# Deep-seated gravitational slope deformations in the highest parts of the Czech Flysch Carpathians: evolutionary model based on kinematic analysis, electrical imaging and trenching

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The Czech part of the Outer Western Carpathians (OWC) is mainly formed by variously bedded flysch that is susceptible to an occurrence of deep-seated gravitational slope deformations (DSGSDs). On contrary to majority of other mountainous regions where the DSGSDs have recently been studied, the OWC are generally aseismic, they didn't experience a postglacial deglaciation debutressing and reach only low to moderate local relief. This study deals with four structurally preconditioned mountain ridges in the Moravskoslezské Beskydy Mts. whose ridgetop parts are spectacularly disrupted by the mass movements. Each study area has been put through a detailed analysis including mapping, speleological research, structural and kinematic analyses, paleoseismological trenching, 2D electrical resistivity tomography and radiocarbon dating. All studied DSGSDs are predisposed by mutual interactions between bedding planes, joint sets, and both normal and strike-slip faults within strongly lithologically and tectonically anisotropic flysch massifs. The orientation of gravitational morphostructures well correlates with a structural fabric of the studied region. The extensive geophysical profiling and trenching on the selected sites revealed significantly higher occurrence of the crevice-type caves and other air-filled voids within the anisotropic rock massifs than it was previously stated. Distinctive subsurface zones with extremely high resistivities (>4000 ohm.m - indicating caves) often continue outside the morphological expressions of the DSGSDs. This finding indicates that the failures initiate inside the ridges at depths mostly 10-40 m. The paleoseismological trenches applied to three sackung-like features revealed complicated inner structures involving faulted and bended strata, cataclastic bands and opened (partly infilled) crevices. These structures are an evidence of gravitationally activated tectonic elements whereas dislocations evolved by both gravitationally-induced movements (e.g. sackung, lateral spreading etc.) and collapse of rock mass above opened crevices. Bedrock structures are overlain by both coarse-grained colluvial wedges and fine-grained colluvia. Radiocarbon dating of organic deposits infilling the gravitational trenches indicates Holocene age of the studied landforms; some of them evolved even during the Late Holocene. Our studied DSGSD are spatially connected with other consequent slope failures like landslides which is valuable contribution for discussion about DSGSD-related catastrophic failures of slopes. Kinematic analysis performed in our study area furthermore indicate that existence of structurally-preconditioned landslides within the area of DSGSD can be only hardly explained applying normal values of angle of internal friction of claystone intercalations, which likely dropped to residual values by long-term creep activity related to DSGSD evolution. This finding suggests the important role of DSGSD for evolution of consequent catastrophic mass movements. Our results indicate that (i) the extensive manifestations of the typical DSGSDs can evolve even in low to medium high mountains - especially, if rock massifs are formed by strongly anisotropic rocks, (ii) beside the known processes such as the lateral spreading, toppling and sackung, the important evolution mechanism of the disrupted ridges involves the collapse and the subsidence of the ridgetop zones due to the deep-seated creep-related opening of the crevices, (iii) the process of the DSGSDs formation continues within studied region up to recent times by the formation of new gravitational structures and activation of older (Pleistocene-Early Holocene) landforms.

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