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Logging of palaeoseismic exposures in a 3D virtual environment integrating hyperspectral imagery and photogrammetric point clouds

Moritz Kirsch (1), Sandra Lorenz (1), Robert Zimmermann (1), Louis Andreani (1), Laura Tusa (1), Philip Hödl (1), Robert Jackisch (1), Gabriel Unger (1), Richard Gloaguen (1), Maarit Middleton (2), Antti Ojala (3), Jussi Mattila (3), Nicklas Nordbäck (3), Jukka-Pekka Palmu (3), Timo Ruskeeniemi (3), and Raimo Sutinen (2)

(1) Helmholtz-Zentrum Dresden-Rossendorf, Helmholtz Institute Freiberg for Resource Technology, Freiberg, Germany, (2) Geological Survey of Finland, Rovaniemi, Finland, (3) Geological Survey of Finland, Espoo, Finland

Palaeoseismology uses evidence from pre-historic earthquakes preserved in the geologic and geomorphic record to reconstruct the seismic history of a fault system and assess the seismic hazard of a region. A common technique in palaeoseismological investigations is to excavate trenches on fault scarps. The documentation of palaeoseismic deformational features of strata exposed in trenches is traditionally accomplished by in-situ field mapping and/or by photomosaic logging. In-situ trench logging is very subjective and requires a lot of time and experience, particularly in unfavourable lighting conditions or if deformational features are subtle. Photomosaic logging is usually based on manual rectification and stitching of photographs, which introduces geometric distortions that may lead to misinterpretation. We present a new workflow for a more unbiased, accurate, and time-efficient logging of palaeoseismic exposures such as trench walls based on a geometrically and radiometrically corrected combination of a Structure-from-Motion (SfM) point cloud and a visible to near-infrared (VNIR) and short-wave infrared (SWIR) hyperspectral datacube. As a case study, the workflow is applied on two palaeoseismic trenches dug across the Vaalajärvi postglacial fault at the Ristonmännikkö site in the northern Finnish part of the Fennoscandian Shield, where seismic activity is attributed to post-glacial rebound. For each of the trenches, a ramp is constructed using an excavator to allow setup of the tripod-based hyperspectral line scanner parallel to the exposed trench wall. Following the placement of ground control points in the scene and their measurement using a total station, ground- and drone-based photographs are acquired. A standard SfM multi-view stereo procedure is utilised to derive validated SfM point clouds from the photographs. The hyperspectral imagery (HSI) is calibrated and corrected using an in-house Python toolbox, processed using various simple image processing and classification algorithms, and co-registered to a projective transformation of the SfM point cloud. Thus a number of HSI-enhanced virtual outcrop models are generated that can be used as a base for palaeoseismic analysis in a 3D environment, allowing (a) an intuitive visualisation of the outcrop, (b) the identification of lithological unit and contacts, and deformational structures based on colour contrast, (c) the extraction of information on the mineralogical composition of the lithological units (d) the assessment of structural orientations using the high-resolution SfM point cloud, (e) an integration with ancillary field observations and sample analytical data within the same 3D framework, and (f) a correlation of strata and faults between outcrops. In our case study, the new approach proved to be a useful complement to the field studies, as it, for instance, helped to identify fault structures within the main units of superficial deposits (till) and bedrock in one of the trenches, which proves that the deposition of the till pre-dated the latest increment of regional palaeoseismic activity.