Evidence of Quaternary faulting in the Idrija fault zone, Učja canyon, NW Slovenia

Znaki kvartarne tektonske aktivnosti v coni Idrijskega preloma pri Učji

Marko Vrabec[1, *]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geology, Privoz 11, SI-1000 Ljubljana, Slovenia

*Corresponding author. E-mail: marko.vrabec@geo.ntf.uni-lj.si

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Abstract: Above the Učja river canyon, NW Slovenia, an outcrop of poorly sorted monomict Quaternary breccia, located in the fault zone of the dextral Idrija fault, is dissected by several NW–SE oriented subvertical faults and associated fault-parallel fractures. Orientation and position of the observed faults match perfectly with one of the strands of the Idrija fault that is exposed in Mesozoic rocks on the other side of the river valley. Brittle structures in Quaternary and Mesozoic rocks are consistent with N–S directed maximum horizontal compression that is believed to prevail in the region since the early Pliocene. This is the first direct evidence of Quaternary to recent deformation along the Idrija fault. Activity of the fault is further indicated by dextral offsets of the Učja river course coinciding with the strands of the Idrija fault zone.

Izvleček: V prelomni coni desnozmičnega Idrijskega preloma nad kanjonom reke Učje v severozahodnem Posočju smo našli izdanek slabo sortirane monomiktne kvartarne breče, ki ga sekajo SZ–JV orientirani subvertikalni prelomi in vzporedne spremljajoče razpoke. Opisani prelomi se po legi in orientaciji popolnoma ujemajo z enim od prelomov notranje cone Idrijskega preloma, ki je razgaljen v mezozojskih kamninah na nasprotni strani reke. Lomne strukture v kvartarnih in mezozojskih kamninah so skladne z maksimalno tlačno napetostjo v smeri S–J, ki v regiji verjetno deluje od začetka pliocena. To je prvi

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neposredni dokaz za kvartarne do recentne deformacije ob Idrijskem prelomu. Aktivnost preloma dodatno kažejo tudi desni zamiki reke Učje ob sekundarnih prelomih cone Idrijskega preloma.

Key words: Idrija fault, active tectonics, Učja/Uccea river
Ključne besede: Idrijski prelom, aktivna tektonika, reka Učja

INTRODUCTION

The NW–SE trending Idrija fault is one of the most prominent faults in the territory of Slovenia. Along the 120 km of its trace, the fault is very clearly expressed both in topography and in geology by up to 15 km of dextral separation of geological units. Due to conspicuous geomorphic expression of the fault and its favourable orientation with respect to the regional N–S to NNW–SSE direction of principal shortening (e.g. VRABEC & FODOR, 2006; WEBER et al., 2010), the Idrija fault is generally considered to be currently active. For example, the 1511 earthquake with estimated M = 6.9, one of the most devastating seismic events recorded in the Eastern Alpine region, is attributed to dextral slip on the Idrija fault (e.g. FITZKO et al., 2005), though the source and mechanism of the earthquake remain controversial (CAMASSI et al., 2011; KOŠIR & CECIĆ, 2011). Adding to the controversy is the apparent lack of recorded instrumental seismicity along the fault trace both in map view and in cross-section (ŽIVČIĆ et al., 2011), implying no significant seismic slip on the fault at least for the last 50 years. Nevertheless, the 1998 and 2004 Posočje seismic sequences on the Ravne fault that runs parallel to the Idrija fault (e.g. KASTELIC et al., 2008) provided direct evidence that NW–SE oriented faults of western Slovenia can be dextrally activated in the current regional stress regime.

Due to the fact that the Idrija fault cuts almost exclusively through Mesozoic rock units, it is quite difficult to confirm its neotectonic activity with conventional geological methods. As a possible indicator of neotectonic deformation, the Quaternary karst poljes located along the fault were interpreted as pull-apart structures (VRABEC, 1994). A detailed LIDAR-based morphological study of a small section of the fault trace at Kanomlja in the Idrija region revealed several geomorphic features that are implying Quaternary displacements in the fault zone (CUNNINGHAM et al., 2006). The Kanomlja site was recently investigated by geophysical profiling, which provided strong indications of recent to sub-recent faulting along the fault zone (BAVEC et al., this volume).

In this paper we present field observations from the NW-most part of the Idrija fault zone, which for the first time confirm Quaternary to presumably recent faulting along the fault.

Geological setting

The roughly E–W trending, deeply incised valley of the Učja (Uccea) river is situated in NW Slovenia, close to the Bovec basin. Ther river canyon crosses the entire width of the Idrija fault zone, which makes it one of the few localities where direct observations of internal structure of the fault zone are possible. The Učja valley was mapped in detail by Čar & Pišljar (1993), who documented several fault strands and the accompanying fracture zones. In their map, the Idrija fault proper comprises three major NW–SE trending faults, which we name the Oslovo brdo strand, the Hlevišča strand, and the Žlebišče strand (Figure 1). Older fault sets, oriented predominately in E–W and N–S directions, also outcrop in the zone (Čar & Pišljar, 1993). Whereas the canyon mainly cuts through Late Triassic limestones and dolomites, two smaller blocks of Jurassic and Creta-

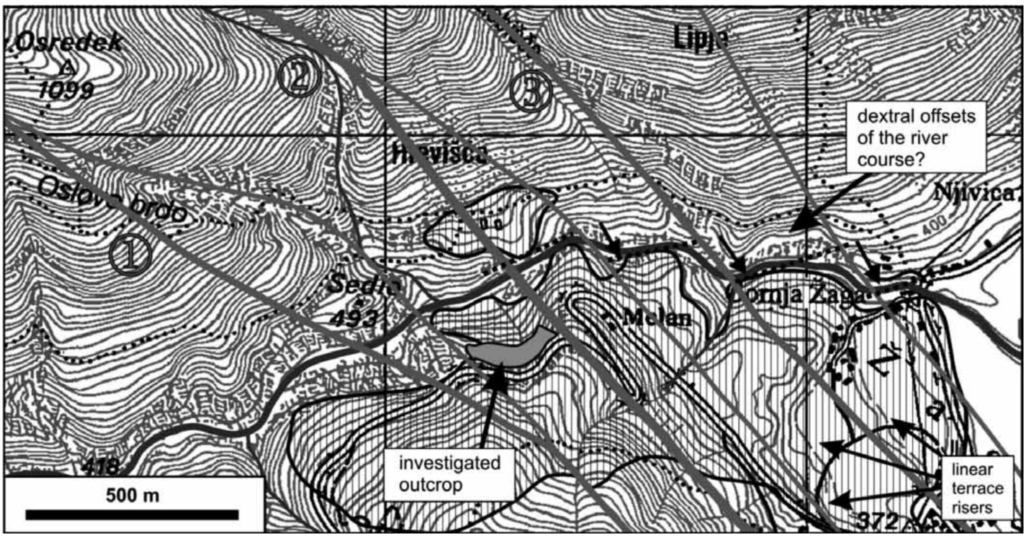

Figure 1. Geographical and structural position of the investigated outcrop in the lower Učja canyon in the central part of the Idrija fault zone. Geological data after Čar & Pišljar (1993). Hatchured areas show the extent of Quaternary sediments. 1) Oslovo brdo strand of the Idrija fault zone. 2) Hlevišča strand. 3) Žlebišče strand. Topographic map from The surveying and mapping authority of the Republic of Slovenia, National topographic map at 1 : 25 000 scale.

ceous rocks are wedged between the Oslovo brdo and Hlevišča strands (BUSER, 1987; ČAR & PIŠLJAR, 1993), indicating significant (km-scale) displacement in this part of the Idrija fault zone. Further to the NW, the Oslovo brdo strand terminates eastward continuation of a low-angle thrust of Late Triassic limestone over the Cretaceous flyschoid formation (BUSER, 1987).

In 2004, a permanent extensometer was installed on the fault plane of the Hlevišča strand exposed at the bottom of the Učja valley. The 8-year time series of measurements suggests a nearly horizontal slip with the average rate of 0.25 mm per year (GOSAR et al., 2011), but the results are currently controversial since the measured slip sense is sinistral, which is in conflict with other geologic and geodetic indicators.

The southern side of Učja valley is predominately covered by Quaternary sediments (BUSER, 1987; ČAR & PIŠLJAR, 1993; see also Figure 1). In the eastern part around Žaga village, several nested terraces in fluvial gravels and conglomerates occur. Linear terrace risers, generally following the NW–SE trend of the Idrija fault suggest possible influence of faulting on shaping of terraces. Between the Hlevišča fault strand and the Žaga village, the NW–SE oriented fault strands successively shift the E–W directed course of Učja river for 100–130 m in a dextral sense that is consistent with the Idrija fault kinematics (Figure 1). Towards the west, the steeper slopes above the terraces are covered by poorly sorted lithified breccias, interpreted as glacial drift (BUSER, 1987; ČAR & PIŠLJAR, 1993). A small, terrace-like remnant of such sediments is preserved also on the northern side of Učja at Hlevišča location (Figure 1), and additional large accumulations occur further to the west along the Učja river (ČAR & PIŠLJAR, 1993).

We examined a large outcrop of Quaternary breccia, situated below the road that follows Učja valley from the Žaga village towards the border crossing with Italy (Figure 1). The outcrop is up to 10 m high and about 100 m in length (Figure 2), and consists of poorly sorted, partly blocky breccia, containing almost exclusively clasts of Late Triassic carbonates. The monomictic nature of the breccia and its large vertical extent along the valley slopes suggest that it may have originated from slope processes rather than from glacial deposition. At the base of the outcrop the breccia is only poorly lithified, which is manifested by a prominent erosional notch (see the right part of Figure 2). Currently we have no firm constraints on the age of the breccia.

Figure 2. View of the investigated outcrop in lithified Quaternary breccia from the north. Showed is the position of faults discussed in the text.

On its western side, the outcrop is bound by a small branch of the Oslovo brdo fault strand (Figure 1), which is manifested by several parallel fault planes in Late Triassic dolomite (see for example the fault plane exposed along the right border of Figure 2). Quaternary breccia is cut by several weakly-expressed fault planes that are parallel to the NW–SE trend of the Idrija fault zone (Figure 2). On its eastern side, the outcrop extends close to the Hlevišče fault strand, but due to poor exposure no faults in Quaternary deposits could be found there.

Structural observations

We recognized four faults cutting the Quaternary breccia (Figure 2).

Fault A (Figure 3) is located at the bottom of a small gully that probably originated along the fault (Figure 2). The core of the subverctical fault zone is up to 1 m wide and consists of (probably) cataclastically modified sedimentary breccia, which is less coherent and darker in color than the surrounding rock (Figure 3a). Along the core zone, prominent intragranular fractures parallel to the fault cut the breccia clasts

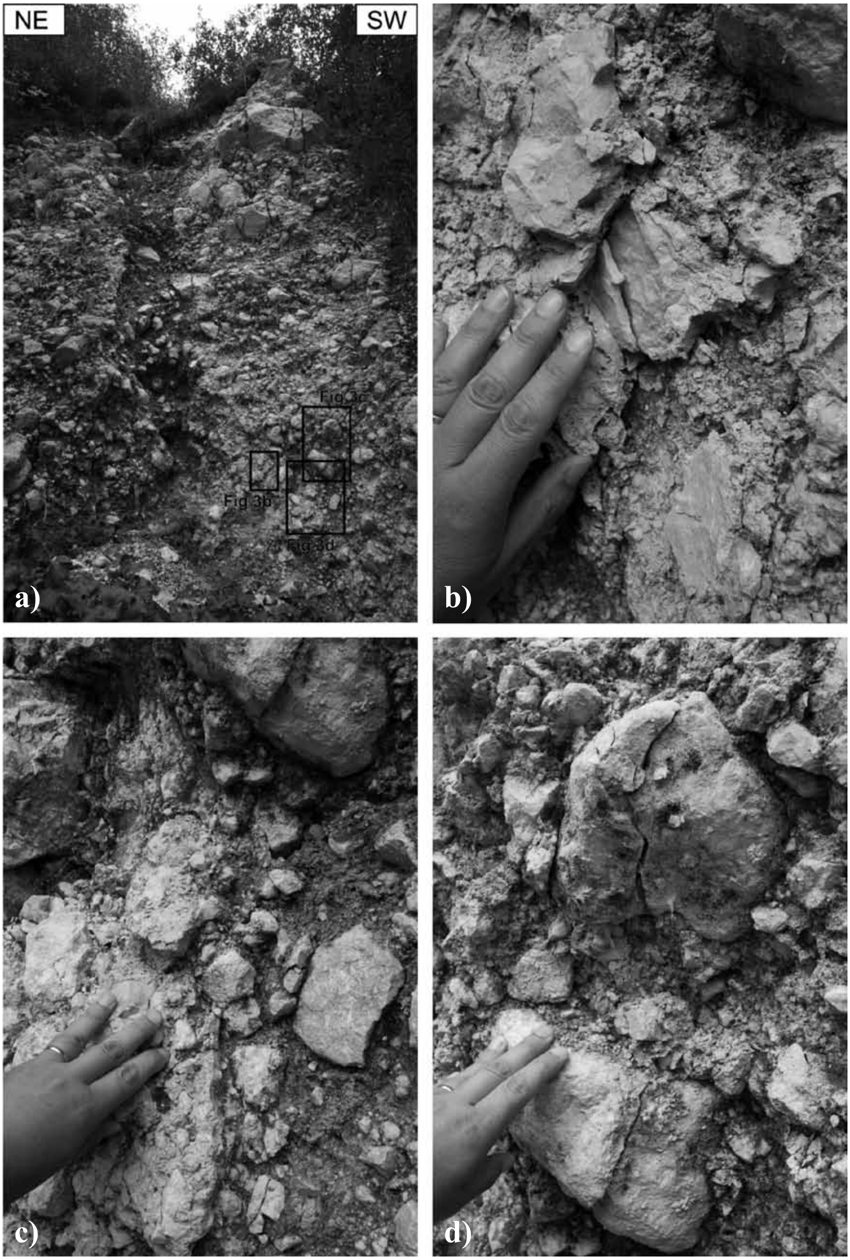

Figure 3. Fault A (refer to Fig. 2 for location). a) View of the core of the fault zone (darker part, up to 1 m wide in the center of the picture with accompanying fracture zone. b) Fractured clasts at the SW boundary of the core zone. c) Weakly developed fault-parallel fractures. d) Fault-parallel transgranular fractures cutting boulders in breccia.

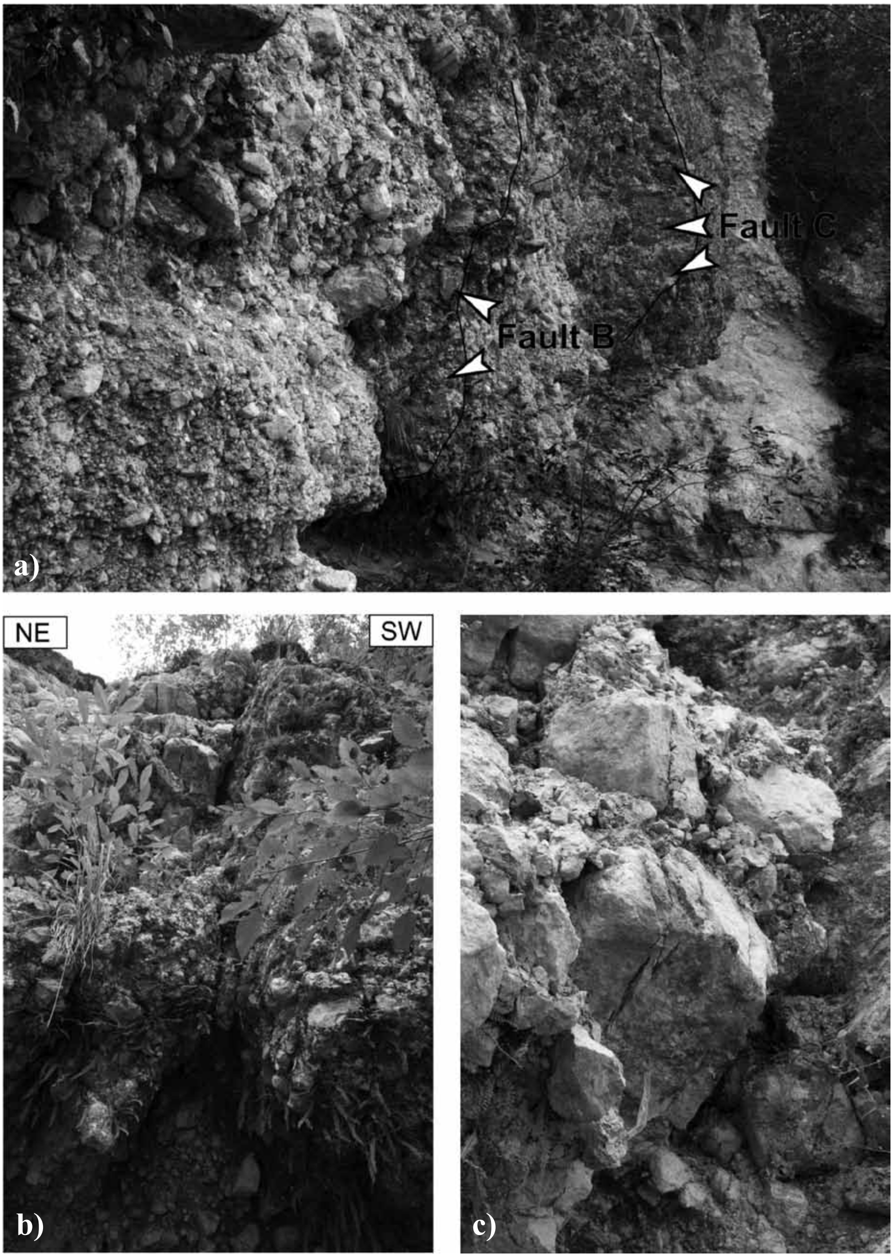

Figure 4. Faults B and C (refer to Fig. 2 for location). a) View towards the SW. Both faults apparently offset the vertical cliff face for ≈0.5 m in a dextral sense. b) Fault B, view from the bottom up. c) Fault B, view of the fault-parallel fractures in large clasts adjacent to the fault plane.

Figure 4. (continued) d) Weakly fractured zone adjacent to Fault B. Note the subvertical planar fabric which is subparallel to the fault plane.

and large boulders (Figures 3a, b, c). Along the entire length of the breccia outcrop such fractures were only found in close proximity to faults. Some of the fault-parallel fractures also cut through the whole rock (Figure 3d). An impression of weak vertical arrangement of clasts along the outer boundary of the core zone (Figures 3c, d) suggests partial modification of the original rock structure by intergranular flow.

Faults B and C (Figure 2, Figure 4a) are discrete subvertical fault planes with up to 0.5 m of apprent dextral shift of the vertical cliff face. Apart from a few very weak subhorizontal ornamentations we were not able to find any on-plane tectonic striations that would reliably constrain slip direction. Prominent subvertical fractures run parallel to the main plane, partly occuring as intragranular fractures in large boulders (Figure 4b, 4c). A weak subvertical planar fabric in breccia, manifested partly by arrangement of clasts and partly by short discrete fractures, was observed along the Fault B (Figure 4d).

Fault D is a prominent feature at the westernmost edge of the outcrop, at the contact of Quaternary breccia with Late Triassic dolomite (Figure 2, Figure 5a). The fault dips moderately

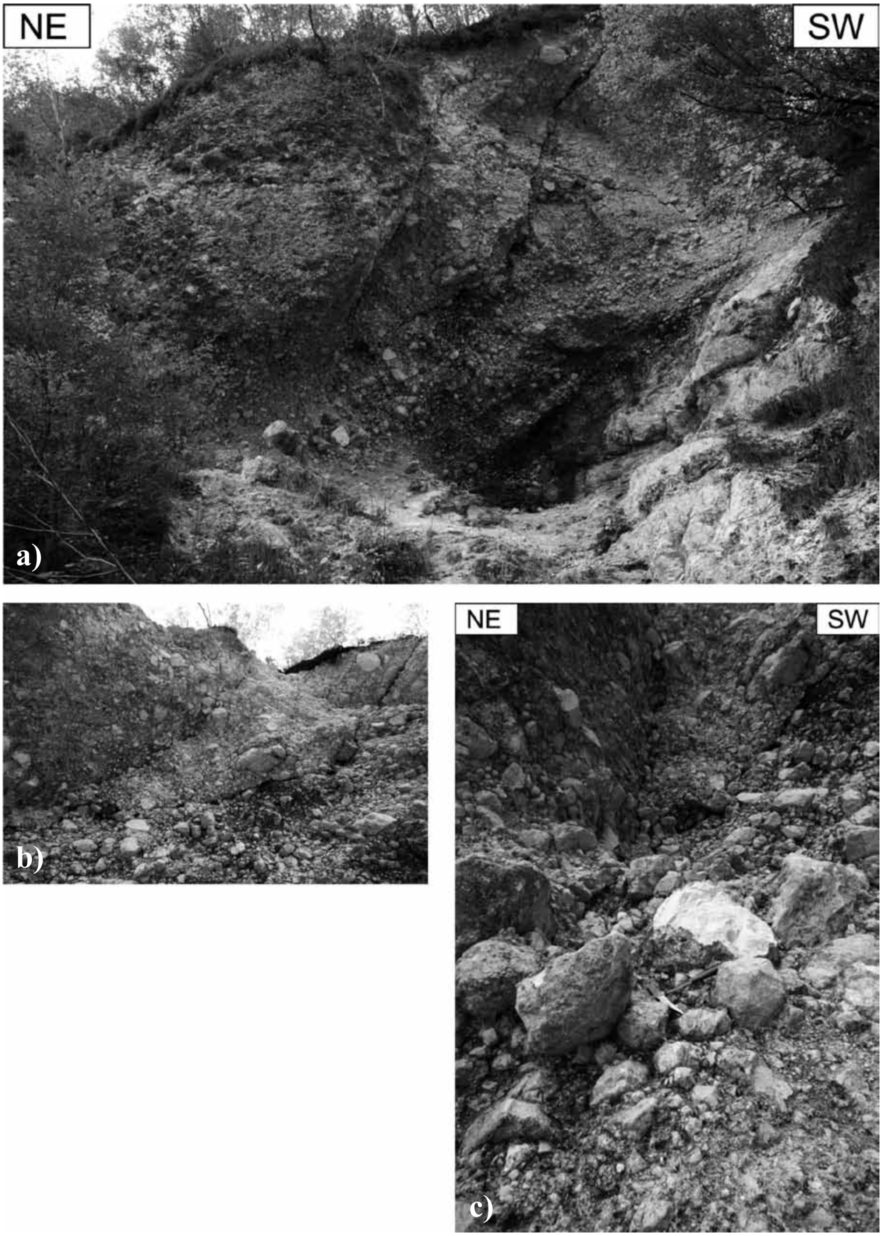

Figure 5. Fault D (refer to Fig. 2 for location). a) View from the north. Note the fault scarp in Late Triassic dolomite in the lower right corner of the photo, covered by inclined strata of Quaternary breccia. b) Fault D, view from the bottom up. c) Fault D. Note how the discrete fault plane, visible in the upper half of the photo, disappears in the lower part of the oucrop which is less strongly lithified.

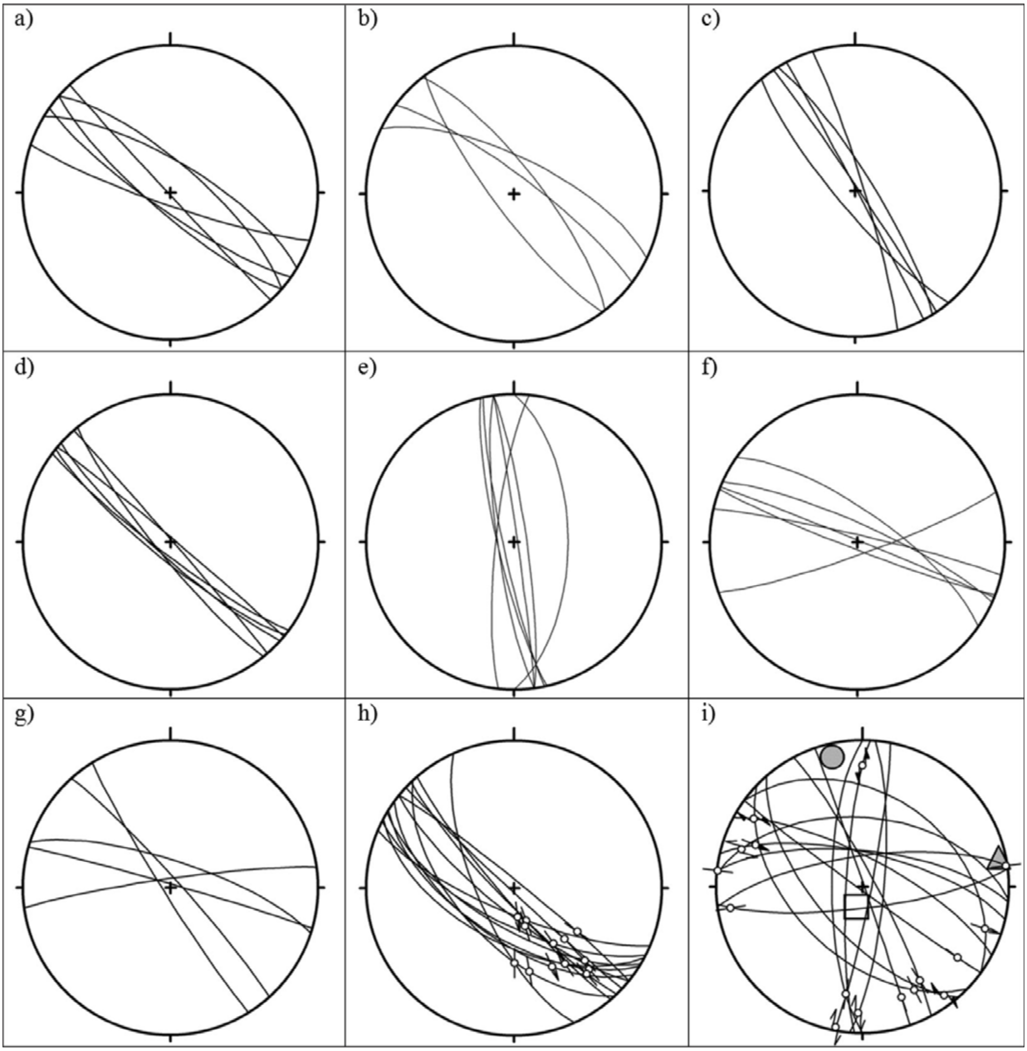

Figure 6. Measured orientations of faults and fractures in equal area projection, lower hemisphere plot. a) Fault A, fractures parallel to the fault. b) Fault A, intragranular fractures in large boulders. c) Fault B, principal fault plane. d) Fault B, fault-parallel fractures and small-scale faults. e) Fault B, intragranular fractures in large boulders. f) Fault D, fractures and intragranular fractures in Quaternary breccia. g) Fault D, fault planes in Late Triassic dolomite below the Quaternary breccia. h) Fault-slip data in Late Triassic dolomite from the Oslovo brdo fault strand, northern slope of Učja valley. i) Fault-slip data and derived paleostress axes orientations from the Drnohla fault zone in the western part of the Učja valley. Circle - σ_1 orientation. Triangle – σ_3 orientation. Square – σ_2 orientation.

steeply to the NE and forks into two branches. Apparent stratification of the breccia, manifested by weak planar structuration and by vertical changes in clast size, is dipping cca 30° towards the NE, and appears draped over the fault scarp in Triassic dolomite that is exposed below the breccia layers (Figure 5a). Otherwise, the stratification of breccia along the entire investigated outcrop, where recognized, is exclusively subhorizontal. The fault is expressed as a predominately planar, partly open fissure of the rock, without parallel fracture zones such as were observed at other faults (Figure 5b). We therefore cannot exclude that this fault originated due to gravitational mass-motion, but as the fault plane strikes nearly perpendicularly to the vertical face of the outctrop, we find this less likely. Downdip, at the foot of the outcrop, the fault plane apparently disappears in the non-lithified section of the breccia succession (Figure 5c), suggesting perhaps that here the displacement was absorbed entirely by intergranular flow. A few weak fractures parallel to the main fault plane, partly intragranular in character, were observed several meters away from the main plane.

The measured orientations of fractures and fault planes from all four sites are presented in Figure 6. Orientations of structures in Quaternary breccia (Figure 6 a–f) very clearly follow the NW–SE trend of the Idrija fault and of the immediately adjacent faults in Mesozoic rocks (Figure 6 g–h). Fault-slip data on the Oslovo brdo strand, measured in Late Triassic dolomite at a site accross the Učja valley in the direct NW-ward continuation of the faults A–D, demonstrates dextral to dextral-normal slip on subvertical to SW-ward dipping fault planes (Figure 6g).

For a sample paleostress inversion of fault slip data (Figure 6i), we used the data measured in Jurassic limestone in the NW–SE oriented Drnohla fault zone (Čar & Pišljar, 1993), which is located a few km west of the study area. Inversion results confirm that the measured dextral slip directions on NW–SE oriented faults are consistent with the N–S oriented compression with E–W oriented tension that is characteristic of the post-Miocene regional stress field (Vrabec & Fodor, 2006).

Discussion and conclusions

The brittle deformation structures, observed in Quaternary breccia that is covering the southern slopes of the Učja river valley, are clearly related to Quaternary – recent motion on the Oslovo brdo strand of the Idrija fault zone. The faults cutting the breccia outcrop are positioned in direct continuation of the well-exposed Oslovo brdo fault zone which dissects Late

Triassic dolomite on the other side of the Učja valley. The NW–SE trending subvertical orientation of fault and fracture planes measured in breccia is identical to orientations of fault planes measured on the Oslovo brdo fault and on other strands of the Idrija fault that are crossing the Učja valley.

The origin of subvertical NW–SE trending fractures and faults observed in this study is consistent with N–S compression in a strike-slip stress regime. A single exception to this are N–S oriented fractures in breccia boulders at the site of Fault B (Figure 6e), which deviate from the prevailing NW–SE orientation. Those fractures could have originated as tensile fractures in response to N–S oriented maximum horizontal compression (e.g. EIDELMAN & RECHES, 1992). The preferred mode of fracturing in Quaternary breccia may depend on local stress conditions, influenced perhaps by the degree of breccia cementation.

Our observations therefore provide for the first time the direct evidence for Quaternary – recent dextral slip in N–S compression along the Idrija fault zone. Due to the setting of the investigated outcrop, it will likely not be possible to constrain the fault slip rate, even with improved dating of the breccia. More favorable location for this could probably be found in the vicinity of the Žaga village, where the NW–SE trending faults apparently offset the Učja river course and shape the alluvial terraces south of Učja (e.g. Figure 1). These geomorphic features suggest that slip is distributed across the entire zone of the Idrija fault. According to mapping of ČAR & PIŠLJAR (1993) and our own geomorphological observations NW of Učja valley, the main fault of the Idrija zone is the Hlevišča strand, implying that the structures that we observed on the Oslovo brdo strand may be relatively minor with respect to the main strand. Further investigations along the strike of individual strands may provide better data on fault slip rates and, perhaps, on paleoseismic events.

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References

Bavec, M., Car, M., Stopar, R., Jamšek, P., Gosar, A. (2012): Geophysical evidence for the recent activity of the Idrija fault in Kanomlja, NW Slovenia. RMZ Materials and Geoenvironment, Vol. 59, pp. 247–256.

Buser, S. (1987): Osnovna geološka karta SFRJ 1 : 100 000, lista Tolmin in Videm. Zvezni geološki zavod, Beograd.

Camassi, R., Caracciolo, C. H., Castelli, V., Slejko, D. (2011): The 1511 Eastern Alps earthquakes: a critical update and comparison of existing macroseismic datasets. Journal of Seismology, Vol. 15, pp. 191–213.

Cunningham, D., Grebby, S., Tansey, K., Gosar, A., Kastelic, V. (2006): Application of airborne LiDAR to mapping seismogenic faults in forested mountainous terrain, SE Alps, Slovenia. Geophysical Research Letters, Vol. 33, L20308.

Čar, J., Pišljar, M. (1993): Presek Idrijskega preloma in potek doline Učje glede na prelomne strukture. Rudarsko metalurški zbornik, Vol. 40, pp. 79–91.

Eidelman, A., Reches, Z. (1992): Fractured pebbles – A new stress indicator. Geology, Vol. 20, pp. 307–310.

Gosar, A., Šebela, S., Košťák, B., Stemberk, J. (2011): On the state of the TM 71 extensometer monitoring in Slovenia : seven years of micro-tectonic displacement measurements. Acta geodynamica et geomaterialia; Vol. 8, No. 4, pp. 389–402.

Kastelic, V., Vrabec, M., Cunningham, D., Gosar, A. (2008): Neo - Alpine structural evolution and present day tectonic activity of the eastern Southern Alps: the case of the Ravne Fault, NW Slovenia. Journal of Structural Geology, Vol. 30, pp. 963–975.

Košir, M., Cecić, I. (2011): Potres 26. marca 1511 v luči novih raziskav. Idrijski razgledi, 56/1, pp. 90–104.

Fitzko, F., Suhadolc, P., Aoudia, A., Panza, G. F. (2005): Constraints on the location and mechanism of the 1511 Western-Slovenia earthquake from active tectonics and modeling of macroseismic data. Tectonophysics, 404, pp. 77–90.

Vrabec, M. (1994): Some thoughts on the pull-apart origin of karst poljes along the Idrija strike-slip fault zone in Slovenia. Acta Carsologica, Vol. 23, pp. 158–168.

Vrabec, M., Fodor, L. (2006): Late Cenozoic tectonics of Slovenia: structural styles at the Northeastern corner of the Adriatic microplate. In: Pinter N., Grenerczy Gy., Weber J., Stein S., Medak D. (eds.), The Adria microplate: GPS geodesy, tectonics and hazards, (NATO Science Series, IV, Earth and Environmental Sciences, vol. 61). Dordrecht: Springer, pp. 151–168.

Weber, J., Vrabec, M., Pavlovčič Prešeren, P., Dixon, T., Jiang, Y., Stopar, B. (2010): GPS-derived motion of the Adriatic microplate from Istria Peninsula and Po Plain sites and geodynamic implications. Tectonophysics, 483, pp. 214–222.

Živčić, M., Čarman, M., Gosar, A., Jesenko, T., Zupančič, P. (2011): Potresi ob Idrijskem prelomu. Idrijski razgledi, Vol. 56/1, pp. 119–126.