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Debris flows in the Hrubý Jeseník Mountains, Bohemian Massif, Czech Republic

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ABSTRACT
Debris flows in mountainous areas have a deep geomorphic impact on slope dynamics. Their activity corresponds with heavy rainfall events. The estimation of these events depends not only on meteorological prediction but also on the knowledge of their spatial occurrence. As debris flows usually occur in the same paths with different frequencies during the Quaternary period, spatial data are needed to obtain more detailed information about debris flow phenomena. This was the reason for the creation of the presented map of debris flow features in the Hrubý Jeseník Mts. A total of 95 debris flow paths and 47 debris flow accumulations (including lobes or levees) have been mapped in the field. A comprehensive spatial database of debris flow features is shown in the map, which could be helpful for future research of Quaternary geomorphic evolution of the landscape and for forest management and state administrative authorities in future planning.

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1. Introduction

Very or extremely rapid slope movements of water-saturated debris occur periodically in established debris flow paths (Hungr, Leroueil, & Picarelli, 2014). They usually originate on steep slopes (over 25°), and their usual trigger is extreme rainfall. Typically, debris flow paths contain specific geomorphological phenomena such as gullies, levees on their sides and poorly sorted accumulations (Iverson, 2004). As debris flows occur on steep slopes, they are most common in tectonically active mountains around the world with high uplift and erosion rates, depending on the geological settings of each location, especially the weathering mantle thickness (Hungr et al., 2014). Debris flows cause forest and infrastructure destruction, and they endanger human lives (Costa, 1984); on the other hand, together with avalanches, they can have a positive ecological impact in some areas (Butler, 2001), and they can be the study subjects of palaeogeographical and palaeoclimatological reconstructions of landscape history (Stoffel et al., 2005). In these cases, cumulative studies have been conducted and maps of debris flow areas produced in many countries such as the USA, China and Russia (e.g. Brabb & Best, 1999; Ellen, Mark, Cannon, & Knifong, 1993; He et al., 2003; Perov, Chernomorets, Budarina, Savernyuk, & Leontyeva, 2017). Recurrence of debris flows in their paths is common and has been reported from many areas around the world (e.g. Perov et al., 2017; van Steijn, 1996; Zimmermann, Mani, & Romang, 1997).

Field geomorphological mapping and analysis of remote sensing data and written sources have been employed to collect debris flow spatial data in the Hrubý Jeseník Mts. (Bohemian Massif, Czech Republic), where the return period of debris flow events is quite long and the debris flow paths could get overgrown by forest before the next debris flow event (Sokol, 1965). Thus, the spatial distribution of past debris flow events (i.e. their paths and accumulations) is very important for estimating the future debris flow activity, because it occurs in the same localities. Debris flows are also a phenomenon related to environmental changes that causes risks and disasters. The presented map introduces the first complex depiction of the spatial distribution of debris flows in the study area, which is useful for future environmental planning, risk assessment and forest management, because the debris flows could occur after forest clearcutting. The map is built on a high-resolution digital elevation model (DEM) and presents the position of debris flow paths and accumulations in different catchments of the mountain range. The location properties of debris flow paths in relation to alpine timberline and infrastructure positions are presented.

1.1. Debris flows in the Hrubý Jeseník Mts.

The Hrubý Jeseník Mts. (maximal elevation Mt. Praděd, 1492 m asl), located in the northeastern part of the Bohemian Massif in Central Europe (Figure 1), consist of metamorphic rocks (gneisses, phyllites,

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quartzites and mica schists – see the geological map on the Main Map). It is a Variscian fault-block mountain range influenced by the reactivation of Variscian faults under the influence of Saxonian neotectonic processes since the beginning of Alpine orogeny (Chlupáč, Brzobohatý, Kovanda, & Stráník, 2011). Tectonic activity was observed even in the current geological epoch, when vertical movements reached values of tens of metres during the Quaternary (Badura et al., 2007; Krzyszkowski & Pijet, 1993; Štěpančíková et al., 2010). Young deep valleys with steep slopes intersect Cenozoic summit planation surfaces (Křížek, 2016) located above the timberline (Treml, Jankovská, & Petr, 2008). During glacial periods of the Quaternary, periglacial (Křížek, 2016; Prosová, 1973) and locally glacial (Křížek, Vočadlová, & Engel, 2012) conditions were present in the Hrubý Jeseník Mts., which caused the formation of a thick regolith. Large old debris flow accumulations with unsorted clasts (sensu Hungr et al., 2014), observable in many valley floors (Křížek, 2016), were considered incorrectly as glacial moraines in past literature (Prosová, 1973 and references therein). Snow avalanches and debris flows are the most dynamic geomorphological processes in this mountain range (Gába, 1992; Krause & Křížek, 2018; Sokol, 1965; Tichavský & Šilhán, 2015) even in present climatic conditions characterized by short wet summers and long winters with long-lasting snow cover. The mean annual temperature on Mt. Praděd is +1.7°C (1960–1990; Coufal, Míková, & Langová, 1992), and the mean annual precipitation is 1231 mm (1947–1985; data of the Jeseníky Protected Landscape Area Authority). Some periglacial phenomena (ploughing blocks, earth hummocks, small sorted circles, nivation hollows and small solifluction lobes) are still active (Křížek, 2016). Since the nineteenth century, debris flow events have been observed many times, for example, in 1880, 1890, 1893, 1903, 1907, 1921, 1938, 1940, 1951, 1965, 1968, 1984, 1991, 1994, 1997 and 2006 (Gába, 1992; Krause & Křížek, 2018; Malik & Owczarek, 2009; Polách & Gába, 1998; Sokol, 1965; Tichavský & Šilhán, 2015). The last most important and fatal debris flow event occurred in the Hučivá Desná Valley (catchment no. 6 in the Main Map) after heavy rainfall on 1 July 1921 (Polách & Gába, 1998; Sokol, 1965). Approximately 50,000 m^3 of regolith was removed by eight debris flows (Figure 2), and the deposit of these debris flows dammed the valley, filling up a lake that collected a huge volume of water in a short time. The dam collapsed a few hours after its formation, and the resultant flood damaged many buildings, all bridges and railway infrastructure and killed four people in villages spread along 25 km of the river. Similar events occurred in 1770 and

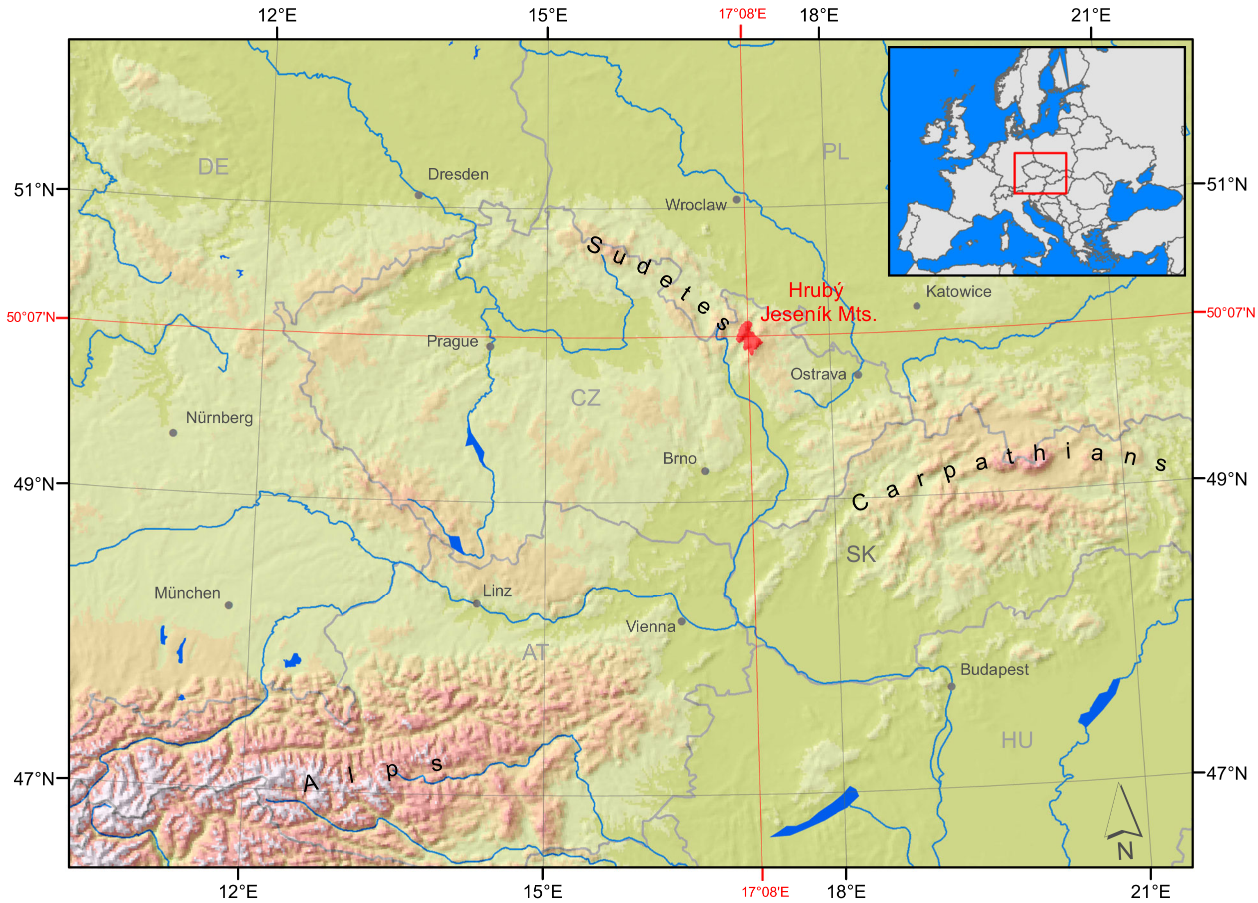

Figure 1. Geographical location of the Hrubý Jeseník Mts.

Figure 2. Debris flow paths in the Hučivá Desná catchment (6) in the year 1921 (old photograph from a postcard on the left), and technical protection built in debris flow paths in order to stabilize the slopes (on the right, photo D. Krause).

1813 (Schön, 1938 in Gába, 1992). The forest management authorities often tried to build erosion control fences in the debris flow paths (Figure 2) and began to grow a non-indigenous dwarf pine (*Pinus mugo*) to stabilize the convex slopes above the timberline where starting zones of debris flows are usually located (Treml, Wild, Chuman, & Potůčková, 2010). Even so, some debris flows still occur repeatedly in their paths (Gába, 1992, 2014; Sokol, 1965; Tichavský & Šilhán, 2015). As the occurrence of debris flows is still a problem in forest management and risk prevention at the present time, the spatial distribution of debris flow paths needs to be examined, yet there has been no cumulative study or map produced constraining these problems.

2. Methods and data collection

2.1. Data collection

The map of debris flow paths is the result of (1) geomorphological field mapping of the valley floors and slopes, (2) remote sensing based on fourth generation (vertical resolution of approximately 30 cm in a 5 × 5 m grid) and fifth generation (vertical resolution of approximately 18 cm in triangulated irregular network) digital elevation models based on light detection and ranging provided by The State Administration of Land Surveying and Cadastre and historical aerial photographs from the years 1936, 1946, 1957, 1958, 1965, 1971, 1975, 1985, 1992 and 1995 obtained from The Army Institute of Geography and Hydrometeorology, and (3) analysis of written sources, e.g. dissertation thesis of Sokol (1965) and Gába (1992) paper about the last well-described debris flow event in the Keprnický potok Valley on 4 September 1991.

Recent debris flow paths and old debris flow accumulations located in valley floors and valley heads have been mapped in the field using a GPS device. Derived raster images (slope, hillshade and curvature) from the DEM have been used to compare debris flow forms observed in the field and to detect exact debris flow morphological features (such as gullies and accumulations). The positions of debris flow path borders have been validated using historical aerial photographs, as debris flows usually destroyed forest canopy, which was clearly visible in the images. Further, evidence about debris flow locations obtained from the literature (Gába, 1992; Kirwald, 1942; Sokol, 1965) has been used for discussion. Additional debris flow paths and accumulations derived from the DEM, aerial photographs and written sources have also been verified in the field.

2.2. Map creation

The Main Map is designed as a physical wall map in dimensions of A1 format, for which the map scale is 1:40,000. Elevation data in the map have been derived from the Digital Terrain Model of the fourth generation (State Administration of Land Surveying and Cadastre): contours with an interval of 50 vertical metres and hillshade tinting (illumination azimuth 315°, altitude 45°) with 50% transparency are used to underline topography on the Main Map. The streams, rivers and summit points have been derived from the

Figure 3. Debris flow accumulations in the Keprnický potok catchment (4; on the left) and the Divoký důl catchment (9; on the right; both photo M. Křížek).

digital terrain model and named according to the GEONAMES database (The State Administration of Land Surveying and Cadastre). The roads, forests and buildings have been visualized by the OpenStreetMap data. The colours used in the map are those commonly used in topographic maps (Kraak & Ormeling, 2013). Highlighted features (debris flow paths and accumulations) are visualized in violet and orange to be easily visible on the basic map. The Projected Coordinate System used in the map is the Czech National System S-JTSK – Krovak East-North. Collected spatial data are visualized in the presented map, which contains two categories of debris flow spatial data in the study area:

(a) debris flow paths with observable transportation zone (polygon features). Most of these debris flows were active since the beginning of the twentieth century, as the morphological forms of whole paths are still visible in the field or were observed on the historical aerial photographs and checked in the field. Many of these paths are overgrown by forests in the present time, but their reactivation in the future is possible;
(b) debris flow accumulations on the valley floors (point features). These landforms are relicts of older debris flow activity with no more morphological evidence about the transport zone, only large accumulations composed by unsorted deposits (Figure 3). Even though these features are remains of older debris flow events, their surroundings could be prone to debris flows in the future.

The debris flow features are located in 11 catchments – sections, shown in the map with unique numbers. Information about the elevation parameters of all debris flow features and about the area of debris flow paths is given in tables next to the map. Two small thematic maps of the same spatial extent as the Main Map are added in the scale of 1:120,000. The geological map depicts the different lithologies within the mountain range, and the slope map shows the locations of the highest surface slope. These maps should enable the reader to compare the distribution of debris flow features to their geological and morphological settings when all studied catchments and debris flow features are printed.

3. Conclusions

Field geomorphological mapping, with the support of remote sensing and previous studies, allowed for the creation of a database of debris flow paths and accumulations for the Hrubý Jeseník Mts. A total of 95 debris flow paths and 47 debris flow accumulations have been mapped and visualized in the Main Map. Most of them are located in the northern part of the study area (catchments no. 1–7). This is caused particularly by geological (see the geological map) and climatic differences between these two parts of the mountains. In the northern part of the study area, the rocks (predominantly gneiss, mica schists and phyllites) are foliated. This foliation forces the speed of weathering, especially when the foliation plane has the same inclination as the surface slopes. The total area of observed debris flow paths in the mountains is 67 ha, which represents 0.25% of the whole study area. The greatest area, 23 ha, covered by debris flow paths is located in the Hučivá Desná catchment (no. 6), predominantly on the slopes of Mt. Červená hora (1333 m asl), as well as on the eastern slope of this mountain in catchment no. 7 (see Table 1). In many cases, the debris flow paths coalesce with other paths in their lower parts. This is observable in catchments no. 1, 3, 4, 5, 6 and 7.

Debris flow starting zones occur between 948 and 1318 m asl. In all catchments except for catchment no. 10, the starting zones of debris flow paths are located above 1000 m asl. This confirms that the debris flows are usually caused by steep slopes in convex upper sections of valley slopes with sufficient amount of regolith. The lowest parts of debris flow paths are located between 703 and 1001 m asl. In catchment no. 6, where the largest debris flow paths active in 1921 are located, there is the highest starting point of debris flows, and this catchment has the highest range of elevations, over 500 vertical metres, containing debris flow paths. Debris flow accumulations on valley floors occur between 617 and 1110 m asl, with the lowest one located in catchment no. 6 and the highest one in catchment no. 8 (Table 1). Most of the recent debris flows originated in the forest, with only some debris flows on Mt. Červená hora (catchment no. 6) having their starting zones above the timberline.

Usually, there are no paths or roads in the debris flow paths. The only exceptions are the debris flow paths in the Hučivá Desná Valley, which have tourist path crossings (catchment no. 6), and one debris flow path in the Červenohorský potok Valley, which crosses a road (catchment no. 7). Both of these debris flow localities were active in 1921 (Sokol, 1965). The activity of debris flows is still concentrated in the same catchments because the accumulations of older debris flows are present in the same areas as the recent debris flow paths. It is probable that future debris flows could appear in these areas again. Therefore, the local forest management authorities should take care about these localities and avoid forest clearcutting in these areas.

The presented map summarizes all above-mentioned mapping results and provides an overview of the spatial distribution of debris flow paths and accumulations in the Hrubý Jeseník Mts. All these features could be compared to geological and slope properties of the studied area. The importance of the map is for palaeogeographical studies as well as for future environmental planning. Because the map data are stored as shapefiles, they could be used in the future for further mapping of geomorphological processes in the area using geographic information systems, which is important for forest and nature protection management, as well as risk assessment.

Software

The database of debris flows and creation of the map was carried out in ArcMap 10.3 (ESRI, 2014). Microsoft Excel was used for basic numerical data analysis. The final layout of the map was produced in ArcGIS Pro (ESRI, 2017).

Table 1. Catchments in the Hrubý Jeseník Mts. with their debris flow features.

Catchment number and name	Number of debris flow paths	Number of debris flow accumulations	Area of debris flow paths (m^2)	Maximal elevation of debris flow paths (m asl)	Minimal elevation of debris flow paths (m asl)	Maximal elevation of debris flow accumulations (m asl)	Minimal elevation of debris flow accumulations (m asl)	Documented debris flow activity
1: Vražedný potok	3	1	48,050	1277	983	772	772	twentieth century
2: Javořický potok	3	2	14,300	1169	1001	824	789	twentieth century
3: Klepáčský potok, Jelení potok	28	7	14,2650	1271	925	866	709	1921, recent
4: Kepnický potok	4	3	33,575	1318	980	955	779	1991
5: Rudohorský potok	8	6	74,525	1213	832	1005	780	1921, recent
6: Hučivá Desná, Poniklý potok	13	6	23,4050	1310	795	886	617	1921
7: Černý potok, Červenohorský potok	17	0	88,950	1274	866	–	–	1921
8: Studený potok, Bukový potok	0	1	–	–	–	834	834	twentieth century
9: Divoká Desná, Divoký potok, Hladový potok, Česnekový potok	11	20	34,625	1126	703	1110	752	twentieth century
10: Tříramenný potok	2	0	750	948	809	–	–	twentieth century
11: Merta, Kamenitý potok, Divoký potok	6	1	3425	1076	767	772	772	recent

Supplemental data

The shapefiles of debris flow paths and accumulations could be provided on request by the authors. The shapefile of the paths is a polygon feature, and the shapefile of debris flow accumulations is a point feature.

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References

Badura, J., Zuchiewicz, W., Štěpančíková, P., Przybylski, B., Kontny, B., & Cacon, S. (2007). The Sudetic marginal fault: A young morphophotectonic feature at the NE margin of the Bohemian Massif, Central Europe. *Acta Geodynamica et Geomaterialia*, *4*(4), 7–29.

Brabb, E. E., & Best, T. J. P. (1999). *Map showing inventory and regional susceptibility for Holocene debris flows and related fast moving landslides in the conterminous United States: Raster data*.

Butler, D. R. (2001). Geomorphic process-disturbance corridors: A variation on a principle of landscape ecology. *Progress in Physical Geography*, *25*(2), 237–238. doi:10.1177/030913330102500204

Chlupáč, I., Brzobohatý, R., Kovanda, J., & Stráník, Z. (2011). *Geologická minulost České republiky* [Geological history of the Czech Republic]. Prague: Academia.

Costa, J. E. (1984). Physical geomorphology of debris flows. In J. E. Costa & P. J. Fleisher (Eds.), *Developments and applications of geomorphology* (pp. 268–317). Berlin: Springer. doi:10.1007/978-3-642-69759-3_9

Coufal, L., Míková, T., & Langová, P. (1992). *Meteorologická data na území ČR za období 1961–90* [Meteorological data from the territory of the Czech Republic from the period 1961–90]. Prague: Czech Hydrometeorological Institution.

Ellen, S. D., Mark, R. K., Cannon, S. H., & Knifong, D. L. (1993). *Map of debris-flow hazard in the Honolulu District of Oahu, Hawaii* (No. 2331–1258). US Geological Survey.

Gába, Z. (1992). Mury pod Keprníkem v červenci 1991 [Debris flows under the Keprník Mt. in July 1991]. *Severní Morava*, *64*, 43–49.

Gába, Z. (2014). *Vlastivědné zajímavosti z přírody Jeseníků* (I. vydání) [Natural interests in the Jeseníky Mts. (Issue no. 1)]. Štíty: Veduta.

He, Y. P., Xie, H., Cui, P., Wei, F. Q., Zhong, D. L., & Gardner, J. S. (2003). GIS-based hazard mapping and zonation of debris flows in Xiaojiang Basin, Southwestern China. *Environmental Geology*, *45*(2), 286–293. doi:10.1007/s00254-003-0884-0

Hungr, O., Leroueil, S., & Picarelli, L. (2014). The Varnes classification of landslide types, an update. *Landslides*, *11*(2), 167–194. doi:10.1007/s10346-013-0436-y

Iverson, R. M. (2004). Debris flow. In A. S. Goudie (Ed.), *Encyclopedia of geomorphology* (p. 225). London: Routledge.

Kirwald, E. (1942). Forstliche Wasserhaushaltstechnik in gefährdeten Mittelgebirgslagen: Untersuchungen über Rutschungen und deren Bekämpfung im Altvatergebirge [Forestry water management technology in endangered mountain ranges: studies on landslides and their control in the Hrubý Jeseník Mountains]. *Tharandter Forstliches Jahrbuch*, *93*(9/10), 429–519.

Kraak, M.-J., & Ormeling, F. (2013). *Cartography: Visualization of spatial data*. London: Routledge.

Krause, D., & Křížek, M. (2018). Dating of recent avalanche events in the Eastern High Sudetes, Czech Republic. *Quaternary International*, *470*, 166–175. doi:10.1016/j.quaint.2017.09.001

Křížek, M. (2016). Periglacial landforms of the Hrubý Jeseník Mountains. In T. Pánek & J. Hradecký (Eds.), *Landscapes and landforms of the Czech Republic* (pp. 277–289). Cham: Springer. doi:10.1007/978-3-319-27537-6_22

Křížek, M., Vočadlová, K., & Engel, Z. (2012). Cirque overdeepening and their relationship to morphometry. *Geomorphology*, *139–140*, 495–505. doi:10.1016/j.geomorph.2011.11.014

Krzyszkowski, D., & Pijet, E. (1993). Morphological effects of Pleistocene fault activity in the Sowie Mts., southwestern Poland. *Zeitschrift für Geomorphologie*, *94*, 243–259.

Malik, I., & Owczarek, P. (2009). Dendrochronological records of debris flow and avalanche activity in a mid-mountain forest zone (Eastern Sudetes—Central Europe). *Geochronometria*, *34*(1), 57–66. doi:10.2478/v10003-009-0011-7

Perov, V., Chernomorets, S., Budarina, O., Savernyuk, E., & Leontyeva, T. (2017). Debris flow hazards for mountain regions of Russia: Regional features and key events. *Natural Hazards*, *88*, 199–235. doi:10.1007/s11069-017-2841-3

Polách, D., & Gába, Z. (1998). Historie povodní na šumperském a jesenickém okrese [Flooding history of the Šumperk region]. *Severní Morava*, *75*, 3–28.

Prosová, M. (1973). Zalednění Hrubého Jeseníku [Glaciation of the Hrubý Jeseník Mts.]. *Campanula*, *4*, 115–123.

Sokol, F. (1965). *Vliv přírodního prostředí a lidské činnosti na vznik svahových sesuvů a dosavadní zkušenosti s jejich rekultivací v Hrubém Jeseníku* [Impact of the natural environment and human activity on the formation of slope landslides and the experience with their reclamation in the Hrubý Jeseník Mountains] (Doctoral thesis). Faculty of Forest Management, Agricultural University in Brno, Šumperk.

Štěpančíková, P., Hók, J., Nývlt, D., Dohnal, J., Sýkorová, I., & Stemberk, J. (2010). Active tectonics research using trenching technique on the south-eastern section of the

Sudetic marginal fault (NE Bohemian Massif, Central Europe). *Tectonophysics*, *485*(1), 269–282. doi:10.1016/j.tecto.2010.01.004

Stoffel, M., Lièvre, I., Conus, D., Grichting, M. A., Raetzo, H., Gärtner, H. W., & Monbaron, M. (2005). 400 years of debris-flow activity and triggering weather conditions: Ritigraben, Valais, Switzerland. *Arctic, Antarctic, and Alpine Research*, *37*(3), 387–395. doi:10.1657/1523-0430(2005)037[0387:YODAAT]2.0.CO;2

Tichavský, R., & Šilhán, K. (2015). Dendrogeomorphic approaches for identifying the probable occurrence of debris flows and related torrential processes in steep headwater catchments: The Hrubý Jeseník Mountains, Czech Republic. *Geomorphology*, *246*, 445–457. doi:10.1016/j.geomorph.2015.06.027

Treml, V., Jankovská, V., & Petr, L. (2008). Holocene dynamics of the alpine timberline in the High Sudetes. *Biologia*, *63*(1), 331. doi:10.2478/s11756-008-0021-3

Treml, V., Wild, J., Chuman, T., & Potůčková, M. (2010). Assessing the change in cover of non-indigenous dwarf-pine using aerial photographs, a case study from the Hrubý Jeseník Mts., the Sudetes. *Journal of Landscape Ecology*, *3*(2), 43. doi:10.2478/v10285-012-0029-9

van Steijn, H. (1996). Debris-flow magnitude–frequency relationships for mountainous regions of Central and Northwest Europe. *Geomorphology*, *15*(3–4), 259–273. doi:10.1016/0169-555X(95)00074-F

Zimmermann, M., Mani, P., & Romang, H. (1997). Magnitude-frequency aspects of alpine debris flows. *Eclogae Geologicae Helvetiae*, *90*(3), doi:10.5169/seals-168173