Extended TOBIA model for the assessment of deep-seated geological induced landslides

Andrea Werner1 Philip Sußer1 Tim Schürmann1 and Fieder Enzmann1

1Institute for Geosciences, University of Mainz, Germany (*correspondence: werner@uni-mainz.de)

Introduction
Slope stability is connected to different kind of conditioning factors2. Past studies have shown that geological and structural settings play an important role in controlling the occurrence of landslides. The geometrical information of bedding planes such as dip angle and dip direction are usually obtained through geological field mapping. However, mapping information for larger areas is resource intensive and time-consuming. This restricts the possibility of using bedding and structural data for the assessment of landslide susceptibility. The wide availability of computer-based methods and digital elevation model data offers new opportunities in structural terrain analyses of large regions.

Methods
Semi-automatic method to extract information on the orientation of bedding planes through the visual interpretation via high-resolution digital terrain models (HRDTM) in which geological settings are perfectly visible by eyes in universal Hillshades.

Morpho-Line Concept
Uses HRDTMs to digitalize bedding traces which are characterized by clear edges of terrain and elevations which repeat periodically in one direction (Fig. 1). To model locations without MLs and validate the calculated bedding orientations field measurements were carried out in selected areas.

Calculation of bedding attitude
A Matlab Script calculates dip and dip direction with the error deviations ε and RMSE by means of the plane equation. It interpolates planes from point data (x,y,z) using the least squares fitting method. After that, the normal vector (\( \vec{n} \)) is calculated from this plane. Then dip and dip direction are derived from \( \vec{n} \) (after Santangelo et al., 2015).

Interpolation of bedding orientation
To interpolate digital and field measurement data into the area, the “accumulated cost” module in SAGA GIS was used. This method takes valleys and faults (breaklines) into account when interpolating bedding orientation values. The Accumulated Cost (AC) tool provides a layer that allocates dip and dip direction to polygons considering borders of and within a grid (Fig.3).

Conclusion
Digital and classical methods were used to investigate the relationship between the bedding orientation and the topography and its influence on landslide susceptibility.

The extended TOBIA model is used to establish the relationships between bedding orientation and the spatial position. Thus the original classification does not give any information about the angular relationship between bedding layer and slope. This requires an additional classification of orthoclinal slopes, which was integrated and tested in the extended TOBIA model. The chord length (L) and the angle difference of slope and dip was used to further classify the orthoclinal slopes....

References

**Figure 6** shows that the proportion of deep-seated LS in cataclinal slopes is over 50%. The anclinal slopes only cover 8% of landslide area and orthoclinal slopes cover almost 40%. When looking at the subclasses, 30% of the cataclinal class are dip slopes. For the orthoclinal class the cataclinal trends like dip and overtopping slopes, have the highest percentage (12%).

**Acknowledgments**

Extended TOBIA model for the whole pilot area. With overlay in (a) are one of the biggest deep-seated landslide area in that area.

**Tobia**
- **CAT**: unmarked
- **CAT-OCL**: unmarked
- **CAT**: dip
- **CAT-OCL**: dip
- **AVA**: undisturbed
- **AVA-OCL**: undisturbed
- **Landslides**: unmarked
- **Breaklines**: faults
- **Topographic Edge**: slope
- **Topographic Edge**: aspect
- **Topographic Edge**: attitude of the terrain

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