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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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APPLICATION OF ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT) IN THE STUDY OF VARIOUS TYPES OF SLOPE DEFORMATIONS IN ANISOTROPIC BEDROCK: CASE STUDIES FROM THE FLYSCH CARPATHIANS

Abstract. Electrical Resistivity Tomography (ERT) has become one of the most applied and user-favourable geophysical technique in geomorphological research. Multiple character of the technology using various electrode arrays significantly reduces measurement time and is suitable for applications even in hardly accessible mountain areas. ERT can be used for various problems concerning slope deformations and accompanying landform assemblages. Our study shows that the best results are obtained in sites with high resistivity contrasts in subsurface environment associated with e.g. changes of lithology or ground water conditions. Good results, which significantly extrapolate geomorphic and speleological investigations, were obtained in elevated gravitationally spread ridges with the presence of crevice-type caves. Resistivity soundings in such settings bring a new insight into the internal structure of deeply disrupted mountain ridges. Very promising seems to be also delimitation of bodies of active, water-saturated landslides or lacustrine deposits behind landslide dams. On the other hand, some problems with the interpretation of ERT record are associated with the study of internal structure and depth of old inactive landslides situated in relatively homogenous flysch layers. Although ERT sounding results must be interpreted critically, they always shed some light on the internal characteristics of slope deformations and in combination with other methods they create a reliable base for the analysis of so far unrecognized features of slope deformations.

Key words: geophysics, Electrical Resistivity Tomography, geomorphology, slope deformations, anisotropic bedrock, Flysch Carpathians

INTRODUCTION

Geoelectrical techniques belong to the most applied geophysical methods in a broad spectrum of environmental studies (e.g. Duras et al. 2005; Maillet et al. 2005; Soupios et al. 2006, etc.). Electrical Resistivity Tomography (ERT or DC-tomography) has recently become the most frequently used geoelectrical application for geomorphological purposes due to its relative simplicity and time effectivity. This technique was used for the investigation of morphotectonics (Suzuki et al. 2000), weathering studies (Beauvais et al. 2006), fluvial geomorphology

(Maillet et al. 2005), permafrost detection (Hauck and Kneisel 2006) or exploration of underground karst structures (Zhou et al. 1999). ERT seems to be especially suitable for the identification of depth and internal structure of various types of slope deformations (e.g. Batayneh and Al-Diabat 2002; Lapenna et al. 2003; Bichler et al. 2004; Lebourg et al. 2005; Drahor et al. 2006; Perrone et al. 2006; Sass 2006; Sass et al. 2008; Van Den Eeckhaut et al. 2007, etc.). In comparison with ground penetrating radar and seismic reflection Schrott and Sass (2007) consider ERT to be the most successful geophysical method for the study of internal characteristics of active and dormant landslides.

Slope deformations are extremely abundant features in the region of the Flysch Carpathians (Starkel 1997). However, their internal structure and depth remain usually enigmatic features (see e.g. Margielewski 2006) and most cross-sections describing deep-seated landslides in this region are based only on tentative, surface-related investigations (e.g. geomorphic mapping). The aim of the presented study is to show ERT advantages and limitations when studying the structure of various types of slope deformations and their accompanying landform assemblages. The study is based on numerous ERT measurements which were performed on slope deformations in mountainous regions of the Czech and Slovak parts of the Flysch Carpathians.

METHODOLOGICAL BACKGROUND

ERT method, which belongs to geoelectric, geophysical methods, is based on the application of electric current into analyzed bedrock and measurement of the intensity of electric resistivity to its conduit. Basically, it gives us information on electric resistivity properties of analyzed material towards passing electrical current (Lazzari et al. 2006; Sass et al. 2008). This data collection is realized by means of 4 electrodes localized in a line (Fig. 1). Two end electrodes emit electric current whose run in the bedrock has character of a part of arc of a circle. The other two electrodes, localized between the emitted electrodes, measure the bedrock electric resistivity in a certain point under the surface (Sass 2006; Schrott and Sass 2008). In this way measurement of all possible combinations of electrodes in the profile is carried out automatically while the function of individual electrodes changes as emitting and measuring functions alternate. This measuring algorithm, called Schlumberger, is the most commonly used in geomorphologic applications at the present time (Schrott and Sass 2008). Its application is especially recommended in the research of horizontal structures (e.g. alluvial plain), however, its use brings quality results also with regard to vertical structures (e.g. tension cracks) (Drahor et al. 2006). Absolute maximal depth in which we are able to measure electric resistivity is theoretically given by maximum spacing of emitting electrodes. The absolute depth can approximately be determined if the length of the continuously measured profile is divided by

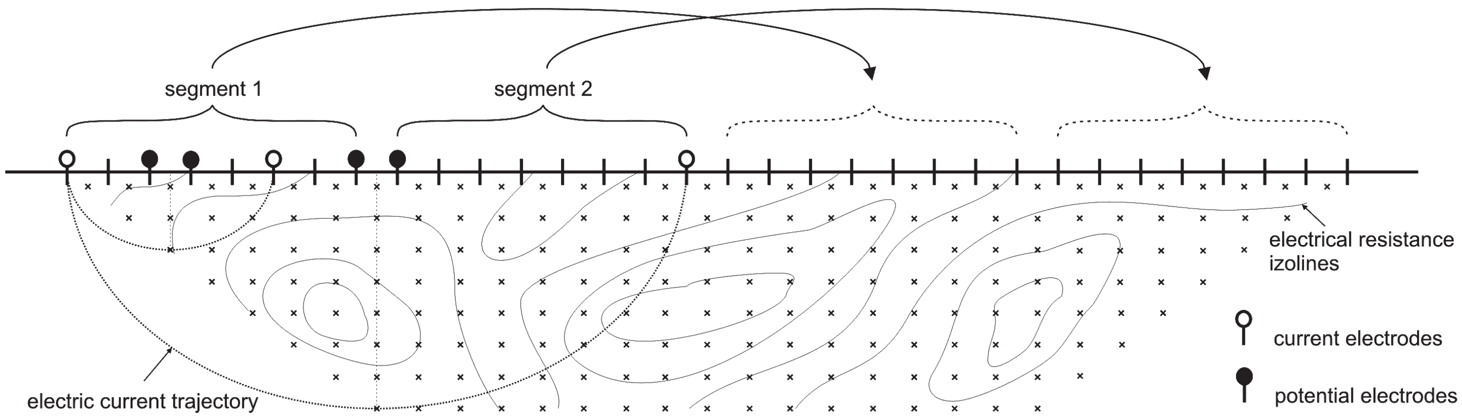

Fig. 1. Schema of configuration electrodes by Schlumberger array

5 to 6 (S a s s 2006; S a s s et al. 2008). The so-called multielectrode set consisting of a random number of segments is used in terrain measurement. One segment of this set contains eight electrodes connected by the so-called multicore-cable in the distance of about 5.5 m. The constant distance interval between electrodes can range from a few centimeters to a maximum value of 5 meters depending on desired details of the research results — the smaller the distance, the more detailed record (S c h r o t t and S a s s 2008). Field measurement provides us with a field of resistivity point values in different levels below the surface. These values are directly recorded by the measurement station and simply converted to a PC for further processing by Res2Dinv Software (B e a u v a i s et al. 2007). The data processing consists in the creation of the inversion of the measured data in order to determine bedrock resistivity features (S a s s 2006; S a s s et al. 2008). Within the software resistivity point values are interpolated and recalculated data are visualized as isolines. Right record interpretation is based on the addition of the data on topography. Without this step, the result may be greatly deformed and does not reflect real resistivity values of the researched rock environment. Since the very landslide area is characterized by broken relief, the risk of wrong interpretation is much higher than in the case of flat relief.

CASE STUDIES

ERT measurements realized in this study comprised typical geomorphological situations commonly related to slope deformations in mountainous areas. They usually involve the problematics of the depth, internal structure, degree of activity, possible lateral continuation of failures and deep structure of rock mass which is affected by a particular slope failure. Although more than 40 measurements were made on various types of slope failures, the following chapters deal only with the most prominent examples. All ERT measurements used Schlumberger electrode array with various spacing (usually 3–5 m). It enabled reaching the depth of roughly 60 meters in the central parts of some measured sections. If possible, obtained results were verified by other geophysical methods, boreholes or at least by published geological reports.

IDENTIFICATION OF DEPTH EFFICIENCY OF LATERAL SPRAEDING ON ELEVATED MOUNTAIN RIDGES

The ridge of Čertův mlýn (1,206 m a.s.l.) is situated in the highest part of the Moravskoslezské Beskydy Mountains. The elevated ridge is oriented in the N–S direction and consists of up to several-hundred-meter thick, tectonically weakened Godula sandstones intercalated by several-centimetre-thick layers of claystones (Silesian unit) (M e n č í k et al. 1983). The ridge is broken by several parallel depressions (up to 100 m long and 4 m deep) indicating lateral spreading and/or toppling mechanism. Several entrances to shallow (up to several meters deep) crevice-type caves are situated on the bottom of trenches (Wagner et al. 1990). Spreading of the ridge takes place preferentially along faults of NNW–SSE and N–S orientations (Krejčí et al. 2002). The whole western slope of the ridge is affected by a large compound deep-seated landslide (750 × 600 m) where Wagner et al. (1990) described two vertical, up to ~30 m deep crevice-type caves.

ERT measurements (4 profiles) were performed across the spread ridge with the aim to recognize the depth efficiency of gravitational spreading of the ridge axis and verify a possibility of relation between deep crevice-type caves on the western slope and ridge-top trenches (Fig. 2). The distribution of resistivity values correlates well with morphological observations. Tension cracks on the ridge are associated with nearly vertical, 25–30 m deep sectors of high resisitivity values (>2,500 ohm · m). These high-resistivity anomalies are observable also in a section situated off the main depression, which can serve as evidence of incipient subsurface progradation and gravitational widening of discontinuities without morphological expressions (Fig. 2B — see the lowermost section). The observation furthermore indicates (by sectors with >5,000 ohm · m) possible continuation of crevice-type caves on the ridge to deeper levels (at least 20 m) that was previously assumed (Wagner et al. 1990). The largest cross-section verifies a possibility of connection between structures situated below the ridge axis and on the western, landslide affected slope (Fig. 2A). This is likely the result of landslide-derived unloading of the upper part of the western slope which has caused stress relaxation and opening of tectonically predisposed fractures above the landslide area.

VERIFICATION OF A CREVICE-TYPE CAVE

The character of this study resembles the above-mentioned investigation. The target was the adjacent area of the Cyrilka Cave (situated in the Pustevny Saddle in the Moravskoslezské Beskydy Mountains) which is the longest crevice–type cave in the Czech part of the Flysch Carpathians (length is more than 370 m according to Wagner et al. 1990). The cave is situated just above a large translational slope deformation of dimensions 1 × 1.2 km. Unlike the previous study, Cyrilka Cave developed in a narrow tectonic zone of the orientation of NNE–SSW, which has, according to Klimeš and Stemberk (2007), character of a sinistral strike-slip fault disturbing rigid, monoclinally inclined sandstones of the Godula Formation (Silesian unit) (Menčík et al. 1983). The cave has character of predominantly narrow (usually up to 1 m wide) horizontal passages. Morphological expression is connected with the presence of shallow grabens following the tectonic zone, but of less conspicuous character than in the Mt. Čertův mlýn Ridge. The aim of ERT sounding was to test whether such a narrow structure can be identified on the resistivity record.

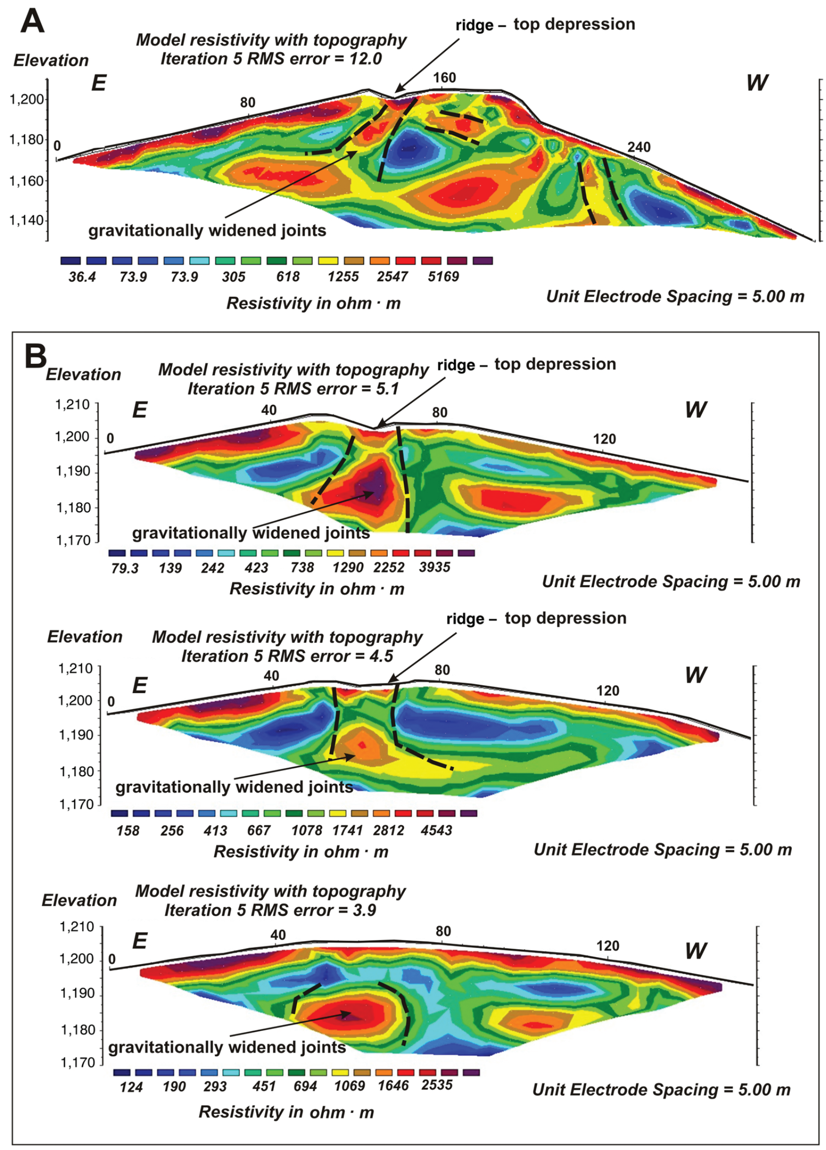

Fig. 2. Results of ERT measurements in the ridge area of the Čertův mlýn Mt (1,206 m) in the Moravskoslezské Beskydy Mountains. Figure A shows the longest section (with the deepest penetration) localized roughly in the central part of the disrupted ridge. Figures B are situated parallel to each other shifted roughly 30 m apart. Note the lowermost profile, which is situated off the morphologically expressive graben. In spite of this fact, high-resistivity zone in the depth of 10–20 m clearly indicates subsurface gravitational opening of fractures and development of crevice-type caves

ERT record clearly reveals passing of Cyrilka Cave and related fault (Fig. 3). Vertical sector of anomalously high resistivity values (>1,000 ohm · m) is laterally bounded by rock mass with ~55 times lower electrical resistivity. Clearly vertical

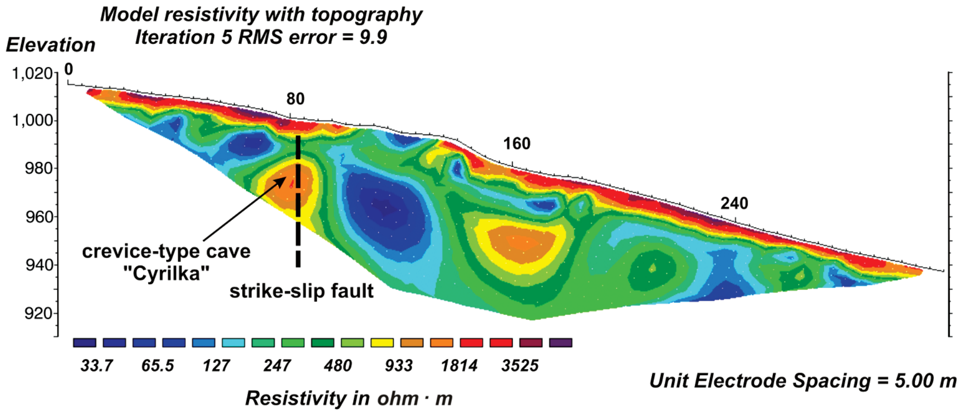

Fig. 3. ERT section across a tectonic zone which predisposed the development of the crevice-type Cyrilka Cave (Pustevny Saddle, Moravskosleyské Beskydy Mountains). Note that the profile is situated roughly 50 m off the entrance to the cave; despite this shift, its structure is very clearly visible in the resistivity record

borders between the structures point out tectonic nature of the geophysical anomaly. The identified structure is more than 40 m deep and reaches below the recognition of the performed ERT sounding. The result fits previous measurement on this site realized by a ground penetration radar (Klimeš and Stemberk 2007).

STRUCTURE AND DEPTH OF ACTIVE LANDSLIDE

Skalice landslide area is one of the largest (1.5 × 0.2 km) and most active systems of slope failures in the Czech part of the Flysch Carpathians. The landslide is situated on the eastern, steep (mostly >20°) slope of the Skalická Strážnice Hill (438 m a.s.l.) in the Podbeskydská pahorkatina Hilly Land (6 km SE from Frýdek-Místek town). The landslide-affected slope is actively undercut by Morávka River, which leads to chronical unloading of unstable bedrock. The deformation consists of several generations of landslides with a different degree of activation. Last reactivation accompanied by economical losses (destruction of several cottages) took place during extreme July 1997 rainfalls. Prior to this event, landslide activity was recorded in 1972 (destruction of a road) and during several phases in 19th century. Besides unloading caused by river erosion, an important precondition for the development of landslides is bedrock character. Tectonically broken sandstones, limestones and shales (mapped faults are of NNE–SSW orientation} of the Lower Cretaceous flysch of the Silesian unit are generally inclined in accordance with the slope orientation.

ERT measurements were carried out in two most active parts of the landslide area (Fig. 4). The longest section is situated in the northern part of the landslide area where the largest landslide was activated during the 1997 floods (Fig. 4A and B).

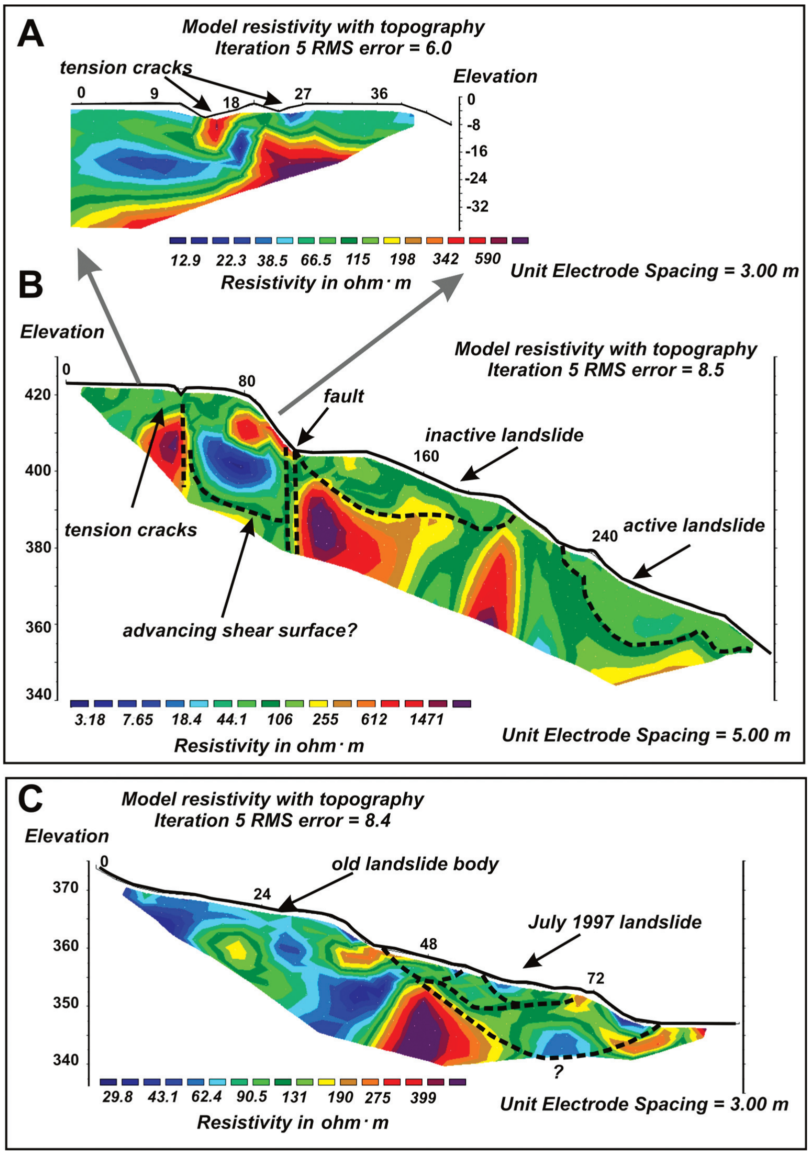

Fig. 4. ERT profiles in the Skalice landslide area (Podbeskydská pahorkatina Hilly Land). Figures A and B display the structure of the largest active landslide in this locality, whereas the uppermost section shows high-resolution ERT record of the tension zone just above the main headscarp. Figure B shows internal structure of a small July 1997 rotational landslide

Several rotated blocks with fresh tension cracks and minor headscarps are delimited at the upper part of the failure with rectilinear 15-m high headscarp. Margin of a flat ridge above the headscarp is disrupted by several active tension cracks (accompanied by crevice-type caves), up to 3-m-deep trenches and related sinkholes. High-resolution ERT measurement (3m spacing of electrodes) in the zone of tension cracks reveals up to 10-m-deep high-resistivity sectors indicating subsurface progradation of cracks and possible presence of caverns. ERT profile with 5m spacing of electrodes covers the whole slope failure including both the area above the main headscarp and the landslide body itself. Vertical electrical contrasts in the zone of tension cracks and main headscarp verify morphological observations and point out tectonic predisposition of the landslide. Rock mass below tension cracks is affected by curved resistivity boundary, which can be evidence of advancing shear surface and possible future position of the headscarp (Fig. 4B). Landslide accumulations below the main headscarp are interpreted as low-resistivity (perhaps water-saturated) bodies of the depth of 10–20 m. Shear surface follows probably the contact between thinly-bedded Těšín-Hradiště Formation overlying thick layers of Těšín limestone (high resistivity zones in the middle part of the section).

Other ERT measurements were performed on a small July1997 rotational landslide in the southern part of the area (Fig. 4C). Although resistivity record is not fully unambiguous (and is perhaps affected by dry conditions during the measurement), the rotated block frontal part at the foot of the slope and several possibly minor shear surfaces inside the slope deformation can be recognized on electrical contrasts.

ERT sounding performed in the area of the Skalice landslide area reveals deep, structurally preconditioned nature of individual slope deformations. In contrast to results obtained in the area by inclinometric measurements (Kovář, L. per. com, 2006) which detected only most shallow shear surfaces, individual landslides in the studied site seem to be segmented into several levels in various depths and are likely deeply rooted.

INTERNAL STRUCTURE AND DEPTH OF A LARGE DEEP-SEATED COMPOUND LANDSLIDE

One of the largest landslides in the Czech part of the Flysch Carpathians is a mostly inactive compound failure situated on the western slopes of Velký Stožek Mt. (978 m a.s.l.) in the Slezské Beskydy Mountains. The slope deformation includes the area of ~2.5 × 0.9 km and affects monoclinally inclined Godula and Istebna Formations of the Silesian unit (Menčík et al. 1983). Published data from a borehole situated in the vicinity of the landslide indicate a more than 100-m-thick complex of rather homogenous sandstone layers with only thin intercalations of shales. A majority of the landslide is developed on a slope conforming to bedding planes. The landslide is mostly inactive, but has conspicuous morphology with several generations of headscarps, rotated blocks and undulating topography.

One of the longest ERT profiles (435 m) covering the whole length of the slope from water divide to the adjacent valley bottom was realized in the studied site (Fig. 5). Resistivity record seems to be rather complicated, showing block nature of the slope failure, probably multiple shear surfaces and depth of the whole slope failure ~50–60 m. The landslide probably consists of two levels of failures, the up-

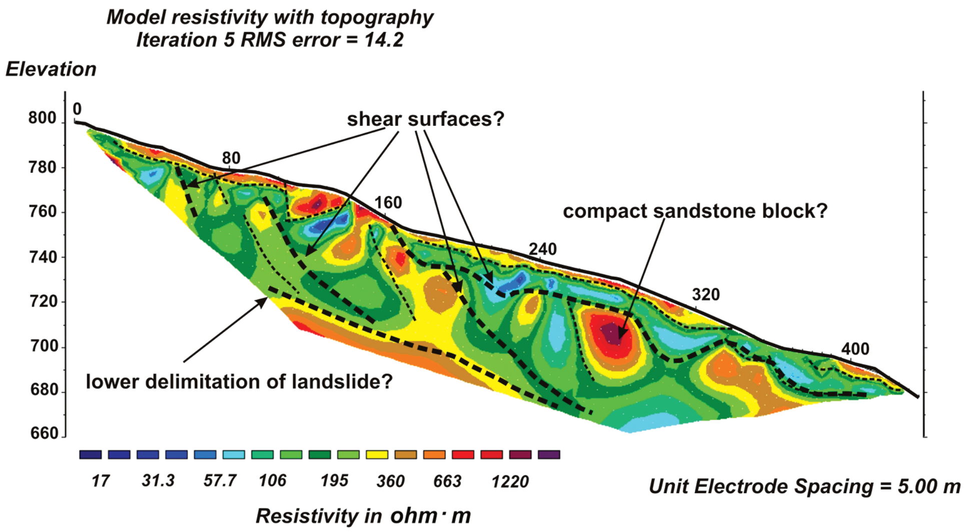

Fig. 5. ERT longitudinal profile of the Velký Stožek Mt. (978 m) compound landslide

per one of which is characterized by a low-resistivity sector (<200 ohm · m) reaching the depth of 15–20 m. However, the internal structure and resulting ERT record seem to be too complicated for a straightforward conclusion and should be verified by other geophysical methods.

DEPTH OF A RECENT FLOW-LIKE LANDSLIDE

Hluboče landslide (the failure developed between 3 and 4 April, 2006) is the largest landslide which has occurred in the territory of the Czech Republic in the last decade. The site is situated on substratum formed by claystone-dominated flysch of the Magura unit in the Bílé Karpaty Mountains. The flow-like landslide developed as a consequence of over-saturation of weathered bedrock due to intensive rainfalls and rapid snowmelt at the turn of March and April, 2006. Although situated in a mountainous area, it caused the destruction of several houses, forest road and pastures. The landslide of the length of ~770 m and maximum width of 110 m has two headscarps which overlap in the central part of the failure and under of this junction continues as a earhflow. Material situated in both depletion zones has not been evacuated yet and thus creates unstable part of the slope for potential future landslide activization. ERT measurements on this slope failure were part of more complex landslide research which was realized after the catastrophic event (Klimeš et al., in press).

The aim of ERT sounding was to infer the thickness of landslide-affected rock mass in both depletion zones of the flowslide (Fig. 6). Three profiles describing

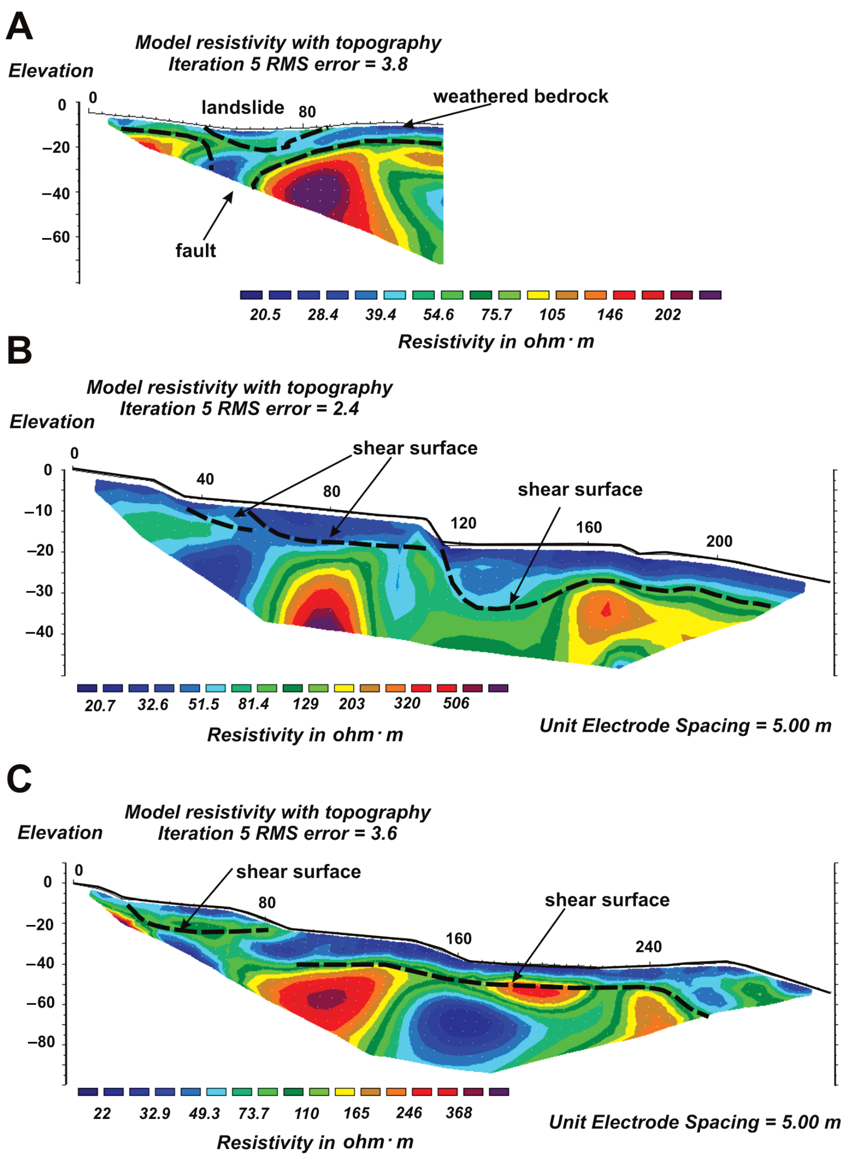

Fig. 6. Structure of depletion zones of an April 2006 Hluboče landslide (Bílé Karpaty Mountains). A — detail of a cross-section situated in the western headscarp of the flow-like landslide, B — Longitudinal section of the upper segment of the western headscarp, C — Longitudinal section of the upper segment of the eastern headscarp

longitudinal and cross-sectional characteristics of the landslide were applied. Resistivity record clearly shows the thickness and geometry of water-saturated landslide material. Low-resistivity layers (<80 ohm · m) indicate the depth of "remaining" material (up to 10–15 m) in both depletion zones (Fig. 6B and C). Cross-section through the western headscarp area furthermore indicates weathered, tectonically weakened bedrock (Fig. 6A) that is indicated by almost vertical low-resistivity zone (<40 ohm · m). The presence of such a fault-related weakened zone (with numerous springs) was expected as a main precondition factor already during geomorphic mapping prior ERT measurements.

DEPTH OF LACUSTRINE DEPOSITION IN AN ANCIENT LANDSLIDE-DAMMED LAKE

Frequently solved problems in geomorphology of slope deformations concern various types of landslide-related deposition such as lacustrine/swamp deposits in near-scarp depressions or impoundments behind landslide dams. Our case study deals with one of the most conspicuous fossil landslide-dammed lake (area of the contemporary dry impoundment is ~7 ha) situated in the Slovakian part of the Flysch Carpathians (Kysucké Beskydy Mountains in the vicinity of Oščadnica village). The lake developed as a consequence of a huge landslide which affected the whole area of the southern slopes of Kykula Mt. (1,087 m) and is nowadays reflected also in a ~50-m-high step in the longitudinal profile of the valley. The aim of ERT measurements was to provide information for further drilling works and infer information about the depth of lacustrine sequences and their relation both to the bedrock topography and the landslide body.

Three ERT profiles were localized across the former lake bottom and adjacent slopes (Fig. 7). All sections demonstratively depict topography of the buried valley bottom. Low-resistivity (<40 ohm · m) lacustrine sequences clearly contrast with the landslide material and bedrock. ERT indicates the depth of lacustrine deposits to ~10–19 m in the deepest parts of the cross sections. Furthermore, a section situated close to the landslide dam nicely shows geometry of the landslide toe which caused the valley blockage (Fig. 7C). High-resistivity landslide material consisting of large sandstone boulders is delimited in accordance to bedrock slope by low-resistivity (<50 ohm · m) shear zone (see Fig. 7C).

DISCUSSION OF ADVANTAGES AND LIMITATIONS OF ERT IN LANDSLIDE STUDIES

The study of inner structure is one of key tasks in the research of slope deformations. However, natural outcrops that provide researchers with this type of information are rarely available in geomorphologically oriented research. Therefore, other methods, both destructive (e.g. excavation pits or drilling) and non-destructive methods including a wide range of geophysical methods, must necessarily be applied (for details see Duras et al. 2005; Saas et al. 2008; Schrott and Saas 2008). Research of slope deformations in anisotropic flysch of

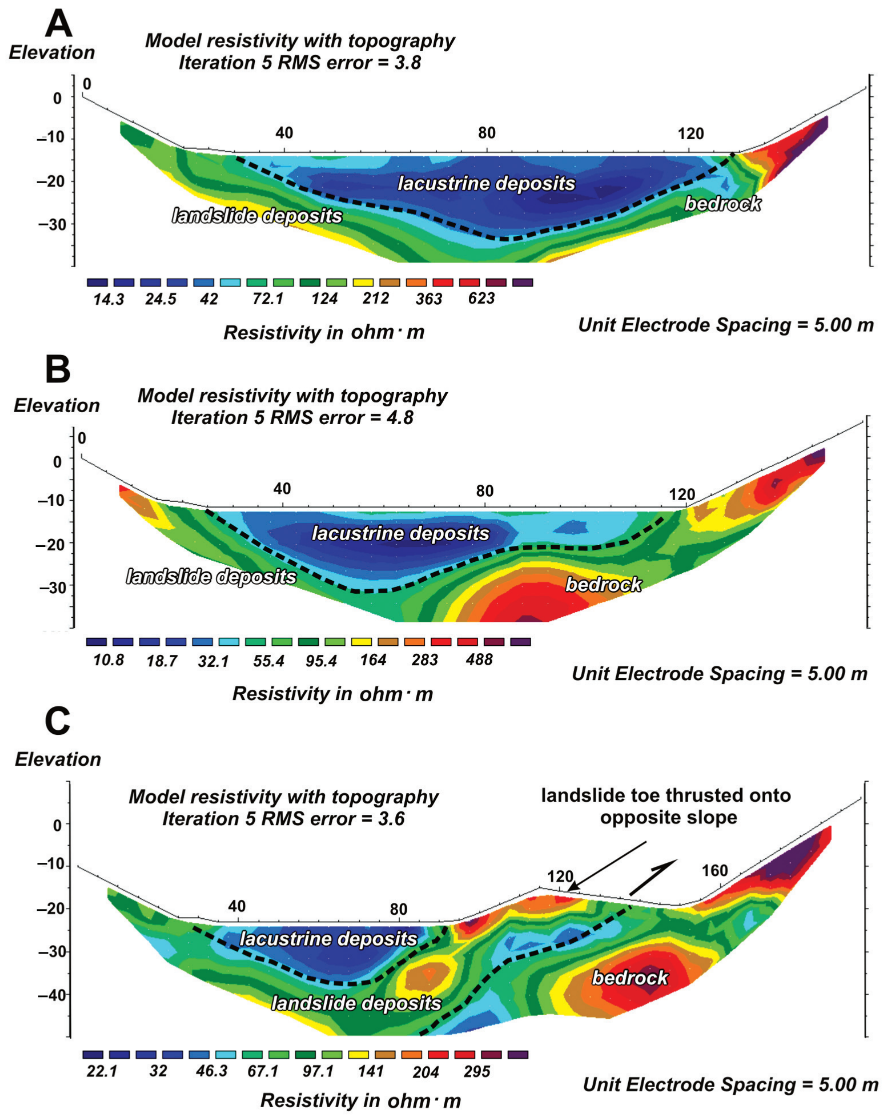

Fig. 7. Cross-sections localized at the bottom of a ancient landslide-dammed lake (Kysucké Beskydy Mountains). Figures A and B show internal structure and topography of a buried valley in the proximal and middle parts of the lake respectively. Figure C reveals the structure of the distal (near-dam) part of the landslide-dammed lake. Note the cross-section right part which clearly displays landslide toe overthrust onto the opposite slope

the Western Carpathians represents suitable environment for the application of geophysical methods, particularly ERT, as research based on natural outcrops or drilling is practically impossible or largely limited in mountain conditions.

Important issues in the inner structure study include the reach depth of a given method and details of partial structures of a slope deformation. This fact is particularly relevant with regard to the recording of potential slip surfaces. In this respect, precise identification of the main slip surface or partial slip surfaces is very problematic and it generally requires using other methods, non-geophysical methods included (compare Schrott and Sass 2008).

Well identifiable boundary lines are results of high resistivity contrasts (Schrott and Saas 2008). However, this effect may have various causes that might not necessarily be evident in the interpretation of tomographic record. Application of more methods is therefore desirable (e.g. Perrone et al. 2004). The boundary line may not be well identifiable also because intervals of measurable resistivity of various types of rock environment show considerable overlaps (Saas et al. 2008). For example Ch. Kneisel (2003) mentions clay resistivity values of 1–100 ohm · m and groundwater resistivity values of 10–300 ohm · m. Both the physical environments are typical identifiers of slip surface (Saas et al. 2008). Slip zone can show very low resistivity, however, at the same time it can be a clay layer or groundwater zone that did not necessarily function as slip surface. This fact can play a very important role in precise localization of slip surfaces in the very flysch conditions. Good contrasts show a boundary line between weathered cover and bedrock (Beauvais et al. 2007; Schrott and Saas 2008), which is a zone of rock environment instability and landslide body detachment in shallow landslides. Determination of the main slip surface is also limited by maximum obtainable depth by ERT method.

Often, only partial slip surfaces can thus be recorded. O. Saas et al. (2008) claims individual landslides blocks can be well identified and distinguished from bedrock structures in silty, comparatively wet and conductive substratum. Less contrastive environment makes drilling and inclinometric measurements the only reliable methods of the verification of geophysical measurement, on the other hand, also very costly. In the context of the case study of active Skalice landslide, ERT method application was considered to be beneficial as it revealed a much deeper slip surface of the slope instability than it was recorded by inclinometric measurement.

ERT method is limited by the presence of coarser regolith (blocky surface or large debris cover) on the surface, which does not allow optimal introducing of electric current into the bedrock. As a consequence, the resulting record can show wrong resistivity distributions that are not primarily displays of resisistivity conditions inside the rock body but technical measurement errors. This effect can appear in conditions of block fields that can accompany certain types of slope deformations (e.g. rock avalanches). In this case, the application of ERT method can be practically excluded. However, the method can be applied in heavily disrupted rock environment containing vertical or subvertical caverns or crevice-type caves. However, a good contact of surface layers with electrodes must be ensured. The occurrence of non-homogeneities in the rock body may not be evident in the georelief character and thus the very ERT method can very well identify the presence of these high resistivity structures.

Relatively easy application of the method in terrain and possibility of repeated measurement seem to be great advantage in the monitoring of active slope deformations. This fact is supported by a case of Hluboče flow-like landslide where increased water saturation of rock environment represented a critical triggering mechanism. ERT method is very effective in the monitoring of active landslides and determination of stable conditions (see also S a a s et al. 2008).

Repeated measurements and subsequent result comparison need to be accompanied by the monitoring of measurement conditions (esp. climatic conditions) which can distort resulting interpretations of slope predisposition to landsliding (e.g. F r i e d e l et al. 2006). The location of the boundary line of landsliding body and "healthy" bedrock represents very important information also for possible landslide mitigation or stabilization of the displays of active landsliding. The usefulness of ERT method for the monitoring of active landslides is thereby more than obvious.

CONCLUSION

ERT geophysical method represents a suitable tool in the research of various aspects of slope deformations in flysch structures, however, particularities of this type of geological structure need be taken into account. Important aspects of the application of ERT method in geomorphologic research of slope deformations are electrode configuration and geoelectric sounding depth. Case studies show convenience of using Schlumberger electrode array with different electrode spacing and length of profile to obtain results with required detail and depth. ERT method represents an effective tool in the research of fossil, deep-seated slope instabilities to which the occurrence of pseudokarst caves is related.

ERT method can also be used in the research of active slope deformations, in order to not only localize inner structure elements, but also monitor them. In terms of the chronology of slope deformations and role of landslides in erosion denudation processes in a basin, ERT method can be used in the study of sedimentary areas of various positions towards the respective landslide. The above mentioned suggests that ERT method is a convenient method that on the one hand brings original results, but on the other hand, needs to be verified by other methods.

In the ERT method application, right interpretation of results requires relating the results to other, mainly geomorphologic and geologic, information.

ACKNOWLEDGEMENTS

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STRESZCZENIE

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ZASTOSOWANIE ELEKTROOPOROWEJ TOMOGRAFII (ERT) W BADANIACH DEFORMACJI STOKÓW W PODŁOŻU ANIZOTROPOWYM: STUDIA W KARPATACH FLISZOWYCH

Zastosowanie badań elektrooporowych (ERT) stało się powszechną techniką w badaniach geomorfologicznych. Złożony charakter technologii, w których są używane różne zestawy elektrod, znacznie skraca czas pomiarów terenowych i są użyteczne w trudno dostępnych obszarach górskich. Są używane do rozwiązywania różnych problemów, a najlepsze wyniki uzyskuje się przy badaniach deformacji stoków górskich i zespołów form tworzonych przez te procesy.

Artykuł przedstawia najciekawsze wyniki uzyskane na obszarach, gdzie występują największe kontrasty oporności elektrycznej w podłożu, związane ze zróżnicowaniem litologicznym lub wodami gruntowymi. Dobre rezultaty uzyskano zwlaszcza w badaniach speleologicznych w obrębie elewowanych grzbietów z jaskiniami szczelinowymi. Sondowania elektrooporowe pozwalają rozpoznać wewnętrzną strukturę grzbietów górskich.

Bardzo obiecujące wydają się również studia zmierzające do określenia zasięgu stref mobilnych w aktywnych, nasyconych wodą osuwiskach lub w osadach jeziornych, po wewntęrznej stronie zapór osuwiskowych. Trudności powstają przy interpretacji zapisów ERT w starych, nieaktywnych osuwiskach, zwłaszcza w obrębie względnie homogenicznych warstw fliszowych. Pomimo potrzeby krytycznego spojrzenia na sondowania ERT, rzucają one jednak trochę światła na wewnętrzną strukturę deformacji stokowych, a przy równoczesnym użyciu innych technik geofizycznych, tworzą dobrą podstawę do badania skutków ruchów masowych na stokach górskich.