## Geophysical evidence of recent activity of the Idrija fault, Kanomlja, NW Slovenia

## Geofizikalni dokazi za recentno aktivnost Idrijskega preloma v dolini Kanomlje

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Abstract: In the Kanomlja valley NW of Idrija, previous geomorphological survey indicated a site where (sub)recent activity of the Idrija fault may be best preserved in relatively young succession of terrestrial deposits. In 2011 a set of geophysical investigations followed geological reconnaissance of the narrowest area of interest. A small alluvial plain of the Kanomlja tributary was surveyed by electrical resistivity tomography and seismic refraction tomography. The results showed remarkably clear and converging evidence of potential activity of the fault in (sub)recent time. A paleoseismological trench is foreseen at the site in late 2012 to further investigate this phenomenon.

Izvleček: V Srednji Kanomlji so predhodne geomorfološke raziskave nakazale lokacijo, kjer bi se lahko v sorazmerno mladih terestričnih sedimentih ohranila sled (sub)recentne aktivnosti Idrijskega preloma. V letu 2011 smo zato v okolici sistema teras Kanomljinega pritoka Bratuševa grapa izvedli geološki in geomorfološki pregled, ki so mu sledile geofizikalne raziskave z metodama električ-

ne upornostne tomografije in refrakcijske seizmične tomografije. Rezultati nakazujejo relativno mlado aktivnost Idrijskega preloma na tem območju. S preiskavo smo omejili območje največjih deformacij in nakazali območje verjetno najmlajše deformacije, kjer bomo pred koncem leta 2012 naredili paleoseizmološki jarek.

**Key words:** Idrija fault, paleoseismology, active tectonics, Kanomlja **Ključne besede:** Idrijski prelom, paleoseizmologija, aktivna tektonika, Kanomlja

#### Introduction

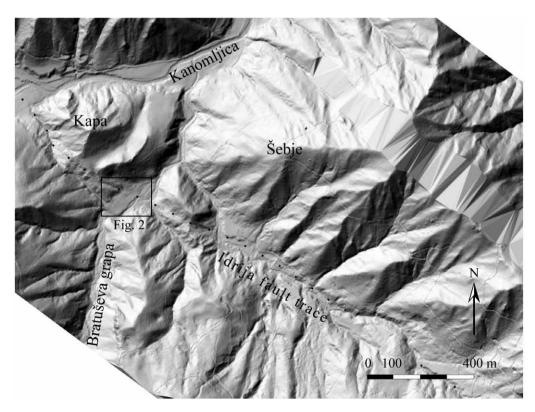
The Idrija fault is one of the most, if not the most, prominent NW-SE oriented ("Dinaric-trending") structural features in W Slovenia. It enters the country at its NW tip, passes the town of Idrija, the Planina and Cerknica karst polies, after which its trace seemingly disappears within the Dinaric thrust structures further to the south. The Idrija fault was first described by LIPOLD (1857), and its tectonic importance and its significance in seismotectonics have been investigated ever since. In the neighborhood of Idrija, the fault plane dips 65° to 75° toward the NE (ČAR, 2010). The estimated average dip along the full length of the fault is 77.5° and its maximum depth is estimated to 14 km (KASTELIC & CARAFA, 2012). The fault formed during the Miocene as an obliquenormal fault, and was reactivated as a dextral strike slip fault at the transition from the Miocene to the Pliocene (VRABEC & FODOR, 2006; ČAR, 2010). Its activity has been quantified by

several methods. From the cumulative displacement of the mercury ore body in the Idrija mine, amounting to 480 m in vertical direction and 2414 m in horizontal direction (Placer, 1982). a long-term slip-rate at around 0.5 mm per year can be postulated. 8-year continuous measurements of recent displacements with a TM-71 extensometer in the Učja valley in NW Slovenia yield average slip-rates at 0.26 mm per year with extreme values up to 0.54 mm per year (Gosar et al., 2011; ČAR & GOSAR, 2011). By modeling active fault displacements in the eastern Adriatic region using a thinshell finite element method Kastelic & CARAFA (2012) calculated slip-rates between 0.06 mm and 0.22 mm per year for the Idrija fault with 0.10 mm per year on the average.

The strongest historic seismic event on the Idrija fault might be the destructive W Slovenia earthquake in 1511 (estimated magnitude 6.8 and maximum intesity X EMS-98; Cecić, 2011). It has to be noted that the his-

toric data does not allow univocal allocation of this particular event to the fault itself (Živčić et al., 2011) and that alternative interpretations of the seismic source are also proposed for the 1511 event (Camassi et al., 2011; Košir & Cecić, 2011).

In the Kanomlja valley, 5 km NW of the town of Idrija, airborne LiDAR survey disclosed several geomorphic indicators of Idrija fault recent activity, such as displaced streams, truncated fluvial terraces, dry valleys, bent ridges, etc. (Cunningham et al., 2006). This was the first application of airborne laser scanning for the purpose of mapping active faults in Europe. Detailed geomorphic field surveying confirmed the suggestion of Cunningham et al. (2006) to focus paleoseismological study to the area south of Kapa hill (Figure 1). We conducted a geophysical survey in this area in order to investigate indications of recent activity and to find an appropriate location for paleoseismological trenching.

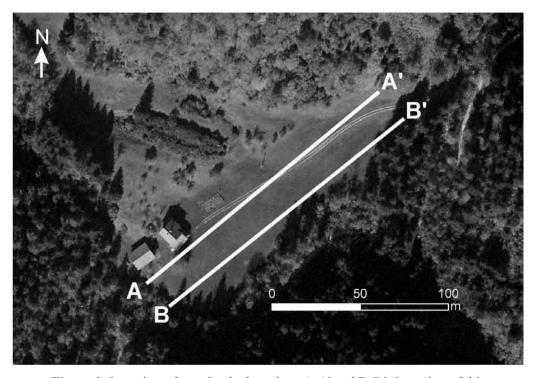


**Figure 1.** Location map on the 2 m grid Digital Elevation Model of bare ground from the LiDAR survey (Cunningham et al., 2006).

#### GEOLOGIC SETTING

By detailed geomorphological and geological mapping of the near vicinity of the target area proposed by Cunningham et al. (2006), we first defined an approximate location such that the fault trace is well expressed and where young sediments are available, for paleoseismological investigations fault deformations must be investigated in young and datable sediments. Both demands were met in the Bratuševa grapa system of fluvial terraces and its near vicinity (Figure 2 and 3). In the W part of the terrace system the Mesozoic

carbonate rocks (pre-Quaternary bedrock) outcrop along the stream channel and are covered by a thin veneer of loose terrestrial deposits of fluvial and slope mass wasting origin (young deposits). Toward the E, the bedrock does not outcrop along the stream anymore; instead the whole outcrop consists of young deposits. We infer that the fault is located where the thickness of young deposits changes from negligible to significant (Figure 4 and 5). At the same locality, the topographically best expressed fault trace crosses the system of fluvial terraces (Figure 3) and the fault probably affects their for-

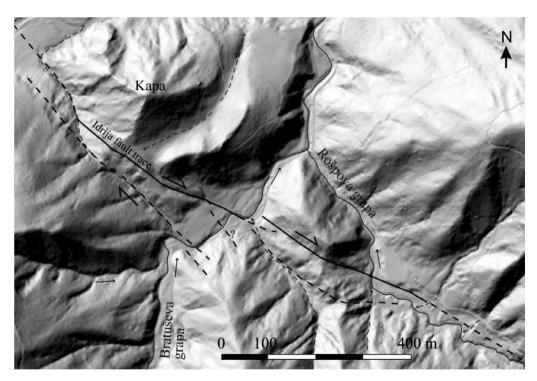


**Figure 2.** Location of geophysical sections A-A' and B-B'. Location of this map is shown as an inset in Figure 1.

mation. Additionally, a stream channel bend, suggesting a dextral offset of approx. 40 m, is located immediately to the SE of the locality (Figure 3). All these observations lead us to focus geophysical investigations to this area.

#### **METHODS**

In an attempt to better constrain the area of maximum and/or most recent deformation along the selected segment of the Idrija fault, we applied four geophysical methods along two sections crossing the inferred fault trace: electrical resistivity tomography (ERT), seismic refraction tomography (SRT), ground penetrating radar (GPR) and active multichannel analysis of surface waves (MASW). In lack of borehole data, vertical electrical sounding (VES) was also conducted in order to estimate typical resistivity of hard rock and young deposits for further use in ERT. Due to field conditions (presence of low velocity layers, clay content, ground water), GPR and MASW did not yield consistent results, therefore we describe here only results of VES ERT and SRT methods.



**Figure 3.** Outline of main geomorphic features within the Bratuševa grapa terrace system on the 2 m grid Digital Elevation Model of bare ground from the LiDAR survey (Cunningham et al., 2006).

Vertical electrical sounding (VES) was conducted using the Schlumberger array with maximum half-distance of probes AB/2 at 10–100 m. Seven VES were performed along the ERT sections and on the outcropping carbonate in the near vicinity of these sections. The measured data were inverted by using RESIXPlus software (Interpex Ltd.).

Two methodologically identical ERT sections were measured using the Wenner array. The unit probe spacing was set at 2 m and the total number of levels accomplished was 15. Each section was 190 m long (lines A and B, Figure 2). In this way we believe to achieve the requested depth penetration of 10-12 m. SYSCAL-R2 resistivity meter and compatible Multinode system (both BRGM) were used. Measurements were conducted in stable weather after a long dry period. Data were modeled by applying various 2D algorithm techniques available in RESIX2DI (Interpex Ltd.) software.

Along the same trace as the ERT, SRT sections A and B were measured (Figure 2). Geophone spacing was 2 m; shot points were selected at every 3<sup>rd</sup> geophone. An 8 kg sledgehammer with metal plate was used as a seismic source and two 24-channel ABEM Terraloc VI seismographs were used to record the signal from 4.5 Hz vertical

geophones. Relatively good signal-tonoise ratio lead to very accurate first
arrival picking and consequently to
reliable results. The elevation of each
geophone was measured in the field
with a leveling instrument for later
topographic correction. A three-layer
seismic model and velocities were
computed by Wayfront method using
Rayfract 3.19 software from Intelligent Resources Inc. Same application
was further used to compute the final
velocity model by 2D WET (Wavepath
Eikonal Traveltime) tomography.

#### GEOPHYSICAL OBSERVATIONS

# ERT- electrical resistivity tomography

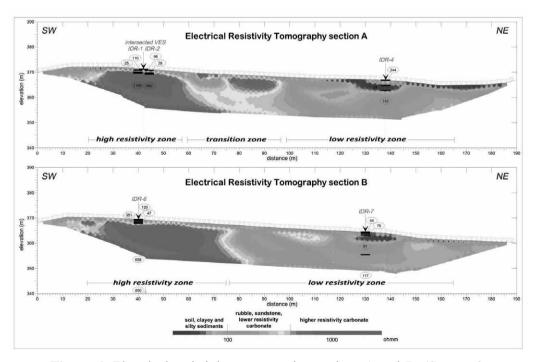
Electrical resistivity of sediments along both sections varies from few tens ohm-meters to over  $1000~\Omega$  m (Figure 4). Given the geological context and VES data, we relate modeled resistivities to three lithological equivalents: 1)  $40{-}100~\Omega$  m: topsoil, clay and silt with gravel; 2)  $100{-}400~\Omega$  m: gravel, clayey/silty gravel, sand and possibly also carbonate bedrock with more terrigenous component; and 3) >400  $\Omega$  m: relatively highly-resistive carbonate bedrock with minor terrigenous component.

Resistivity model (Figure 4) shows four distinctive units that appear in both sections:

- The surface layer (up to 2 m thick) with low specific electrical resistivity  $(40-100 \ \Omega \ m)$  is interpreted as overbank deposit of the Bratuševa grapa creek and organic-rich topsoil.
- Relatively homogenous high-resistivity unit (>800  $\Omega$  m) underlying the surface layer in the SW part of both sections and exceeding the surveying target depth of 12 m is interpreted as Mesozoic (carbonate) bedrock.
- Heterogeneous unit with patchy distribution of subunits of very low resistivity (few tens ohm-meters) and subunits of resistivity between

- $100~\Omega$  m and  $250~\Omega$  m is interpreted as a sequence of mass wasting events (landslides, sedimentary mass flows), potentially interfingered with fluvial sediments of Bratuševa grapa creek.
- Heterogeneous unit at 60–95 m in section A (missing in section B) that may resemble a faulted zone (marked as transition zone in Figure 4) within the bedrock.

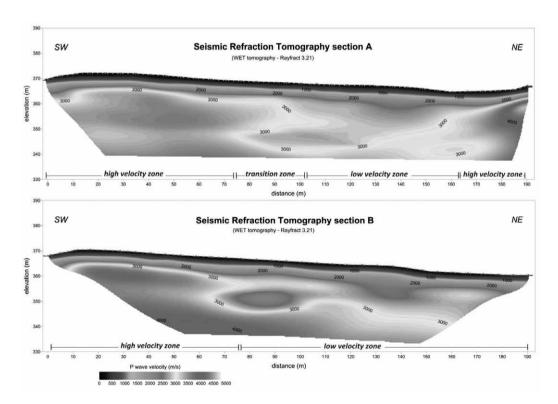
SRT- seismic refraction tomography The final result of SRT is presented on Figure 5. Atop the sections is a thin (1–1.5 m) low-velocity layer (veloc-



**Figure 4.** Electrical resistivity tomography sections A and B. (STOPAR & CAR, 2011). The main trace of the Idrija fault is inferred at between 60 m and 95 m in section A and between 70 m and 80 m in section B.

ity at around 500 m/s) that stretches along the full length of both sections. It is interpreted as overbank deposit of the Bratuševa grapa creek and organic topsoil. Underneath this low-velocity layer, the velocity increases to above 1000 m/s in a layer that stretches along the full length of both sections. The reason for this could be lithological as well as the increase in groundwater content. Below these two layers lies a layer with a significantly higher velocity (above 3000 m/s). This high-velocity layer appears close to the surface

(approx. 5 m deep) in the SW parts of both sections, but is much deeper towards the NE. A sharp change in depth of the high-velocity layer is observed between 80 m and 100 m distance in section A, and between 70 m and 80 m distance in section B. The lateral decrease in velocity observed within the layer could be interpreted as a presence of tectonically crushed bedrock, or as juxtaposition of two different bedrock lithologies. Both interpretations are consistent with the fault crossing the sections.



**Figure 5.** Seismic refraction tomography sections A and B. (Stopar & Car, 2011). The main trace of the Idrija fault is inferred at between 80 m and 100 m in section A and between 70 m and 80 m in section B.

#### Interpretation and conclusions

Joint interpretation of the two independent geophysical methods is fully consistent with geological and geomorphological observations, that indicate the presence of a recently active fault. Both methods show a significant change in geophysical properties underneath the surface layer at a depth between 1 m and 5 m. A drastic drop in electrical resistivity coincides with a drop in seismic velocities within that zone, which is only few meters to tens of meters (at most) wide. SW of this zone both sections are interpreted to consist of relatively solid bedrock covered by a veneer of gravel and overbank deposits. NE of the zone the geophysical signature is much more heterogeneous compared to the SW parts. We attribute this geophysical heterogeneity to heterogeneous lithology within the upper few meters of section. Given the geologic setting, we interpret the NW part to consist of deposits of mass wasting (consecutive landslides and/or mass flow events) that are possibly interfingered with gravely deposits of the Bratuševa grapa creek.

Geophysical surveying indicated a contact between the Mesozoic bedrock and relatively young terrestrial deposits in the area of Bratuševa grapa terrace system, which we attribute to (sub)recent activity of the Idrija fault. However, the amount of displacement

can not be inferred from these data Given the promising result we aim to continue the study by paleoseismological trenching in late 2012. According to geophysical observations, a paleoseismological trench should be located between 70 m and 100 m distance along the section A, and between 70 m and 80 m distance along the section B. A potential trenching target is also the area of low resistivity between 55 m and 75 m in the section A. However, for the final decision on a trench site, geomorphic and geologic indicators will also be taken into account in search for the youngest (and not necessarily most prominent) deformation.

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