3D-modeling of ground conditions for the engineering geology map of the city of Magdeburg

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Abstract: Engineering geological surveying presently uses methods and tools for the computer modelling of 3D-structures of the geological subsurface and geotechnical characterization as well as the application of geoinformation systems for management and analysis of spatial data, and their cartographic presentation.

The State Geological Survey of Saxony-Anhalt has prepared engineering geological maps of the city of Magdeburg at a scale of 1:10 000, each tile consisting of 7 different thematic map sheets. Innovative, interactive computer modelling techniques of the three-dimensional structures of the subsurface were established as part of the map preparation process.

A workflow was chosen, on the one hand, by applying GIS methods using ESRI ArcGIS software for data acquisition, maintenance, and presentation and on the other hand, by applying three-dimensional spatial modelling with a interactive 3D modeller (Rhinoceros NURBS modelling for Windows). Based on Non-Uniform Rational B-Splines, any geometric shape can be modelled. Besides surfaces of the different engineering geological units, solids using boundary representation techniques were modelled.

The objectives of the engineering geological maps of the city of Magdeburg are to present the construction conditions with regards to the subsurface to at least 10 meters below ground. To achieve this aim, visualization of the geological model and a standardized interpretation, like engineering geological boundaries, interpretative maps (thickness and base of artificial ground, base of Quaternary deposits, overburden thickness and elevation of geological rockhead), cross sections as well as perspective views of the 3D model were prepared.

Résumé: Actuellement, pour dresser une carte topographique d´ingenieur en géologie, on utilise des méthodes et des outils qui modèlent le sous-sol et ses caractéristiques géotechniques en 3 dimensions ainsi que des systèmes de géoinformation qui administrent et analysent les données topographiques et leur répresentation cartographique.

L`office du pay des géologie et l`inspection des mines de Saxe-Anhalt ont établi des cartes topographiques d´ingenieur en géologie de la ville de Magdeburg à l´échelle de 1/10 000. Chaque feuillet contient 7 cartes thématiques. Comme innovation, un modelage interactif des structures des terrain à bâttir en 3 dimensions, a été intégré au déroulement du travail du dressage de la carte.

En outre, on a choisi un procédé de préparation, de disposition et de présentation des données avec le systéme de géoinfomation ESRI ArcGIS ainsi que le modelage avec un modeleur interactif en 3 dimensions (Rhinoceros NURBS modelling for Windows). Grâce au NURBS, on peut modeler les structures á volonté. A côté des modèles en surface, on a créé des corps des volumes suivant les limites des tolérances. Le but des cartes topographiques d`ingenieur en géologie de la ville de Magdeburg, c´est de mobiliser des informations sur tout ces qui concerne les fondertions des constructions allant jusqu´ á 10 m de profondeur. En plus, on a visualisé des modèles géologiques, des évaluations standardisées comme par, exemple des cartes de plans horizontaux, des cartes thématiques (épaisseur et coucher inférieures de remblais, coucher de base des stratifications des l`ére quaternaire, épaisseur des superpositions et stratigraphie du substratum de l`écorce terrestre) et toute une série de couper en profil.

Keywords: 3D Models, engineering geology maps, geographic information systems, geology of cities, planning, urban geosciences.

INTRODUCTION

As a foundational assignment, the Department of Engineering Geology and Planning Geology at the State Geological Survey of Saxony-Anhalt compiled applied thematic engineering geological survey maps of major towns and minor towns, where it was important to understand the nature of the subsurface, in the State of Saxony-Anhalt. The building project organizers as well as the project finance partners receive copies of these foundational geological documents so that geotechnical aspects can be taken into consideration during preliminary project planning. Such maps cannot replace on-site investigations of the subsurface. However, they do convey significant primary information, especially for optimising geotechnical analyses.

The past State Geological Agency of Saxony-Anhalt published conventional printed (analogue) multi-sheet maps at a scale of 1:10 000 of the minor towns of Merseburg and Lutherstadt Eisleben in the 1990’s. In spite of the myriad of representative elements, the disadvantages remained that the map’s contents were static and could not be extrapolated (non-selective and could not be merged). A different approach proved necessary for the major towns, where there was an immense amount of subsurface geodata (usually several thousand bore core samples from ground explorations).

The focus of this project was to combine the available data sets with a comprehensive, computerised engineering geological interpretation of the existing map views, spatial modelling of engineering geological units as well as data processing techniques and cartographic presentation of the subsurface. The city of Magdeburg (State of Saxony-Anhalt) was chosen for this new approach to engineering geological surveying (Figure 1).

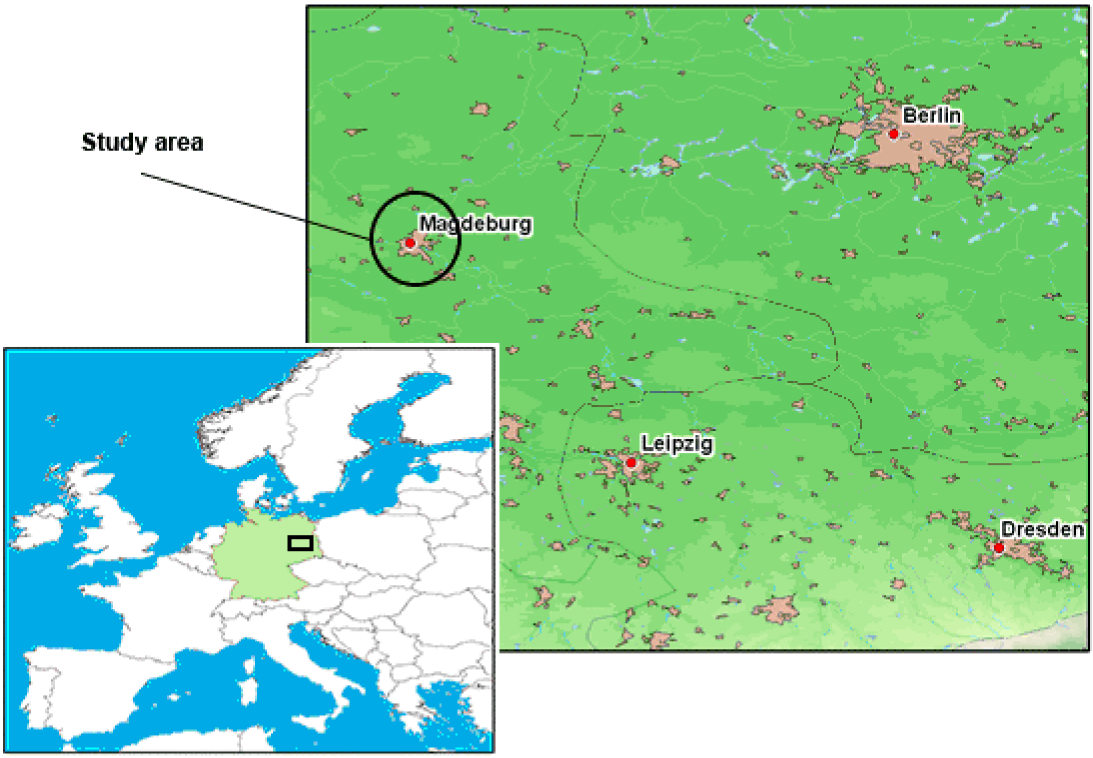

Figure 1. Location of the study area (city of Magdeburg)

GEOLOGY AND ENGINEERING GEOLOGY OF THE CITY OF MAGDEBURG

The majority of the city of Magdeburg has a predominately anthropogenic soil that in places is thickly developed. West of the Elbe, the soil profile is characterised by redevelopment and landscaping, including waste material, in the upper surface soil layers. To the east of the Elbe, the soil profile is distinguished by measures taken to prevent flooding, which ultimately alter the landscape. Also east of the Elbe, filled-in gravel excavation sites and lakes are present.

West of the Elbe, under a wide-spread cover, there are remnants of a former loess and loess loam cover, which is underlain by a series of interbedded marly till and melt-water sand of the Drenthe stage and Warthe stage of the Saale ice age. Loam and alluvial mud have been deposited along some of the Elbe's tributaries.

East of the Elbe, the cover is thin and is underlain mainly by floodplain clays, in turn underlain by Holocene and Vistula ice age fluvial valley sands, gravels and boulders. A few old channels of the Elbe are filled with peaty clay and alluvial mud.

Eocene greensand (Rupel basement sand) and isolated Oligocene Rupel clays are found throughout the area underneath the Quaternary strata. Almost everywhere, greensand overlies Palaeozoic bedrock. At some locations, younger beds were deposited on top of the bedrock, which occasionally outcrop (for example, sandstones of the Rotliegende at the Domfelsen).

The subsurface in-situ Palaeozoic rocks in the city of Madgeburg are a part of the regional geological Flechtingen-Rosslauer Scholle. They dip gently to the southwest so that in this direction, increasing younger units are encountered. The geological sequence ranges from Carboniferous greywacke and shale, Rotliegende sandstone, and limestone, gypsum and claystone belonging to the Zechstein, and siltstone, sandstone, and claystone from the Buntsandstein. Rhenish and Herzynish striking faults, partially thrust faults, dissect the area.

Table 1. Geological succession in the city of Magdeburg

Stratigraphy		Genesis	Thickness	Lithological Description
Quaternary	Holocene	anthropogenic	1.0 – 5.0 m (max. 10 m)	Made Ground, filled-in sites, and landfills. Variable composition.
		fluvial	1.0 – 2.0 m	Floodplain loam or floodplain clay Silt to fine sand ± clay, variably sandy and pebbly, non-calcareous in the Elbe floodplain, limestone in the tributaries. Some organic matter
	Pleistocene	limnic-fluvial	1.0 – 3.0 m	Sapropel. Silt, with variable amounts of fine sand or clay. Heavily interspersed with organic matter.
	Vistula	aeolian	1.0 – 3.0 m	Loess, partially bedded. Silt, slightly sandy (fine grained), calcareous but non-calcareous in upper part
		fluvial	5.0 – 10.0 m	Elbe River gravel, partially melt-water sands. Pebbly sands, partially with silt inclusions; often stony at the base.
	Saale	fluvioglacial	3.0 – 8.0 m (<1 m - 10.0 m)	Melt-water sand and gravel. Sands and gravels with boulders. Localised silt inclusions.
	Oligocene	glacial	2.0 – 10.0 m (max. 20.0 m)	Silt, sandy, pebbly, calcareous, partially clayey. Variable erratic content.
	Rupel	marine	2.0 – 10.0 m (<1.0 m - 10.0 m)	Clay (Rupel clay), with septarian (calcareous) concretions. Variable silt content, increasing towards the base.
		marine	3.0 – 5.0 m (some up to 10.0 m)	“Greensand” Silty, fine sand, locally medium grained, glauconite-bearing (green to dark green), locally cemented (iron oxide, dolomite).
Triassic	Buntsandstein	marine	Up to 100.0 m	Siltstone, platy, bedded, ± fine sand. Sandstone, fine grained, clay and silt inclusions. Rogen stones
Permian	Zechstein	marine	≥ 20.0 m	Limestone (Zechstein limestone), anhydrite and shale. Residual clay, mixed and experienced lixiviation
	Rotliegend	continental	> 50.0 m	Sandstone, fine to medium grained, cemented calcareous-clayey, some siltstone.
Carboniferous	Dinant	marine	> 100.0 m	Greywacke, medium to fine grained with siltstone inclusions. Variable thickness, secondary reddening (red-violet) at the boundary to the Rotliegend.

An inventory of the available database of geotechnical data revealed that for parameter-oriented modelling of the subsurface, there was insufficient data points. Therefore, the engineering geological model units were derived from the lithological, geotechnical and genetic properties of the geological units. 8 soil units with sufficient homogeneous engineering geological properties were selected, including fills / covers as well as 4 bedrock units. Table 2 shows the geotechnical properties associated with the 8 engineering geological soil units.

Table 2. Geotechnical properties from 8 engineering geological soil units

Unit	SG*	SC	ϕ'	c'	γ	Es
Peat, peat clay, sapropel, topsoil (Holocene)	HN, HZ, F, OU	2 - 3	10 - 20	0 - 5	11 - 15	0.5 - 5
Silt; sandy, humus (Holocene)	TM, TL, UL, UM	4	20 – 22.5	5 - 10	17 - 20	5 - 10
Silt; fine sandy, with basement boulders (Pleistocene)	TL, UL	4	25 - 28	3 - 10	18 - 20	5 - 15
Sand and gravel; partially, stony (Pleistocene)	SE, SI, GI, GE	3	30 – 32.5	0	18 - 20	20 - 40
Sand; pebbly, partially, silty (Pleistocene)	SU, SW, GW	3	32 - 35	0	18 - 20	30 - 50
Silt; sandy, pebbly, partially, clayey (Pleistocene)	TL, ST	4 - 5	28 - 30	10 - 15	20 - 23	15 - 25
Clay; silty, partially, fine sandy (Tertiary)	TA, TM, UM	4 - 5	17.5 - 25	12 - 20	18 - 21	10 - 20
Silt; fine sandy to fine sand; silty, partially, clayey (Tertiary)	SU	3 - 4	25 - 35	0 - 5	17 - 20	20 - 35

* SG – Soil group DIN 18196, SC – Soil class DIN 18300, ϕ' – effective angle of friction (°), c' – effective cohesion (kN/m^2), γ - specific gravity, moist earth (kN/m^3), Es – stiffness modulus (MN/m^2) for the stress range 130 – 260 kN/m2

METHODOLOGY

Each topographical map at a scale of 1:10 000 was processed according to the following steps

- Data preparation
- Creation of cross sections through the area
- Geological / engineering geological processing
- Geometrical modelling
- Evaluation and presentation

At the beginning of processing, representative bore core samples were selected from the state bore core sample database. These representative samples were then converted to an interpreted engineering geological profile and subsequently connected by a lattice of profile lines. The bore core samples were drawn true to their position and elevation in the profile. Cross-sections and were manually correlated (Figure 2). In these constructions profiles, existing surfaces (e.g., digital elevation models or solid rock surfaces) could be drawn as cross sectional lines. During the construction, regional geological knowledge of the processor was applied for the modelling.

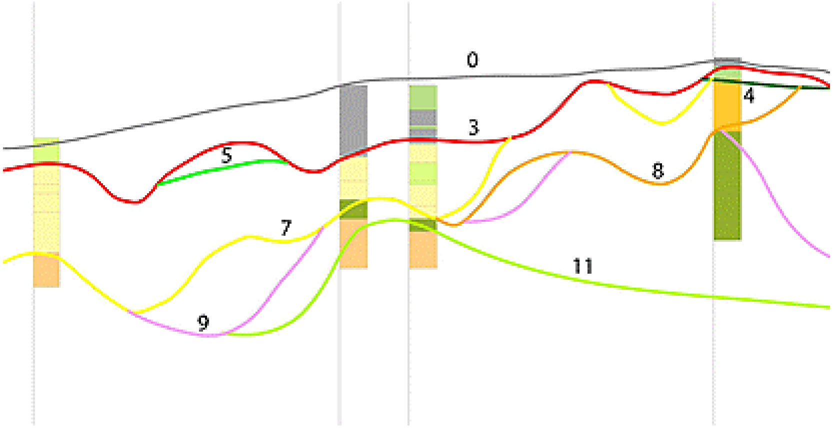

Figure 2. Section of a construction profile with correlating base bed boundaries of model units (elevation exaggeration is X10)

The bore core points and the profile cross-sections that were produced were then transferred to the modelling software Rhinoceros - NURBS modelling for Windows. Through interactive modelling techniques, the profile and bore core points laid out a free-form surface over the cross section segments. The morphology of the surface can be adjusted later to suit the geologist by shifting the control points (Figure 3). The tool provides the user with a multitude of intuitive, useful functions to configure the geometry.

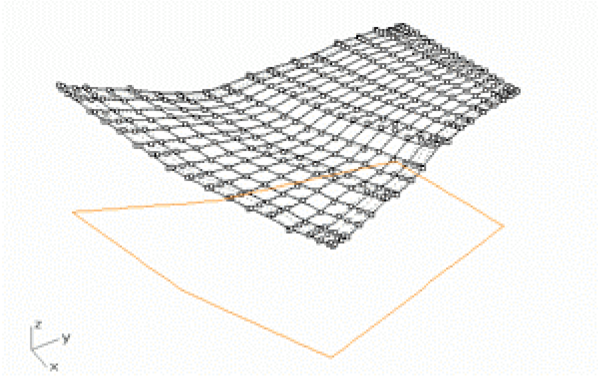

Figure 3. Example of a free-form surface with control points to adjust the model. The corners are supported by bore core samples and the edges by cross-sections

Using this method, a lower boundary surface was constructed for each geological unit. Free-form modelling presents an effective method to incorporate bore core samples and structures between the profile cross-sections as well as bed boundaries into the surface model.

In a further step, volume models of the geological units were created from the surface models. A three-dimensional block model was created through this with some removed bed bodies.

Figure 4 shows, for example, a three-dimensional model within the area of Magdeburg as an exploded view with fluvial terraces, interbedded melt-water sands and marly till, Tertiary sands and clays as well as the underlying solid rock, which has been affected by a tectonic activity. The Elbe channel and excavations from gravel extraction are recognizable in the Elbe terrace.

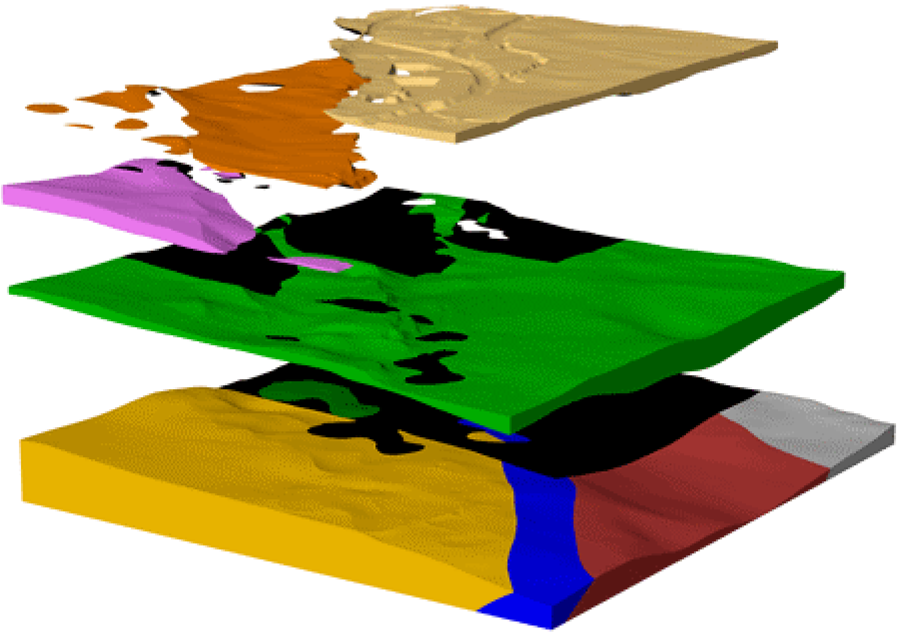

Figure 4. Perspective block model view of a section of the engineering geological map of the city of Magdeburg (exploded view)

The model is the basis for visualization and evaluation. These can be partially executed with the modellers (cross sections, plan views, block views) or a geoinformation system (cross sections, faults, grid-based evaluations). To do this, the geometries of the surfaces and their limits are first converted to a vector format.

Figure 5 shows six perpendicular cross-sections from the volume model, drawn from a NE-SW perspective. Other visualization possibilities emerge after transforming the model to a three-dimensional grid (Voxel model), for example, by hiding the model or the range of values. There are many software products available for the visualization of such types of models.

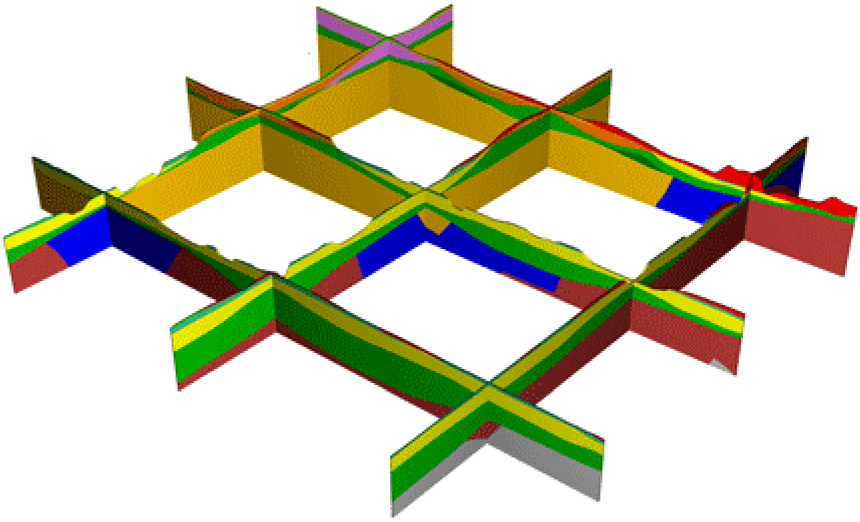

Figure 5. Cross section lattice through part the engineering geological model of the city of Magdeburg.

EVALUATION AND CARTOGRAPHY

The primary goal of engineering geological maps is to evaluate the development potential of the subsurface to at least 10 meters below the surface. Thus, standardized visualization of geological models, in the form of engineering geological plan views, model slices, profile cross-sections as well as block views or perspective views, can be created.

As a standard evaluation, the complete set of maps includes a total of 7 sheets, where each sheet is a 1:10 000 topographic map. This evaluation method has been implemented into a geographic information system along with:

- A **documentation map** (with the database from the cartographic assessment)
- Two **profile cross-sections** (N–S and E–W running lattice profile)
- The subsurface (as of 2 meters below the surface),
- **Geological surfaces of the natural subsurface and artificial ground** (including the thickness of anthropogenic deposits and the formation of the in-situ, natural subsurface),
- The **depth and composition of the Quaternary**
- The **surface of the solid rock**.

Other documentation describes the database used to build the model. The position and depth of around 6000 bore core samples from geotechnical investigations and the investigations of contaminated sites within the city limits of Magdeburg were also noted. The positions of the profile cross sections were also drawn in.

The main map represents the engineering geological properties of the subsurface (2 meters below the surface) at a usual depth for foundations. The map is produced from a geometric cut of the 3-dimensional model within the reference area (digital surface model minus 2 meters). Figure 6 shows a section of the subsurface map.

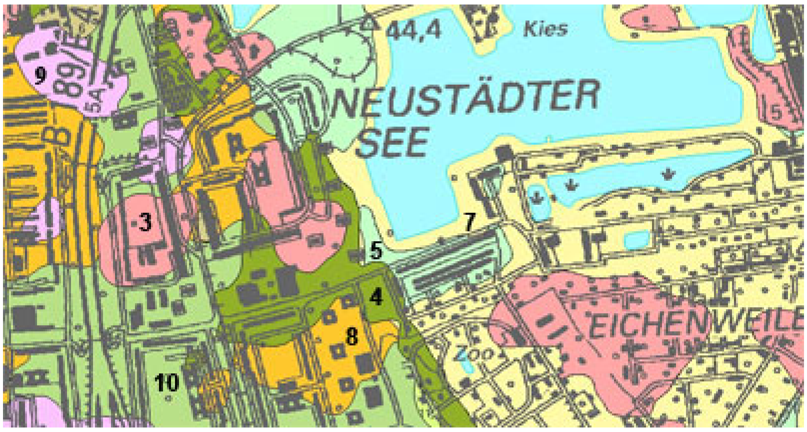

Figure 6. Section of the subsurface map from the engineering geological map of the city of Magdeburg (Annotation: 3 – anthropogenic coverage, 4 – peat, peaty clay, sapropel, alluvial mud, 5 – alluvial clay, 6 – loess and loess loam, 7 – valley sand, gravel, pebbles and boulders, 8 – melt-water sand, 9 – marly till and glacial drift, 10 – Rupel clay, 11 – greensand)

The profile cross-section illustrates engineering geological properties, including the layering relationships, with a depth range to around 50 meters below the surface. Every sheet includes 8-10 approximately parallel sections.

The map shows the distribution and thickness of the anthropogenic deposits as well as the nature of the underlying in-situ, natural subsurface engineering geology. A section of this map is shown in Figure 7.

Figure 7. Engineering geological map of the city of Magdeburg (Annotation: distribution of anthropogenic deposits with thickness contours. See Figure 5 for explanation of the numbers).

The depth position and nature of the Quaternary base show the distribution of the pre-quaternary units as well as their mutual surface area in relation to sea level.

The evaluation map of the area of solid rock emphasises at which depth interval the engineering geological rockhead can be expected. The total thickness of the soil cover can also be derived from the model. In addition, the known and suspected tectonic faults can be predicted.

Methods for the evaluation can be summarized as including the stratigraphic position of different beds, horizontal or vertical cross sections through the model and derived, georeferenced engineering geology information.

SUMMARY AND OUTLOOK

A three-dimensional model of the subsurface of the city of Magdeburg at a scale of 1:10 000 was generated using the available engineering geological data provided by the State Geological Survey of Saxony-Anhalt.

The chosen combination of tools for modelling, evaluating and presenting was used in the technical, organisational and financial project areas. Upon request, a tailored product was created with up to date, applicable information. This tailored product consists of different map sheets, which summarise the engineering geology of the city of Magdeburg. Furthermore, an evaluation and visualisations can be derived from the model data and be provided as a printed or electronic document upon request.

The models are currently generalised to a scale of 1:25,000 and combined to produce one single model. Within this context, other areas outside of the current map sections are being created and integrated. Alignment of data at the map edges constitutes one major challenge and another one concerns the handling of large, complex three-dimensional models.

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