Geomorphologic landslide inventory by air photo interpretation of the High Agri Valley (southern Italy)

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Consiglio Nazionale delle Ricerche
National Research Council

Scale: 1:30.000
If printed in A0

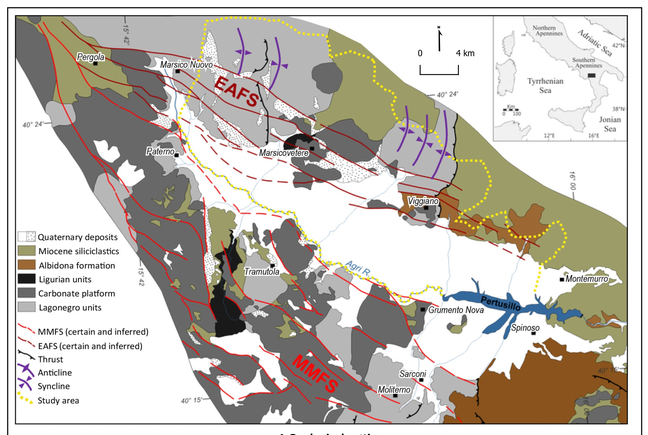
We present a geomorphological landslide inventory map for the NE margin of the High Agri Valley Basin, Basilicata, Italy, at 1:30,000 scale. The map covers an area of 235 km^2 and encompasses the E-side of the fault bounded, intramontane High Agri Valley. The basin formed in the Quaternary in response to extensional tectonics that cut pre-existing folded structures of the Apennines belt (**inset 1**). To prepare the map, we interpreted visually two sets of stereoscopic aerial photographs, including panchromatic images taken in 1955 at 1:33,000 (**inset 2a**) and in 2003 at 1:32,000 (**inset 2b**) nominal scale. A total of 71 partially overlapping photographs were examined (**inset 2c**).

The geomorphological survey was mapped at the 1:10,000 scale (Carta Tecnica Regionale – Regione Basilicata - https://rsdi.regione.basilicata.it/), and published at 1:30,000 scale which appears to be the most adequate to illustrate the overall landslide variability over the study area. It is also compatible with the scale of the aerial photographs used for the survey.

For the visual interpretation we used the freeware software StereoPhoto Maker (SPM, http://stereo.jpn.org/eng/stphmkr) that allows for the anaglyph or shutter glasses 3D view of stereo-pairs.

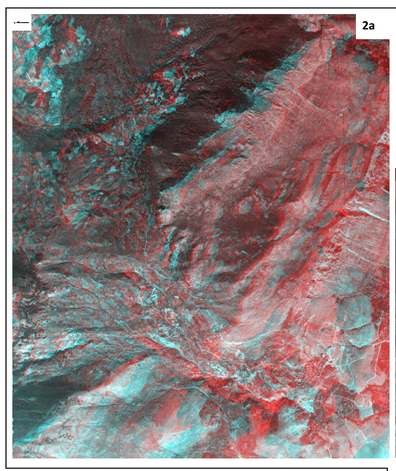
Landslide and other geomorphological information was interpreted on the stereoimages and directly drawn visually on 1:10,000 scale digital topographic base maps in a Geographical Information System (GIS). Drawing was aided by the combined use of contour lines and shaded relief derived by a high resolution (1 meter) LiDAR-derived shaded relief. The interpretation of the aerial photographs was aided by the analysis of pre-existing geomorphological, and geological information. Focused field checks were performed to validate the informative content of the map.

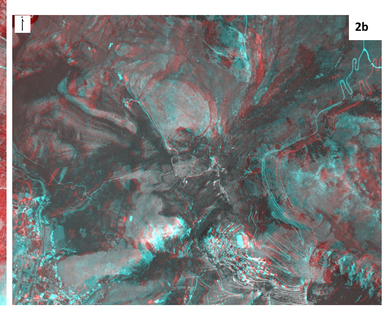
Landslides recognized in the study area were classified according to *Cruden and Varnes, (1996) and Hungr et al. (2014)*, and are primarily slides, flows, slide earthflows, and complex movements. In addition, according to *WP/WLI (1990, 1993, 1995)* landslides were classified based on the estimated depth (as shallow or deep-seated), the inferred relative age (as relict, very old, old or recent), and the degree of uncertainty (identification, delineation, classification). For the deep seated landslides, the crown area marking the upper part of the depletion zone, was mapped separately from the deposit. Finally, the landslide map was completed by mapping of other geomorphological elements associated with slope evolution, namely areas affected by widespread shallow mass wasting processes, and recent and relict, alluvial deposits and alluvial fans. The map has seven additional maps of the same landslides classified based on relative age (**panels R1-2, V1, O1-4**), according to the criterion indicated by *Keaton and DeGraff, (1996)*, and to the nomenclature proposed by *Santangelo et al., (2014)*. A further map shows the same landslides classified based on uncertainty degree, (**panel LU**). Finally, a plot summarizes the distribution of landslide number and size by relative age and type of movement (**panel LS**).



1 Geological settings

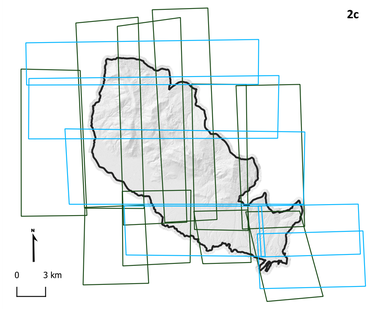
Geographical location and regional geological setting of the study area, with six main lithological complexes. Modified from (*Giocoli et al., 2015*)

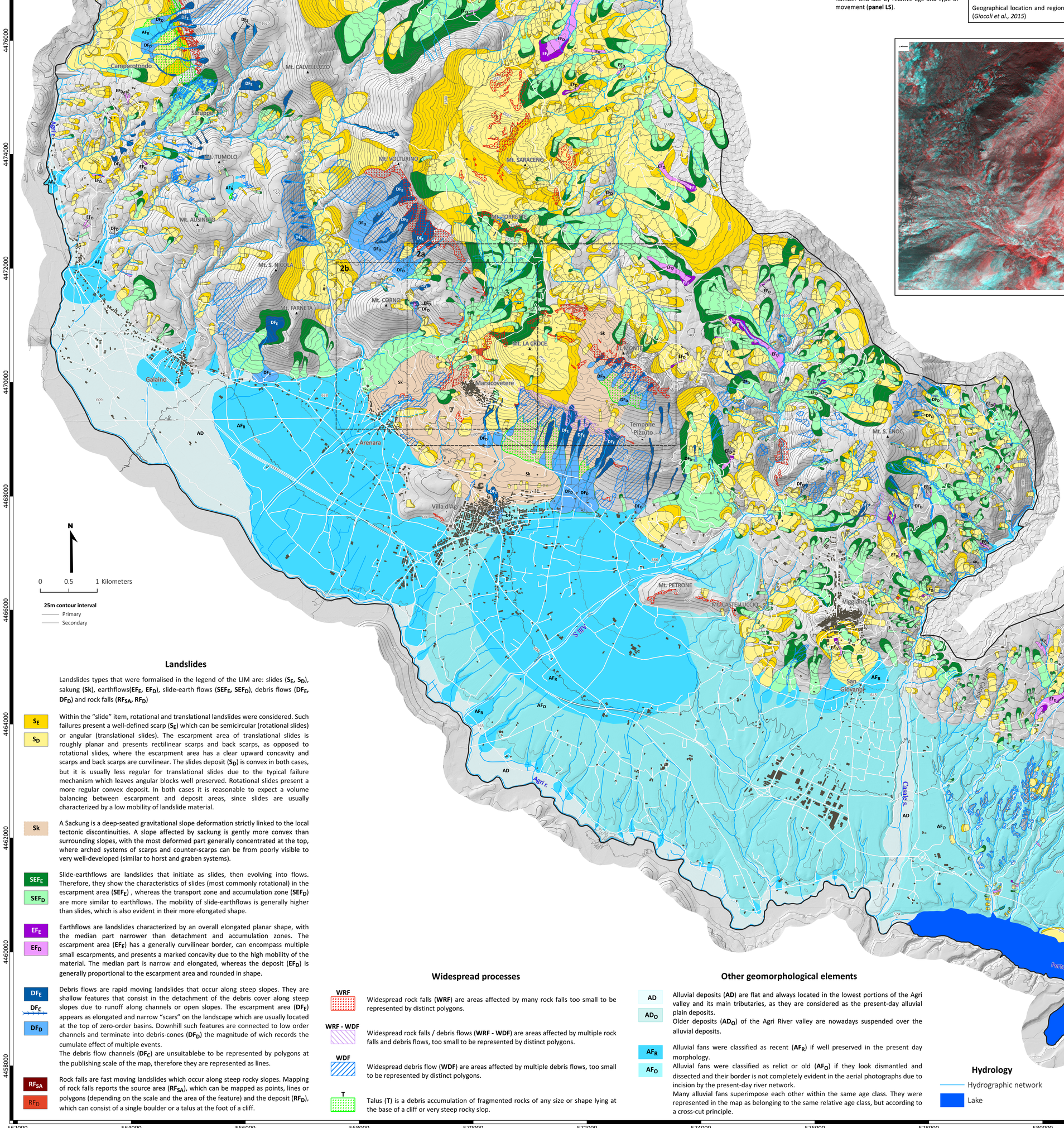




2 Stereo pairs

Stereoscopic aerial photographs acquired in 1955 (**2a**) and 2003 (**2b**), respectively at 1:33,000 and 1:36,000 scale. The aerial photographs are shown in the two anaglyphs that exemplify the signature of geomorphological settings in the study area. In particular, image 2a shows evidences of a large sackung, while image 2b shows evidences of a relict slide-earthflow. The approximate location of aerial photographs is shown on Main Map (dashed outlined rectangles). Image **2c** shows the flight plan of 1955 (pink rectangles) and 2003 (light blue rectangles)





Landslides

Landslides types that were formalised in the legend of the LIM are: slides (S_E, S_D), sakung (**Sk**), earthflows(EF_E, EF_D), slide-earth flows (SEF_E, SEF_D), debris flows (DF_E, DF_D) and rock falls (RF_{SA}, RF_D)

S_E **S_D**

Within the "slide" item, rotational and translational landslides were considered. Such failures present a well-defined scarp (S_E) which can be semicircular (rotational slides) or angular (translational slides). The escarpment area of translational slides is roughly planar and presents rectilinear scarps and back scarps, as opposed to rotational slides, where the escarpment area has a clear upward concavity and scarps and back scarps are curvilinear. The slides deposit (S_D) is convex in both cases, but it is usually less regular for translational slides due to the typical failure mechanism which leaves angular blocks well preserved. Rotational slides present a more regular convex deposit. In both cases it is reasonable to expect a volume balancing between escarpment and deposit areas, since slides are usually characterized by a low mobility of landslide material.

Sk

A Sackung is a deep-seated gravitational slope deformation strictly linked to the local tectonic discontinuities. A slope affected by sackung is gently more convex than surrounding slopes, with the most deformed part generally concentrated at the top, where arched systems of scarps and counter-scarps can be from poorly visible to very well-developed (similar to horst and graben systems).

SEF_E **SEF_D**

Slide-earthflows are landslides that initiate as slides, then evolving into flows. Therefore, they show the characteristics of slides (most commonly rotational) in the escarpment area (SEF_E) , whereas the transport zone and accumulation zone (SEF_D) are more similar to earthflows. The mobility of slide-earthflows is generally higher than slides, which is also evident in their more elongated shape.

EF_E **EF_D**

Earthflows are landslides characterized by an overall elongated planar shape, with the median part narrower than detachment and accumulation zones. The escarpment area (EF_E) has a generally curvilinear border, can encompass multiple small escarpments, and presents a marked concavity due to the high mobility of the material. The median part is narrow and elongated, whereas the deposit (EF_D) is generally proportional to the escarpment area and rounded in shape.

DF_E **DF_C** **DF_D**

Debris flows are rapid moving landslides that occur along steep slopes. They are shallow features that consist in the detachment of the debris cover along steep slopes due to runoff along channels or open slopes. The escarpment area (DF_E) appears as elongated and narrow "scars" on the landscape which are usually located at the top of zero-order basins. Downhill such features are connected to low order channels and terminate into debris-cones (DF_D) the magnitude of wich records the cumulate effect of multiple events.
The debris flow channels (DF_C) are unsuitablebe to be represented by polygons at the publishing scale of the map, therefore they are represented as lines.

RF_{SA} **RF_D**

Rock falls are fast moving landslides which occur along steep rocky slopes. Mapping of rock falls reports the source area (RF_{SA}), which can be mapped as points, lines or polygons (depending on the scale and the area of the feature) and the deposit (RF_D), which can consist of a single boulder or a talus at the foot of a cliff.

Widespread processes

WRF

Widespread rock falls (**WRF**) are areas affected by many rock falls too small to be represented by distinct polygons.

WRF - WDF

Widespread rock falls / debris flows (**WRF - WDF**) are areas affected by multiple rock falls and debris flows, too small to be represented by distinct polygons.

WDF

Widespread debris flow (**WDF**) are areas affected by multiple debris flows, too small to be represented by distinct polygons.

T

Talus (**T**) is a debris accumulation of fragmented rocks of any size or shape lying at the base of a cliff or very steep rocky slop.

Other geomorphological elements

AD **AD_O**

Alluvial deposits (**AD**) are flat and always located in the lowest portions of the Agri valley and its main tributaries, as they are considered as the present-day alluvial plain deposits.
Older deposits (AD_O) of the Agri River valley are nowadays suspended over the alluvial deposits.

AF_R **AF_O**

Alluvial fans were classified as recent (AF_R) if well preserved in the present day morphology.
Alluvial fans were classified as relict or old (AF_O) if they look dismantled and dissected and their border is not completely evident in the aerial photographs due to incision by the present-day river network.
Many alluvial fans superimpose each other within the same age class. They were represented in the map as belonging to the same relative age class, but according to a cross-cut principle.

Hydrology

Hydrographic network
Lake

Topographic base source

Base Maps:
Roads, hydrographic network, place name, buildings.
Format: Shapefile
(© Regione Basilicata Sevizio RSDI)

Coordinate System:
UTM WGS 1984;
ZONE 33 N;
EPSG: 32633

Hillshade:
(Based on 2014 LIDAR 1m)
Format: GeoTIFF
© ENI S.p.A

Contour lines:
(Extracted from 2014 LIDAR 1m)
Format: SHP
© ENI S.p.A.

Landslides by relative age

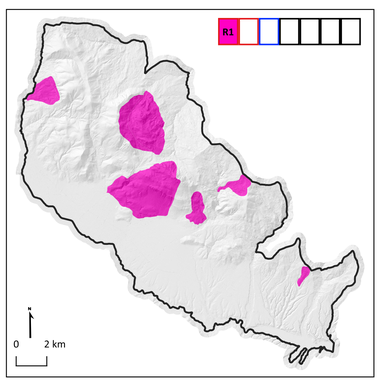
The seven panels on the left, (from **R1** to **O4**) show the entire inventory disaggregated according to the seven levels (time steps) of the relative age classes recognised. The sequence of the seven panels represents a timeline, where landslides of each time step are shown in purple, whereas landslides belonging to older time steps are represented in yellow. The location of each panel within the reconstructed time sequence is emphasized by the timeline bar, located at top right in each panel.
The seven age levels are the result of major and minor subdivisions. The former refer to the general morphologic appearance of landslides, the latter follow a generation principle within each major age class. The criterion for the major age subdivisions is based on the assumption that evidences of landslides become less obvious with the increasing age, due, for example, to erosion processes, vegetation growth, and occurrence of other landslides. Hence, older landslides are more difficult to detect than more recent ones.
Based on this criterion, the three major classes of relative age are (i) relict landslides (red bounded **R1** and **R2** panels) (ii) very old landslides (blue bounded, **V1** panel), and (iii) old landslides (black bounded **O1** to **O4** panels). The second criterion, a crosscut principle, defines the minor subdivisions within each age class: younger landslides (purple polygons in each time step) cover the older ones (yellow polygons in each time step). As opposed to the three major age classes, the minor subdivisions can be applied only to landslides that overlap. Therefore, whithin a same age class (e.g., "old") no relative age information is given for landslides that have no spatial relationship.

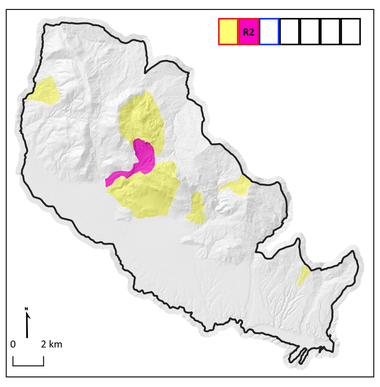
Landslides by uncertainty

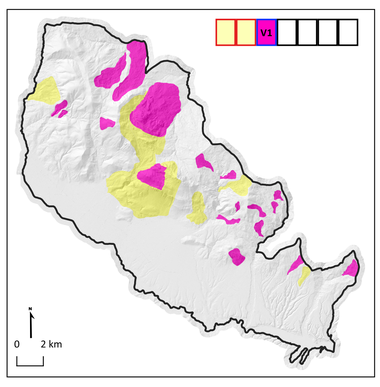
Uncertainty levels (panel **LU**) associated with each landslide detected were also defined, namely uncertainty in landslide (i) delineation, (ii) classification, and (iii) identification. A landslide which was mapped with uncertainty in the delineation was clearly detected and classified, but at least in some locations along the border, the delineation was not unambiguous. When also classification is uncertain, it means that even less evidence was present to also define the type of movement of the landslides. When landslides appear strongly dismantled, particularly large, and not unambiguously defined as slope failures, uncertainty was associated also with landslide identification. Only very old and relict landslides show degrees of uncertainty, as opposed to old landslides, which are considered all certain.

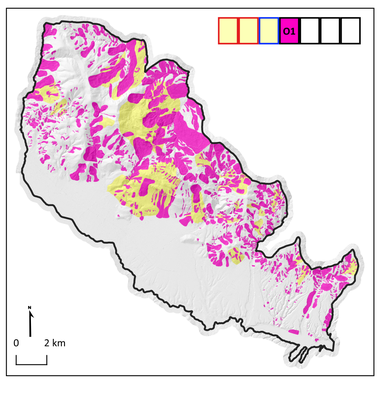
Landslides statistics

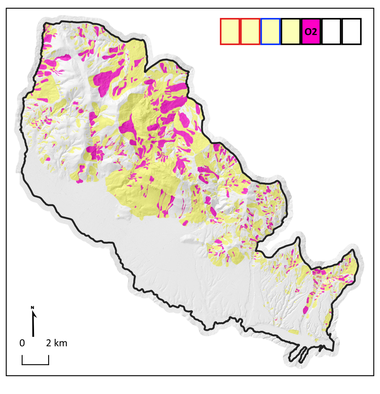
Panel **LS** shows landslides number (represented by a colour gradient and labels) and cumulated area (proportional to circle sizes), grouped by relative age classes and landslide type. Visual inspection of the plot reveals that relict and very old landslides are not represented by small landslides, and in particular by debris flows, rock falls and earth flows, which tend to be small and easily obliterated by erosion and subsequent failures. A further evidence is that a large portion of the total landslide area is occupied by few relict and very old kilometre-scale large slope failures, whereas a decreasing trend both in cumulate area and total number of landslides is evident through time for all landslide types within the "Old" relative age class. The evidence suggests a threshold size effect of previous landslides on subsequent slope movements.

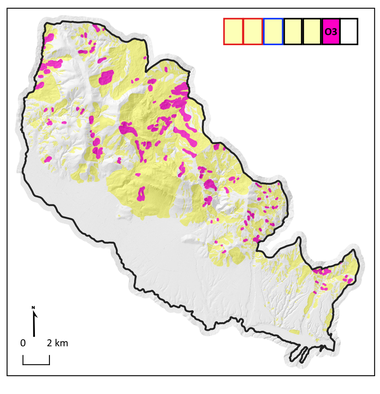


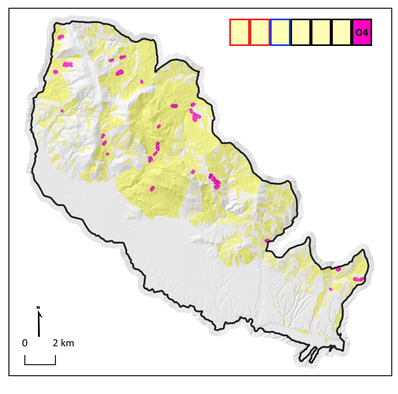


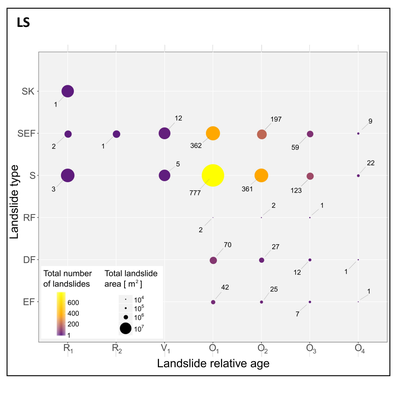


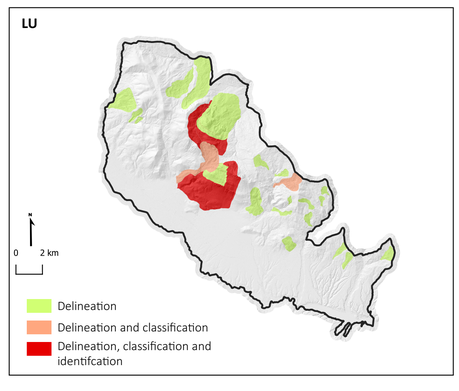












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