markers from borehole logs (surfaces B and C) and by digitizing published maps (surfaces D and E). The units along axes X (easting), Y (northing) and Z (altitude above sea level) are given in meters. (The same holds for Figures 3 – 6.) For reference, surface rivers (blue) and district borders (red) are draped over the digital elevation model (surface A). The step-wise morphology of surface D resulting from tectonic faulting becomes apparent.

Due to the scale and resolution, surfaces B and C are not visible in Figure 2. The large map extent of app. 20 x 20 km² and the small thickness of the fine-grained cover and the gravel layer (2 – 20 m) prohibit their presentation in the block diagram if deep layers are to be displayed at the same time.

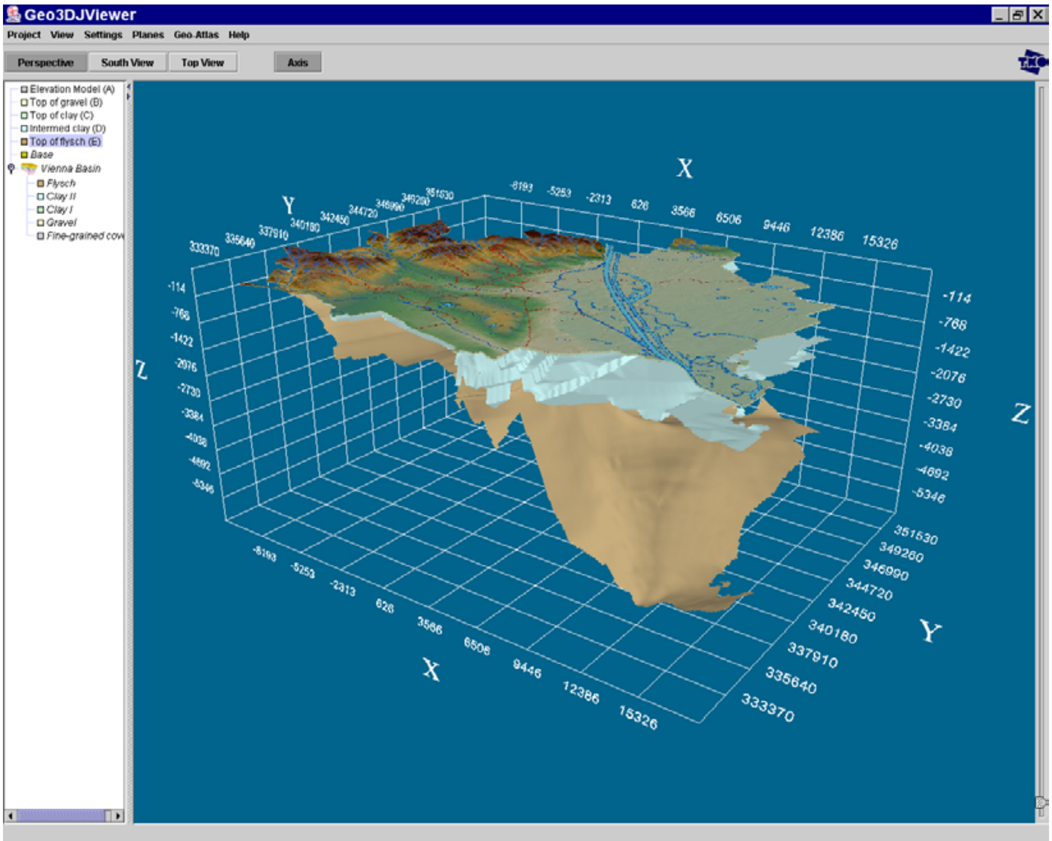

Fig. 2: Surfaces constructed for the layer model

Filling the volumes between these surfaces leads to a layer model of the subsurface geology of Vienna displayed as a block diagram in Figure 3.

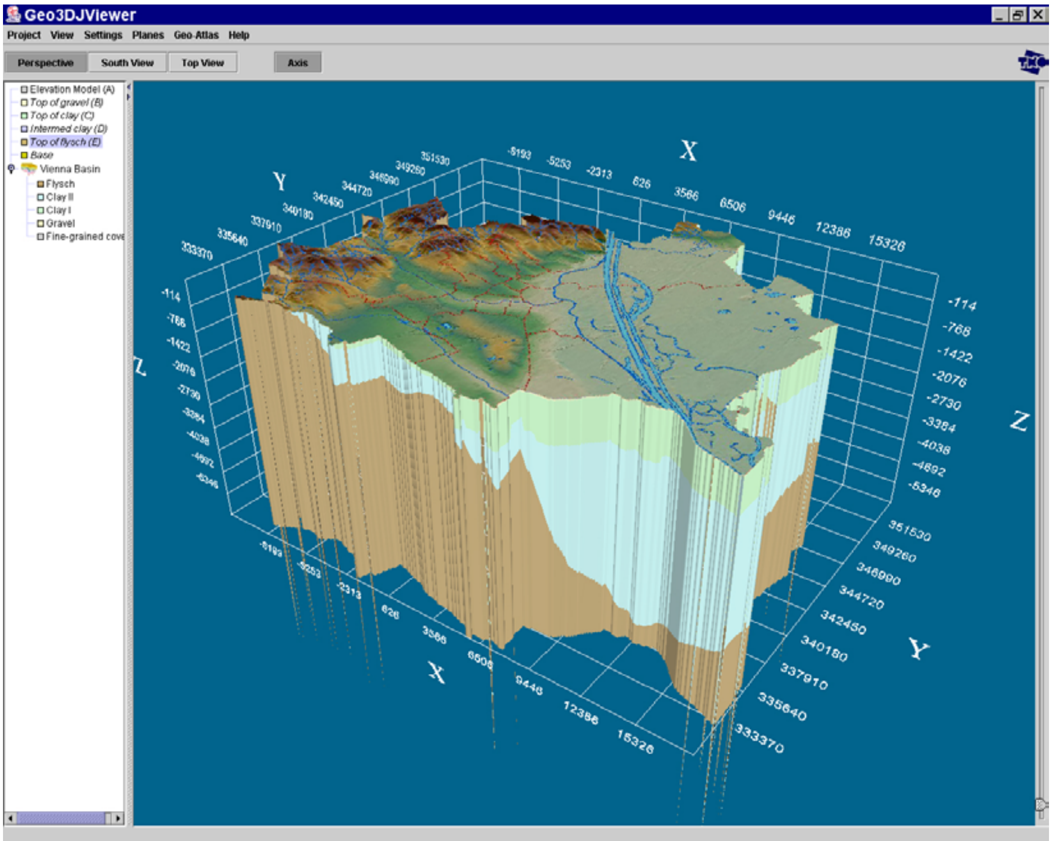

Fig. 3: Block diagram of the subsurface geology of Vienna seen from south-east

The same diagram is shown in Figure 4 dissected by two vertical clip planes trending north-south and east-west. The activation of clip planes represents a quick and user-friendly means to construct geological cross-sections of any orientation and at any location. In Figure 4 the shape of the Vienna basin at depth becomes immediately apparent.

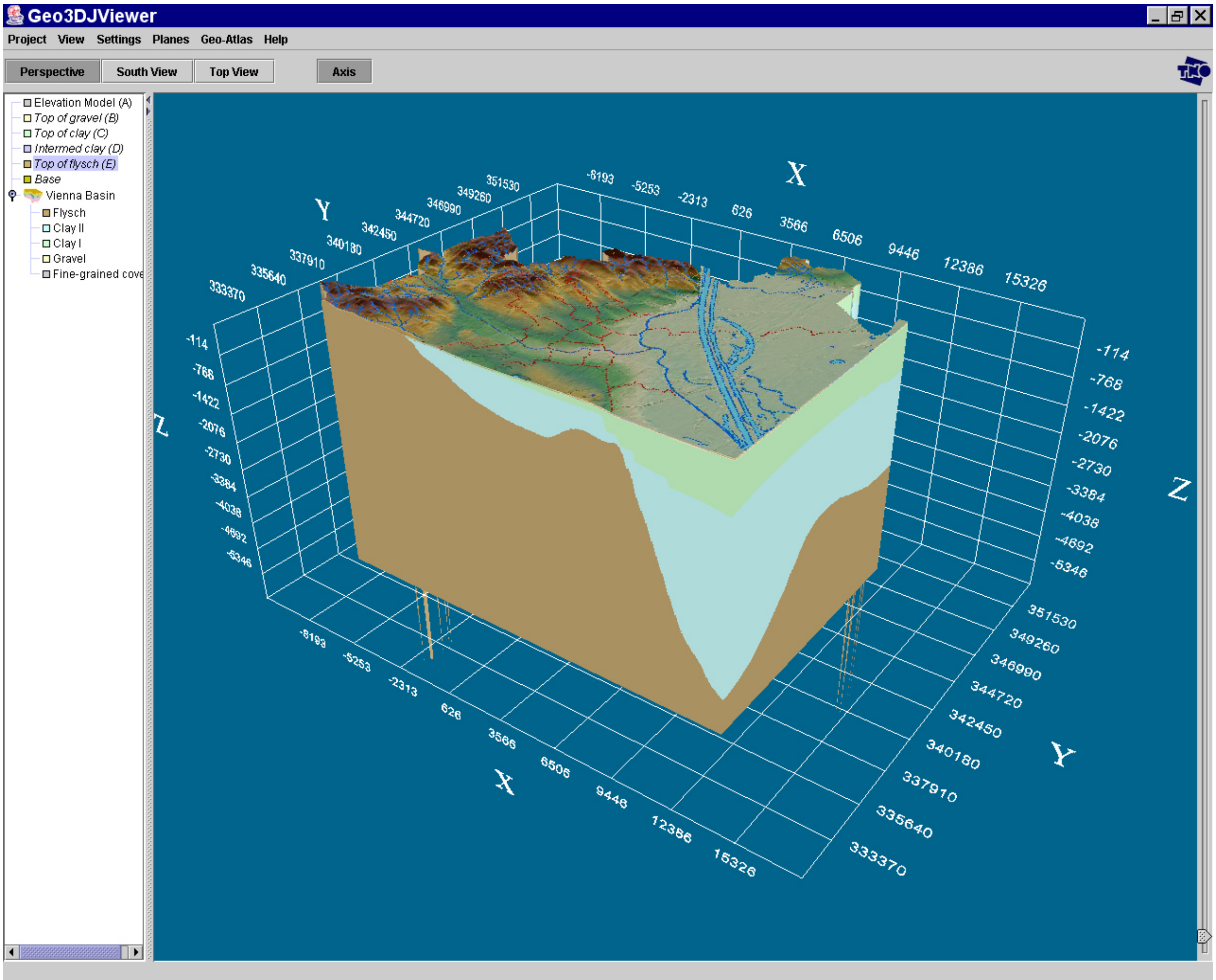

Fig. 4: Block diagram of Fig. 3 dissected by two clip planes trending N-S and E-W

For most underground activities in urban areas, representation of the thin gravel layer and its overlying fine-grained cover is much more relevant than the deep structure of the Vienna basin. Construction projects such as major buildings, road or subway tunnels, waste water treatment plants or fuel storage facilities are situated at depths of 10-50 m below ground.

In order to present the thin layers (between surfaces A, B and C), Figure 5 zooms into a small area in the central part of Vienna. The close-up extends over an area of 1 x 0.8 km² and displays the top three layers of the model. Here, the city map of Vienna is draped over the digital elevation model to show individual housing blocks (dark grey), traffic routes (light grey) and recreational areas (green).

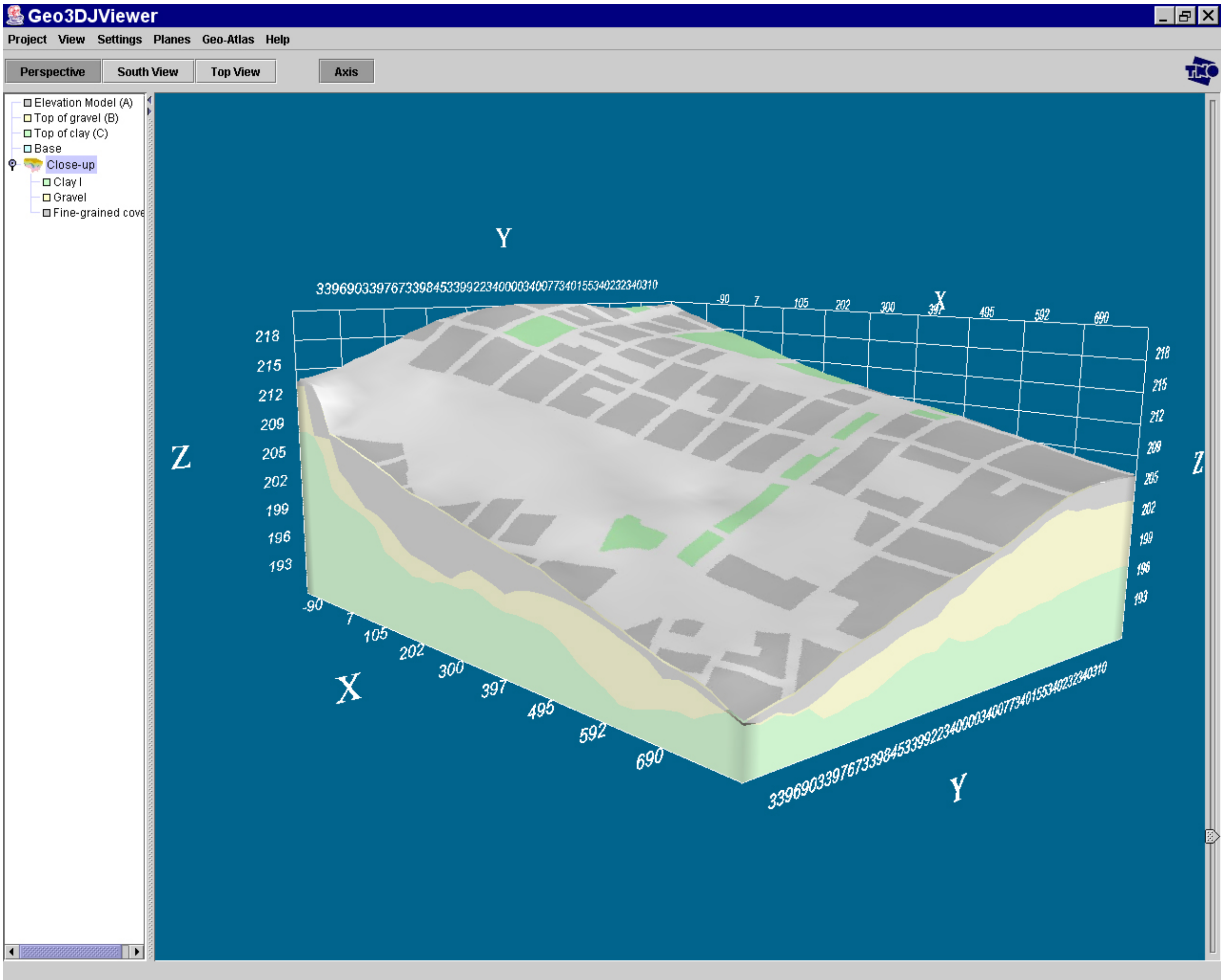

Fig. 5: Close-up view of the geological layer model in the central part of Vienna

Activating some clip planes reveals the structure and depths of geological layers in form of a fence diagram (Fig. 6). This way, the preview of a planned excavation for a construction site including the faces of pit walls can be simulated. Such a simulation is of vital importance to engineers assigned, for example, the task of planning the foundation of a building. Together with material properties of the geological layers, it allows not only to predict which material will be found at what depth but also to plan the design of the excavation, to forecast safety measures with respect to the stability of pit walls and to estimate the costs of operation. Therefore, analysing the layer model with the aid of a geo-viewer represents a fast, inexpensive and powerful tool to assist city planners and engineers with their day-to-day work.

Increasingly, the City Administration of Vienna is required to communicate planned building projects to the broader public. The Municipal Department MA18 - Urban Development and Planning, for example, is in charge of coordinating the public information and documentation during the planning process of major projects. For this purpose, our visualisation of the geological model with a geo-viewer is equally well suited, offering graphic and easy-to-understand illustrations of underground ventures.

5 FUTURE WORK

Ongoing collaboration with the City Administration of Vienna (MA29 and Municipal Department MA45 - Water Engineering) focuses on the integration of hydraulic and engineering parameters such as permeability, grain size and water content into the model. Data on these material properties exist in various data bases and simply need to be geo-referenced and linked to the geological layers. Retrieving this information per mouse-click is envisaged in order to further facilitate the communication among engineers, spatial planners and urban developers.

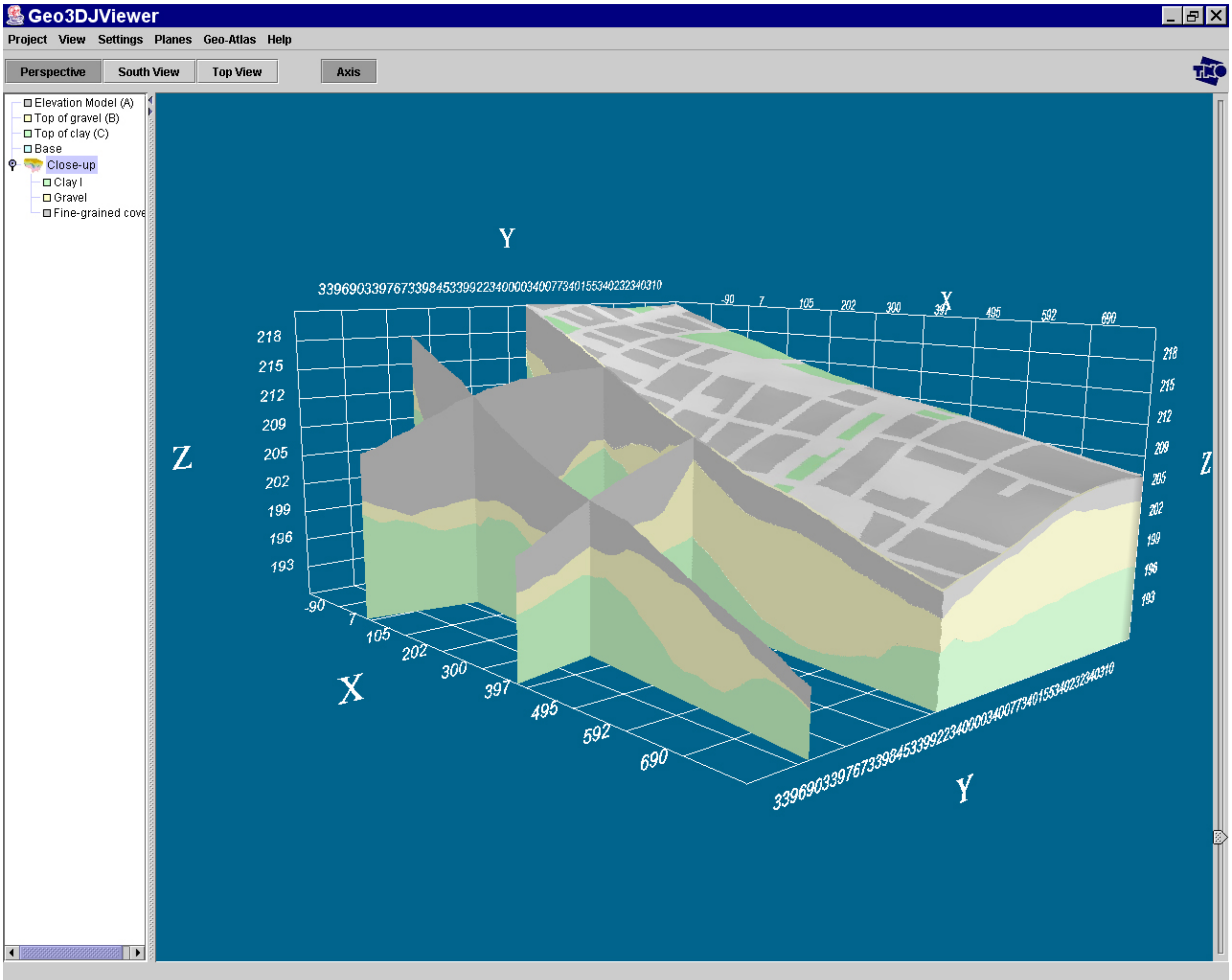

Fig. 6: Fence diagram of the close-up view of Figure 5

6 LITERATURE

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7 ACKNOWLEDGEMENTS

The authors are grateful to J. Auer (Vienna City Administration MA29) for providing the data, as well as to H. Reitner and M. Heinrich (Geological Survey of Austria) for helpful discussions and reviewing of the manuscript.