Introduction

Qualitative interpretation of anomalous potential fields (gravity, magnetic) by means of various “edge detectors” gives valuable and important information in the process of detection of lithological contacts and tectonic structures in lateral dimensions. Various ratios of higher derivatives of anomalous field are widely used as edge detectors (good overview can be find e.g. in Pilkington and Keating 2010). On the other hand, among these methods during last years, also became popular approaches based on the analysis of the curvature properties of the potential fields (e.g. Cevallos 2014; Li 2015).
In this contribution, we present results obtained by means of a new approach (Dirstein et al. 2013) of anomalous field geometrical properties analysis and its comparison with other standardly used edge detectors on one synthetic model and a real world dataset (Bouguer anomaly field, evaluated for a selected part from the regional gravity dataset in Slovak Republic in the scale 1:25000).

Method description

Potential fields (e.g. Bouguer gravity) can be considered to have a form of a surface. Methods for surface analysis are described in Differential geometry. One of the basic properties of a surface is curvature. Complex characterization of surface normal curvature is effectively given by so called Dupin’s indicatrix. It describes values of curvature of all normal sections of a surface at a particular point. This descriptor is valid for every regular point at its infinitely small environment (Krcho 2001). However, methods defined in differential geometry are suitable for continuous surfaces only. Digital representation of a surface in form of discrete set of numbers is not differentiable. This makes all apparatus of differential geometry impossible to apply directly for analysis of a digital surface.
Presented approach is respecting theories of differential geometry but rather than direct application of differential geometry formulas it uses digital geometry and numerical methods. Key moment is calculation of Dupin’s indicatrices (Figure 1) for every discrete point of a digital surface. This enables calculation of all normal curvatures for the whole surface. Principal curvatures and gradient-related curvatures are then used to extract features from the analysed surface. All features are stored in a geo-database for further data-mining and interpretation process. Multiple geometric and morphometric attributes are calculated for every object enabling selection of objects based on combination of different criteria or spatial relationship. Detected objects are automatically extracted and analysed on several “levels-of-detail” providing so called “multi-scale” information (Dirstein et al. 2013).

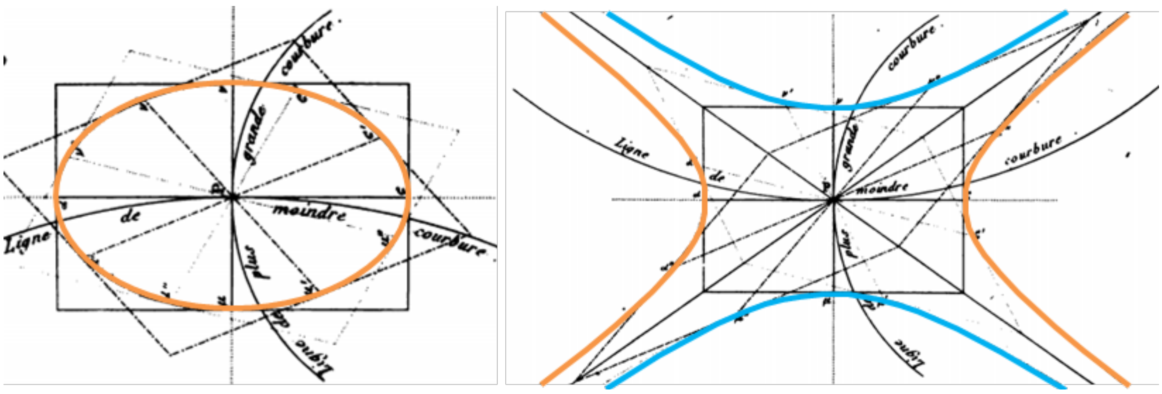

Figure 1 *Dupin indicatrix (D.I.) is a local descriptor of surface shape. Elliptical D.I. (left) is associated with convex and concave areas, double hyperbola characterizes mixed convex-concave areas (modified after Dupin 1813).*

Synthetic model example

To present the excellent detection properties of the presented method for the determination geometric properties of digital surface, we have selected following synthetic model study. Model describes a typical geological situation – a deeper seated density structure is plunged below a shallower one (Figure 2). To solve such a situation is always a great challenge for common methods for qualitative interpretation of anomalous gravity field – to determine the edge of the plunged body in the area of the shallower structure. All numerical derivatives evaluation (entering into standard edge detectors) has been evaluated in the Fourier spectral domain using the regularized derivatives approach (Pašteka et al. 2009). As it can be seen in Figure 2, horizontal gradient, tilt-derivative and "cos(theta)"-derivative (and also other transformations, not shown here) have quite nicely defined the outer boundary of the complex of both bodies, but the right-hand edge of the plunged body left uncovered. On the other hand, analysis of concave/convex features was able to detect this edge indirectly – it is defined by the boundaries of the determined local concavity area (Figure 2, bottom-right hand map).

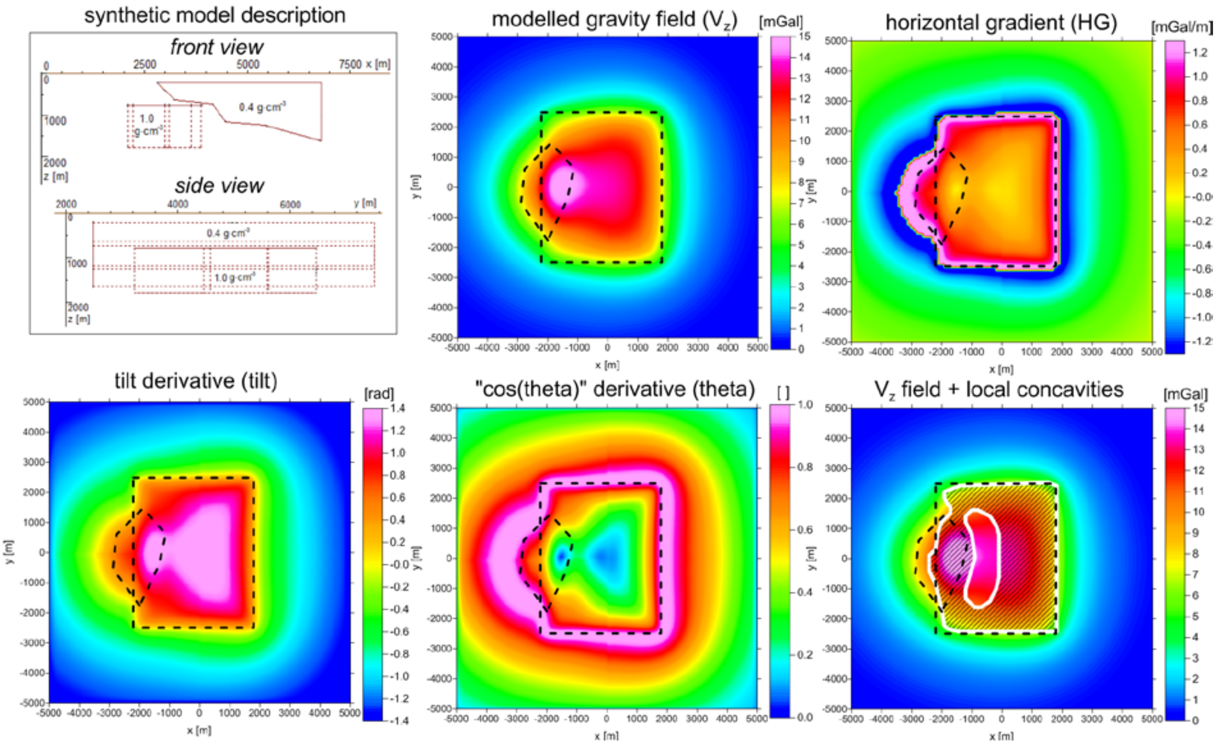

Figure 2 *Interpretation of synthetic gravity field V_z for a model of two polygonal prisms (modelled by means of POTENT 4.11.6 software) by means of standard edge detectors and presented concave/convex features analysis – filled polygon with white colour boundaries in the bottom-right hand figure defines the area of local concavity. Dashed black colour polygons plot the planar view of the tested synthetic model shape.*

Case study – Bouguer anomalies qualitative interpretation, SW Slovakia

As a real world case study we present here results of the qualitative interpretation of regional Bouguer anomaly field (average acquisition points density in this area is 2-5 points/km^2) in the area of Slovak Republic (Pašteka et al., 2014), where we have focused on its SW territory, build by the Danube Basin region. Danube Basin is the NW part of the Central European Panonian Basin System. Interpreted territory is in its northern part bounded by Western Carpathians core mountains composed of pre-Alpine Tatric basement with Mesozoic sedimentary cover and mostly carbonatic nappes of the Fatric and Hronic thrust systems (Figure 3, upper-left hand figure, modified after Lexa et al., 2000). Tectonic development of the Danube Basin has a multistage character – combining Neogene lateral tectonic movements together with thermal subsidence. Average depths of the pre-tertiary basement in the central part are about 1 - 3 km (Hrušecký, 1997).
Results of the qualitative interpretation of the anomalous gravity field by means of classical edge detectors (selected are displayed in Figure 3) show a complex pattern of the whole area, mainly the lateral boundaries of three Tatric units in its northern part, but also few low amplitude features in the space of Danube Basin itself (in southern part). Results of the presented analysis of concave/convex features of the field brought more detailed figure, emphasising a great number of low amplitude features (Figure 3, central row, right-hand figure, polygons with brown colour boundaries) – in this case slopeline concavities are displayed.

Here we have selected an interesting structure of a buried Neogene stratovolcano (Kráľová) in the southern part of the basin – covered by approx. 2 km of sedimentary filling. This geological object was detected by drilling one well, one 2D reflection seismic profiling (MXS2/92) and it is well visible in the anomalous magnetic map (Figure 3, central and bottom rows) (Hrušecký, 1997).

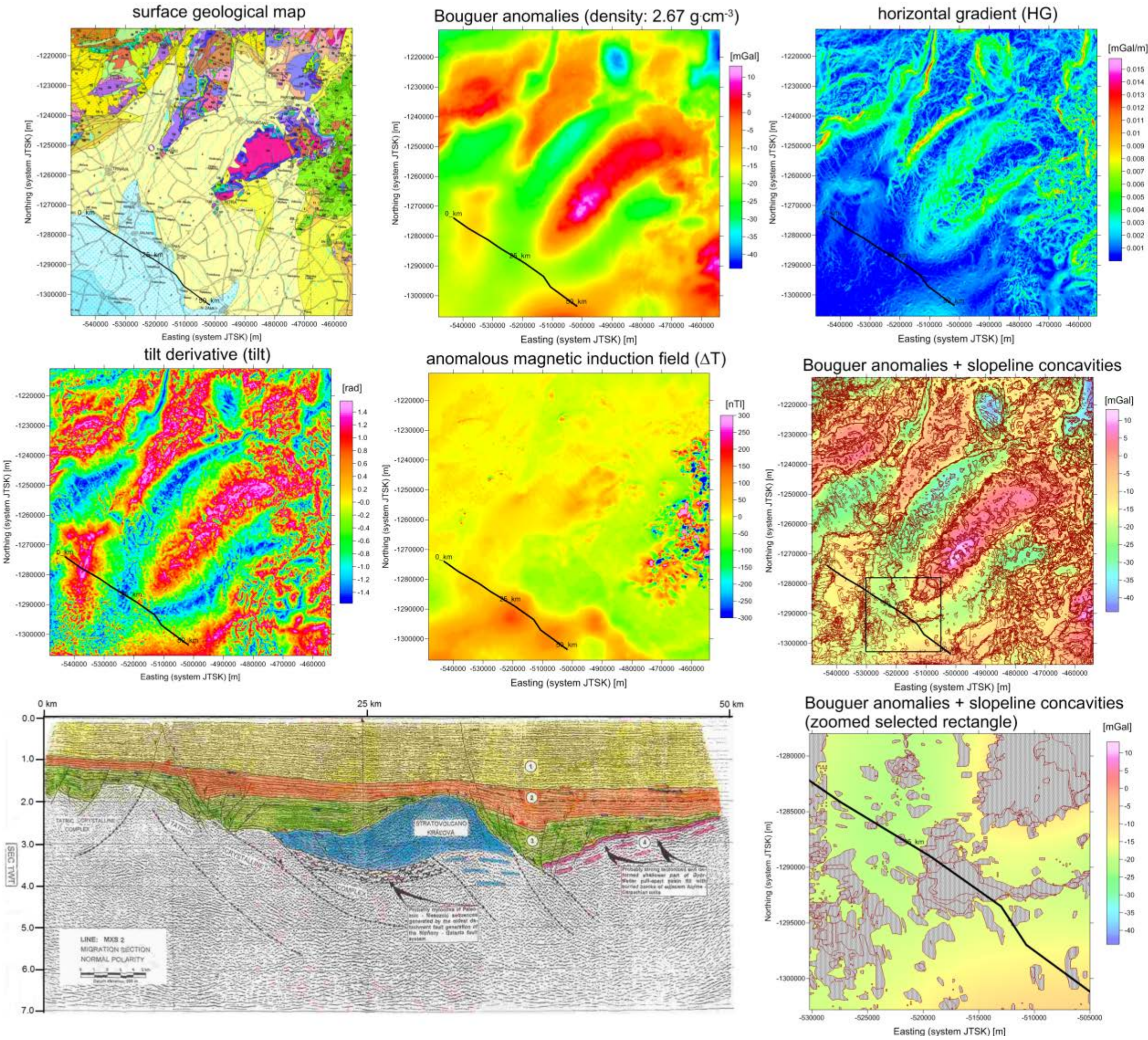

***Figure 3** Interpretation of a selected part of Bouguer anomaly field from the Danube Basin region by means of standard edge detectors and presented concave/convex features analysis. Interpreted structure in focus is the buried Kráľová stratovolcano (zoomed in the in the bottom-right hand figure), detected by drilling one well, one 2D reflection seismic profiling and in anomalous magnetic map. Interpreted time section of seismic reflection profile MXS/92 is shown too (with its position on maps).*

Anomalous pattern of the buried Kráľová stratovolcano structure cannot be seen in the standard Bouguer anomalies visualisation (Figure 3, upper row, central figure) and this is valid also for the used classical edge detectors (here are shown horizontal gradient and tilt derivative). On the other hand, its magnetic character is well presented in the anomalous magnetic field (Figure 3, central row, central figure). Results of the presented new analysis of concave/convex features have identified several important objects – here defined as closed polygons (with all recognized levels-of-detail), defined by the slopeline concavities as boundaries (zoomed area of interest is displayed in Figure 3, bottom-right hand map). Received result is very valuable. The lateral distribution of the detected polygonal objects has a complex pattern and can be interpreted as the areal shape of the volcanic complex. This fact can be checked by a reinterpretation of older geoelectric datasets (deep DC soundings) in this area (not realized yet). There are many other features in the analysed concave/convex features of the interpreted Bouguer anomaly map, but there is no space in this abstract to describe them all (this is planned to be given in our presentation).

Conclusions

Presented results show great potential of the concave/convex features analysis, based on the evaluation of the Dupin's indicatrices. Comparison with the standardly used edge detectors in potential fields interpretation shows its larger sensitivity to the recognition of small amplitude parts of the interpreted anomalous field. Our example with the buried volcanic complex below a sedimentary filling is a good example – this approach can be effective also in the detection of salt-tectonics units and in other small scale non-structural oil/gas traps recognition. Very important fact (not mentioned yet) is that the presented algorithm is fully automated and objective and outputs are vector objects (not raster format, like in standard edge detectors) – this is a great advantage in processing of large datasets. One of the "by-products" of the presented method are values of stabilized lateral derivatives (connected with the estimated gradient-related curvatures), which can used in various other interpretation approaches.
Beside objective qualitative analysis (edges and objects detection) there is a large space for the introduction of these results into the area of quantitative interpretation of potential fields.

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