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The identification of neotectonics based on changes of valley floor width

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Abstract: This paper concerns the identification of neotectonics structures on the basis of topographic maps analysis. The investigation parameter is valley floor width (VFW), this being applied to the drainage basin of the Bečva river, Czech Republic. It is firstly necessary to determine the theoretic profile of the VFW downstream increment. For its construction the magnitudo was used (Shreve, 1966). Then, the differences between the real VFW and the theoretical VFW were calculated. The differences were classified according to the associated bedrock lithology. The sections where differences were widely divergent from the average are assumed to be have been affected by neotectonics.

Key words: the Outer Western Carpathians, flysch, neotectonics, morphometry, topographic maps analysis, valley floor width

Introduction

The standard initial procedure in the geomorphological investigation of large areas is an analysis of landscape morphometry from topographic maps. The main purpose of the preparatory works is, of course, to find out the locations in the terrain which are worthy of more detailed field examination. The places which exhibit neotectonic activity, an important constructive process in the Earth's surface evolution, are of special interest.

The method described here was applied to the valleys of the Vsetínská Bečva and Rožnovská Bečva rivers. Both are located in the Outer Western Carpathians (Fig. 1).

Bedrock of the basins is built from flysch rocks of the Raca and Silesian nappes. It consists of alternating layers of sandstone and claystone. The rock resistance varies according to the component ratio of both and the degree to which they are consolidated. According to geophysical and geodetic evidence the whole area has been subjected to continuous uplift, which has resulted from persistent activity at the contact of the Carpathians and the North European Platform (Vyskočil & Zeman, 1980). However, the overall uplift of nappes does not exclude the possibility of some local tensional structures (Fig. 2).

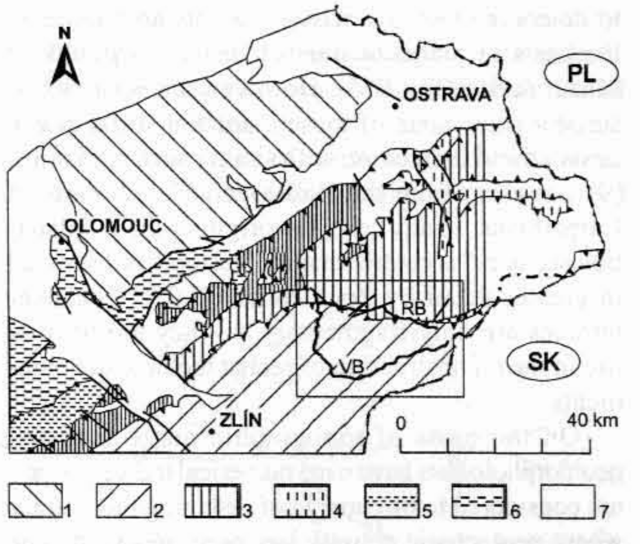


Fig. 1. The location of study area of Vsetínské vrchy Hills within the territory of the Czech Republic
1 – Bohemian Massif, 2 – Raca nappe of Magura group, 3 – Silesian nappe of Krosno-Menilite group, 4 – Subsilesian nappe of Krosno-Menilite group, 5 – Karpatian of the Carpathian Foredeep, 6 – Badenian of the Carpathian Foredeep, 7 – Pliocene; RB – Rožnovská Bečva river, VB – Vsetínská Bečva river (based on Stráník *et al.*, 1993)

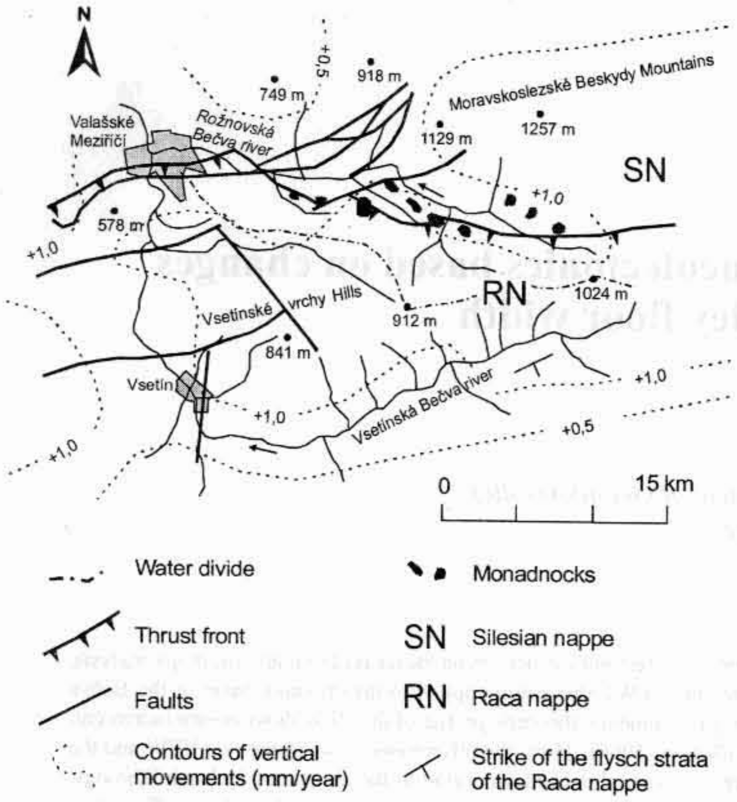


Fig. 2. The location of the study area with major geological and geomorphological phenomena. Contours of vertical movements magnitude are adapted from Vyskočil & Zeman (1980)

A reconstruction of the tectonic history of the area is difficult, since there is a dearth of geological evidence. In the past, the attempts have been made to detect the tectonic activity and its amplitude on the basis of planation surface analysis (Stehlík in Mazúr & Stehlík, 1965). However, this approach is suspect since none of these planation surfaces can be dated and correlation with similar surfaces is simply based on from the Polish and Slovak parts of Carpathians. In any case, the origin of these "planation surfaces" is controversial. This topic is discussed in greater detail by Zuchiewicz (1998). The river terraces are only fragmentary, so they are of little use in the reconstruction of recent tectonic developments.

On the basis of topographic maps analysis, geomorphologists have used numerical indices, which are considered to be capable of detecting those areas where neotectonic activity has been prevalent. The most frequently employed indices are e.g. the mountain front sinuosity index (MFS) and the valley floor width to height ratio (VF) (Bull & McPhadden, 1980) or SL index (Hack, 1973). The MFS index is based on the knowledge that active fault planes along mountain fronts are often simple landscape elements in comparison with slopes in areas dominated by erosion (i.e. those slopes created in periods of tectonic stability).

During the investigation of Vsetínské vrchy Hills it was difficult to decide, which of these numerical indices was the most useful by which to describe the tectonic setting. As the Vsetínské vrchy Hills are bounded by river valleys, the MFS index could not be used. The VF index is based on the presumption that areas subjected to uplift exhibit incised valleys with narrow valley floors and a greater depth of V-shaped valleys. The application of this index is complicated by the problem of valley depth definition, and, especially, the delimitation of the right and left watershed heights. In the author's, these data may not necessarily be related to active tectonic movements. The effects of erosion and denudation in the upper sections of a valley may decrease their values, especially within mountain passes. The ideal case would be the utilisation of the height of the upper valley edge but this is counteracted by its generally unreliable delimitation from crenulation analysis on topographic maps. In any case they are only infrequently present in landscapes. The utilisation of VFW would theoretically be much more reliable and unambiguous.

The SL index is based either on stream channel gradient or valley floor gradient. It is possible to establish the stream channel gradient only in areas where it has not been altered by the human activities (especially by stream channel straightening). The valley floor gradient is also subject to human impacts (although to a lesser extent than that of the stream channel gradient); further, and more importantly it is subject to rapid changes. When a valley fill is present, a knickpoint may arise as a reaction to base level change or uplift within the river basin. The knickpoint may of course be rapidly obliterated owing to the low erosional resistance of a valley fill. Another problem is that of upstream knickpoint migration by the process of headward erosion. In this case also the SL index value moves headward and, after a certain it is not coincident with the tectonic dislocations which created it. On bedrock channels, where the position of the knickpoint may be preserved for some time (for example in a form of rapids), the situation is different.

The numerical indices used in landscape analysis are convenient tools for tectonic movement detection (Zuchiewicz, 1995). Nevertheless, in the author's, other elements of the geological and geomorphological setting must be taken into account. However in areas where there is a uniform lithology and an absence of human impact in stream channels or within bedrock channels, the SL index may be a powerful analytical tool.

The theoretical model

The method employed here is based on the presumption that valley floor width will increase commensurately with basin area increase. In further considerations, the basin area is substituted by the magnitudo (Shreve, 1966), which expresses the number of first-order stream channels and basin dimensions, respectively (Fig. 3). A very positive correlation between magnitudo and basin area ($r = 0{,}96$) was shown in a set of forty basins of third and higher order (Bíl & Máčka, 1999); thus, in further considerations, basin area may be replaced by the magnitudo. The substitution makes topographic map analysis more effective since, for each individual basin, it is much easier to count magnitudo than to measure basin area. The values of VFW were measured at right angles to the course of a valley, at 1 km intervals from mouth to source.

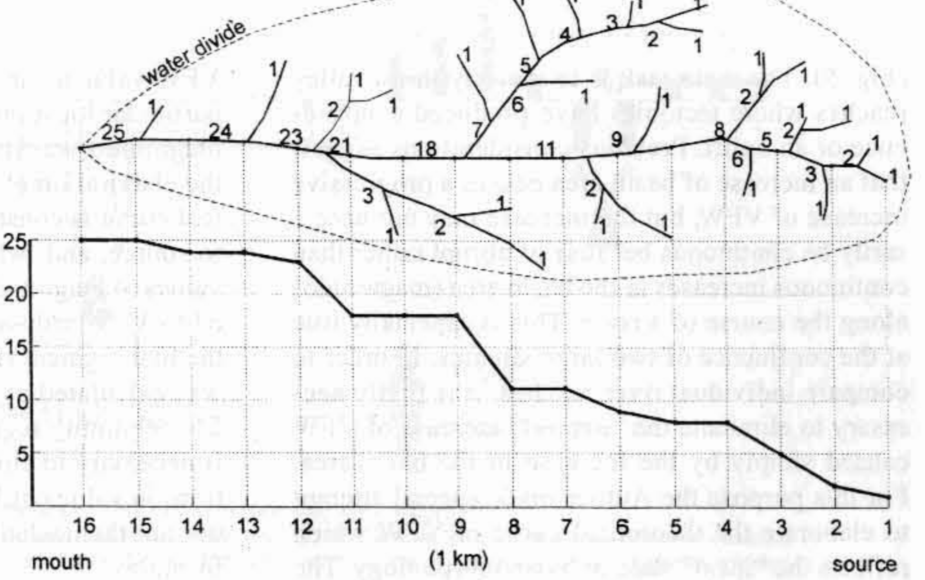
The Fig. 4 (case 1) illustrates the ideal case of a river basin which has uniform lithology and with no obvious neotectonic features. The increase of both values on the graph has only illustrative purpose. Generally, the Author considers that the relationship between the VFW and the basin area is non-linear. When more than one type of rock is present, their erosional resistances play an important role. The VFW should theoretically vary according to the location of the analysed reach. In a section with less resistant rocks, the valley floor width would be greater than that in a section with harder rocks and vice versa; this arises from the greater resistance of harder rocks to lateral erosion of a stream channel and associated slope movements. The case 2a (Fig. 4) shows the impact of a less resistant rock outcrop on a plot of VFW values. The dashed area indicates the extent of the low resistant rocks. With increase in the width of the less resistant rock outcrop, the size of this area increases. In case 2b (Fig. 4) the VFW decreases, owing to the presence of harder rocks. Both examples illustrate that a change in VFW values does not necessarily indicate tectonic activity.

Another case shows a river basin which has uniform bedrock lithology but also tectonic dislocations. The VFW in a reach influenced by tectonic uplift would be lower than in one without tectonic movements (example 3b, Fig. 4), i.e. these become antecedent valleys, where uplift is balanced by an increase in the depth of erosion of the stream channel. Stream energy is consumed by depth erosion and, as a result, very narrow valley floors develop here. If tectonics in the form of localised subsidence takes place (example 3a, Fig. 4), the value of the VFW would be higher than in other reaches which have not been influenced by tectonics. This is usually the case for grabens.

In the simple cases outlined above it is not difficult to establish the cause of VFW changes. Examples 2a, 3a, 2b and 3b (Fig. 4) may have the same effect on values of VFW. However it is obvious that the both causes of VFW variability may overlap and it is not than possible to identify the causes of VFW changes. For that reason, the Author has developed the following method of differentiating between tectonic and rock resistance influences in the development of valley cross-profiles.

Where two types of rocks with different resistance are present, a tectonic explanation is preferred

Fig. 3. Example of magnitudo (M) calculation for a river network: The M value increases from head to mouth at each junction by the increment value of the tributary. Magnitudo represents a total number and has no unit. Application of the equation (1) yields a theoretical profile (TP) of valley floor width (VFW)



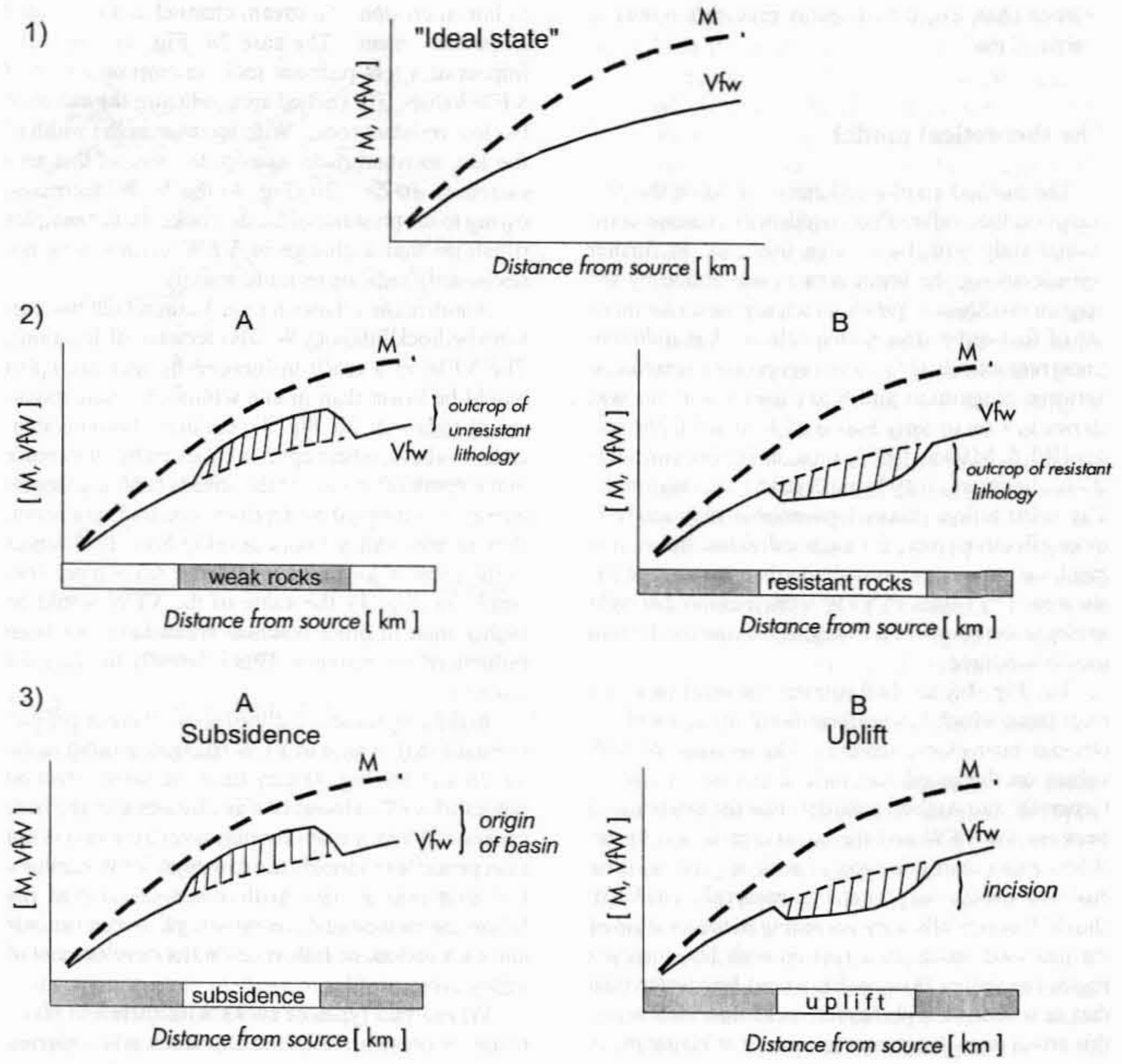


Fig. 4. The examples of "ideal" cases of external variable influences on VFW values. In order to highlight the illustrated facts the magnitudo (M) and VFW increases are the same

(Fig. 5). The main task is to identify those valley reaches where tectonics have produced a subsidence or an uplift. Previous considerations suggest that an increase of basin area causes a progressive increase of VFW, but the increase may not necessarily be continuous because of abrupt rather than continuous increases in the basin area (magnitudo) along the course of a river. This is especially true at the confluence of two large streams. In order to compare individual river reaches, it is firstly necessary to eliminate the "natural" increase of VFW caused simply by the increase in the basin area. For this purpose the Author made special attempt to elaborate the theoretical curve of VFW which reflects the "ideal" state of basin morphology. The VFW value is directly related to magnitudo in any particular location within a drainage network. The magnitudo was therefore employed as a basis for the elaboration of a theoretical curve. The theoretical curve is constructed in the direction of mouth to source, and, whereas its shape is related to the values of magnitudo, the values have been converted to VFW values. It is very important to delimit the first segment value of the theoretical curve. This was calculated as value as an arithmetic mean of 5% beginning segment values of the real curve (It is necessary to eliminate possible random fluctuations in values of VFW). The following VFW values are then calculated according to the empirical formula:

$$t_n = t_{n-1} (1 - (M_{n-1} - M_n) / M_{n-1}) \quad [\mathrm{m}], \qquad (1)$$

where t is the theoretical valley floor width, and M is the magnitudo of a particular segment.

The real and theoretical curves are then compared, the result being a set of numerical differences. The values of the differences do not necessarily reflect the trend and may be a subject of mutual comparison (owing to their continuous increase along the river course it is not possible to compare values of segments situated at different distances from the river source). Since rocks of different resistance are present within a river basin, it then becomes necessary to calculate the average difference for each rock type. A rock type of "average" resistance would show the minimal difference between the real and theoretical curves. Resistant rocks show negative values of differences and weak rocks positive ones (cases 2a and 2b on Fig 4). The influence of varied rock resistance is thus eliminated by calculating the mean values. In the next step, it is necessary to evaluate the variability of differences values within each group, in comparison with the group average. The values which show a significant deviation from the mean are considered to be influenced by factors other than rock resistance and distance from the source. This is based on a presumption that the adjusted values have random variability and are the subject of normal frequency distribution. The value of ± 2σ *(sigma)* bounds those areas with extreme values which face outside the area which contains 95% of the data.

On the basis of these anomalies, certain areas reveal themselves as being specially important for field research, because they show some anomalies. In further steps, it is necessary to exclude the influence of other variables which have not been taken into account in the previous analysis. Firstly, there is the factor of rock structure, which is far from easy to quantify. It is obvious that rock resistance depends, for example, on the orientation of sedimentary strata or the presence of crush zones etc. Only after the evaluation of these variables is it possible to identify the existence of recent tectonics. Tectonics thus becomes explanation of anomalous values of VFW. Anomalous values of VFW thus reveal neotectonic phenomena.

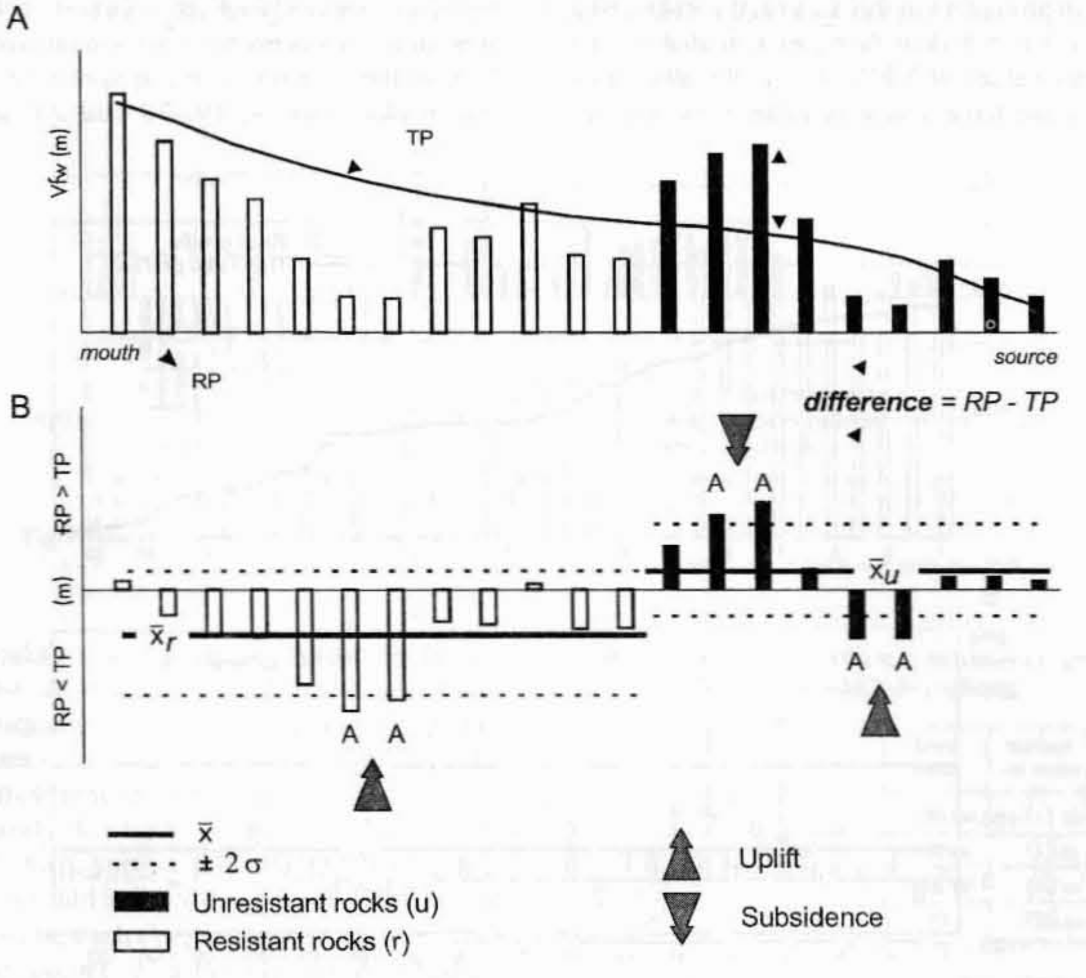


Fig. 5. The case when two lithologies with different rock resistance are present

A – the columns show the real (RP) and lines theoretical (TP) curve of VFW. The graph illustrates the way the differences are derived; B – anomalous values of differences (exceeding the value of 2σ) are indicated by the letter A, the average difference is indicated by the thick line

The method application

Rožnovská Bečva river

As it is built by the rocks of similar erosional resistance the valley of Rožnovská Bečva river is an example of case 3 on Fig. 4. On the graph (Fig. 6), the real curve has a shape which is nearly identical with that of the theoretical curve. This close coincidence precludes the possibility of major tectonic activity in this river basin. The values of standard deviation are exceeded in segments 7 and 10, being higher than the theoretical values of VFW (see Table 1).

Table 1. VFW characteristics of the Rožnovská Bečva river

Average VFW	452 m
Mean difference (RP – TP)	68 m
$X + 2\sigma$	197 m
$X - 2\sigma$	–61 m

The Zubří–Pinďula tectonic zone, which is strikingly expressed in the morphology of the Moravskoslezské Beskydy Mts to the N as a prominent pass is still prominent in this area. In the Rožnovská Trough, it has a forked form, as revealed by the anomalous values of VFW. The rocks along this tectonic zone have a low resistance to destruction, so it is probable that the higher values of VFW here are the result of their low resistance. Nevertheless, it is not entirely possible to eliminate tectonic subsidence as the cause of this effect. The lower rock resistance in the valley of Rožnovská Bečva river is also manifested by the number of monadnocks built from harder sandstone; there are outliers, derived from the erosion of a Raca nappe (see Fig. 2). The landforms of the Rožnovská Bečva valley appear to be "older" than those in surrounding areas (Vsetínské vrchy Hills, Moravskoslezské Beskydy Mts.). However, the low erosional resistance of the rocks in this area dictates that any manifestation of active tectonics would be soon obliterated by the general process of denudation. In such a case, geophysical methods should be employed.

Vsetínská Bečva river

In this area the situation is more complicated. In terms of rock resistance, it is possible to define three groups (see Table 2 and Table 3).

Approximately two thirds of the valley segments lie in the area of medium resistant rocks. Seven anomalous segments have been identified (Fig. 7). Four of these lie within the area of medium-resistant rocks (Nos. 4, 19, 20 and 24) and three on hard rocks (Nos. 5, 6 and 7). The relatively narrow segments, 4 and 7, lie within the area of medium resistant and hard rocks, however, in places where stream channel runs across flysch strata. These narrow reaches of the valley floor thus originated mainly due to the orientation of the valley relative to the direction of strata. Otherwise, narrow valleys could indicate the tectonic uplift (in fact, this cannot be excluded, because seismic tremors have been recorded in the vicinity of Valašské Meziříčí (Havíř & Skácelová, 1998). The seismic activity may be the effect of vertical movements in this area).

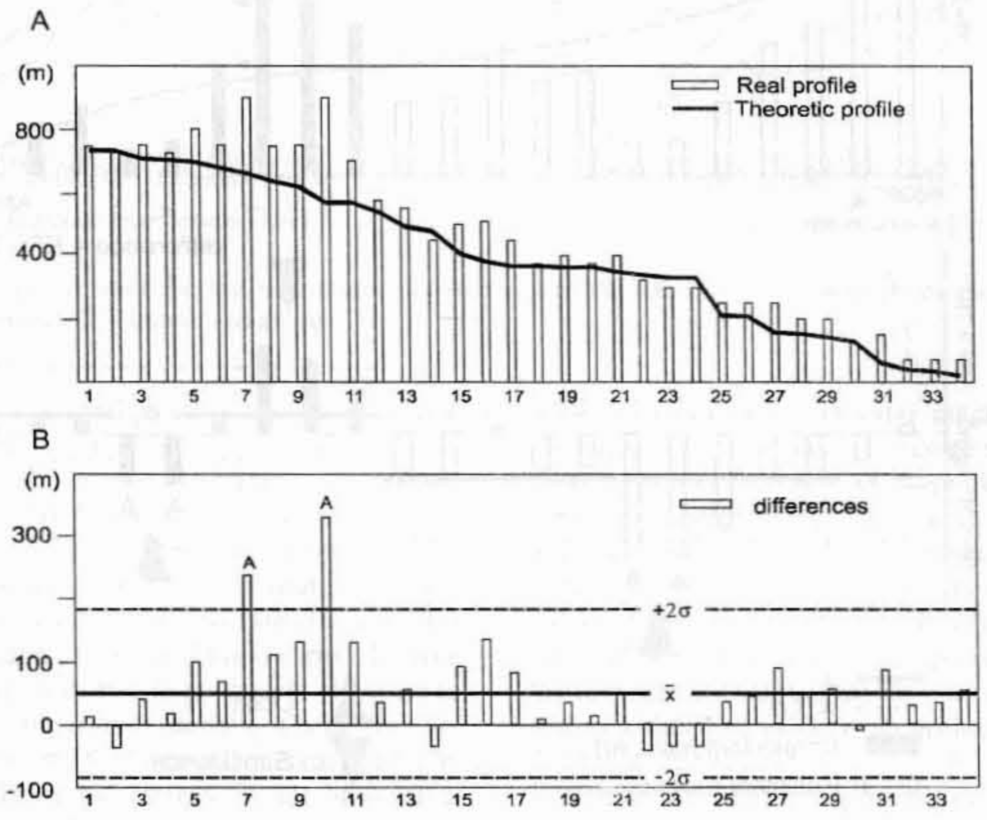


Fig. 6. The location of the Rožnovská Bečva valley
A – the more or less continuous increase of VFW indicates a smaller influence of external variables; B – the segments with anomalous VFW are indicated by the letter A

Table 2. Classification of rocks according to their resistance to erosion

Hard rocks	Medium resistant rocks	Weak rocks
Rusava Member *predominantly claystones*	Vsetín Member *predominantly claystones*	Beloveza Formation *predominantly claystones*
Luhačovice Member *coarse grained sandstones*	Ráztoka Member *sandstones and claystones*	Lower variegated Member *predominantly claystones*
Lukov Member *predominantly sandstones*	Hostýn Member *sandstones and claystones*	Krosno Formation *unconsolidated sandstones*
Kyčera Member *predominantly sandstones*	–	–
Újezd Member *coarse grained sandstones*	–	–

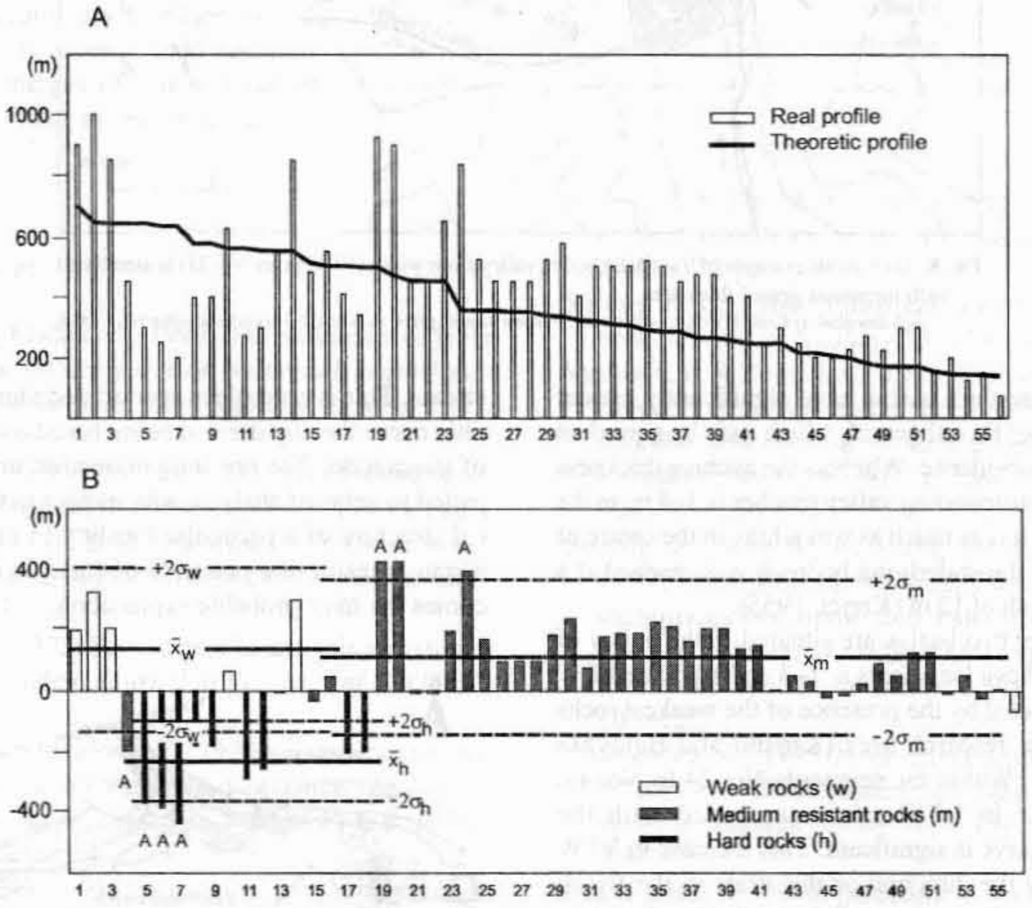


Fig. 7. The location of the Vsetínská Bečva valley
A – fluctuating course of VFW indicates considerable influence of external variables; B – the segments with anomalous VFW are indicated by the letter A

Table 3. Characteristics of the rock resistance categories in the Vsetínská Bečva valley

	Hard rocks	Medium res. rocks	Weak rocks
Average VFW	380 m	415 m	651 m
Mean difference (RP – TP)	–260 m	113 m	146 m
$X + 2\sigma$	–130 m	362 m	420 m
$X - 2\sigma$	–390 m	–136 m	–128 m

The situation in segments 19, 20 and 24 is different (Fig. 8). Krejči (1955) considered that this valley has been segmented by recent faulting. Certainly, of bore-

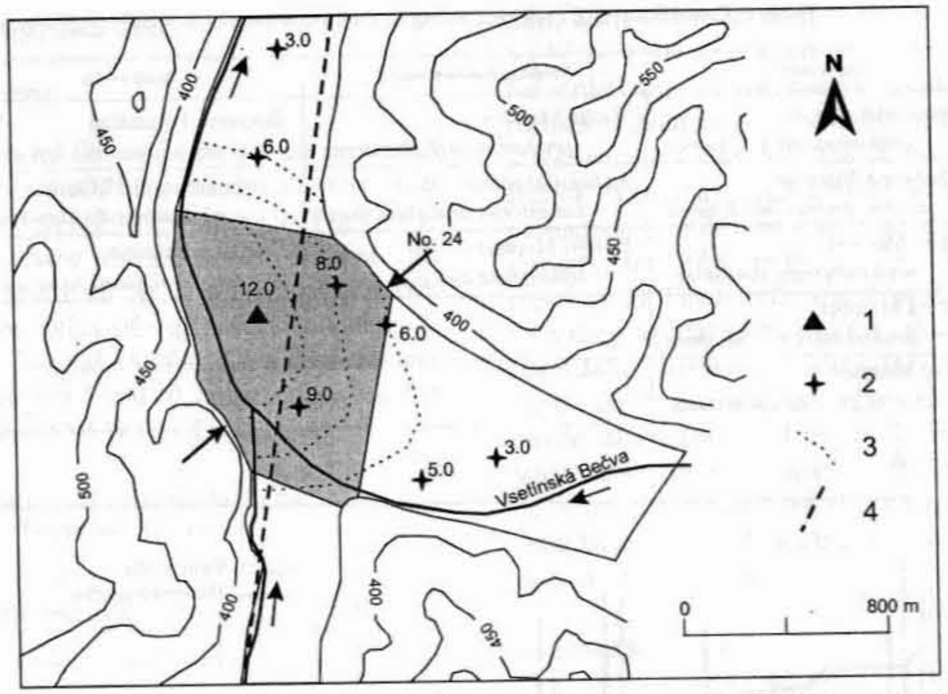


Fig. 8. Anomalous example of Vsetínská Bečva valley floor width (VFW point No. 24) is associated with increased gravel thickness
1 – well described by Krejčí (1955), 2 – other wells, numbers indicate gravel thickness, 3 – isopachs of valley fill, 4 – fault

holes in these fault basins have significantly greater thicknesses of fluvial gravel, which may be a product of tectonic subsidence. Whereas the average thickness of gravel in surrounding valley reaches is 3–4 m, in the fault basins, it is as much as 9 m while, in the centre of fault basins, the underlying bedrock was reached at a borehole depth of 12 m (Krejčí, 1955).

The other two basins are situated in the valley of Vsetínská Bečva (segments n. 1–3 and 14). The VFW value is affected by the presence of the weakest rocks of the entire research area (Krosno and Beloveza Formations). Within the segments No. 24 to No. 41, the increase in VFW when compared with the theoretical curve is significant. This increase in VFW is caused by the direction of the strata in the flysch nappes, which, here, are parallel to with the valley axis.

Conclusion

The present study of neotectonics in the Vsetínské vrchy Hills was based on a new morphometric method, which is based on VFW evaluation. The method is based upon the presumption that, in an ideal condition, VFW increases along the course of a stream in relation to basin area increments. In the general case, this trend is disturbed by the presence of relatively weaker and relatively stronger rocks or by tectonic activity. In order to detect the locations which are tectonically active, it is necessary to eliminate the effect of rock resistance variability as well as the trend of a continuous increase of VFW along the course of a stream. This is a simple matter of procedure, the theoretic curve thereby derived being based on increments of magnitudo. The resulting anomalies are then subjected to detailed analysis with respect to the geological structure of a particular locality. In the case of a negative result, the presence of tectonic activity becomes the most probable explanation.

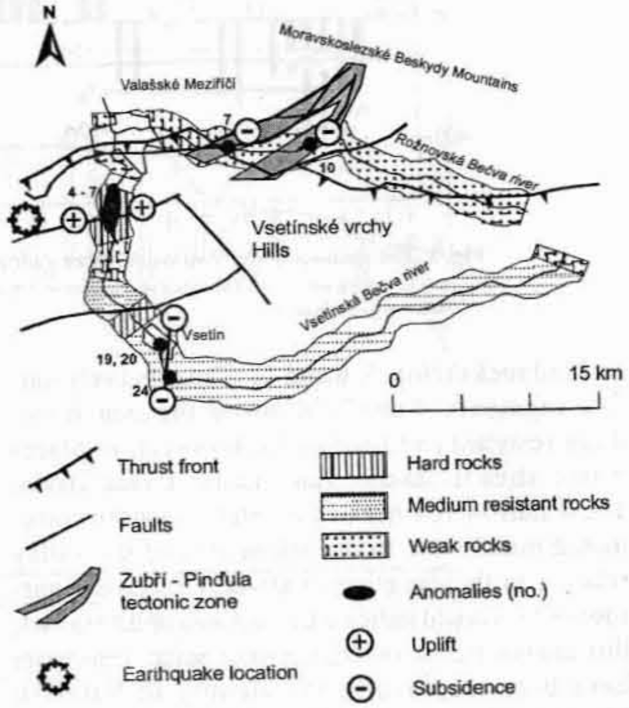


Fig. 9. The location of the established anomalies with direction of probable vertical motion. Earthquake location is based on Havíř & Skácelová (1998)

Nine anomalous reaches have been identified on the stream channels by this method (Fig. 9 and Table 4). Three of these are attributed to tectonic subsidence (Vsetínská Bečva: Nos. 19, 20 and 24); four anomalies to tectonic uplift or a local stratal altitude (Vsetínská Bečva: Nos. 4, 5, 6 and 7) and two are due to their locations on coincident zones of relatively low rock resistance (Rožnovská Bečva: No. 7 and 10).

This method is a convenient tool, along with other morphometric methods, for preliminary landform assessments which precede field research. Other advantages of this method are that it is neither time consuming nor expensive.

Table 4. Anomalous VFW characteristics and the estimated causes

Site No.	Res.	VFW	Difference (RP –TP)	Deviation	Probable/possible cause
Rožnovská Bečva river					
7	w	882 m	237 m	2.6σ	Lower rock resistance/subsidence
10	w	885 m	329 m	4.0σ	Lower rock resistance/subsidence
Vsetínská Bečva river					
4	m	456 m	–205 m	3.0σ	Uplift
5	h	304 m	–395 m	2.1σ	Uplift
6	h	253 m	–400 m	2.2σ	Uplift
7	h	203 m	–450 m	2.9σ	Uplift
19	m	937 m	405 m	2.4σ	Subsidence
20	m	911 m	403 m	2.3σ	Subsidence
24	m	848 m	390 m	2.2σ	Subsidence

Explanations: Res. – rock resistance categories, w – weak rocks, m – medium resistant rocks, h – hard rocks.

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