LANDFORMS AND MORPHOGENETIC PROCESSES IN THE LOCALITY OF GEODETIC OBSERVATORY PECNÝ, ONDŘEJOVSKÁ VRCHOVINA HIGHLAND

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ABSTRACT

The presented paper deals with physical-geographical environment and landform patterns in the locality of Geodetic Observatory Pecný (GOPE) in the Ondřejovská vrchovina Highland. Landforms transience of the Ondřejovská vrchovina Highland by erosion and denudation processes is proportional to a high potential energy of the relief due to progressive tectonic uplift of the central part of the Bohemian Massif in the late Cenozoic. The Seradovský potok Brook valley between the Pecný Ridge (545 m a.s.l.) and the Sázava valley bottom (284 m a.s.l.) intersects several levels of planation surfaces and its source area erodes the etchplain exhumed during the Palaeogene. In the lower part of the valley, the stream deepened during the late Quaternary by approximately 50 m, whereas the relatively steep erosional slopes of the canyon-like part of the antecedent Sázava valley have a relative height of 60–75 m.

In the rugged terrain of the GOPE locality, there are visible marks of regelation and frost processes, gully and fluvial erosion, slow slope movements and anthropogenic activities. Intensity of recent morphogenetic processes with its maximum in spring corresponds to combination of seasonal changes of air and soil temperature and at the same time to increased water content in the rock massif and in the weathered mantle. The suitable geodynamic location of scientific observatories on the Pecný ridge, stable from engineering-geological and geomorphological point of view, and in its near neighbourhood is menaced by increasing intensity of anthropogenic activities in the landscape.

Keywords: landform evolution, recent morphogenetic processes, Ondřejovská vrchovina Highland

Received 19 July 2016; Accepted 4 October 2016

1. Introduction

1.1 Definition of the topic

The Geodetic Observatory Pecný (GOPE) of the Research Institute of Geodesy, Topography and Cartography and observatories of the Astronomical Institute of the Czech Academy of Sciences are located in the ridge part of Pecný (545.8 m a.s.l., latitude 49°54′49.33″ N and longitude 14°47′08.23″ E) which is the highest summit of the Ondřejovská vrchovina Highland (Fig. 1). Astronomical and geoscientifical observatories in the Ondřejovská vrchovina Highland are a historically important experimental area of Czech science traditionally dedicated to long-term research projects (see for instance Ondřejovská hvězdárna 1998; Kostelecký et al. 2005a,b). From the engineering-geological viewpoint, this is a very stable territory in the central part of the Bohemian Massif (Kalvoda et al. 2004). The large complex of the GOPE with its permanent GPS station and other high-quality geophysical and meteorological equipment has an excellent position for research into recent geodynamics of morphostructural units in Central Europe.

The natural environment of the Ondřejovská vrchovina Highland is quite varied and so is also the dynamic morphostructural and climate-morphogenetic evolution of its landforms in the late Cenozoic. Regional geomorphological research into the Ondřejovská vrchovina Highland and its near territories was already treated in several papers paying attention mainly to orographic aspects and river network development (Daneš 1913; Moschelesová 1930; Novák 1932; Kuncová 2005; Balatka, Štěpančíková 2006; Balatka 2007; Kalvoda 2007; Balatka, Kalvoda 2010). Geological structure of this region

Fig. 1 Aerial photograph of polygenetic relief of the Ondřejovská vrchovina Highland taken from the south. The complex of the Astronomical Institute of the Czech Academy of Sciences and of the Geodetic Observatory Pecný (GOPE) of the Research Institute of Geodesy, Topography and Cartography are located above the village of Ondřejov, partly on forested ridges of the hills of Žalov, Pecný (545 m a.s.l.) and Ostrá Skála. Photo: JAS AIR spol. s.r.o.

was studied in detail by Orlov (1933), Vajner (1960), Kachlík (1992), Domas et al. (1993) and in the context of the Bohemian Massif´s long-term development among others by Chlupáč et al. (2002). The increasing heterogeneity and quality of geophysical and geodetical measurements, a great extent of appropriate databases and efforts to interpret them in a complex way impose at present high requirements on knowledge of types and intensity of recent climate-morphogenetic processes, tectonic and also anthropogenous activities in localities of scientific observatories.

The main aims of the paper are 1) characteristics of the physical-geographical environment and landform patterns in the research observatories locality, 2) evaluation of local climatic conditions in relation to recent morphogenetic processes, and 3) description of geomorphic profile between the Pecný ridge and the Sázava valley and its erosional evolution during the Quaternary. It is a communication of running results of experimental research into recent climate-morphogenetic processes going on in the near-surface part of the rock massif as well as in its weathered mantle. These geomorphological processes determine present changes of landforms having developed during a long period of the late Cenozoic. Detailed exploration of geomorphic processes in the area of GOPE was integrated with systematical studies of physical-geographical phenomena and landform evolution in the Ondřejovská vrchovina Highland. Geomorphological mapping of the region (locality) also supported selection of specific sites to long-term observations of running and/or expected (slow) changes of landforms. The research in the locality of astronomic and geoscientific observatories was carried on simultaneously with the research into the system of river terraces and Sázava valley evolution (Kalvoda 2007; Balatka, Kalvoda 2010; Balatka et al. 2010a,b, 2015), including reconstruction of the progressive development of the deep erosional cutting of this river during the Quaternary.

A complex approach to using available palaeogeographical findings and current experimental data related to geomorphic history and to recent landscape changes enables a progressive integration of geodetical, geophysical and geological measurements and observations and studying of landforms of variable evolution and age (Kalvoda 2005). During the last twenty years complexity of geodetical and geophysical measurements carried on at the GOPE significantly increased, e.g. performing continuous observation of GPS satellites, research into tidal and non-tidal variations of acceleration of gravity, meteorological measurements and the analytical centre

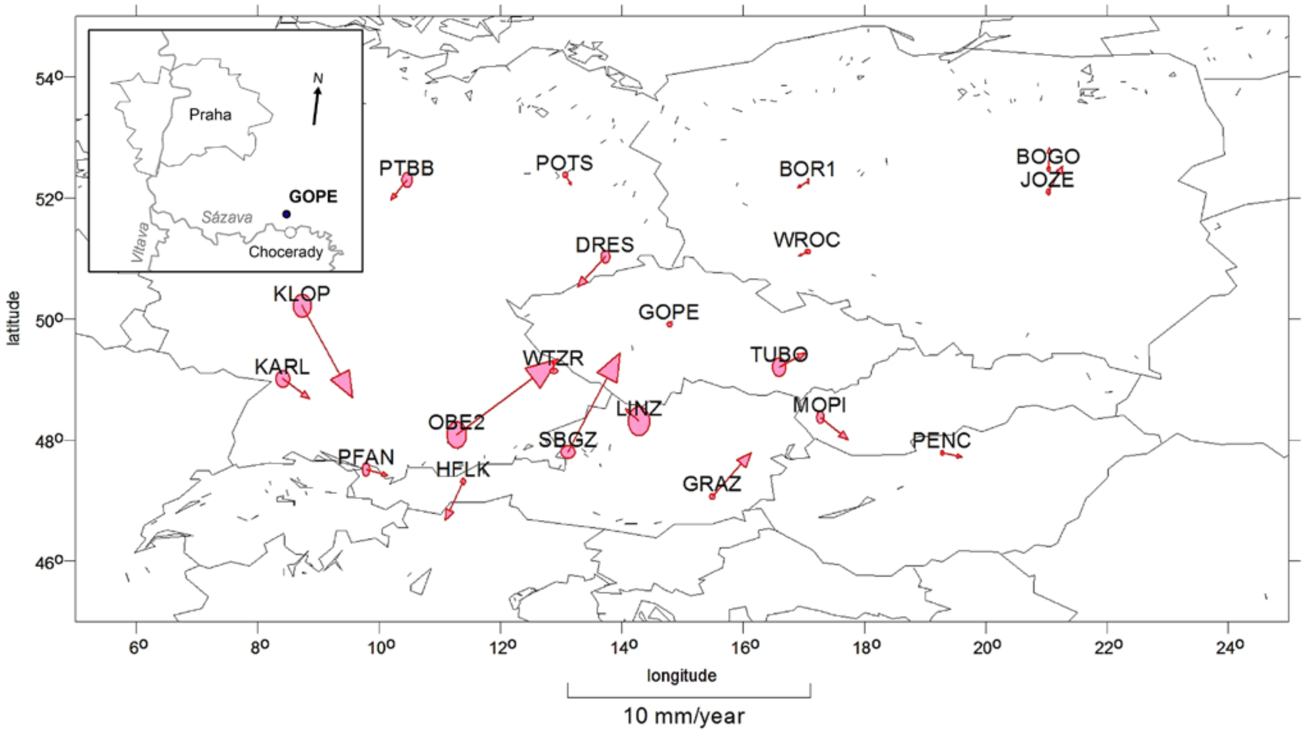

Fig. 2 Relative motions of EUREF Permanent Network (EPN) stations with respect to GOPE in the period from 1996 to 2002 (Kalvoda et al. 2004). The GPS measurements analysis is based on time-changes of coordinates of 20 EPN stations. From the 3D-coordinates of stations referenced to a common epoch a vector was computed (see arrows) with its origin in the GOPE station and the end point in the respective station (one sigma error ellipses, in detail see Kalvoda et al. 2004). The relative stability of morphostructural blocks of the Hercynian Platform (e.g. POTS, BOR1) is confirmed. The approaching of the northern wing of the Eastern Alps nappes and of their molasse foreland (OBE2, SBGZ) to the Hercynian blocks of Central Europe, especially to the Bohemian Massif is obvious. It is highly probably a manifestation of ongoing tectonic activity, including the pressure of alpine structures on the Hercynian consolidated block of the Bohemian Massif. This trend is also proved by the directions of relative movements between the northern part of the Rhine Graben (KLOP) and the molasse foreland and the Helvetian nappes of the northern wing of the Western Alps.

for satellite technology (in detail see Kostelecký et al. 2005a,b). For example, the results of gravity variations measured at the GOPE by the absolute FGS gravimeter were the first ones of this type in the Czech Republic (Pálinkáš, Kostelecký jr. 2003). Their analysis also enables separation of local, mainly hydrological and meteorological phenomena, from global (e.g. non-tidal) changes of the gravitational field. When elaborating and interpreting the time series of GPS technology, application of the continuum was developed for the data obtained from the European network of permanent GPS stations (Kostelecký, Kostelecký 2003). An evaluation and geodynamic interpretation of results of measurings in the network of selected permanent GPS stations in Central Europe was elaborated (Fig. 2). An example of using these experimental papers can be progress in diagnostics of natural hazards and risks and in predicting catastrophic events and phenomena.

1.2 The physical-geographical environment of the research observatories locality in the Ondřejovská vrchovina Highland

Heterogeneity of the natural environment of the locality of scientific observatories located in the southern part of the Ondřejovská vrchovina Highland is due to varied geological structure and to the evolution of its rugged relief in the late Cenozoic. This is the area of Central Bohemian Pluton and of its metamorphosed islands (Fig. 3) following in the east in Palaeozoic sedimentary rocks of the Blanická brázda Furrow. The Central Bohemian Pluton intruded in the zone of Central Bohemian deep fault between the Moldanubian and the Assynt blocks in the Brittany stage of Variscan orogenesis (Mísař et al. 1983). The oldest rocks of this territory originated during the Pre-Cambrian period. After solidification of magmatite rocks, the Central Bohemian Pluton was developing as a whole (Bouček, Kodym 1963). The original mantle of Central Bohemian Pluton (e.g. Říčany granite, granitoid rocks of Sázava type) was contactly metamorphosed during the Upper Proterozoic and the Lower Palaeozoic. Faulted or by faults limited remnants of this mantle are preserved in denudational relics of intruded blocks as metamorphosed islands in the Central Bohemian Pluton. Chocerady, Čerčany and Ondřejov metamorphosed islands affected by contact as well as by regional metamorphosis are of the Proterozoic age. The sensibly younger Voděrady-Zvánovice metamorphosed island was formed mainly in the Ordovician (Vajner 1960; Kachlík 1992; Domas et al. 1993). The area of Central Bohemian Pluton and of its metamorphosed islands is limited in the east by fault system of the Blanická brázda Furrow (Fig. 4) formed in the Upper Carboniferous during the Asturian stage of Variscan orogenesis. After the Variscan orogeny, intermontane basins divided by faults were formed in the territory of the Bohemian Massif in the Upper Palaeozoic (Chlupáč et al. 2002). During the Carboniferous and the Permian, there were depositing in these basins thick groups of layers of fluvial and lacustrine sediments (Domas et al. 1993) which are partly maintained in the Formation of Český Brod and the Formation of Kostelec nad Černými Lesy.

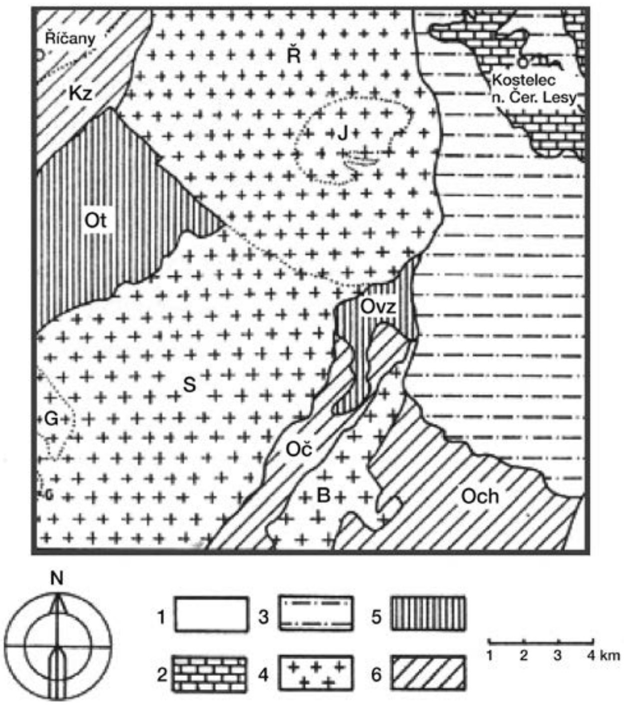

Fig. 3 Main geological units of the Ondřejovská vrchovina Highland (modified according to Domas et al. 1993); 1 – Moldanubian; 2 – sediments of the Bohemian Cretaceous Basin; 3 – Permian-Carboniferous sediments; 4 – magmatites of the Central Bohemian Pluton (G – gabbro bodies; Ř – granites of Říčany type; S – granodiorites to diorites of Sázava type; B – quartz diorite of Benešov type; J – granites of Jevany type); 5 – Lower Palaeozoic rocks of metamorphosed islands (Ot – Tehov island; Ovz – Voděrady-Zvánovice island), 6 – Proterozoic of the Barrandien and island zones (Oč – Čerčany island; Och – Chocerady island, Kz – Kralupy-Zbraslav group).

Fig. 4 The Ondřejovská vrchovina Highland is in the east markedly limited by the northern part of the Blanická brázda Furrow filled by Upper Palaeozoic sedimentary rocks and also by fluvial and slope sediments of the Quaternary age. On the aerial photo (www.strimelice.banet.cz) there are, looking from south to north, in the foreground the village of Stříbrná Skalice and the Hruškovský rybník Pound, in the background on the left the village of Kostelní Střimelice and the eastern hillside of structural-denudational slopes of the Skalka ridge.

Fig. 5 Northern structural-denudational slopes of ridges of Pecný (545 m a.s.l.) and Ostrá Skála rising above the relics of an etchplain-type planation surface in the Ondřejovská vrchovina Highland. Photo: T. Steklá.

During the Neogene, the central part of the Bohemian Massif was characterized by ongoing stages of tectonic activity and stability. During tectonic stability, local planation surfaces were formed at different height levels (Král 1985; Demek et al. 1987). In the Neogene, river valleys were shallow and vale-shaped with prevailing lateral erosion. In the southern part of the Ondřejovská vrchovina Highland, the Pliocene deepening of the Sázava River valley reached 125–145 m, the lowest plateaus in the Pre-Quaternary vales being interpreted as typical valley pediplains. Pliocene sediments in the Ondřejovská vrchovina Highland are of fluvial or fluvial-lacustrine origin, but they are only residues of originally much larger accumulations.

According to regional geomorphological classification, the Ondřejovská vrchovina Highland is a part of the Středočeská pahorkatina Hilly Land (Balatka, Kalvoda 2006). It has the character of planation surface the denudation of which had been going on already since the Upper Palaeozoic. The orographic district of the Ondřejovská vrchovina Highland is followed in the north by the Jevanská pahorkatina Hilly Land and in the east by the Černokostelecká pahorkatina Hilly Land. The Jevanská pahorkatina Hilly Land is formed mainly by volcanic rocks of the Central Bohemian Pluton (Chlupáč et al. 2002), while in the geological structure of the Černokostelecká pahorkatina Hilly Land Permian and Cenomanian sandstones, mudstones and conglomerates prevail. Demek et al. (1987, 2006) characterized the Ondřejovská vrchovina Highland as a flat highland of mean altitude between 450 and 550 m. Still at the beginning of the Cenozoic, the region was a part of denuded relief formed here in the place of the original Variscan mountains. Denudational plateaus are probably relics of Pre-Tertiary etchplain, the thickness of eroded material is not known. Due to water streams erosion, relics of planation surfaces are preserved only on flat or slightly inclined parts of the highland in altitudes about 500 m (Fig. 5). Hilly parts of the Ondřejovská vrchovina Highland are thus situated in a belt of planation surfaces (above 470 m a.s.l.) and they were formed by selective erosion and denudation of crystalline rocks (Kalvoda 2007). In the neighbourhood of Zvánovice and Struhařov, these planation surfaces are bound to milder denudational slopes and flat hills which are considered as the oldest and the highest relics of a planation surface of etchplain type between the catchments of Labe and Sázava. The Ondřejovská vrchovina Highland is situated in the basin of Sázava River rising in the Českomoravská vrchovina Highland. Sázava crosses the Ondřejovská vrchovina Highland from the mouthing of Doubravice (river km 41.25) to the mouthing of a brook in Lštění (river km 35.67) in a length of about 6 km. The locality of scientific observatories near Ondřejov is drained to the south by right-bank affluents of Sázava.

Stepped structure of denudational plateaus and slopes going from the upper parts of the Ondřejovská vrchovina Highland down to the bottom of the Sázava antecedent valley documents a neotectonic uplift of the central part of the Bohemian Massif during the late Cenozoic. This uplift manifested by a pronounced deepening of the valley of Sázava and its tributaries during the Quaternary; this river forms here a canyon-like valley with valley bottom relics of Pre-Quaternary age. Pleistocene fluvial accumulations are preserved only in the Sázava valley as relics of formerly larger river terraces (Fig. 6). Characteristics of these sediments are substantially influenced by climatic changes in the Quaternary manifesting for instance by frost smashing of the skeleton of underlying rocks and by eolic admixture. At the end of the Pleistocene and in

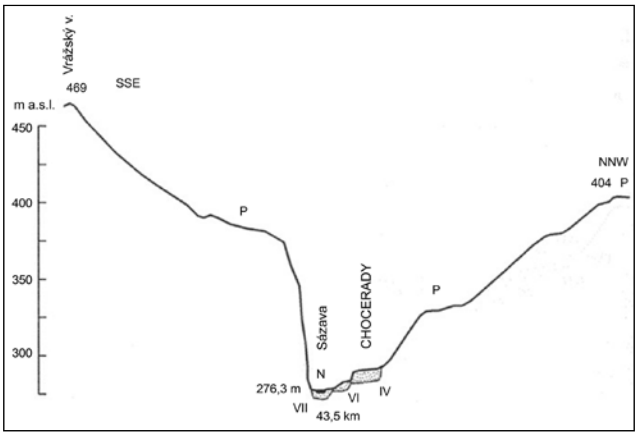

Fig. 6 Crosswise profile of the Sázava valley near Chocerady (Balatka, Kalvoda 2010); P – planation surface; N – Holocene fluvial plain; IV, VI, VII – Pleistocene terraces 10 times exaggerated.

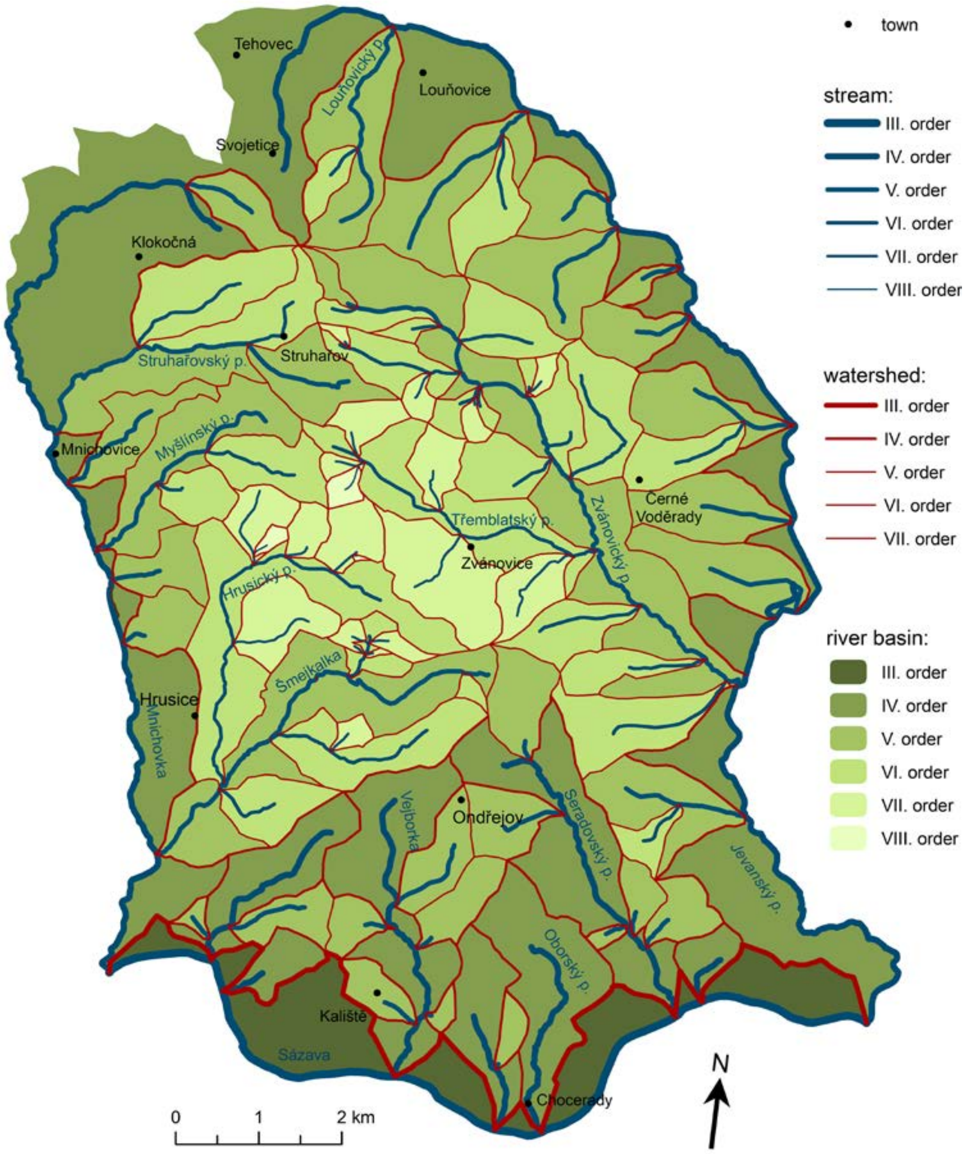

Fig. 7 Hydrographical classification and structure of water streams network in the Ondřejovská vrchovina Highland (Steklá 2012).

the Lower Holocene, a great quantity of linear landslides occurred in the Ondřejovská vrchovina Highland (Domas et al. 1993). The thickness of slope accumulations is variable (maximally 6 m) and depends mainly on variability of the relief and on the character of bedrock.

The relief of the Ondřejovská vrchovina Highland is more influenced by the right-bank tributaries of Sázava which are, in comparison with the left-bank ones, shorter and their gradient is higher (Daneš 1913). Source area of streams generally merges into a flat open dell which disturbs planation surfaces of different ages and geneses. In the middle and lower course, backward erosion formed markedly incised to canyon-line valleys (Kuncová 2005; Kalvoda 2007). The main conspicuous valleys are those of the Jevanský potok Brook, the Zvánovický potok Brook and Mnichovka. Hydrological situation in the Ondřejovská vrchovina Highland is shown in Fig. 7.

The Jevanský potok Brook with its catchment of 75.94 km^2 rises in the village of Svojetice at 450 m a.s.l. Morphological character of its valley is determined above all by its rock underlayer formed in the upper course by Jevany granodiorites, whereas the south-western part of the catchment with a mild gradient is based in Permian-Carboniferous sediments of the Blanická brázda Furrow. The flow of the Jevanský potok Brook manifests a considerable seasonal oscillation with its maxima in spring; the mean flow rate of the Jevanský potok Brook being 0.28 m^3 s^{-1} (Vlček et al. 1984; Osmančik 2005). The elongated shape of the Jevanský potok Brook valley lead in the past to its frequent damming and a regionally important system of pounds was built there (Slezák 2002). At present, only 12 pounds are maintained along the whole course of the Jevanský potok Brook, as Vyžlovský (20 ha), Jevanský (17 ha), Louňovický (7 ha) and Požár (4 ha). The major affluent of the Jevanský potok Brook is the Zvánovický potok Brook rising near the village of Struhařov at 485 m a.s.l. Its oblong catchment of 16.3 km^2 is NW–SE oriented (Kohoutková 2002; Steklá

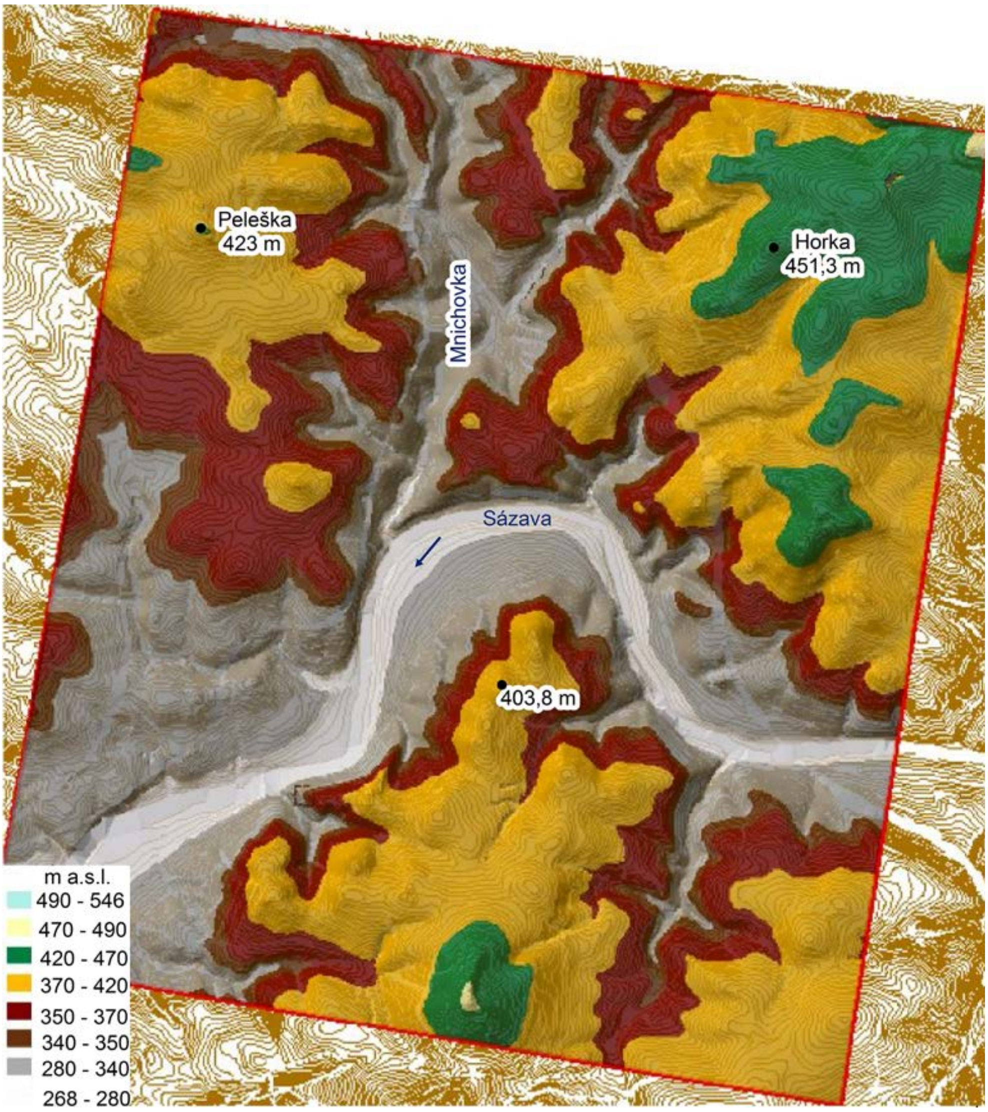

Fig. 8 Topographical scheme of the rugged relief of canyon-like valleys at the Mnichovka mouthing into Sázava (Kuncová 2005).

2012). Crosswise profiles of the valleys of the Zvánovický potok Brook and of its main tributaries, Habrovský potok Brook and Třemblatský potok Brook, are predominantly V-shaped which is typical for the majority of right-bank affluents of Sázava.

Mnichovka, thanks to its uniform underlayer with predominant Sázava granodiorites, has a relatively stable gradient curve (0.08‰). But in its upper and lower course canyon-like valleys were formed witnessing about presence of a fault zone and about backward erosion impact (Fig. 8). The first hundreds of metres from the Mnichovka's mouthing into Sázava are marked concussion slopes of an incised meander with steep erosional slopes (Kuncová 2005). In the middle course of Mnichovka, a larger valley of almost trapezoid shape is preserved. In Novak's opinion (1932), an older stream of N–S orientation used to be in the area of the present-day Mnichovka in the Neogene.

Rocks of the Central Bohemian Pluton in the Ondřejovská vrchovina Highland are characteristic by a predominance of fissure water over pore water found only in the upper weathered zone. Rocks of metamorphosed Upper Proterozoic and Ordovician form a fissure collector with an increased permeability in the near-surface zone (Vajner 1960; Kodym et al. 1963). Fissure water is bound there mainly to crosswise dislocations, transversal fissures are mostly impermeable and abundant sources are situated only in larger faults (Domas et al. 1993). The most abundant sources of underground water in the Ondřejovská vrchovina Highland are however Quaternary sediments and alluvial landforms. In the territory of metamorphosed rocks, especially debris sources are frequent, but their abundance is nevertheless low and irregular. On the contrary, rocks of the Central Bohemian Pluton have permanent and well mineralized sources. Underground water is used for local consumption, when it is not polluted by nitrates, Fe and Mn (Kohoutková 2002). Its quality is negatively influenced by growing anthropogenic activities. Pollution of brooks is mainly due to waste water discharging, the lower Sázava course having strongly polluted water.

Tab. 1 Climatic conditions in the Ondřejovská vrchovina Highland according to classification by Quitt (1971), see also Atlas podnebí Česka (2007).

		SW9	SW10	SW11
1	amount of summer days	40–50		
2	amount of freezy days	110–130		
3	amount of icy days	30–40		
4	amount of cloudy days	40–50		
5	amount of clear days	120–150		
6	amount of days with snow cover	60–80	50–60	
7	amount of days with precipitation over 1 mm	100–120	90–100	
8	mean temperature in January	−3 – −4 °C	−2 – −3 °C	
9	mean temperature in March	6–7 °C	7–8 °C	
10	mean temperature in July	17–18 °C		
11	mean temperature in October	7–8 °C		
12	precipitation amount in vegetation period (mm)	400–450	350–400	
13	precipitation amount in winter period (mm)	250–300	200–250	
14	amount of days with mean temperature over 10 °C	140–160		

SW – slightly warm region

According to regional climatic classification (Quitt 1971), the Ondřejovská vrchovina Highland belongs to three climatic regions MT 9, MT 10 and MT 11. The northern part of this highland belongs to MT 9 region characterized by long, warm and dry summers and mild winters with only a short presence of snow cover. MT 10 region in the western part of the Ondřejovská vrchovina Highland is characterized, in comparison with MT 9 region, by higher air temperature in the first half of the year. MT 11 region situated along the Sázava valley up to the top of Pecný (545 m) is characterized by longer transitional seasons (spring, autumn) and by drier summers than in MT 9 and MT 10 regions (Table 1).

Classification of the Ondřejovská vrchovina Highland as mildly warm climatic region is supported also by the majority of selected climatologic characteristics ascertained in the Ondřejov station in the years 1961–2000 in the framework of the National Climatological Programme of the Czech Republic (Květoň 2001). Long-term monthly mean temperature curve (Table 2) has a simple course with its maxima from June to August and its minima from December to February. The locality of observatories near Ondřejov is characterized by higher rainfall during the growing season and by lower rainfall in winter. According to Sobíšek (2000), the average wind direction in this territory is 247.9° and its average speed is 2.40 m s^{-1}. Due to rugged relief, the microclimate of ridge and valley parts of the Ondřejovská vrchovina Highland is significantly different.

Soils in the Ondřejovská vrchovina Highland are very diverse, mainly because of their varied bedrock with a rich content of minerals. Humus horizons are determined by phytocoenosis of forest and agricultural communities (Pelíšek, Sekaninová 1979). The most frequent reference soil class in the Ondřejovská vrchovina Highland is group of cambisoils. These soils were formed in the dissected relief on volcanic rocks of Central Bohemian Pluton and on metamorphosed rocks of its islands as well as on slope and fluvial non-carbonate sediments (Cicha et al. 1984; Tomášek 2003). Cambisoils in the Ondřejovská vrchovina Highland are mostly acid to strongly acid with low humus content, in suitable habitats they manifest also gleying.

On slightly inclined slopes, typical gleyed luvisoil developed, its parent materials being silica sediments, polygenetic clays and acid intrusive materials. Occasional overwetting of luvisoils causes higher concentrations of iron deposits (Cicha et al. 1984; Tomášek 2003). Near water streams in wet dells typical gleys were formed on subjacent non-carbonate slope, fluvial and alluvial sediments. Due to seasonal overwetting, pseudogleys have locally developed, mainly on weathered silica sediments and acid intrusive rocks, as well as on polygenetic clays. Flat valley bottoms of water streams are covered by typical and gleyey fluvisoil. Humus horizon is here situated directly on alluvial non-carbonate sediments. On weathered limestones south-westwards from Stříbrná Skalice rendzines developed (Cicha et al. 1984; Tomášek 2003). Production potential of soils in the Ondřejovská vrchovina Highland is very variable in agricultural and forest soils (Domas 1993). Soils are here endangered mainly by water erosion and denudation, locally also by stagnation of underground and surface water. Acid rains are another thread as soil is little to middle resistant to them.

According to biogeographical classification (Culek et al. 1996), the Ondřejovská vrchovina Highland belongs to the Sázava region which is a part of Hercynian sub-province. Characteristic for this region is impoverished mesophylic biota formed by oak-hornbeam forests, acidophilic oak forests and flowering beech forests. However, most of the forests were in the past replaced by artificial spruce

Tab. 2 Mean monthly and annual air temperature (°C) in Ondřejov, 1961–2009 (Květoň 2001; *Steklá 2010).

year/month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	year
1961–1990	−2.8	−1.2	2.5	7.2	12.2	15.3	16.8	16.5	13.1	8.1	2.4	−1.2	7.4
1991–2000	−1.2	−0.2	3.2	8.2	13.0	15.9	17.8	17.9	13.0	7.8	2.3	−1.0	8.1
2003–2009*	−1.5	−0.3	3.3	9.3	13.3	16.9	18.2	17.6	13.7	8.2	3.6	0.6	8.6

and pine monocultures. In lower situated regions, original beech forests mixed with spruce and hazel. Natural forest composition in this region has been intensively influenced since the 18th century, mainly by logging and using of improper seedlings. Damaging of forests was also natural due to strong winds in 1735 and 1737. Today, natural covers and seedlings of local origin are used for forest rehabilitation. Original mostly deciduous forests were superseded by agricultural activities and logging up to the ridge parts of the Ondřejovská vrchovina Highland (Kohoutková 2002; Tomeček 2007). In present-days, agriculturally used areas form the landscape matrix of this region.

According to Neuhäuslová et al. (1998), without anthropogenous interventions into vegetation, there would be in the Ondřejovská vrchovina Highland communities of cow wheat oak-hornbeam forests, wood rush beech forests, fir oak forests and beech forests with Dentaria ennephyllos. At present, the herbaceous layer is formed mainly by Central European flora species. Some local species can be classified as subatlantic flora (wavy bitter cress, mountain speedwell). Exceptionally, mountain species can be found there, for instance mountain arnica or Lastrea libosperma. In valley forests, there grow for instance European wild ginger, Lilium martagon, addersmeat or yellow archangel. On valley rocks, we can find field sagewort, blue fescue, Medicago sativa and others. Dry slopes are covered by yarrow and sheep fescue. According to Culek et al. (1996), there was an island of peat meadows Caricion fuscae near Ondřejov. Fauna of the Ondřejovská vrchovina Highland is a relic of formerly more varied species composition (Kunský 1968). Abundance of roebuck and wild boar is a result of absence of natural predators. The most important beasts of prey are red fox and pine marten. Eurasian eagle-owl is rare. Water birds as wild duck or grey heron live near numerous pounds and water basins. Fish as carp, pike, catfish, perch or sander live in pounds.

The extent of anthropogenous activities and their impact on the natural environment of the Ondřejovská vrchovina Highland was significantly changing in the Upper Holocene. Already in the Neolithic, the extent of settlement was changing and so was land use, especially due to agricultural activities and logging. A more significant impact of human activities was registered as late as in the Bronze Age, when settlement, agriculture and logging developed. Anthropogenous processes led to a significant increase of slope movements and soil erosion which led also to formation of large sediments of alluvial clays (Ložek 1973). In the period of the maximal extent of prehistoric settlement, the Ondřejovská vrchovina Highland was settled only in the immediate proximity of Sázava (up to 300 m a.s.l.) and along the Jevanský potok Brook and Mnichovka.

Near the boundary of the island zone of Central Bohemian Pluton and Permian-Carboniferous sediments, hydrothermal polymetallic mineralization occurred which led to formation of deposits of polymetallic ores and rare metals. These deposits were often exploited in the past. The oldest preserved mining of these deposits is documented near Hradební Střimelice, where copper bearing ores and polymetallic ore veins were mined in the 12th century. Other historic mining localities are Stříbrná Skalice, Kostelní Střimelice and Černé Voděrady, where silver was mined in the 19th century (Domas et al. 1993). On the left bank of the Zvánovický potok Brook between Černé Voděrady and Zvánovice remnants of mill stones made from Říčany granite and used for ore grinding in different degrees of shaping are maintained. Granitoid rocks of Sázava type are used for production of crushed stone, whereas the Říčany granite is used as gravel for construction and material for concrete production. In the present-day landscape, settlement area and other engineering works as roads, water basins, soil heaps and deposits are more and more frequent.

2. Landform patterns and climate-morphogenetic processes of the Pecný ridge

The top of Pecný (545 m) is a part of a structural ridge running in the NE-SW direction. This ridge (520–536 m a.s.l.) forms a watershed region between the Seradovský potok Brook and Šmejkalka. Geological structure of the Pecný ridge is varied (Fig. 9). On an area of about

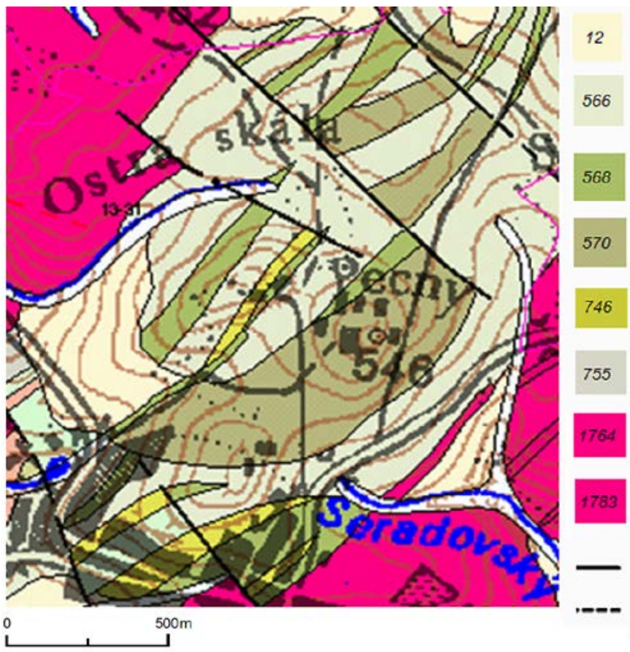

Fig. 9 Geological structure of the Pecný ridge in the Ondřejovská vrchovina Highland (GeoINFO 2004); 12 – sandy-clayey to clayey-sandy diluvial sediments (Holocene); 566 – slates and metagreywackes (Ordovician); 568 –greywackes (Ordovician); 570 – conglomerates, sandstones, quartzites (Ordovician); 746 – coarse-grained greywackes (Proterozoic); 755 – phyllitic slates and greywackes (Proterozoic); 1764 – granodiorite of Benešov type (Carboniferous, Permian); 1783 – granodiorite, tonalite, quartz diorite of Sázava type (Carboniferous, Permian); — fault ascertained; --- fault assumed.

Fig. 10 Geomorphological sketch of the scientific observatories area in the neighbourhood of Pecný (modified according to Steklá 2010); 1 – structural plateau, inclination 0°–2°; 2 – denudational plateaus, inclination 2°, summit; 3 – denudational plateaus, inclination 2°, saddle; 4 – denudational plateaus, inclination 2°, slope; 5 – erosional-denudational slopes, slightly inclined (2°–5°); 6 – erosional-denudational slopes, medium inclined (5°–15°); 7 – dell; 8 – source basin; 9 – ravine; 10 – erosional furrow; 11 – source; 12 – artificial basin; 13 – debris; 14 – frost cliff; 15 – rock outcrop; 16 – steps in riverbed; 17 – water stream; 18 – contour lines (2 m).

3 km^2 there are four rock belts of different origin and age NE–SW oriented. In the eastern part of the locality of scientific observatories (on the Ostrá skála Hill) there are granodiorites of Benešov type linked in the west to Proterozoic rocks of the Čerčany and the Ondřejov metamorphosed islands. South-eastwards from the top of Pecný the bedrock is formed by granodiorites and tonalites of Sázava type. The top of Pecný is built by Ordovician quartzites which are a part of the Voděrady-Zvánovice metamorphosed island. The belt of quartzites is limited in the north by a NW–SE oriented fault zone.

The summit part of the Ondřejovská vrchovina Highland (546–490 m a.s.l.) is a relic of a by denudation lowered surface (etchplain) of probably Pre-Cretaceous age exhumed probably during the Palaeogene (Kalvoda 2007; Pánek, Kapustová 2016). Landforms of the ridge part of Pecný are documented in Fig. 10 (Steklá 2012). The ridge with the Pecný top is asymmetrical with markedly steeper south-eastern slopes (above 10°). Inclination of these slopes is increased mainly by erosion of the Seradovský potok Brook and of its tributaries. Northern and western slopes are milder (up to 7°) and are linked to flat saddles at 520 m a.s.l. (Fig. 11). They have been formed mostly by backward erosion of the Šmejkalka Brook and of its left-bank affluent which have formed large source basins with gley soil type. Rock massif has been exposed in the summit part of Pecný. The weathered mantle has been slowly sliding to the foothill where stony to clayey-stony deluvium is being accumulated having in lower position a thickness up to several metres (Steklá 2012).

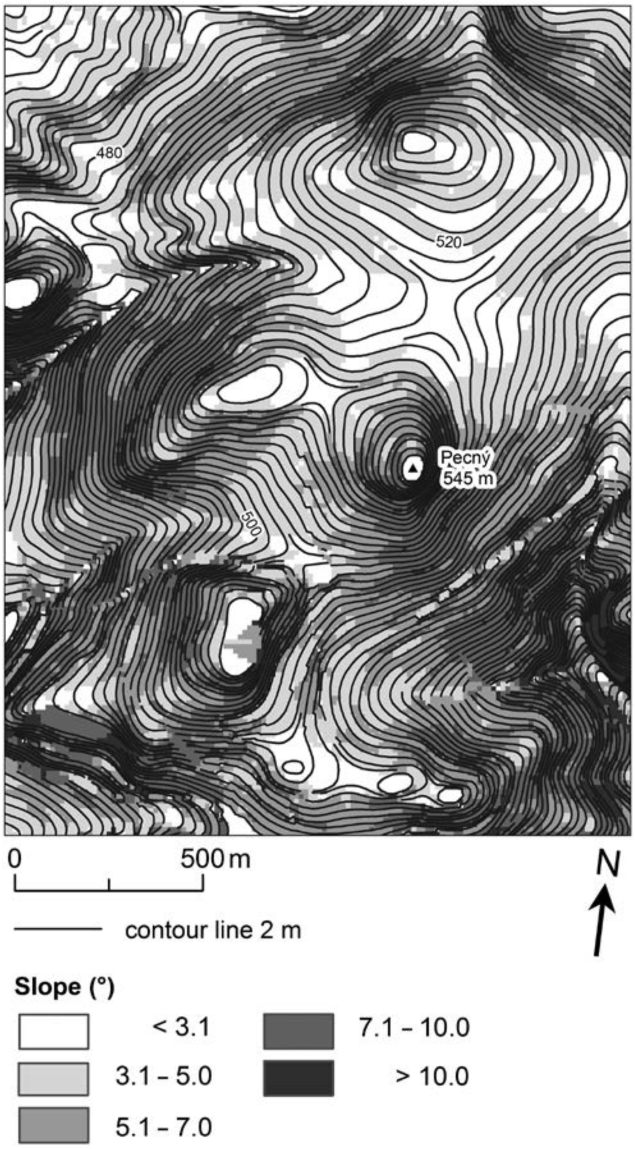

Fig. 11 Inclination of slopes of the rugged relief in the southern part of the Ondřejovská vrchovina Highland (modified according to Steklá 2010).

Fig. 12 Degraded frost cliff of Ordovician sandstones and quartzites (500 m a.s.l.) at the eastern slope of Pecný ridge, partly damaged by quarrying. Photo: T. Steklá.

On weathered quartz sediments of northern and eastern slopes of the Pecný top pseudogleys developed, but the major part of the studied locality is covered by acid cambisoil (Cicha et al. 1984).

Highlands and mountain ranges of the Bohemian Massif were situated in cold periods of Quaternary in the periglacial environment when rocks were long-term and seasonally frozen (Czudek 2005). Also on the Pecný ridge there are relics of cryogenic landforms. At the eastern slope of the Pecný top there is a partly deteriorated frost cliff (Fig. 12) formed in resistant quartzites. A part of the denudational slope is also covered by fossil stone field of debris and boulders of Ordovician quartzites (Fig. 13).

Relics of periglacial processes impact in the Upper Quaternary are relatively frequent on denudational and erosional slopes of the Ondřejovská vrchovina Highland. They are mainly degraded tors (Fig. 14), frost cliffs, stone fields and slope sediments, at present stabilized by vegetation. Locally, there are eolic sediments formed in the coldest period of glacials. Eolian accumulations are the best visible in the neighbourhood of Jevany, where homogenous loess covers are maintained on leeward slopes against south-west oriented air circulation (Brunclík 1956). On these loess covers solifluction streams later developed, they were ascertained also on sandy weathered granitoid rocks (varps, Ambrož 1943) in the upper part of the Zvánovický potok Brook valley. In the Ondřejovská vrchovina Highland there are also frequent fossil landslides, mainly on erosional slopes of stream valleys. These landslides were developing in several stages from the end of the Pleistocene to the Middle Holocene, when significant changes of climatic conditions occurred accompanied by slope processes (Steklá 2012) and development of large accumulations of slope clays.

In the long-term perspective, the natural environment of the scientific observatories area is influenced by anthropogenous activities. The summit part of Pecný has been deforested and GOPE buildings and communications, including a historically important geodetic watching tower (Fig. 13) and stands of measuring devices, have been built there. Deforested have been also neighbouring tops and saddles. During land works connected with the construction of the Ondřejov (astronomical) observatory, Žalov hill has been lowered by several metres. Before the

Fig. 13 By vegetation partly covered and stabilized stone field situated eastwards from Pecný (545 m a.s.l.), in the background is visible historical geodetical lookout tower in the GOPE area. Photo: T. Steklá.

Fig. 14 Degraded tor of Říčany-type granites (430 m a.s.l.) eastwards from the Čihadlo ridge developed mainly by frost weathering of rocks and by regelation processes during the Holocene. Photo: T. Steklá.

beginning of construction of the astronomical observatory, Žalov was covered by pine forest, at present there is an arboretum with rare woody plants (Ondřejovská hvězdárna 1998). Slopes and plateaus near the Pecný top are used for agriculture and a playing field has been built there. The afforested part of Pecný is covered by beech forest passing progressively on northern and eastern slopes into spruce monocultures, whereas southern and western slopes are covered by mixed forest.

Essential for studying recent morphogenetic processes in the GOPE locality are measurings of microclimatic conditions, including monitoring of soil moisture and temperature conditions and underground water level monitoring. In the years 2002–2010, these data had been obtained in the summit part of Pecný, i.e. directly in the GOPE observatories area, mainly by measuring by the automatic measuring station of Department of Physical Geography and Geoecology of the Faculty of Science, Charles University (Kastner et al. 2012). Annual course of air temperature in the GOPE locality has its (expected) maxima in summer months and minima in winter (Tab. 3 and Fig. 15). Annual amplitude of monthly mean air temperature reached in the years 2003–2009 the value of 22.2 °C and absolute annual temperature amplitude 46.5 °C. The number of characteristic days in individual years of this period is given in Tab. 4. In the GOPE locality, there were every year in average 5 tropical days, 27 summer days, 95 frost days, 44 icy days and 6 arctic days (Steklá 2010).

Average monthly rainfall in the year 2004–2008 shows (Table 5) that during growing periods the average rainfall was 380.72 mm and during winter periods only

Tab. 3 Mean monthly and annual air temperature (°C) in the GOPE locality, 2003 – 2009 (Steklá 2010); LA – long-term monthly and annual average

month\year	2003	2004	2005	2006	2007	2008	2009	LA
I.	−2.18	−3.12	0.03	−5.02	3.47	0.96	−4.50	−1.48
II.	−3.31	−1.17	−3.30	−2.20	2.91	2.48	2.34	−0.32
III.	4.68	2.79	1.83	0.49	5.76	2.48	4.98	3.29
IV.	7.62	8.69	9.75	8.19	11.50	7.14	12.13	9.29
V.	15.06	11.04	13.25	12.71	14.42	13.31	12.99	13.25
VI.	19.83	14.94	15.85	16.87	19.47	16.80	13.96	16.82
VII.	18.63	17.09	17.58	21.96	17.54	17.10	17.51	18.20
VIII.	21.00	18.53	15.80	14.85	17.31	17.32	18.38	17.60
IX.	14.33	13.68	14.72	15.64	10.99	11.77	14.72	13.69
X.	5.08	9.42	9.95	10.82	7.58	8.27	6.40	8.22
XI.	4.75	3.25	1.90	5.50	0.54	3.70	5.75	3.63
XII.	−0.22	−0.66	−1.06	3.16	−1.42	−0.18	4.48	0.59
year	8.77	7.87	8.02	8.58	9.17	8.43	9.09	8.56

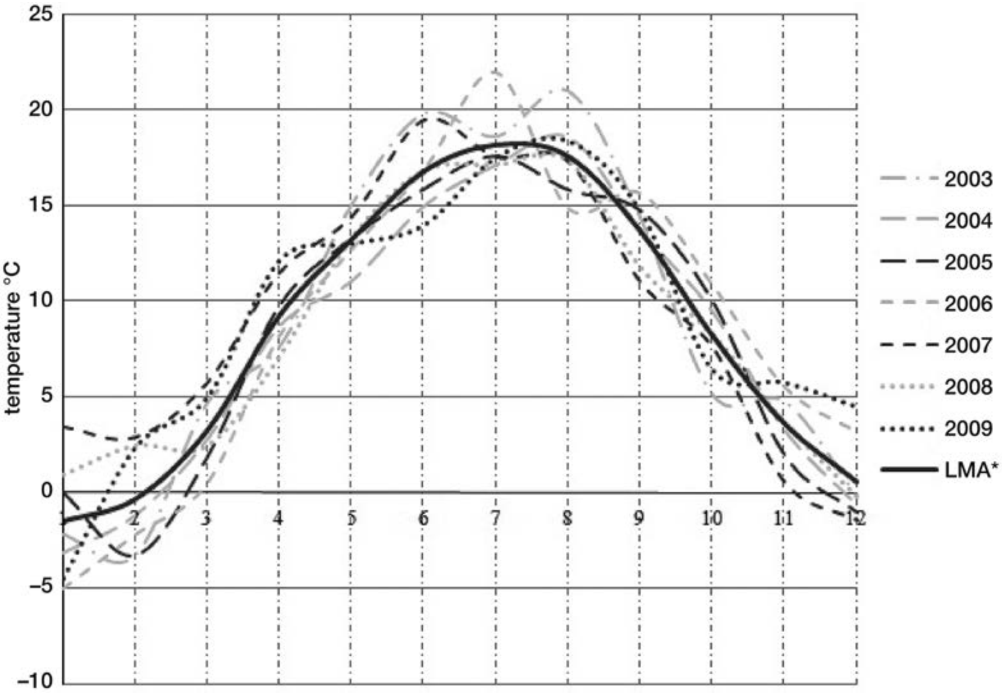

Fig. 15 Annual course of air temperature in the GOPE locality (2003–2009, Steklá 2010); LMA – long-term monthly average.

Tab. 4 Amount of characteristic days in the GOPE locality, 1961–2009 (Květoň 2001; Steklá 2010).

	2003	2004	2005	2006	2007	2008	2009	2003–09	1961–91
tropical days	11	1	3	10	5	1	1	4.57	3.8
summer days	50	12	22	32	31	26	13	26.57	29.0
freezy days	111	104	108	89	67	95	89	94.71	114.8
icy days	47	48	59	49	36	27	43	44.14	45.3
arctic days	8	6	7	9	0	1	12	6.14	1.2
days with mean temperature ≥ 10 °C	173	150	173	177	166	158	173	167.14	×

194.08 mm (Fig. 16). Average annual rainfall was 574.80 mm. Total rainfall higher than 1 mm was registered in average in 102 days per year, and that with significant differences going from 82 days (2008) to 116 days (2004). Water content in soil is higher in winter periods, its maxima being reached in spring when snow is melting. Summer minimum is often disrupted by torrential rains (Steklá 2012). Seasonal soil moisture amplitude is getting smaller in lower depths. Changes in daily course of soil moisture are not significant during most days of the year, maxima are usually reached in morning hours. The highest speed of wind is reached in winter months (Tab. 6). During the year, south-western wind is prevalent (Fig. 17), the least frequent is wind from the north and the south. Values of mean monthly and annual air pressure are given in Tab. 7.

Important meteorological factors determining types and course of recent morphogenetical processes are soil temperature and air temperature. In the observed locality, both daily and annual course of soil temperature are

Tab. 5 Mean monthly sum of rainfall (mm) in the GOPE locality, 2004–2008 (Steklá 2010).

month/year	2004	2005	2006	2007	2008	2004–2008
I.	×	41.3	24.9	49.7	7.9	30.95
II.	15.6	48.0	32.3	40.2	4.4	28.10
III.	52.4	19.1	55.5	34.4	21.1	36.50
IV.	31.9	24.4	51.9	0.3	215.3	64.76
V.	83.3	71.1	84.1	59.1	48.0	69.12
VI.	49.9	51.4	137.9	33.4	66.5	67.82
VII.	53.6	124.3	24.2	64.3	84.0	70.08
VIII.	41.5	80.6	136.7	35.5	34.9	65.84
IX.	45.1	36.7	16.0	126.3	17.9	48.40
X.	21.7	10.7	25.3	13.9	54.8	25.28
XI.	65.3	19.7	29.9	76.9	38.9	46.14
XII.	14.1	28.0	19.9	12.0	31.0	21.00

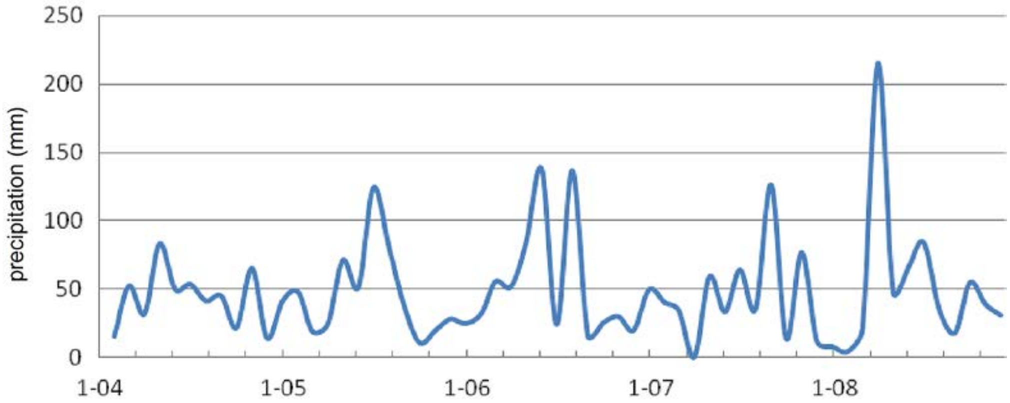

Fig. 16 Average monthly rainfall in the GOPE locality (2004–2008, Steklá 2012).

Tab. 6 Mean monthly and annual wind speed (m s^{-1}) in the GOPE locality, 2003–2009 (Steklá 2010).

month/year	2003	2004	2005	2006	2007	2008	2009	2003–2009
I.	2.56	2.25	3.53	1.77	4.90	2.93	1.74	2.81
II.	1.68	2.25	2.42	2.36	2.59	2.59	2.90	2.40
III.	1.93	2.56	2.63	2.29	2.60	3.10	2.79	2.56
IV.	2.31	2.02	2.01	2.09	2.05	2.24	2.14	2.12
V.	4.06	1.82	1.85	2.16	2.02	1.54	1.79	2.18
VI.	1.43	1.90	1.60	1.40	1.64	1.74	1.94	1.66
VII.	1.73	1.77	2.03	1.37	2.66	1.84	1.99	1.91
VIII.	1.56	1.87	1.74	2.26	1.67	2.01	1.52	1.80
IX.	1.44	1.96	1.44	1.91	2.10	1.66	1.68	1.74
X.	2.06	1.61	1.54	1.66	1.42	1.81	2.39	1.78
XI.	1.97	3.01	1.65	2.79	2.69	2.53	2.91	2.51
XII.	2.56	2.06	2.57	2.13	1.80	2.59	2.51	2.32
year	2.11	2.09	2.08	2.02	2.35	2.22	2.19	2.15

Tab. 7 Mean monthly and annual air pressure (hPa) in the GOPE locality, 2003–2009 (Steklá 2010).

month/year	2003	2004	2005	2006	2007	2008	2009	2003–2009
I.	950.28	945.39	951.70	959.57	945.00	954.62	950.85	951.06
II.	956.38	940.73	943.69	948.84	947.43	960.23	948.44	949.39
III.	958.41	955.14	951.12	946.08	950.91	941.51	947.84	950.14
IV.	952.03	952.93	950.51	949.82	956.61	946.62	951.09	951.37
V.	954.42	951.04	952.72	952.51	948.54	952.66	955.30	952.46
VI.	953.39	953.37	954.64	952.50	950.83	952.56	951.71	952.71
VII.	953.88	954.05	951.94	956.64	950.77	951.78	952.28	953.05
VIII.	956.48	953.45	953.25	947.59	951.86	951.63	955.29	952.79
IX.	958.04	956.12	955.54	954.19	954.19	954.67	956.64	955.63
X.	949.13	949.31	958.24	952.71	958.60	953.70	951.57	953.32
XI.	954.04	953.56	953.25	954.35	951.26	949.68	947.47	951.94
XII.	953.40	954.10	950.52	960.16	957.59	953.09	944.11	953.28
year	954.16	951.60	952.26	952.91	951.97	951.90	951.05	952.26

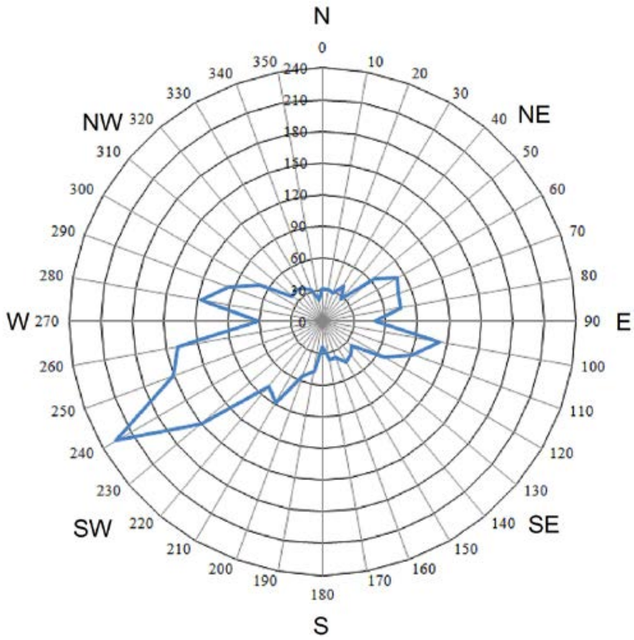

Fig. 17 Wind directions in the GOPE locality (2003–2009, Steklá 2010).

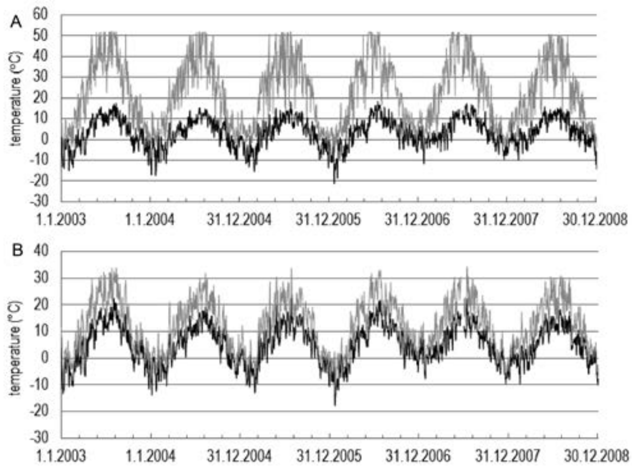

Fig. 18 Annual course of soil and air temperatures in the GOPE locality (2003–2008, Steklá 2012). A – soil temperature, B – air temperature; black line – daily temperature minimum, gray line – daily temperature maximum.

more pronounced than that of air temperature (Fig. 18). Exemplary are periods, when soil temperature repeatedly oscillates near to freezing point. It means that daily soil temperature minima do not exceed 0 °C, whereas daily soil temperature maxima are above zero. Fig. 18 shows that these temperature conditions in the Pecný ridge part occur seasonally from October to April, exceptionally even to May. The highest differences between minimal and maximal daily soil temperatures values are registered in spring (March, April, May) when their difference exceeds 30 °C. The highest temperature amplitude of 48.2 °C was registered on 20 May 2007. Minimal soil temperatures are registered in spring, mostly during morning hours between 5 and 7 a.m., less frequently then about midnight. The highest soil temperatures were measured mostly in afternoon hours between 1 and 2 p.m.

Changes of maximal and minimal values of soil temperature are significantly higher than changes of air temperatures and a similar course is evident also in their annual amplitudes. Mean seasonal soil and air temperatures are compared in Tab. 8. When compared with the daily course of soil temperature, also daily course of air temperature manifests more equilibrated values. The highest difference of minimal and maxima air temperatures was registered in April when it was more than 30 °C. Minimal air temperatures are registered mostly just before daybreak and sometimes about midnight. Maximal air temperatures were registered in afternoon hours.

Soil moisture and underground water level characteristics were elaborated according to a database of continuous measurements in GOPE (Jakub Kostelecký et al.), measuring sensors being placed at about 50 m from the main observatory building on a denudation slope with western exposition. Bedrock of this stand is formed by Ordovician quartzites which act as a fissure collector with an increased permeability in the near-surface zone (Cícha et al. 1993). For soil moisture analysis, a sensor placed south-eastwards from the main building was selected; it measures in the cover of slope weathered material in depths of 12 cm, 32 cm, 60 cm, 86 cm and 120 cm. For basic information on underground water level, long-term measurements in the well north-westwards from the main GOPE building were used.

Seasonal course of soil moisture in the GOPE area is shown in Fig. 19. The quantity of water in soil increases during the winter period and culminates in the beginning of spring when snow and ice melting causes a significant soaking of upper soil layers. On the contrary, the lowest values of soil moisture are registered in summer; occasional increased soil moisture in this period is due to increased rainfall. The daily course of soil moisture manifests the same character almost during the whole year. Soil moisture minima are registered in the afternoon, whereas the maxima are mostly bound to morning hours. Oscillations of soil moisture are not very significant during the day, as at 345 days of the year they do not exceed 3%. The highest differences in soil moisture during the day occur during the period April – September, when they reach up to 10%. More into the depth the seasonal amplitude of soil moisture is getting lower. Whereas soil moisture in

Tab. 8 Mean seasonal soil and air temperature (°C) in the GOPE locality, 2003–2012 (Steklá 2012).

soil	spring	autumn	air	spring	autumn
minimum	3.11	3.09	minimum	5.79	5.80
maximum	22.63	22.37	maximum	13.25	13.19
amplitude	18.59	18.65	amplitude	7.02	6.89

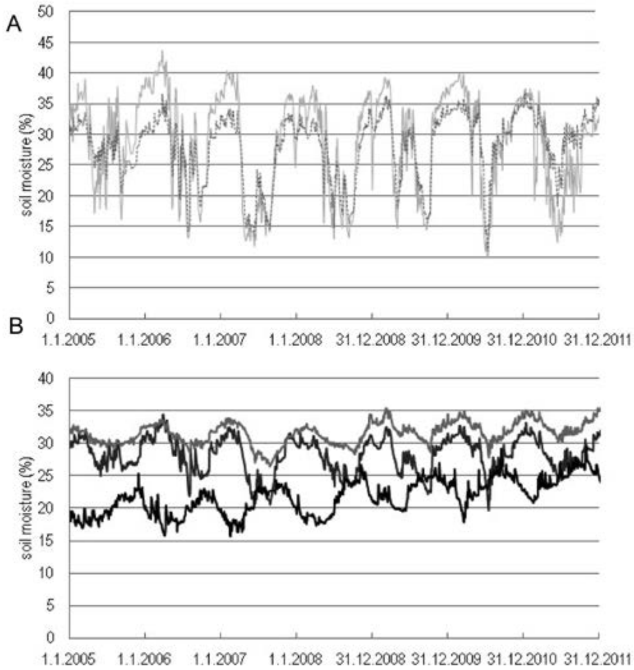

Fig. 19 Mean daily soil moisture in the GOPE locality in depths of 12 to 120 cm (2005–2011, Steklá 2012): A solid line – 12 cm, dotted line – 31 cm; B dark grey line – 60 cm, light gray line – 86 cm, black line – 120 cm.

summer period reaches in depths of 12 and 31 cm nearly the same values, during winter period the difference of soil moisture in these depths reaches about 5%. Fig. 19 shows clearly than in the depths of 60 cm, 86 cm and 120 cm the course of soil moisture is significantly more equilibrated. In the depth of 120 cm the seasonal minima and maxima of soil moisture are even shifted by up to 3 months and maximal soil moisture is registered in this depth in autumn.

Another important element influencing rock weathering processes and soil processes is the level of underground water. Fig. 20 shows seasonal oscillations of water level in the well near the main GOPE building. In winter, the underground water level reaches the lowest values, and that even −10 m, because a great part of water is bound in snow and ice. Underground water level significantly rises in spring because of snow, ice and frozen soil layer melting, when it is about 6 m to 5 m under the surface. Comparing Tab. 5 and Fig. 20 makes it evident that during summer period the underground water level is significantly influenced by rainfall quantities. The shape of the curve of underground water level is influenced mainly by extreme rainfall events; for instance in the years 2005 and 2006 higher rainfall contributed to a longer period with increased level of underground water. In September 2007 extreme rainfall resulted in an increase of the curve of underground water level manifesting a general decrease tendency. On the contrary, the significant rainfall anomaly in April 2008 did not have any more significant impact on the level of underground water. This might have been caused by insufficient rainfall during the precedent winter period which resulted in a significant reduction of the volume of melting water in spring.

Daily amplitudes of underground water levels are equilibrated. A difference higher than 5 cm was registered in underground water levels only in about 20 days in a year. The highest difference in underground water level was measured on 13 July 2002, when it reached 1.97 m. In spring period, the highest changes in underground water level are registered in March, when this difference is nearly 1 m. In autumn, the differences in underground water level are significantly lower (maximally 0.5 m) and they continue to decrease with the coming winter.

To determine the period with the highest intensity of climate-morphogenetic processes, seasonal course of the above-described time series was compared (Steklá 2010, 2012). Optimal conditions for activities of these processes in the weathered mantle and in the near-surface part of rock massif are in spring, when several climatic factors significantly manifest. In the spring period, soil and air temperature frequently oscillate near the freezing point. Differently from the winter period, soil temperature is characterized by more pronounced daily amplitudes reaching up to 30 °C. Frequent oscillations of soil temperatures near 0 °C stimulate activity of regelation and slope processes (Fig. 21), mainly if this oscillation is accompanied by increased soil moisture. This concurrence is typical especially in spring months when soil moisture oscillates about 35%. Nevertheless, more to the depth soil moisture is decreasing during spring months to reach in the depth of 120 cm only about 20%.

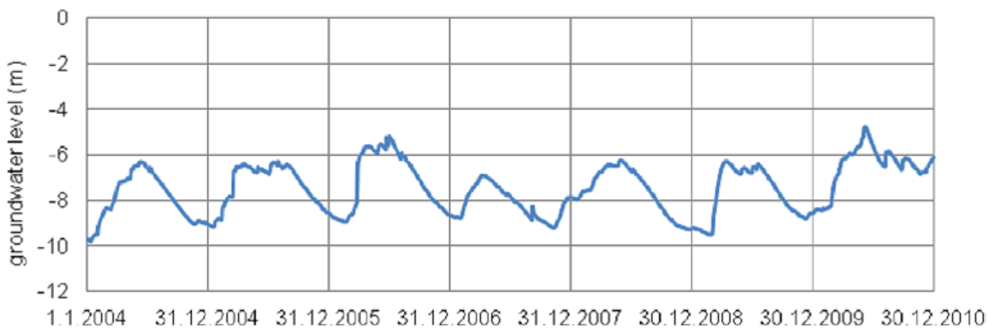

Fig. 20 Mean daily water level depth in a well in the GOPE area (2004–2010, Steklá 2012).

Fig. 21 Biogenic weathering of the granite surface of a degraded tor on a structural-denudational slope of the Čihadlo ridge. Photo: T. Steklá.

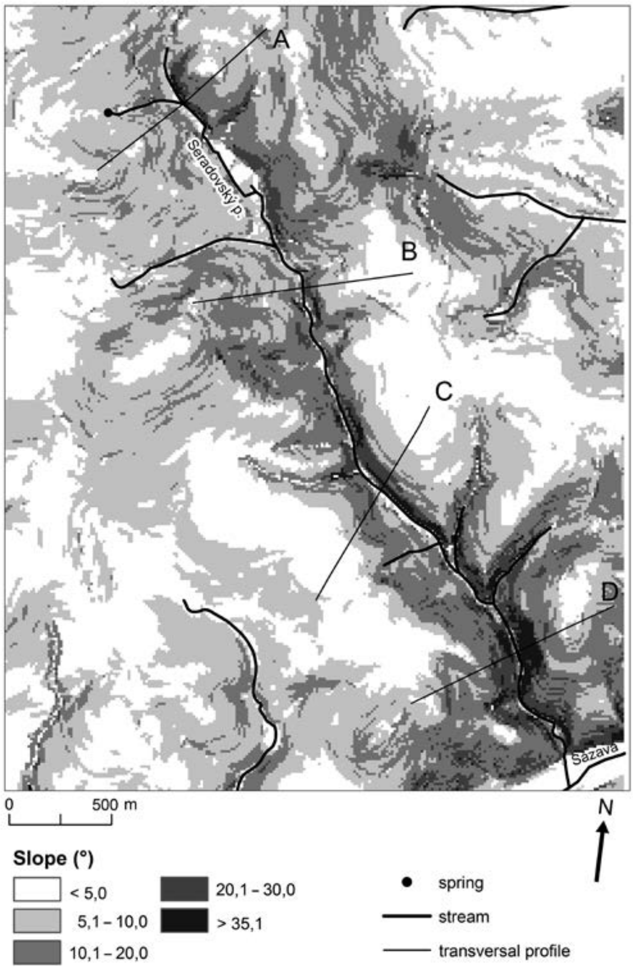

Fig. 22 Slope inclination in the Seradovský potok Brook valley and location of crosswise profiles in the valley. Data: ZABAGED®, Praha ČÚZK; Digital database DIBAVOD [data files], Praha VÚV TGM, 2006.

Daily course of air temperature has in spring months a typical course with minimal temperatures before daybreak and maximal temperatures in the afternoon. Snow, ice and frozen soil melting results in spring also in a significant increase of underground water level. Increased level of underground water causes an increased pressure in rocks (Záruba, Mencl 1987) which contributes to intensity of slope processes, including (in this area mostly slow) slope movements. Another important season of slope processes activities is autumn, when minimal as well as maximal soil and air temperatures are near to spring values. Their mean values are nearly identical and a similar situation was ascertained also in soil moisture. Substantial differences between spring and autumn periods are not found either in underground water level which oscillates around 7 m. Daily course of underground water level is more equilibrated in autumn than in spring and it changes during the day by 2 cm.

3. Geomorphic section between the Pecný ridge and the Sázava valley

Structural-denudational slopes of the south-eastern part of the Pecný ridge rise up above a large asymmetrical source basin and following shallow dell of the Seradovský potok Brook (490–455 m a.s.l.). The height difference between the Pecný top (545 m a.s.l.) and mouthing of this brook into Sázava (284 m a.s.l.) is 261 m at a distance of only less than five km (Fig. 22). This rugged terrain is due to a tectonic uplift of the central part of the Bohemian Massif during the late Cenozoic which significantly increased the intensity of erosional-denudational processes. An example is the development of the Sázava river network in the Quaternary when this tectonic uplift conditioned a pronounced deepening of the Sázava canyon-like valley and significantly influenced also the valleys of its tributaries (Balatka 2007; Balatka, Kalvoda 2010). The impact of deep and retrogressive erosion is evident in the Ondřejovská vrchovina Highland mainly in right-bank affluents of Sázava with V-shaped incised valleys. The most pronounced canyon-like valley southwards from the Pecný ridge is a segment of the lower course of the Seradovský potok Brook mouthing to Sázava (at its river km 46) about 2 km from Chocerady. In the upper part, the Seradovský potok Brook's rock underlayer is formed mainly by wackes and metawackes of the Čerčany metamorphosed island, whereas the lower course valley is deepened into phyllites and porphyries of the Chocerady metamorphosed island. The Central

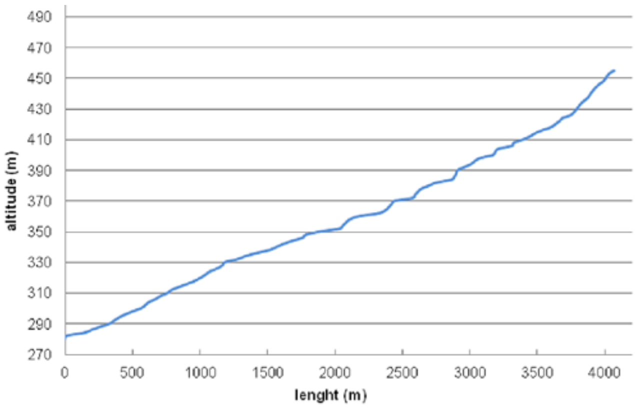

Fig. 23 Lengthwise profile of the Seradovský potok Brook (12 times exaggerated, modified according to Steklá 2012): upper course (river km 4.2–3.5) with maximal valley inclination (51–43‰); middle course (river km 3.5–1.8) with inclination decreased to 38‰ and with frequent changes in the gradient due to accumulations of proluvial sediments and rock steps in the riverbed; lower course (river km 1.8–0.0) with a marked break in the gradient (330 m a.s.l.) at river km 1.2 (up to 42‰) formed by retrogressive erosion of the stream during the Quaternary.

Bohemian Pluton reaches to the Seradovský potok Brook valley by quartz diorites of Benešov type.

Erosional processes in the Seradovský potok Brook valley were examined by geomorphic research inclusive of interpretation of lengthwise and crosswise valley profiles. The shape of the lengthwise profile reflects underlayer lithology variability, presence of discontinuities in the stream bed and vertical movements across the watercourse (compare Bíl, Máčka 1999) as well as changes of erosional base or character of the material in the river bed. For the Seradovský potok Brook valley (Fig. 22) lengthwise profile was created (Fig. 23) as well as four crosswise profiles. Selected crosswise profiles (Fig. 24) are located so as to depict the morphometry of this valley in its different parts (upper course 3.7 km, middle course 2.5 km, lower course 1.5 km and 1 km from its mouthing to Sázava). The position of the documented crosswise profiles is depicted in Fig. 22.

During the 4.07 km of its permanent course, the Seradovský potok Brook has the height difference of 171 m and mean inclination of 42‰. In the lengthwise profile of the Seradovský potok Brook (Fig. 23), three characteristic segments were delimited. The source of the Seradovský potok Brook is in an altitude of 455 m in a large dell situated up to 490 m a.s.l. This dell is deepened into an etchplain of probably Pre-Cretaceous age (546–490 m, Fig. 5) exhumed already in the Lower Palaeogene (Kalvoda 2007; Balatka, Kalvoda 2010). On the upper course between river km 3.4 and 4.0, the Seradovský potok Brook valley inclination is 51‰. From river km 3.7 inclination progressively decreases to 43‰ which is due to more resistant underlying rocks (Benešov granodiorite) as well as to the progressive development of the gradient conditions of the valley. A consequence of lower inclination of the valley bottom is an increased accumulation of proluvial and slope (mostly clayey) sediments of Holocene age. These accumulation landforms are also depicted in the course of crosswise profile A (Fig. 24A) at river km 3.7, where a valley bottom flattening is visible at 430 m a.s.l. These Holocene accumulations are bound to the mouthing of

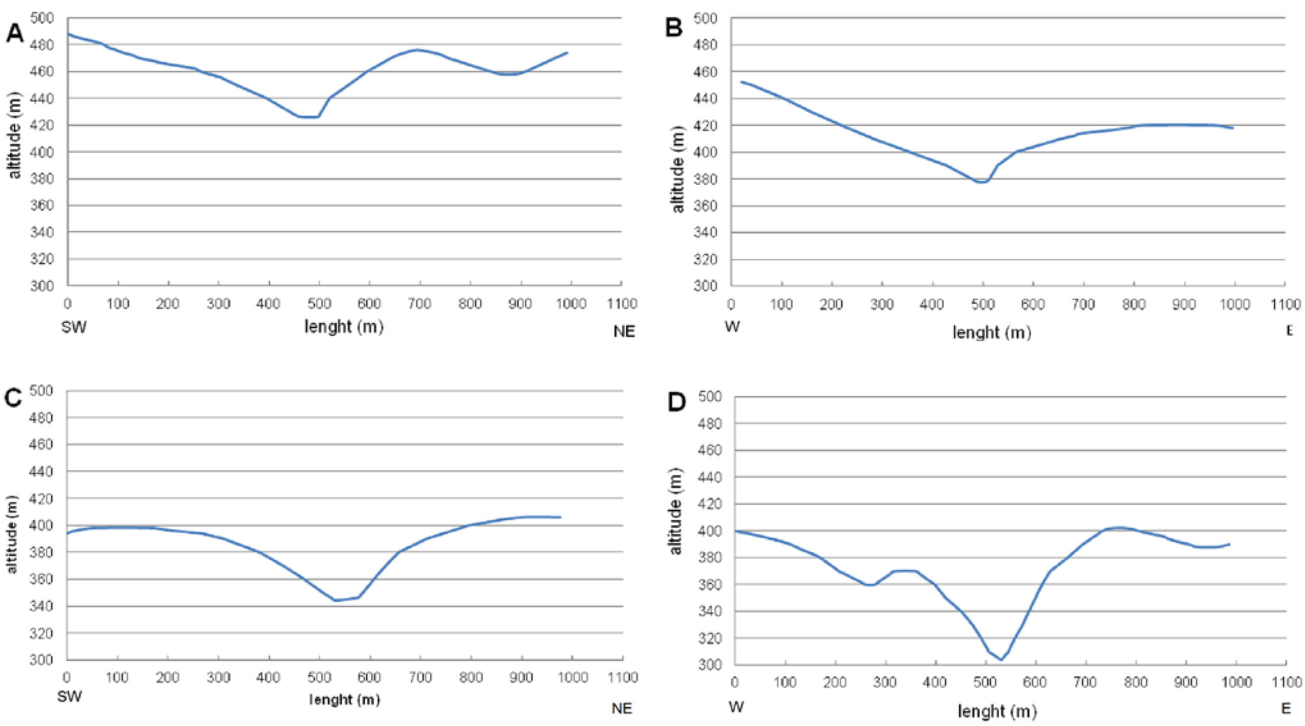

Fig. 24 Crosswise profiles of the Seradovský potok Brook valley (2.5 times exaggerated, modified according to Steklá 2012): position of profiles A to D is depicted in Fig. 22.

the first left-bank affluent of the Seradovský potok Brook. The western part of the profile A cuts the southern margin of a flat dell in the source area of the stream (480 m a.s.l.). The eastern arm of the crosswise profile A depicts a steep slope on the left bank up to the altitude of 480 m, where are relics of mild denudational slopes articulated by erosion of tributaries and ravines of the Seradovský and the Jevanský potok Brooks.

A decreased inclination (38‰) is visible also in the middle course of the Seradovský potok Brook. The bedrock is formed there by medium resistant phyllites of the Chocerady metamorphosed island. In this segment of the crosswise profile there is a great quantity of reduced inclination caused mainly by marked accumulations of proluvial sediments in the place of mouthing of tributaries and ravines and, to a lesser extent, by rock steps in the river bed. At river km 2.5 is the crosswise profile B (Fig. 24B). The western arm of the crosswise profile cuts the eastern slope of the ridge of 493 m a.s.l., i.e. approximately in the altitude of relics of the oldest graded level. Flattening of the valley bottom is caused by a marked alluvial cone at the mouthing of the first right-bank affluent of the Seradovský potok Brook. The right arm of the profile is linked to denudational plateaus and slopes at 420–370 m a.s.l., markedly articulated by stream erosion in the Pleistocene (Kalvoda 2007). Significantly increased inclination in the lower part of the eastern slope is visible in profiles A and B. In profile A, this can be explained by different resistance of the bedrock, whereas in profile B the increased valley slope inclination is probably linked with NW-SE oriented fault zone.

The lowest selected segment of the Seradovský potok valley is situated between river km 0.0 and 2.0. At river km 1.5 is situated the crosswise profile C (Fig. 24C), where the canyon-like character of the valley is already visible (Fig. 25). Due to homogenous bedrock formed by Neo-Proterozoic phyllites and porphyries of the Chocerady island (Fig. 26) the left and the right banks manifest a very similar character. From the flat valley filled by deluvial sediments steep valley slopes rise on both sides, at about 400 m a.s.l. they merge into denudational plateaus and slopes (420–370 m a.s.l.). In the segment between river km 1.0 and 2.0 from the mouthing, the bottom inclination of this valley reaches values only up to 28‰.

Nearer to the Seradovský potok Brook mouthing into Sázava inclination is increasing again to reach values up to 42‰. A break in the gradient of these valley segments is situated in a similar altitude than a pronounced erosional edge of the canyon-like Sázava valley between Ondřejov and Chocerady. Also these parts of the valley are formed in phyllites of Neo-Proterozoic age. These morphological features show that the described break in the Seradovský potok Brook valley gradient represents the reach of the advance of retrogressive erosion during the late Quaternary, when this valley got incised by approximately 50 m. The character of this canyon-like valley is shown in the crosswise profile (river km 1, Fig. 24D). The course of this crosswise profile shows a pronounced canyon-like deepening caused by deep and retrogressive erosion. Profile D is situated in the place of the highest valley gradient and recent erosional activity of the stream, so that no fluvial and slope sediments are deposited there. An increased sediment accumulation is visible in the Seradovský potok Brook valley bottom in the place of a decrease of the gradient, which is at about river km 0.2.

In the Seradovský potok Brook valley anthropogenous terrain changes are visible in several localities. Erosional activities have been significantly reduced in a large dell of the source area of the first left-bank affluent of the Seradovský potok Brook, where an asphalt road retains water outflow from the neighbouring slopes.

Fig. 25 Canyon-like valley in the lower part of the Seradovský potok Brook is formed by deep and retrogressive erosion stimulated by a tectonic uplift of the Ondřejovská vrchovina Highland during the Quaternary. Photo: T. Steklá.

Fig. 26 Eroded outcrops of metamorphosed basalts and porphyries up to 2 m high at the foot of a steep erosional-denudational slope on the brook left bank in the lower part of the Seradovský potok Brook valley. Photo: T. Steklá.

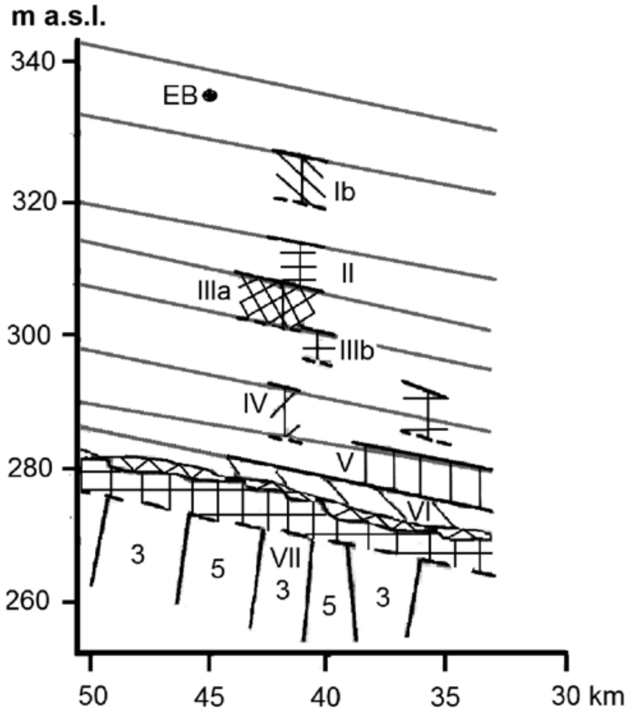

Fig. 27 Segment of the crosswise profile of the Sázava terrace system between river km 35 and 50 in the Ondřejovská vrchovina Highland (Balatka, Kalvoda 2010). I–VII – main levels of Sázava river accumulation terraces of Quaternary age (—— surface, --- base); EB – Pliocene erosional base of the Seradovský potok Brook; 3 – metamorphosed volcanites of the Jílové belt and other metamorphosed Upper Proterozoic rocks, including metamorphosed islands: rhyolites, dacites, andesites, basalts, porphyries, amphibolitic slates and hornstones; 5 – Moldanubian and Central Bohemian Pluton: granites, granodiorites, tonalites and diorites.

Fig. 28 Sázava valley eastwards from Chocerady with relics of the VIth (Poříčí) terrace and flood sediments of Holocene age. Photo: T. Steklá.

Other interventions into the relief are cottages and communications both on erosional slopes and valley bottom accumulations.

Deep and retrogressive erosion of the Seradovský potok Brook is significantly linked to antecedent deepening of the Sázava valley. During the Quaternary, there were formed during the gradual Sázava deepening seven main accumulation terraces and two levels of accumulation or erosion-accumulation origin (Balatka, Kalvoda 2010). It may be ascertained from the local position of relics of river accumulation terraces that the strongest deep erosion occurred in the Middle Pleistocene between the formation of the surface of the IInd and the IIIrd terrace (Fig. 27), when the Sázava valley got deepened by up to 40 m. In the Sázava valley segment between river km 35 and 50, localities of low terrace levels up to 20 m of relative height prevail. In the neighbourhood of Chocerady, only relics of terraces IV, VI and VII are present (Fig. 6), and that in the convex parts of meanders. Near Hvězdonice a small plateau of the IVth (Týnec) terrace is situated (Passer 1967), the surface of which is 17 m above the river level (291 m a.s.l.) and the base 9 m above the water level (283 m a.s.l.). Absence of sediments of the Vth terrace indicates a higher impact of erosion even in the period before the formation of the base of terrace VI. Sediments of the VIth (Poříčí) terrace are maintained in a narrow belt of the fluvial plain (Fig. 28). The surface of this terrace is 5–6 m above the Sázava level and it passes through a mild slope into the alluvial plain with its surface at 283 m a.s.l. and its base at 278 m a.s.l. Sediments of the VIIth terrace form the filling of the present-day valley bottom which is covered by flood sediments.

4. Discussion

The present-day state of the landscape environment in the GOPE locality which can be documented by different observations and measurements is only a short segment of palaeogeographical history of the Ondřejovská vrchovina Highland in the Quaternary. Recent morphogenetic processes are governed by co-evolution of climate, water supply (e.g. soil moisture dynamics) and vegetation. Monitoring of recent landform changes in the area of GOPE confirmed that regelation and frost processes, gully and fluvial erosion, slow slope movements and anthropogenous activities have a significant impact in rugged relief. Intensity of exogenous processes corresponds (according to our expectations) to combination of seasonal air and soil temperature changes and above all to water content in the rock massif and the weathered mantle. Fortunately, rapid geomorphic events and processes in the area of GOPE were not identified during more than 20 years of observations. Serious exceptions were a) the thunderbolt during windstorm in August 2013 which directly hit and damaged meteorological station in the area of GOPE, and b) continuing man-made deforestation of the Pecný ridge. It substantially changes thermal conditions on the surface of slopes, accelerates circulation of precipitation water (and snow) and also supports movements of weathered rocks, slope sediments and soils. Analysis of impacts of recent morphogenetic processes on multiannual course of geophysical (e.g. gravimetrical) measurements is now being performed.

Suitable location of scientific observatories on the ridge of Pecný and in its near neighbourhood is to a certain degree menaced by steadily increasing population density, transport network and growing and forestry activities in the Ondřejovská vrchovina Highland. Efforts to locally limit anthropogenous impacts directly in the observatories area are insufficient and, mainly from the long-term perspective, little efficient. In addition, the whole region is affected by increasing dust and/or industrial air pollution as well as by light pollution (due to Prague and other settlement complexes) which have been long years limiting or excluding number of astronomical and geodetical observations. Unique characteristics of the area of scientific observatories in the southern part of the Ondřejovská vrchovina Highland are: 1) favourable location in the central part of the Bohemian Massif enabling their integration into international networks measuring recent dynamics of main tectonic units in Central Europe and 2) a specifically differentiated geodiversity of this orographical unit with a high energy of the relief which has been developing already since the Palaeogene.

Development of the antecedent Sázava valley in the late Cenozoic had a significant impact on formation of landform patterns of the Ondřejovská vrchovina Highland which is markedly articulated by the valley of Sázava and its tributaries. The present-day river network has been formed already since the Upper Miocene when Saxonian tectonic movements caused breaking of the original Oligocene planation surface. Uplift of the watershed area between Labe and Sázava in the Neogene resulted into significant changes in the Sázava course (Novák 1932; Balatka, Sládek 1962; Balatka, Kalvoda 2010). Erosional activities of this new stream revived at the same time retrogressive and deep erosion on its affluents. The extent of the Pliocene deepening of Sázava in the territory of the Ondřejovská vrchovina Highland is near to the height difference of the Palaeogene planation surface (470–420 m a.s.l.) and the upper erosional edge of the canyon-like Sázava valley (350–340 m a.s.l., Kalvoda 2007).

The ongoing epirogenetic uplift of the central parts of the Bohemian Massif during the Quaternary resulted into intensification of erosion-denudational processes (Balatka 2007; Balatka, Kalvoda 2010). In the southern part of the Ondřejovská vrchovina Highland lateral and deep erosion formed relatively steep slopes of the canyon-like Sázava valley with a relative height of 60–75 m. Geomorphological analysis and interpretation of valley profiles of the Seradovský potok Brook indicate that during the Quaternary the retrogressive erosion reached river km 1.2 (Steklá 2012). This is documented above all from the position of a pronounced gradient break in the longitudinal profile across the Seradovský potok Brook valley in the place of the probably Pliocene erosional base of the stream. This step is in an altitude of about 330 m, which is near to the local height of the erosional edge of the Sázava antecedent valley between Ondřejov and Chocerady at 350–340 m a.s.l. (Kalvoda 2007). In the lower part of Seradovský potok Brook valley the stream deepened approximately by 50 m during the Upper Quaternary. These phenomena of pronounced deep and retrogressive erosion were ascertained also in the development of valleys of other affluents in the lower course of Sázava (Kuncová 2005; Balatka, Štěpančíková 2006). Right bank Sázava affluents in the Ondřejovská vrchovina Highland and also in its lower course are shorter than the left bank ones and have also a higher gradient. Significant from the morphostructural perspective are lithological characteristics of rocks and boundary of individual geological units.

Geomorphology as a part of the Earth Science deals with the dynamics of landforms at the interface of lithosphere, atmosphere, hydrosphere and biosphere. Determined geomorphic evolution of the Ondřejovská vrchovina Highland during the Quaternary as well as monitoring of present-day climate-morphogenetic processes in the GOPE locality give substantial evidence for high intensity of landform and landscape transience. Observing and measuring of recent geodynamical processes and phenomena must be interpreted on the basis of data on palaeogeographical and current changes of the environment in the area of scientific observatories. Correlation of present-day geomorphic phenomena with running geophysical measurements can also be a contribution to bridge the gap between studies of recent morphogenetic processes and recognition of long-term history of landforms.

5. Conclusions

Astronomical and Earth sciences observatories in the Ondřejovská vrchovina Highland are traditionally an important experimental locality in Central Europe. The large complex of GOPE with its permanent GPS station and other high-quality geophysical and meteorological equipment has an excellent morphostructural position for research into recent geodynamics of orographic units in Europe. This paper deals with the physical-geographical environment and landforms in the GOPE locality, inclusive evaluation of local climatic conditions in relation to recent morphogenetic processes and evolution of geomorphic profile between the Pecný ridge and the canyon-like Sázava valley in the Ondřejovská vrchovina Highland.

In the rugged terrain of the GOPE locality there is a significant impact of regelation and frost processes, gully and fluvial erosion, slow slope movements and anthropogenous activities. Intensity of recent morphogenetic processes and phenomena corresponds to combination of seasonal air and soil temperature changes and above all to water content in the rock massif and its weathered mantle. It was confirmed that optimal conditions for these processes are in spring, when soil and air temperatures often oscillate about the frost point. Differently from the winter period, soil temperature manifests also more pronounced daily amplitudes reaching up to 30 °C. Frequent soil temperature oscillation about 0 °C is very favourable for activities of regelation and slope processes, especially when this oscillation is connected with increased soil moisture of about 35%. Snow, ice and frozen soil melting in spring causes an increased level of underground water which supports intensity of slope processes, including the small ones. Another period of slope processes activities is autumn when both minimal and maximal soil and air temperatures and also increased soil moisture are near to the spring values.

The extent of landform changes in the southern part of the Ondřejovská vrchovina Highland caused by erosional and denudation processes is proportional to the high potential energy of the relief due to tectonic uplift of the central part of the Bohemian Massif in the late Cenozoic. This progressive uplift is documented above all by gradual layout of denudational surfaces and slopes from the hill parts of the Ondřejovská vrchovina Highland down to the antecedent Sázava valley. The extent of erosional and denudational processes between the Pecný ridge (545 m a.s.l.) and the Sázava valley (284 m a.s.l.) was documented by the development of the Seradovský potok Brook valley, the source area and the upper course of which are disturbing in the Palaeogene exhumed etchplain. The middle part of the Seradovský potok Brook valley crosses lower denudational plateaus (420–370 m a.s.l.) the erosional dissection of which occurred probably in the period going from the Upper Pliocene to the Lower Pleistocene. In the lower part of its valley, the Seradovský potok Brook deepened during the late Quaternary approximately by 50 m, whereas the relatively steep erosional slopes of the canyon-like part of the Sázava valley have a relative height of 60–75 m. Besides the tectonic uplift, lithological and structural characteristics of bedrock, development of landforms and specific geodiversity of the Ondřejovská vrchovina Highland were significantly influenced by changes of climatic conditions during the Quaternary.

At present, we analyse and interpret, from the geodynamical perspective, impacts of ascertained climate-morphogenetical processes on multiannual course of geophysical and geodetical measurements in the GOPE locality. Favourable geodynamic location of scientific observatories on the ridge of Pecný, which is stable from engineering-geological and geomorphological perspective, and in its near proximity is to a certain degree menaced by increasing intensity of anthropogenous activities in the landscape.

Acknowledgements

The paper was carried out under auspices of the project LC506 "Recent dynamics of the Earth" of the Ministry of Education, Youth and Sport of the Czech Republic and the programme PRVOUK No. 43 "Geography" of the Charles University. The authors wish to thank to RNDr. Jiří Kastner for his valuable cooperation during meteorological observations at the GOPE.

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RESUMÉ

Povrchové tvary a morfogenetické procesy v lokalitě Geodetické observatoře Pecný, Ondřejovská vrchovina

Práce se zabývá fyzicko-geografickým prostředím a souborem povrchových tvarů v lokalitě Geodetické observatoře Pecný (GOPE), hodnocením místních klimatických podmínek ve vztahu k recentním morfogenetickým procesům a kvartérnímu vývoji reliéfu mezi hřbetem Pecného a kaňonovitým údolím Sázavy v Ondřejovské vrchovině. V členitém reliéfu lokality GOPE se

výrazně uplatňují regelační a mrazové procesy, stružková a fluviální eroze, pomalé svahové pohyby a antropogenní činnost. Intenzita recentních morfogenetických procesů a jevů odpovídá kombinaci sezónních změn teploty vzduchu a půdy a zejména množství vody v horninovém masivu a zvětralinovém plášti. Bylo potvrzeno, že optimální podmínky pro aktivitu těchto procesů jsou na jaře, kdy dochází k častému kolísání teploty půdy a vzduchu kolem bodu mrazu. Na rozdíl od zimního období se teplota půdy vyznačuje také výraznějšími denními amplitudami, které dosahují až 30 °C. Častá kolísání teploty půdy okolo 0 °C jsou velmi příznivá pro aktivitu regelačních a svahových procesů zejména tehdy, je-li toto kolísání spojeno se zvýšenou vlhkostí půdy, která se pohybuje kolem 35 %. Vlivem tání sněhu, ledu a zmrzlé půdy dochází na jaře i k výraznému nárůstu hladiny podzemní vody, což podporuje intenzitu svahových procesů, včetně svahových pohybů. Dalším významným obdobím aktivity svahových procesů je podzim, kdy jsou minimální i maximální teploty půdy a vzduchu a také zvýšená vlhkost půdy velmi blízké jarním hodnotám.

Rozsah změn povrchových tvarů Ondřejovské vrchoviny působením erozních a denudačních procesů je úměrný vysoké potenciální energii reliéfu, která vznikla postupným tektonickým výzdvihem centrální části Českého masivu v mladším kenozoiku. Údolí Seradovského potoka mezi hřbetem Pecného (545 m n. m) a dnem údolí Sázavy (284 m n. m.) protíná několik úrovní zarovnaných povrchů, přičemž jeho pramenná oblast eroduje etchplén exhumovaný v paleogénu. Údolí střední a dolní části Seradovského potoka prochází napříč denudačními plošinami (420–370 m n. m.), přičemž k jejich eroznímu rozčlenění došlo pravděpodobně v období od svrchního pliocénu do staršího pleistocénu. Ve spodní části údolí Seradovského potoka došlo během mladšího kvartéru k zahloubení toku přibližně o 50 m, přičemž poměrně strmé erozní svahy kaňonovité části antecedentního údolí Sázavy mají relativní výšku 60–75 m. Kromě tektonického výzdvihu, litologických a strukturních vlastností hornin se na vývoji povrchových tvarů a specifické geodiverzity Ondřejovské vrchoviny významně podílely změny klimatických podmínek v kvartéru.

V současné době se zabýváme analýzou a geodynamickou interpretací vlivů zjištěných recentních klimato-morfogenetických procesů na víceletý chod geofyzikálních a geodetických měření v lokalitě GOPE. Výhodné geodynamické umístění areálu vědeckých observatoří na inženýrsko-geologicky stabilním hřbetu Pecného a v jeho blízkém okolí je ohrožováno zvyšující se intenzitou antropogenní činnosti v krajině.

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