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The Drava River and the Pohorje Mountain Range (Slovenia): Geomorphological Interactions

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With 6 figures

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Zusammenfassung: Die Drau und das Bacher Gebirge in Slowenien: Geomorphologische Zusammenhänge. – In dieser geomorphologisch-tektonischen Studie untersuchen wir die domartige Struktur des slowenischen Bacher Gebirges (Pohorje) und seine Interaktion mit einem der bedeutendsten Flüsse der Alpen, der Drau. Geologisch befindet sich das Bacher Gebirge am südwestlichen Rand des steirischen Beckens und nahe einer tektonisch sehr aktiven Zone der Europäischen Alpen: das Periadriatische Lineament.

Etwa 10 km nordwestlich des Bacher Gebirges verlässt die Drau das Miozän-Pliozäne Klagenfurter Becken und verändert ihre Fliessrichtung von Ost nach Süd, der Lavanttal/Labot-Störung folgend. Am Nordwesteck der Antiform des Bacher Gebirges wird die Drau wieder in eine Ost-Richtung abgelenkt, anstatt dem tektonischen und geomorphologischen Lineament der Lavanttal-Störung weiter nach SE zu folgen. Ab diesem Knick fliesst die Drau parallel zur Längsachse durch den Dom nach Osten. Geomorphologische und sedimentologische Hinweise zeigen, dass das Flusstales der Drau im zentralen Bereich des Gebirges um 1 km nach Norden an seine heutige Position verlagert worden ist. Pliozäne Flusssedimente im Paläo-Flusslauf stellen die Altersobergrenze der Verlegung dar. Diese Verlagerung des Flusslaufes weist, zusammen mit der Geometrie des Entwässerungsnetzes, der Kurvenform von longitudinalen Flussprofilen und der Ablenkung verschiedener Flüsse auf geomorphologisches Ungleichgeweicht und lokale Hebung hin. Die Ursache dieser Hebung findet man in der Beckeninversion während des späten Miozän und Pliozän, als die ost-west-gerichtete Dehnung im Pannonischen Becken zu Ende war. Das Hebungsmuster des Bacher Gebirges wird mit einem Model beschrieben, wo durch asymmetrische Hebung und Rotation an einer ost-west orientierten Achse der Südteil des Gebirges schneller gehoben wird als der Nordteil.

Summary: In this combined geomorphological-tectonic study we describe a dome-like form in the Slovenian Pohorje Range and its interaction with one of the main rivers of the Alps, the Drau/Drava. Geologically, the Pohorje Mountains are situated at the southwestern corner of the Miocene Styrian Basin and near a very active tectonic feature of the European Alps: the Periadriatic Lineament.

About 10 km northwest of the Pohorje area the Drava leaves the Miocene-Pliocene Klagenfurt Basin and changes its course from east to south, following the northwest-southeast striking Lavanttal/Labot Fault. Instead of following this tectonic and geomorphological lineament further south, the Drava is deviated at the northwestern corner of the Pohorje antiform, now flowing through its northern part towards east almost parallel to the axis of the antiform. Geomorphologic and sedimentologic evidence show that the Drava channel was shifted 1 km from a southern position to its modern course in the central part of the antiform. Pliocene sediments provide the upper age limit for this event. This shifting indicates, together with the geometry of the drainage pattern, the form of longitudinal river profiles and the deviation of rivers, a topographic disequilibrium and local uplift. The reason for this local uplift can be found in the basin inversion during the Late Miocene/Pliocene to recent, when the east-west extension in the Pannonian Basin ceased. The uplift pattern is described in a model with asymmetric uplift rotation of the Pohorje Range along an east-west axis, with the southern part lifted up faster than the northern part.

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1. Introduction

The Pohorje and the Kozjak Ranges in northern Slovenia (Fig. 1a) lie at a geologically very exiting location. In this area one of the main fault systems of the Alps, the Periadriatic Lineament (Fig. 1b), is offset by the still active Lavanttal/Labot Fault. The region forms the southwestern margin of the largest Miocene extensional basin in the Alpine and Carpathian region, the Pannonian Basin (see Fodor & al. 1998). The mountain range forms a dome-like structure with its long axis oriented approximately east-west (Fig. 1a). The highest peak is Crni Vrh with 1543 m and the lowest surface elevation is found at about 250 m at the bottom of the southeastern flank in the Mura Basin. The whole Pohorje-Kozjak Range covers an area of about 1000 km^2. The Drava (Drau in Austria) river channel cuts the range centrally down to an elevation of a mere 300 m.a.s.l., flowing from Dravograd in the west to Maribor in the east, north of the roughly east-west oriented watershed.

Interestingly, marine sediments as young as ca. 13 Ma (Badenian/Sarmatian) are uplifted to significant surface elevations, while the Koralpe and other adjacent regions of high topography do not show such high locations of marine sediments. This indicates that the topography of the Pohorje Range and the age of the Drava valley in this region may be extremely young. This is the reason why we are currently investigating the geomorphological history of this region. This paper presents a brief progress report on our current research. For topographic analyses we used the NASA SRTM digital elevation model (DEM) data with a resolution of 3 arcseconds (Farr & Kobrick 2000).

2. Geological setting

The main portion of the Pohorje Range (Fig. 1b) is part of the Austroalpine basement realm of the Eastern Alps. Lithologically the basement unit consists of paragneisses and micaschists with basic and some ultrabasic lenses and probably Permian pegmatites. In the western part these basement rocks overlay Paleozoic rocks (low-grade micaschists with interlayered marbles and basic rocks) which are attributed to Magdalensberg Series of the Gurktal nappe system (Hinterlechner-Ravnik & Moine 1977).

2.1 Cretaceous to Paleogene Evolution

In Cretaceous times the basement rocks of the Austroalpine unit suffered ultra-high to high-pressure metamorphism and were subsequently exhumed together with mantle rocks (Janak & al. 2004, Sassi & al. 2004). Locally unmetamorphosed sediments of the Cretaceous Gosau formation were deposited on these basement units in the west of the Pohorje Mountains (Fig. 1b).

The central part of the mountain range consists of an elongated (east-west) intrusive body which is about 10 km long and 4 km broad. The tonalite is part of the Periadriatic intrusive suite and interpreted to be of Oligocene age (Altherr & al. 1995, Pamič & Palinkaš 2000). In the western and northern part abundant dacitic sub-volcanic rocks intruded at about 14–16 Ma (Sachsenhofer & al. 1998).

2.2 Neogene to Recent

The Neogene alpine event in the eastern part of the Eastern Alps is characterized by contemporaneous crustal thinning and subsidence linked to both lateral extrusion tectonics in the Eastern Alps and slab retreat in the Eastern Carpathians (Royden & al. 1982, Horváth & al. 1995). The formation of local intramontane pull-apart basins along strike-slip faults within the Eastern Alps and of local purely extensional basins along the eastern margin of the Eastern Alps can be attributed to this tectonic environment (e.g. Marton &

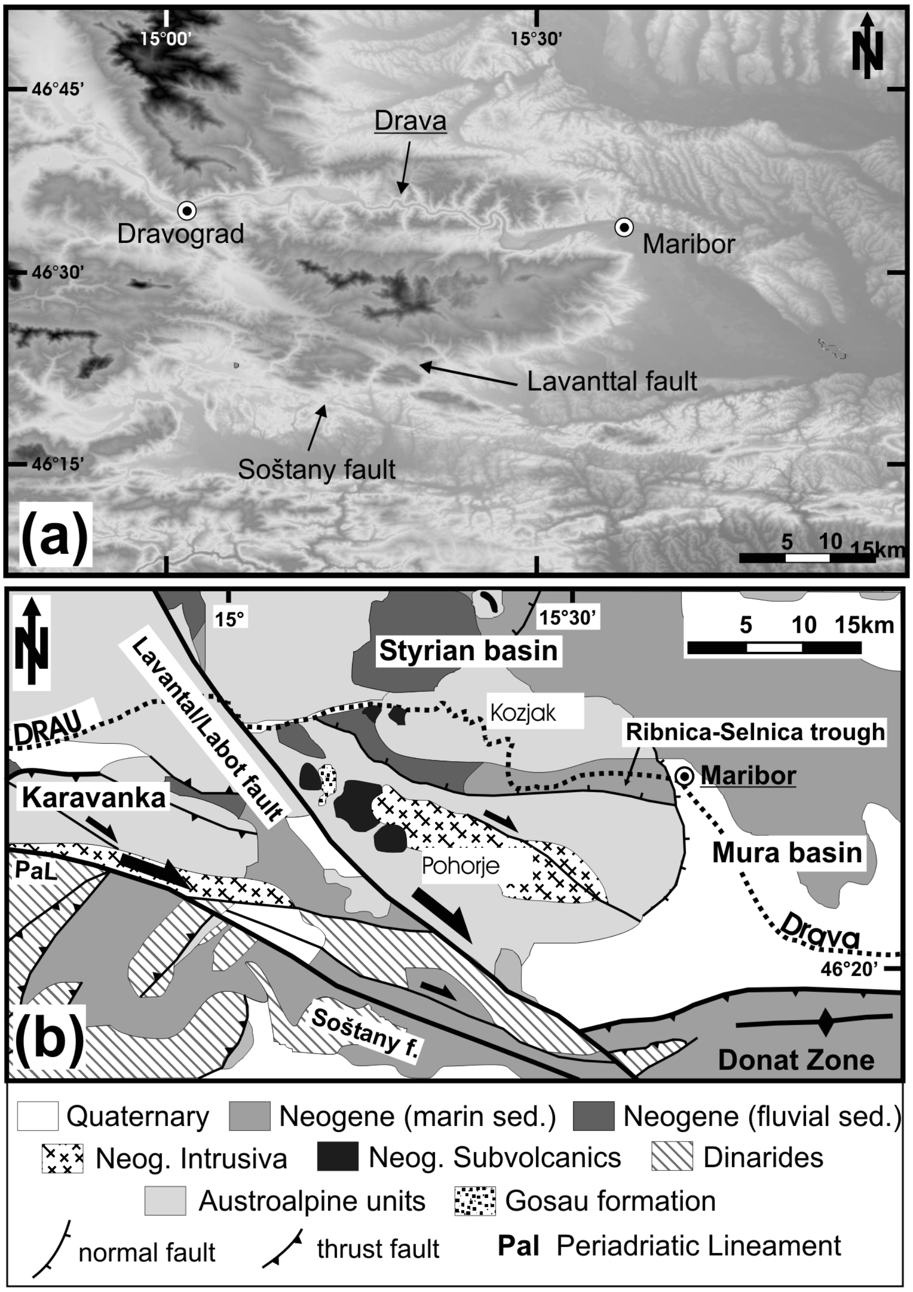

Fig. 1: (a) Digital elevation model of the study region (NASA SRTM data, Farr & Kobrick 2000), black colours indicates altitudes above 1400 m (central Pohorje Range), white colors altitudes between 300 and 350 m. (b) Geological map, adapted from Fodor & al. (1998) and Vetters (1980).
(a) Digitales Höhenmodell des Untersuchungsgebietes (NASA SRTM Daten, Farr & Kobrick 2000), schwarze Farben zeigen Höhen über 1400 m an (zentrales Pohorje Gebirge), weisse Farben Höhen zwischen 300 und 350 m. (b) Geologische Karte, adaptiert nach Fodor & al. (1998) und Vetters (1980).

al. 2000). Rapid subsidence was accompanied by sedimentation generally starting at Early Micene (about 18 Ma) times and ending at about 8 Ma in both the intramotane basins in the west and the marine Pannonian basins in the east (see Huismans & al. 2002).

This general tectonic history is also present in the Pohorje area, where Miocene sediments show the transition from fluvial to marine sedimentation at the eastern margin of the Paratethyian sea. Here the local marine sub-basins of the Pannonian realm are called southern Styrian Basin and Mura-Zala Basin (Fig. 1, see Fodor & al. 1998). Unfortunately the age of the sediments in this area is poorly constrained but correlation with similar sediments in other parts of neighbouring intramontane or Pannonian basins is possible. The earliest sediments lie transgressively on basement rocks and are high-energy breccia, conglomerates and sandstones (Basisschichten and Radl-Schotter at Radlpass, Winkler-Hermaden 1951), followed by lower-energy conglomerates, sandstones and claystones with coal layers (Eibiswaldschichten, Karpatian, Winkler-Hermaden 1951), which constitute the main portion of Neogene fluvial sediments of the Pohorje Range. Pliocene conglomerates near Lovrenc represent the youngest Tertiary fluvial sediments of the area. Marine Early Miocene (Ottnangian and Karpatian) sediments can be found in the eastern part of the area and include marine sandstones, siltstones and marls. They reach a total thickness of about 1000 m (Mioč 1977). They are unconformably overlain by Badenian marine sediments with algal reef limestones (Sachsenhofer & al. 1998).

Tectonically, the Miocene-Pliocene fluvial and marine sediments were bound to the east-west running Ribnica-Selnica trough (Fig. 1a) which is bounded by steep normal faults and passed into the Mura-Zala Basin (see Sachsenhofer & al. 1998). The Ribnica-Selnica trough is the continuation of the Klagenfurt Basin in as much as the age of fluvial sedimentation overlaps (compare Nemes & al. 1997). Both basins are aligned in an east-west direction and they fit together, when the ca. 15 km dextral (Fodor & al. 1998 and references therein) offset along the Lavanttal Fault is taken back (see Fig. 1b).

From investigations on detrital components in Miocene fluvial sediments it is evident that the Drava constituted a main drainage system from the Oligocene onwards (Benedek & al. 2001, Brügel & al. 2003) and did not significantly change the geometry and orientation of its river network since Sarmatian times (12 Ma).

Another major tectonic structure in the area is the Oligocene-Lower Miocene Periadriatic Lineament, which accommodates the lateral displacement between the Adriatic and the Apulian plate, resulting in a dextral transpressive, east-west oriented strike-slip fault system. In the Pohorje region the Periadriatic system juxtaposed Austroalpine basement rocks in the north and south-Alpine carbonate cover rocks (Dinarides) in the south. In the Pohorje area, the Periadriatic Lineament changes from an east-west orientation west of the Pohorje into an ESE-WNE orientation south of it. The continuation further east is unclear (Fodor & al. 1998). The bending was caused by the Late Miocene Lavanttal/ Labot Fault, which dextrally offset the Periadriatic Lineament (Fodor & al. 1998). The Lavanttal Fault is a transtensive strike-slip fault and represents the southeastern part of the Miocene extrusion system in the Eastern Alps (Ratschbacher & al. 1991).

3. Geomorphological Observations

Geomorphological elements on a larger regional scale are strongly linked to the inactive and active brittle faults systems described above. The Drava for example follows the Periadriatic Lineament in western Carinthia, the Miocene extensional trough (Klagenfurt Basin) in eastern Carinthia and the Lavanttal Fault northwest of Pohorje. In the Pohorje Range the Drava flows partly through the Miocene Ribnica-Selnica trough. The mountainous part north of the Drava river (Kozjak Range) is limited by an east-west striking Miocene normal fault towards the Styrian Basin (Fig. 1). To the soutwest the Pohorje Range is bordered by an NNW-ESE valley following the Lavanttal/Labot Fault. Depressions linked to Miocene basins (Mura Basin and sub-basins) border the geomorphologic high of the Pohorje to the south and the east.

3.1 Topography

In any DEM of the study area (Fig. 1a), the antiformal structure of the Pohorje Range is the most obvious geomorphological structure apart from several valleys following brittle strike-slip and normal faults. From a north-south running topographic profile (Figs. 2, 3) it is evident that the antiform is not restricted to the Pohorje Range but includes the Kozjak Range as far north as the Styrian Basin. The dimensions of the antiform are 33 km north-south and 44 km east-west. The profile also shows an asymmetry of the topographic dome with a steep southern and a less inclined northern flank.

Apart from the modern Drava river channel another depression, located about 1 km south of it, is visible in Figs. 2 and 4. From the presence of Miocene to Pliocene fluvial sediments with detritus matching today's catchment of the Drava this valley is interpreted as the Paleo-Drava river channel until Pliocene times. From the distribution of Neogene fluvial sediments (Fig. 1b), the Miocene-Pliocene Paleo-Drava must have been flowing along a path similar to that of the modern Drava river across the Klagenfurt Basin and in the eastern part of the Pohorje Range, while it was south of the modern channel in the central and western part of Pohorje.

3.2 Drainage system

In its present position, the Drava channel is located in the central part of the Pohorje antiform. At Dravograd the Drava is deviated 90 degrees from north-south within the Lavant Valley to west-east in the Pohorje Range (Fig. 3). The absence of any evident morphological barrier capable of anticipating further south-directed flow across the Mislinja valley (continuation of the Lavant valley and Lavanttal Fault south of Dravograd) indicates differential uplift of some parts south of Dravograd. The Mislinja river flows

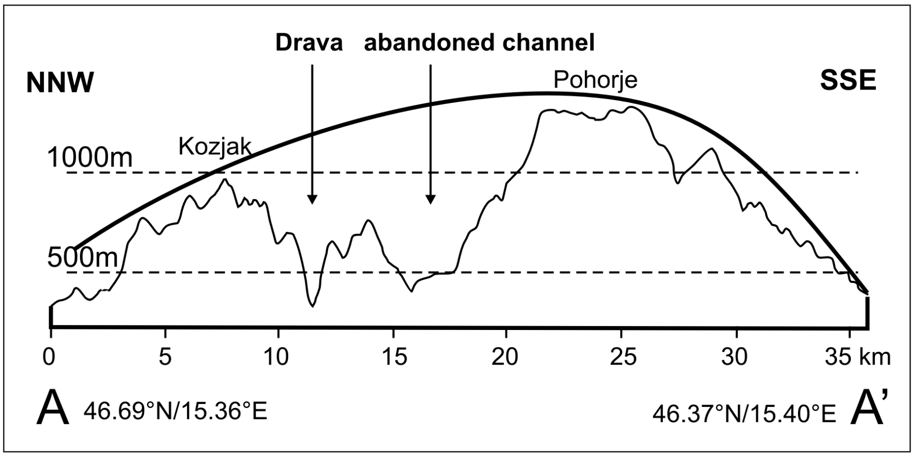

Fig. 2: The topographic profile through the Pohorje dome from the Styrian Basin (A) to the southern flank of the Pohorje Range (A´), almost perpendicular to the axis of the topographic antiform. The location of the profile is shown in Fig. 3.
Topographisches Profil des Pohorje Doms vom Steirischen Becken (A) bis zur südlichen Flanke des Pohorje Gebirges (A´). Das Profil liegt annähernd senkrecht zur Achse der topographischen Antiform. Die Lage des Profils wird in Abbildung 3 gezeigt.

from the southwest flank of the Pohorje through the Mislinja valley towards north to join the Drava at Dravograd (Fig. 3). While the Drava cuts through Paleozoic series during the first few km east of Dravograd, the channel widens and forms two basins with Quaternary terraces when it reaches Neogene sediments. At the eastern end of the basins the channel starts to meander through basement rocks incising a very narrow, V-shape valley with about 300 m high, steep channel walls. The channel walls show the highest average slope angle of the Pohorje Range. In this part the general flow direction changes from east to ESE. Near Zala the Drava leaves the narrow valley making a 90 degree bend to follow the Miocene Ribnica-Selnica trough in an east-direction towards Maribor (Fig. 3). Here the valley becomes wide and deposition dominates over erosion, evident from large amounts of Quaternary fluvial sediments.

The river network (Fig. 3) is contorted and irregular in the Pohorje-Kozjak area, typical for layered metamorphic rocks (Howard 1967). Very few orders of streams are present. The water divide runs parallel to the long axis of the dome and the topographic divide (ESE–WNW) in the eastern part of the Pohorje. In the central part of the antiform, the topographic divide bends slightly towards northwest, while the orientation of the watershed does not change and departs from the topographic divide. Near Mislinja the

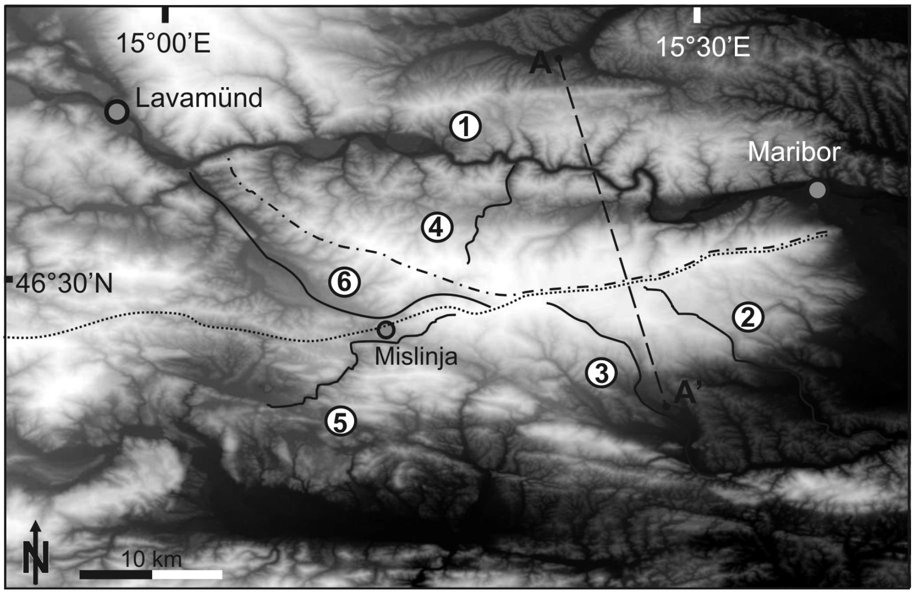

Fig. 3: Digital elevation model of the Pohorje-Kozjak area showing the main geomorphological features. Dark colours indicate low, bright colours high elevation values. Rivers are outlined with continuous lines. (1) to (5) refer to the Drava, Bistrica, Oplotnica, Velka and Paka river, respectively, used to calculate channel profiles in Fig. 5. The watershed of the Pohorje Range (dotted line) deviates from the topographic divide (dashed-dotted line) in the western part of the Pohorje Range, visible from the course of the Mislinja river (6). The dashed line (A-A´) indicates the location of the topographic profile in Fig. 2.
Digitales Höhenmodell des Pohorje-Kozjak Gebietes mit den wichtigsten geomorphologischen Merkmalen. Dunkle Farben zeigen niedrige, helle Farben höhere Lagen an. Wasserläufe sind als durchgehende Linien dargestellt. (1) bis (5) zeigen die Wasserläufe Drau, Bistrica, Oplotnica, Velka und Paka in dieser Reihenfolge an. Die longitudinale Flussprofile dazu sieht man in Abbildung 5. Im westlichen Teil des Gebirges weicht die Wasserscheide des Pohorje Gebirges (gepunktete Linie) von der Linie der topographisch höchsten Punkte (gestrichelt-gepunktete Linie) ab. Dies erkennt man am Verlauf der Mislinja (6). Die strichlierte Linie (A-A´) zeigt die Lage des topographischen Profils in Abbildung 2.

watershed intersects the Lavanttal Fault forming a topographic rise, which seems to interrupt an otherwise continuous depression following the Lavanttal Fault. The deviation of topographic and watershed produces a very complex drainage network in the western and southwestern part of the Pohorje (Fig. 3). This configuration again indicates differential uplift and a non-steady-state status of the landscape in the Pohorje area.

Fig. 5 presents some of the channel profiles of rivers sourcing in the Pohorje Range. Their location is shown in Fig. 2. The profile of the Drava in Fig. 5a starts at the border Italy/Austria and ends at 16° east of Greenwich near the Slovenian/Croatian border. Two artificial lakes in the Klagenfurt Basin change the natural profile in the central section. The overall channel gradient, except for the first mountainous part of the river, in this profile is 0.0010 m/m. The channel gradient of the Drava in the Pohorje area is 0.0012 m/m, slightly higher than the overall gradient. The channel profile in Fig. 5a shows that there is a significant change in slope near Maribor. Here the gradient reaches 0.0030 m/m, which is very high compared to the average gradient of the Drava through the Pohorje. Interestingly, no change in lithology or channel morphology, except for the course (changing from east to SSE), is present at that channel segment. After Maribor, the gradient decreases to 0.0008 m/m.

All rivers from the southern steep flank of the Pohorje Range (Bistrica and Oplotnica in Fig. 5b) show convex upwards channel profiles within the Pohorje, indicative for disequilibrium and local uplift (Merritts & Vincent 1989). The rivers at the northern flank of the Pohorje Range instead show convex downward profiles (Fig. 5c), indicating equilibrium topography. The central flat part of the channel profile in Fig. 5c is caused by the presence of soft Miocene sediment fills, where the Paleo-Drava channel crosses the Velka. The fact that all rivers at the northern flank of the Pohorje Range do not follow the Paleo-Drava channel with a natural east-slope and its soft rocks, but cut through the

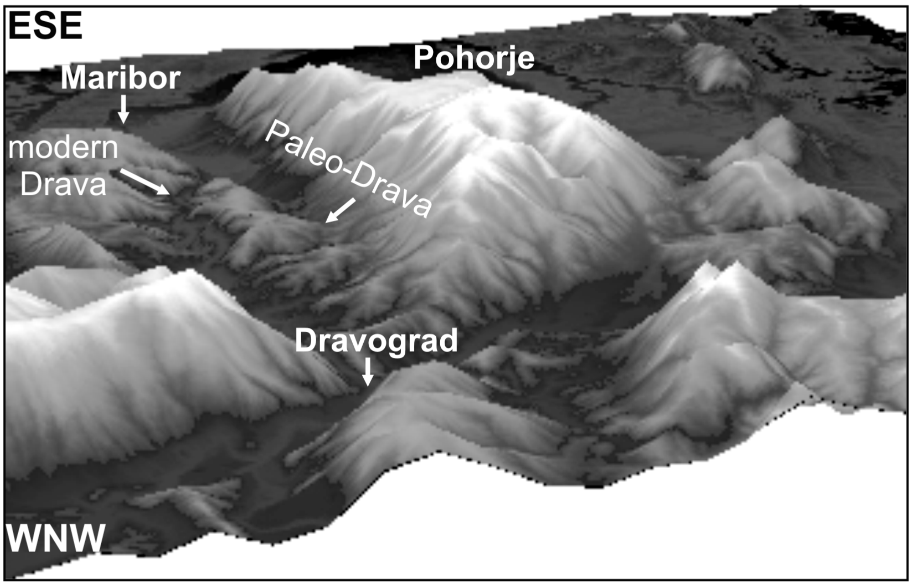

Fig. 4: Three-dimensional view of the Pohorje-Kozjak area, showing the Paleo-Drava and the modern Drava channel. View from an elevation of 2000 m, about 25 km NNW of Dravograd with a vertical exaggeration of 2.
Blick aus einer Höhe von 2000 m, etwa 25 km NNW von Dravograd auf das drei-dimensionale digitale Höhenmodell (2-fach überhöht) des Pohorje-Kozjak Gebietes. Zu erkennen sind das Paläeo-Flussbett der Drau und das Flussbett der modernen Drau.

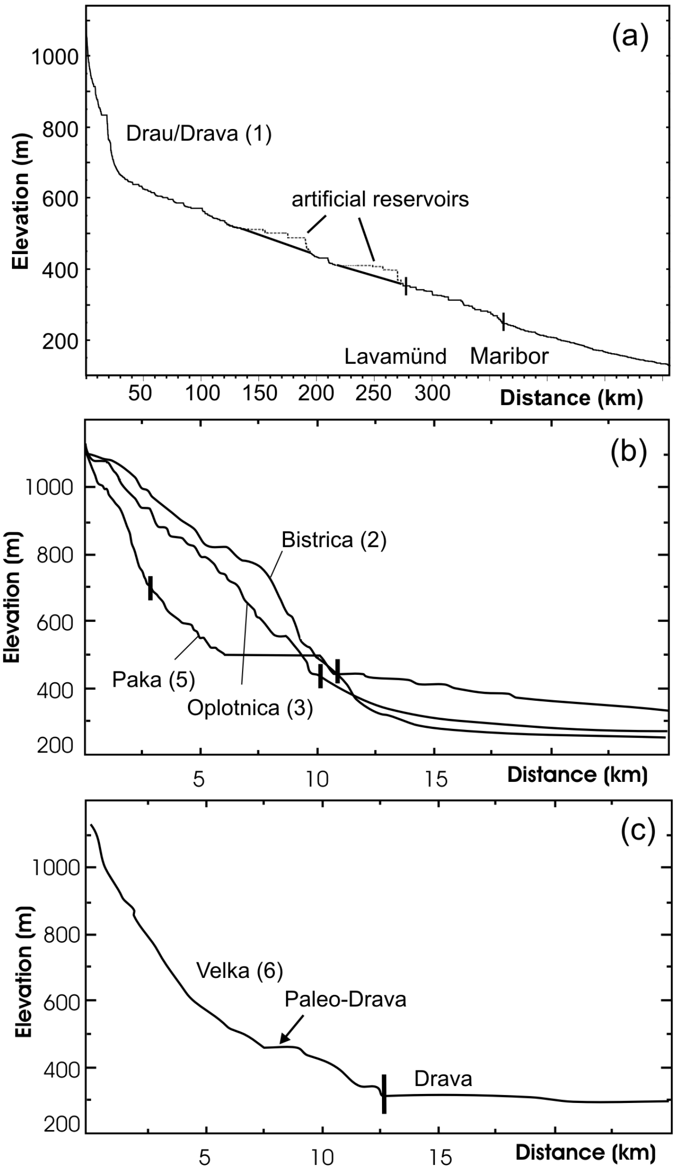

Fig. 5: The number with the name of the river refers to Fig. 2, where the location of the channels is shown. The thick vertical lines in Fig. 5b indicate the point where the river leaves the Pohorje Range, in Fig. 5c, where the Velka river joins the Drava river. (a) River profile of the Drava from the Italian-Austrian border to 16° east of Greenwich (length: 512 km, total slope 0.0029 m/m, flat part 0.0010 m/m from Spital a. d. Drau, 0.0030 m/m near Maribor), (b) Rivers of the southern flank of the Pohorje Range, (c) Velka river: northern flank of the Pohorje Range
Die Nummer des Wasserlaufs bezieht sich auf die Abbildung 2, wo die Lage der Wasserläufe dargestellt wird. Die dicken vertikalen Linien in Abbildung 5b zeigen die Stelle, wo der Fluss das Pohorje Gebirge verlässt, in Abbildung 5c dagegen die Stelle, wo die Velka in die Drau mündet. (a) Flussprofil der Drau von der italienisch-österreichischen Grenze zu 16° östlich von Greenwich (Länge: 512 km, Gefälle gesamt: 0,0029 m/m, im flachen Teil ab Spital a. D. Drau 0,0010 m/m, 0,0030 m/m bei Maribor), (b) Bäche am Südhang des Pohorje Gebirges, (c) der Bach Velka am Nordhang des Pohorje Gebirges

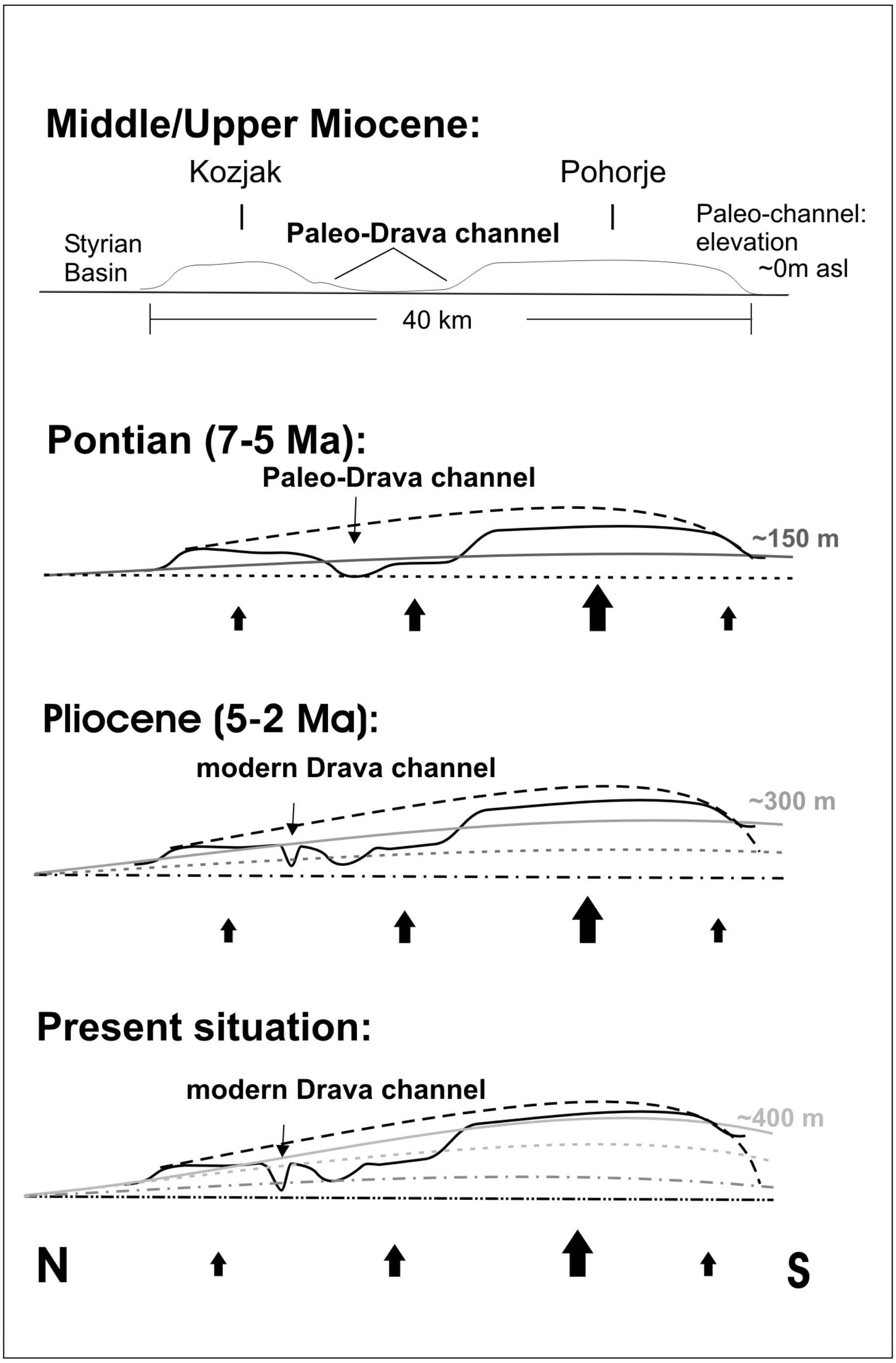

Fig. 6: Uplift model for the Pohorje-Kozjak Range showing different time steps of the geomorphological evolution.
Modell der Hebungsgeschichte des Pohorje-Kozjak Gebietes. Die einzelnen Abbildungen zeigen verschiedene Zeitschritte der geomorphologischen Entwicklung.

barrier of basement rocks north of the channel, also indicates disequilibrium morphology and local uplift. The Paka river (Fig. 5b) leaves the Pohorje Range to the west and shows an anomalously convex part, where it flows through the Pohorje and changes to a convex downward form, when it reaches the Lavanttal/Labot Fault.

4. Interpretation

A number of geomorphological features show that the Pohorje and the Kozjak Mountains are in morphological disequilibrium caused by local uplift. These include: (i) the deviation of the Drava from the Paleo-channel with soft sediment fills towards the north into harder basement rocks, (ii) the convex upward form of rivers flowing through the southern flank, (iii) the high gradient of the Drava channel near Maribor, (iv) the low number of stream orders and (v) the deviation of rivers at the northern flank of the Pohorje. The asymmetric geometry of the Pohorje-Kozjak topographic antiform suggests an asymmetric uplift pattern with faster uplift rates in the southern part of the Pohorje Range. This model is consistent with the northward shift of the Drava channel, the deviation of the Drava from a southeast to an east-flow direction at Dravograd and the deviation of the second order rivers at the northern flank of the Pohorje. From the general elongated form of the Pohorje Range the rotation axis must run east-west. To the east, the doming must end near Maribor, where the Drava river exhibits a drastic change in slope, indicating stronger uplift of the Drava west of Maribor. To the west, the limits of the dome are not easy to define, but it terminates most probably at the Lavanttal Fault, which represents a major tectonic line definitely separating the Pohorje from the Karavanka block. This is constrained by the form of the Paka river profile, which changes significantly at the Lavanttal/Labot Fault. To the north, there is a clear gradient of relief from higher peaks in the Kozjak Range to low peaks in the Styrian Basin across its southern tectonic margin.

With respect to the timing of uplift the youngest sediments present in the Paleo-Drava channel give the upper limit of the deviation of the Drava and herewith active uplift of the area. The abandonment of the Drava Paleo-channel during Pliocene times indicates that the system was already active at that time. Fodor & al. (1998) documented a change from east-west extension to north-south convergence in the Pohorje at 6 Ma, which is a reasonable cause of the local uplift and shift of the Drava in the Pohorje. Similar results were obtained from other north-Slovenian areas (Tomljenovič & Csontos 2001) and the whole Pannonian region (Bada & al. 1999).

A tentative model of the uplift history of the Pohorje-Kozjak Range is presented in Fig. 6, but still the exact timing of discrete events, like the northwards shift of the Drava channel, is not known. Therefore our plan for future investigations is to date indicative sediments and than quantify the model in order to test it.

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