3D laser mapping and dynamic visualisation of the Domica cave, Slovakia

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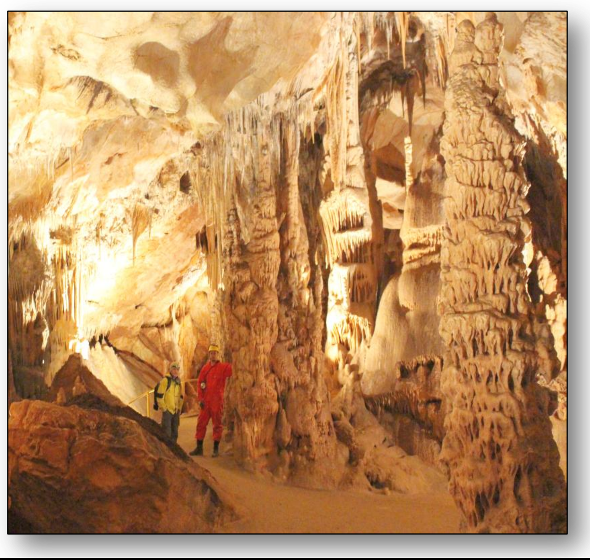
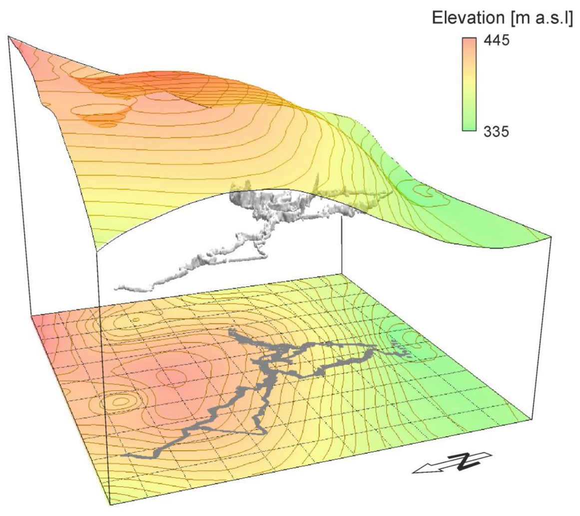


Research overview

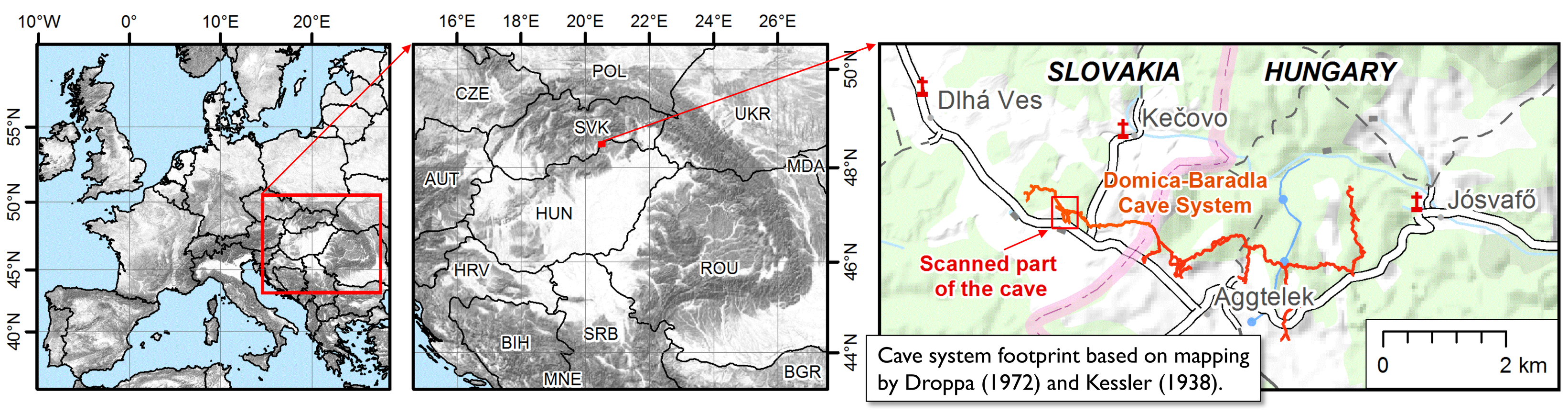
Recent developments in the laser scanning technology provide new tools and methods for a very accurate and cost-effective way of mapping complex volumetric landscape features such as caves. It is difficult to map such 3D features using traditional surveying methods without a large loss of detail. Also, the extreme environmental conditions in the cave (darkness, water, moisture, or mud) make the mapping very challenging (Buchroithner, 2015). In this work, we have collected terrestrial laser scanning (TLS) data coupled with airborne laser scanning (ALS) data and orthoimagery to build a volumetric, 3-D model of the Domica Cave and its surrounding area.



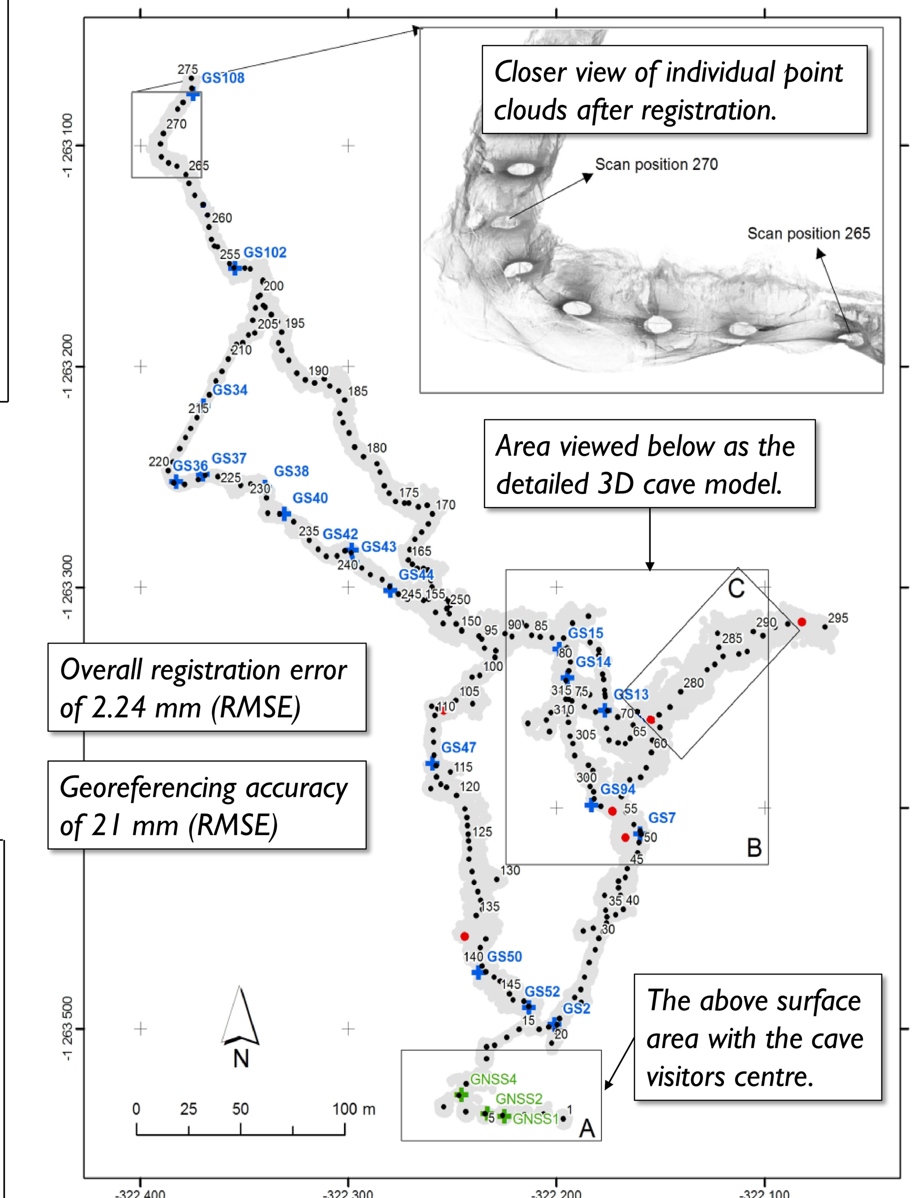
Combining the TLS and ALS data resulted in a 3D model of the area supplemented by other data representing several landscape components and factors potentially contributing to the development of the cave system (water flow routing, temperature, moisture in the cave). We have used several visualisation methods to represent the cave system which, if mutually combined, provide a better means of portraying the complexity of the karst landscape. By this means, we can better understand functioning of the cave system and dynamics of the spatial processes contributing to its the development.

Study area

The Domica Cave originated in the largest karst region in the West Carpathians at the state border of Slovakia with Hungary. The total length of the cave system is around 5,400 m, however, it does continue into the Aggtelek karst region in Hungary as the Baradla Cave with a combined length of 26,065 m.



Cave system footprint based on mapping by Droppa (1972) and Kessler (1938).



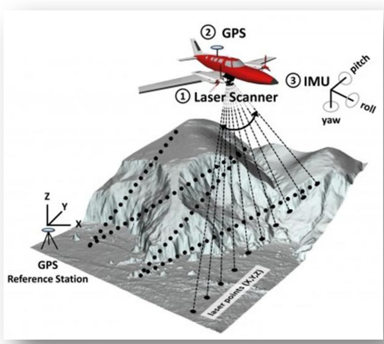
Orthogonal projection of the TLS point cloud footprint with the scanner positions and network of reference points from GNSS survey and previous surveys.

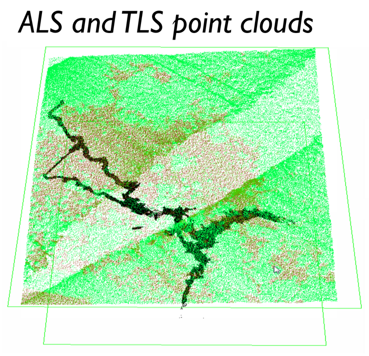
Terrestrial laser scanning

We conducted the **TLS** in March 2014 using a FARO Focus 3D S120 scanner mounted on a GITZO carbon fibre tripod with a panoramic head. This unit comprises an inbuilt electronic compass, barometer and inclinometer, which speed up the process of orienting the scans. Its relatively low weight (5 kg) and compact size, makes this scanner easily portable and it can be used in extremely narrow spaces where larger systems requiring a traditional survey tripod cannot be installed.

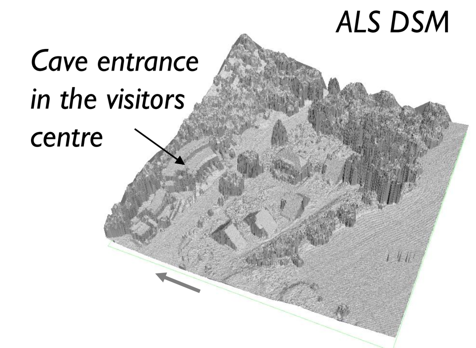
The collected 'point cloud' contains over 11.9 billion of measured points, captured in 5 days from 327 individual scanning positions. The dataset represents almost 1,600 m of the cave passages. Semi-automatic registration of these scans was carried out using reference spheres placed in each scene. Georeferencing of the final registered point cloud from its local coordinate system to the national cartographic system (SJTSK, EPSG 5514) was based on 4 reference points labelled as GNSS1-3, GS108 in the map.

Airborne laser scanning

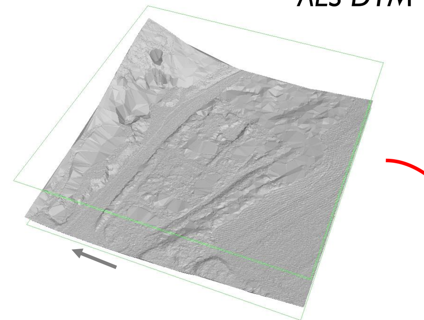




ALS and TLS point clouds



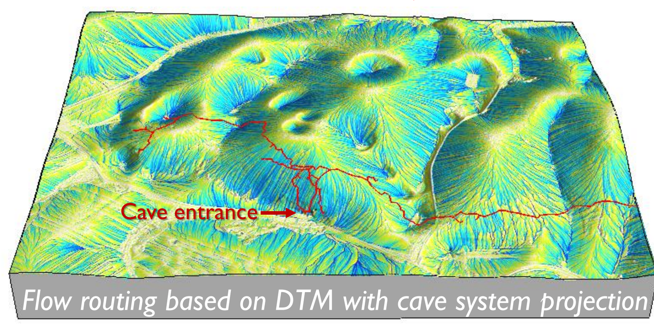
ALS DSM



ALS DTM

In addition to the TLS data, **ALS** data were acquired with a Leica ALS-60 scanner in collaboration with Photomap s.r.o. in August 2014 during the leaf-on season. The achieved average point density on the ground is between 0.5 to 6 points per metre squared depending on the land cover (i.e. forest, grass land, scrubs). The accuracy of georeferenced point cloud is in the order of few centimetres. The ALS data were filtered and processed to derive a digital terrain model (DTM) and a digital surface model (DSM) of the area in the form of regular raster grid (1 m cell size) with the LAStools software suite (Isenburg, 2014).

The terrain above the cave contributes to the development of the cave system via a complex interaction between flowing water and the subsurface limestone rock forming the cave. Geomorphometric methods using GRASS GIS (Neteler & Mitasova, 2008) were used to identify specific karst geomorphic features such as sinkholes in the forested area.



Flow routing based on DTM with cave system projection

3D interactive viewing, profiling and analysis of the models in GIS.

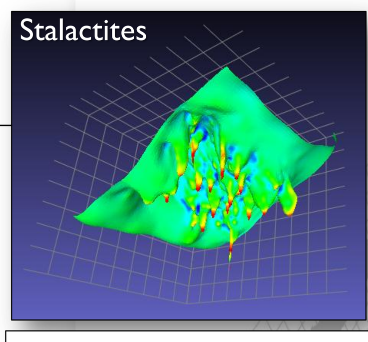
Integration of the digital terrain model and 3D cave model in GIS

3D spatial modelling, analysis, and visualisation

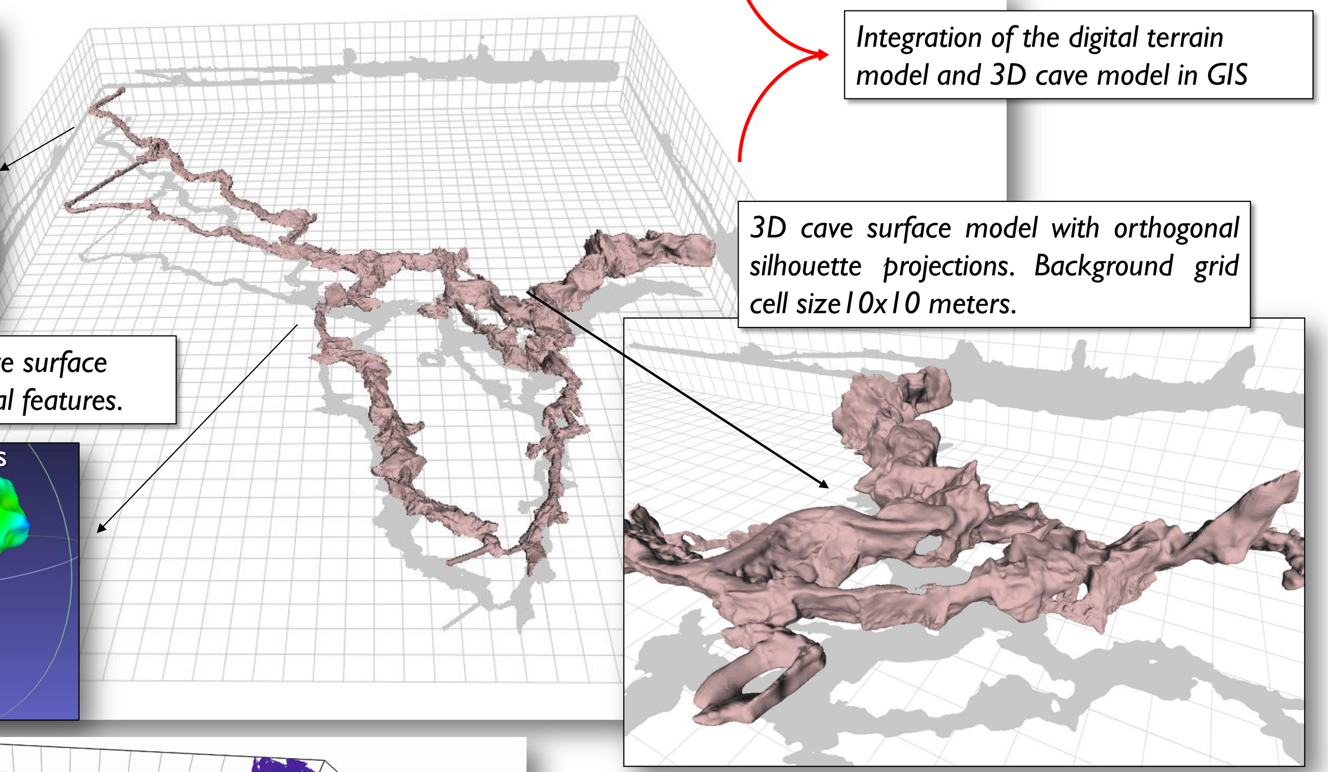
The TLS point cloud data were viewed and analysed as cross-sections, 3D views and dynamic fly-troughs via the FARO Scence and Bently Pointools softwares. 3D cave surface model was generated from a decimated point cloud comprising only 0.03% of the original points (Gallay et al. 2015a). The model was generated as a triangular mesh in Meshlab (Cignoni & Ranzuglia, 2014) using the Poisson surface reconstruction method by Khazdan et al. (2006).

The 3D model enabled volumetric calculations and parameterization of the cave surface properties. Mean curvature of the 3D cave surface model was calculated in Meshlab using the algorithm of Guennebaud & Groos (2007) to parametrize convexity/concavity of the cave surface thus identify specific cave features such as stalactites, stalagmites fault lines (Gallay et al. 2015b).

The digital terrain model and 3D cave surface model were integrated in ArcGIS, which provided means for a complex perception of the cave system with the surface above it. More importantly, the integration enabled spatial analysis of the data in 3D as surfaces, not just the 3D points.

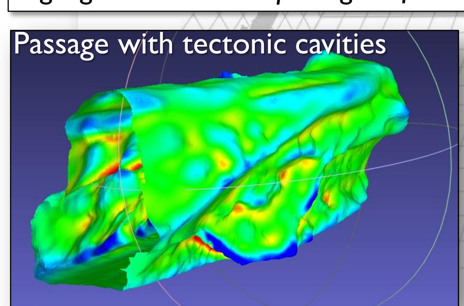


Stalactites

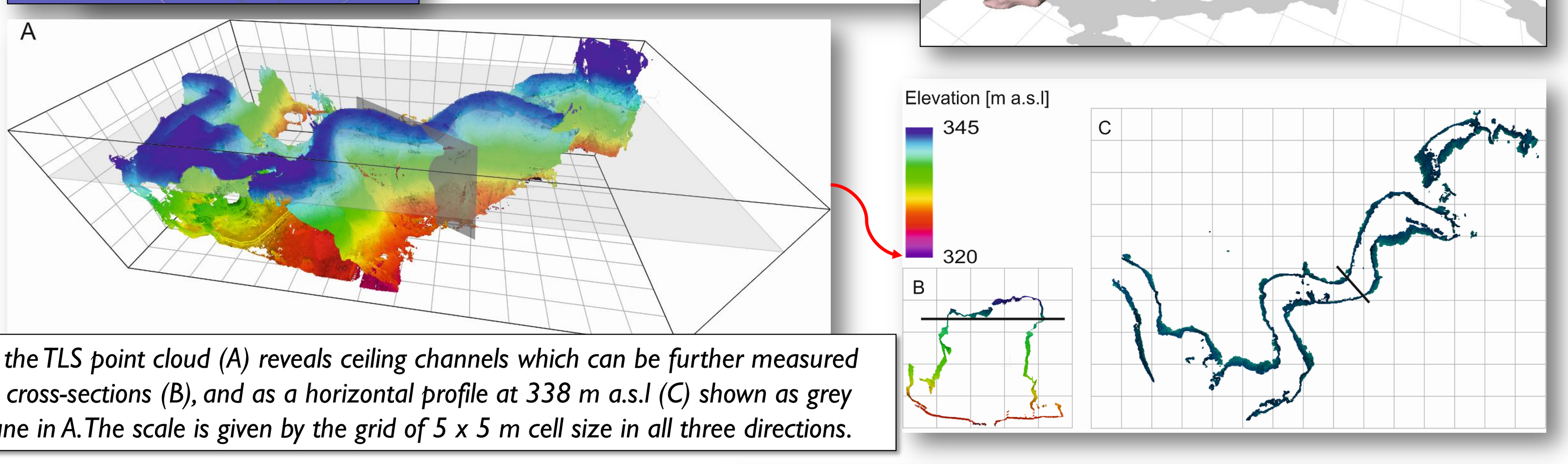


3D cave surface model with orthogonal silhouette projections. Background grid cell size 10x10 meters.

Mean curvature of the 3D cave surface highlights distinct morphological features.

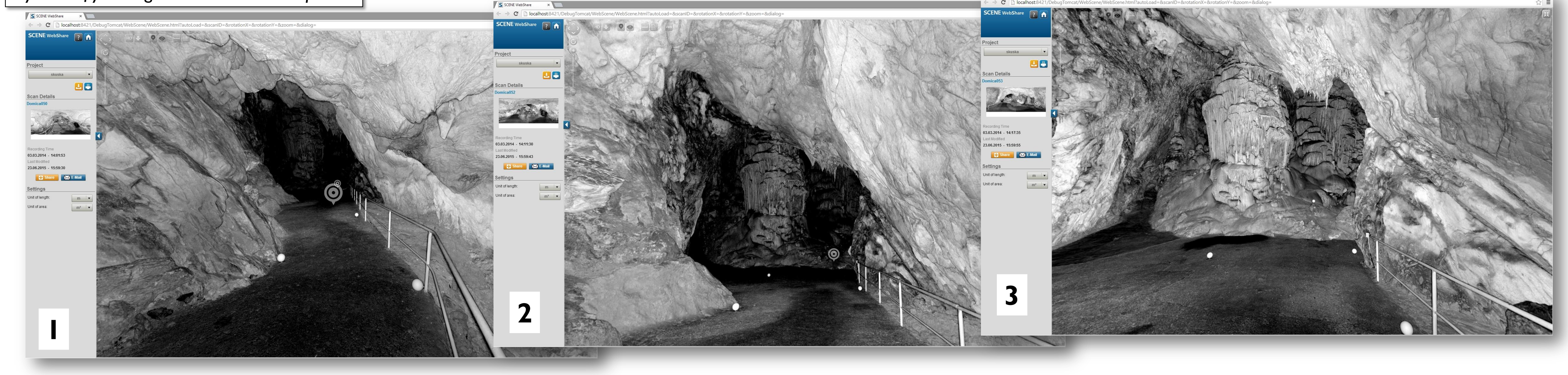


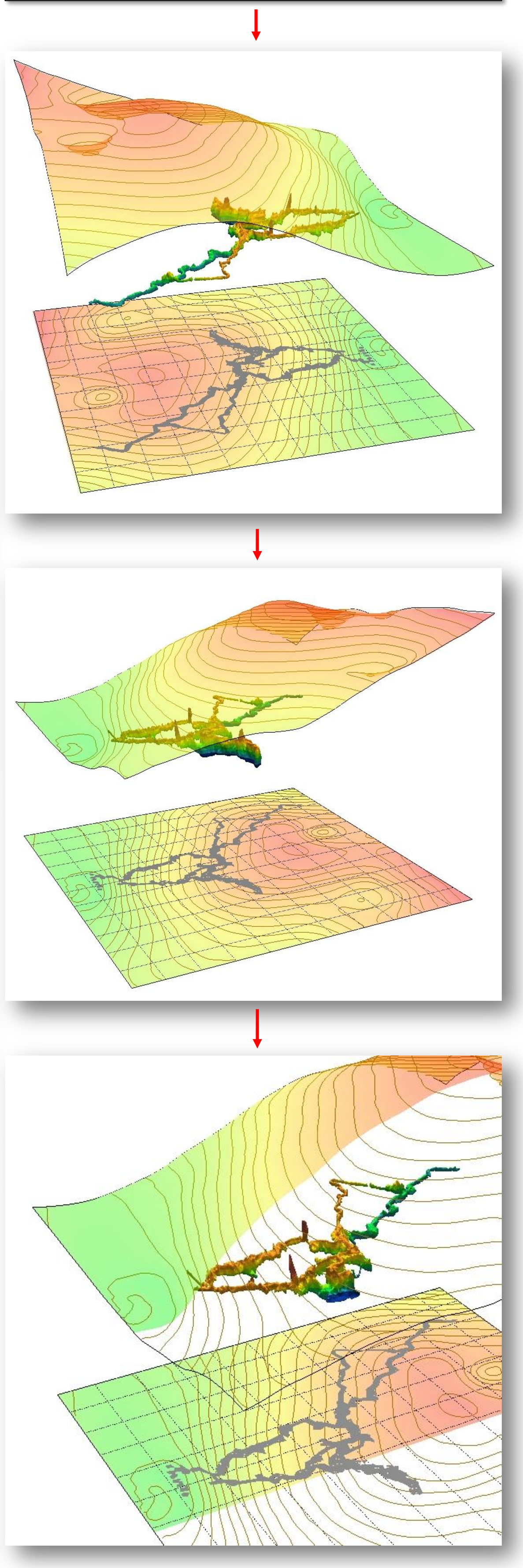
Passage with tectonic cavities



Colorizing the TLS point cloud (A) reveals ceiling channels which can be further measured as vertical cross-sections (B), and as a horizontal profile at 338 m a.s.l (C) shown as grey cutting plane in A. The scale is given by the grid of 5 x 5 m cell size in all three directions.

Dynamic fly-through towards Samson's pillars





Vertical cross-sections of the 3D landscape model enable studying relationships between the underground and the surface above.

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