10. Geomorphology or Shaping Earth Surface

Cristian Scapozza, Nikolaus Kuhn, Dorota Czerski, Caroline Bolliger, Reynald Delaloye, Isabelle Gärtner-Roer, Elisa Giaccone, Christoph Graf, Margreth Keiler, Julia Krawielicki, Isabelle Kull, Mario Kummert, Christophe Lambiel, Géraldine Regolini, Julie Wee

Swiss Geomorphological Society

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10.2 *Battista G., Schlunegger F., Burlando P., Molnar P.*: Combining numerical modelling and geomorphic mapping to study sediment provenance in a pre-Alpine river basin

10.3 *Raab G.*: The Tor Exhumation Approach (TEA) – Dealing with continuous and reversed exhumation patterns to determine surface denudation rates

10.4 *Vos H., Eckardt F., Fister W., Kuhn N*: Surface boundary conditions for dusts emission from the agricultural lands in the Free State, South Africa

10.5 *Wicki A., Jansson P.-E., Lehmann P., Hauck C., Stähli M.*: Performance analysis of simulated vs. measured soil moisture dynamics for regional landslide early warning in Switzerland

10.6 *Zaki A.S., Edgett K.S., Gupta S., Maurizio P., Davis J., Hughes C.M., Watkins S.E., Valero L., Grindrod P., Thomas N., Cremonese G., Castelltort S.*: Fluvial landforms in Antoniadi crater: Evidence for two intervals of water-generating landscapes on Mars

POSTERS:

P 10.1 *Mair D., Lechmann A., Delunel R., Yeşilyurt S., Tikhomirov D., Vockenhuber C., Christl M., Akçar N., Schlunegger F.*: Millenial scale denudation of the steep Eiger headwalls through thermo-cryogenic pre-conditioned rockfall

10.1
3-D models of the overdeepenings in the Aare and Gürbe valleys using gravimetry

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Interpretations of the processes leading to the formation of overdeepened valleys, where the bedrock lies well below sea level today, are contested as the overdeepenings have been filled by sediments or host lakes making observations difficult (Cook and Swift, 2012). Here, we combine gravimetric, GNSS (Global Navigation Satellite System) and borehole data within a 3D forward modelling framework, Gravi3D, to assess the subsurface geometry of such overdeepenings in 3D. We particularly aim at reconstructing the geometry of overdeepened valleys' walls, which bears information on the erosional mechanism leading to the formation of these features. We focus on two valleys, the Aare valley and the Gürbe valley.
In this region, the occurrence of overdeepenings, or alternatively tunnel valleys, has already been disclosed through drilling (Reber and Schlunegger, 2016), but the details about the geometry have not been elaborated yet. The study region is characterized by three low ranges made up of Burdigalian Upper Marine Molasse bedrock with c. 300 m-deep and c. 1 km-wide valleys in-between, where overdeepenings with a >100 m-thick Quaternary fill have already been identified by drilling. The gravity data, which we collected, along an 8km long profile with stations spaced between 100 and 300 m yield a Bouguer anomaly that ranges from c. -99 to -106 mGal. We infer this anomaly to the regional trend (c. 2 mGal over 8 km) and to the effect of the overdeepenings sedimentary fillings (2-4 mGal over 1 km), disclosing a sharp anomaly pattern over the inferred tunnel valleys. The removal of the signal related to the regional trend results in a residual Bouguer anomaly of c. 1 mGal for the Belpberg hill in-between the valleys that is made up of Molasse bedrock, and 2.6 and 3.8 mGal for the Gürbe and Aare valley overdeepenings, respectively. Furthermore, preliminary interpretations of the residual gravity anomaly of the Belpberg bedrock hill suggest a density of 2.4 kg/m^3 for the Molasse bedrock. This value will be better constrained with the Nettleton method for the quantification of an accurate density contrast between the Molasse bedrock and the Quaternary fill.
Finally, and most important, we prepare a forward modeling program written in Python, Gravi3D, which allows to calculate a theoretical gravity effect of a geological body with variable geometries and densities to detail the geometry of the overdeepenings on the lateral flanks of the bedrock hills (Kissling and Schwendener, 1990). This program is designed such as it can be employed by the larger scientific community. It has two components referred to as PRISMA and BGPoly, where analytical solutions for the gravity effect of prisms and of polygons by Nagy (1966) and Talwani & Ewing (1960) are implemented. PRISMA allows first order estimates of the spatial extent and density of a simple structure, while BGPoly is intended to fit complex 3-D geometries with a series of horizontal polygons similar to lines of equal height in topographic maps. The results will be integrated within a GIS environment for comparison purposes. We then use published information on the near-surface bedrock geometry of the target area together with information on the densities of the geological units as initial constraints for the calculation of the gravity effect, which will be compared with the Bouguer gravity survey's results. We iteratively improve on the model geometry and the densities until we reach a best fit between the observed and the modeled Bouguer anomaly. The goal is to refine the 3-D geometrical details of the target overdeepenings.

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10.2
Combining numerical modelling and geomorphic mapping to study sediment provenance in a pre-Alpine river basin

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Sediment mobilization in a river basin takes place by means of multiple processes and from a variety of sources, such as landslides, hillslopes, riverbed and banks. Next, the transport processes in the river network allow for mixing, deposition and further erosion (e.g. Jerolmack and Paola, 2010). The complexity of these mechanisms makes the provenance of the sediment load at the outlet very difficult to predict (e.g. Roering et al., 1999). However, such information is key to identify areas of excessive soil erosion and the main sources of sediment. The information about sediment provenance is also essential for denudation rate studies that are based on cosmogenic radionuclide (CRN) dating. CRN-based estimates of catchment-average denudation rates rely on the assumptions that a riverbed sediment sample at the basin outlet is representative of the long-term erosion rates of the basin, and that all the basin areas contribute material proportionally to their erosion rates (Von Blanckenburg, 2005).

The aim of this work is to use a physically-based and spatially-explicit modelling framework where we simulate the sediment production from localized sediment sources and track the material flux from the sources to the outlet. To do so, we combined the hydrology-sediment model Topkapi-ETH presented in Battista et al. (2020) with geomorphic mapping of potential localized sediment sources at the scale of the entire basin. This allows us to account for the periodic activation of incised areas and landslides by the combined action of hillslope runoff and river discharge (see Figure 1). Furthermore, in the presented framework the sediment mobilized from different sediment sources is routed in parallel, thus allowing us to keep track of the sediment load, its provenance and its variability in time at the outlet. We apply this modelling framework to the pre-Alpine Kleine Emme river basin (Switzerland), where we quantified the relative contribution of sedimentary material derived from localized sources and overland flow erosion to the suspended load at the basin outlet.

We found that the modelling of suspended sediment fluxes in the study basin substantially improves when localized sediment sources are considered, and that accounting for overland flow erosion only fails to explain the pattern of suspended loads of sediment at the basin outlet. We therefore introduced a parameter for the competence of gullies on landslide surfaces to produce sediment, which allowed us to simulate two extreme behaviours of the catchment: from a scenario where channel-processes dominated sediment production to a mechanism where hillslope-processes exert the strongest control. We tested these two scenarios with two independent model validations. The first one bases on the surface roughness analysis of the landslides, whereas the second validation uses observed ^{10}Be concentrations as a sediment tracer. Both validations suggest that channel processes are likely to be the dominant sediment production process in the study basin.

The modelled temporal dynamics allows to draw two main recommendations for cosmogenic sampling: (a) sampling during low flow conditions should be preferred, while sampling during and immediately after extreme events should be avoided; (b) sediment should be sampled as close as possible to the low flow channel, in order to reduce the risk of collecting high-flow deposits. Finally, we propose that the presented framework can be used to complement fingerprinting techniques, because it allows to extrapolate the measured sediment apportionment to other flow conditions, by linking it to climatic variables and hydrological conditions.

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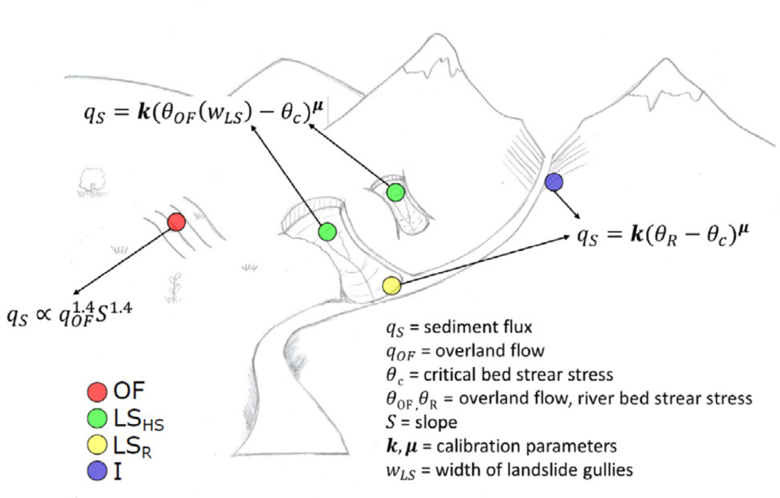

Figure 1. Schematic description of the model. Four processes can generate sediment mobilization: overland flow erosion on hillslopes (OF), overland flow erosion on the body of landslides (LS_{HS}), river flow erosion of landslide toes (LS_R) and of incised areas (I). Figure from Battista et al., 2020b.

10.3
The Tor Exhumation Approach (TEA) – Dealing with continuous and reversed exhumation patterns to determine surface denudation rates.

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Landscapes are subjected to changing environmental conditions. Yet, capturing the surface denudation variations over geological time-scales remains challenging due to the lack of suitable archives. Therefore, the Tor Exhumation Approach (TEA) was developed in recent years (Raab, 2019), unlocking a new in-situ archive with continuous surface denudation records. It uses the exhumation pattern of tors (i.e. large residual rocks) and surface exposure dating paired with numerical modelling. So far, the TEA has successfully provided continuous surface denudation histories in magmatic (granite; Raab et al., 2018, 2019) and metamorphic (schist) landscapes (Raab et al., under review).

Here a summary of the diverse results and achievements of these new investigation technique is presented. In example, rates in a granitic upland of southern Italy (Sila, Calabria) have clear exhumation pattern also in dependency of their landscape exposition. There, the variations of the surface denudation rates range about 0.06 to > 0.30 [mm $year^{-1}$] for the last 100 ka. An investigation at the meta-sedimentary Otago upland (New Zealand), revealed (Raab et al., 2018, 2019) similar exhumation and consequently surface denudation speeds in the range of about 0.02 to 0.22 [mm $year^{-1}$] over period of 200 ka (Raab et al., under review).

In addition, the process on how to deal with outliers and reversed exhumation patterns, as found at Otago, is discussed. There it is considered that some exposure patterns are the result of mushroom-like exhumation by undercutting and repeated rock breakoffs.

In summary, the applicable of the TEA in geomorphological and tectonic studies for surface evolution reconstructions from Pleistocene age and younger is disclosed.

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10.4
Surface boundary conditions for dusts emission from the agricultural lands in the Free State, South Africa

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The Free State has been identified as a dust emission hotspot, whereby the agricultural fields are expected to be the main emitters of dust. Besides the direct soil degrading effect of dust emission, the transported fines can also have detrimental effects on human health, regional and global climate, and global bio-chemical cycles. Depending on the crop type and the agricultural management, which in some cases include measures against wind erosion, a great variability in dust emissions from fields can be observed on the ground and in satellite images, even at times of constant high winds. A Swiss National Science Foundation (SNSF) and South African National Research Foundation (NRF) co-funded project tried to gain insight in the factors controlling wind erosion on these fields, as well as the relationship between these factors and the agricultural practices. We will present data from field measurements that address the erodibility on several temporal scales: from decimetre scale variation, to within field variation, to large-scale variation between fields.

Small-scale measurements were done using a Portable In-Situ Wind Erosion Laboratory (PI-SWERL), which assesses the potential PM10 emission of a surface of 30 cm diameter. These measurements were performed on different adjacent surface types that are created by agricultural activities, such as track rows, disturbed soils, and undisturbed, crusted areas. Together with the dust emission, other soil characteristics were measured, such as the surface strength, soil texture, carbon and moisture content. Gradient Boosting Machine (GBM) models were used to gain insight in the relative influence of these surface characteristics on the overall dust erodibility and spatial variability of the potential PM10 emissions. In addition, field-scale measurements were performed by monitoring the sediment flux during wind events using Big Spring Number Eight (BSNE) poles, and by measuring the threshold velocity of grain saltation.

Our data shows a juxtaposition of the factors that control the emission on these different scales. On a small scale, for example, on average areas with freshly broken up tracks emit 2.6 times more PM10 than crusted areas (1.263 mg m^{-2} s^{-1} and 0.488 mg m^{-2} s^{-1} respectively). Emission from both surface types are strongly affected by the presence of saltating sand grains which abrade the surface. However, the influence of other factos differ greatly per surface types, such as the silt and clay content that only has a protective effect on tracks. For the erosion of particles on a field scale, surface roughness appears to be of additional importance. Peanut fields are the main emitters of suspended particles. These fields have a horizontal sediment mass flux that is approximately 100 times higher than that of a harvested maize field with some stubble and straw cover.

These results indicate that the interaction between soil cohesion, abrasion by the presence of moving sand, and the surface form and cover controlling the threshold wind velocities, determines the occurrence of dust emissions in the Free State. Consequently, to predict and control the emission of dust in the Free State, all these different factors need to be integrated in modelling and management approaches.

10.5
Performance analysis of simulated vs. measured soil moisture dynamics for regional landslide early warning in Switzerland

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In mountainous regions, rainfall-triggered landslides pose a risk to people and infrastructure due to the widespread occurrence and the short time interval between activation and failure. Landslide early warning systems (LEWS) have demonstrated to be a valuable tool to inform decision makers about the imminent landslide danger and to move people or goods at risk to safety. While most existing LEWS are based on empirically derived rainfall-exceedence thresholds, recent studies have shown improvement of the forecast goodness by including in-situ soil moisture measurements.

The use of soil moisture sensor networks bears specific limitations such as the sensitivity to local conditions, data quality issues, and costly installation and maintenance, which could be overcome by the application of numerical models. However, soil moisture models are demanding both dynamic input data and details on soil, plant and atmospheric conditions to provide a realistic representation of various environments. Ultimately, this rises questions about the reliability and representativeness of simulation-based early warnings compared to using measurements.

To assess the reliability of simulation-based LEWS, a one-dimensional heat and mass transfer model (CoupModel; Jansson, 2012) was applied at 35 sites in Switzerland to calculate soil moisture during the period of 2008 to 2019. For that purpose, soil hydraulic properties were estimated using different types of pedotransfer functions. By applying a statistical framework (Wicki et al., 2020), the temporal variation of simulated soil moisture was quantified and the forecast goodness for rainfall-triggered landslides was analysed through the comparison with a national landslide database. Next, the forecast goodness was compared to a measurement-based model by applying the same statistical framework to measured soil moisture available at the same sites and time period. Finally, the model was applied to additional 120 sites without measured soil moisture (using meteorological data and estimates of soil hydraulic properties) to assess the effect of increasing the network density on landslide prediction.

First results show that (i) a similar forecast goodness is achieved for both simulation- and measurement-derived early warnings and that (ii) the forecast goodness could be increased for short distances between modelling site and landslide location if more modelled sites are included. These findings encourage the use of a combination of modelled and measured soil moisture to improve current LEWS.

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10.6
Fluvial landforms in Antoniadi crater: Evidence for two intervals of water-generating landscapes on Mars

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Studies of remotely sensed data have been used extensively to suggest that hundreds of water bodies formed under wet climate conditions that occurred on early Mars. However, theoretical climate models propose that the early climate on Mars was wet, but they also suggest that there might not have been enough water to feed and sustain large bodies of water (e.g., Haberle et al., 2015). Here, we examine fluvial landforms in one of the largest putative paleolake basins on Mars, Antoniadi (Fassett and Head, 2008), to assess the amplitude, scale, and frequency of fluvial activity using paleo-morphological reconstructions of a wide range of paleo-hydrological processes. Our reconstructions are primarily based on study of high spatial resolution images (0.25 to 6 m/pixel) from the Context Camera (CTX), High-Resolution Imaging Science Experiment (HiRISE), and Color and Stereo Surface Imaging System (CaSSIS).

Antoniadi exhibits diverse landforms that resulted from surface and subsurface processes. These landforms include valley networks, sediment fans at valley outlets, and short, stubby branched ridges (inverted paleo-stream forms). The valley networks, coupled with the fan-shaped deposits, occur in terrain on the western rim of the crate; they display well-preserved, short distance, source-to-sink fluvial systems, suggesting precipitation-fed runoff (Figure 1A). One of the fans is composed of three lobes aggraded at different elevations. These lobes might have formed as a result of changing water levels. Using crater counting, we have estimated the crater retention age of the valley networks and the fan-shaped deposits to be 3.7 ± 0.1 Ga.

In the central part of Antoniadi, a deflated surface yielded a crater retention age of 2.4 ± 0.1 Ga. This surface covers an area of 700 km^2 and hosts short, stubby drainage networks that today stand as ridges (Figure B and C). The inferred paleo-streams debouched into low-relief terrain via a 0.6 – 2 km-wide, 30-km-long trunk. The morphology of these branches supports episodic groundwater release as the primary driver of this later, second interval of fluvial activity, as they originated near a set of faults that might have served as conduits that brought the water to the Martian surface. An example site of sappping valley networks on Earth that exhibits a drainage network of similar scale and form occurs in Florida Panhandle (Figure 1 D; Schumm et al., 1995). This analog suggests that the formation of such drainage networks on Mars requires highly permeable soil, coupled with existing, abundant groundwater.

In conclusion, the modeled ages, coupled with morphological reconstruction, suggest fluvial erosion and deposition triggered by precipitation-fed runoff during the Noachian, followed by groundwater processes during early Amazonian. Once the period of fluvial activity declined, erosion inside Antoniadi was dominated by aeolian processes, which exposed paleo-stream ridges.

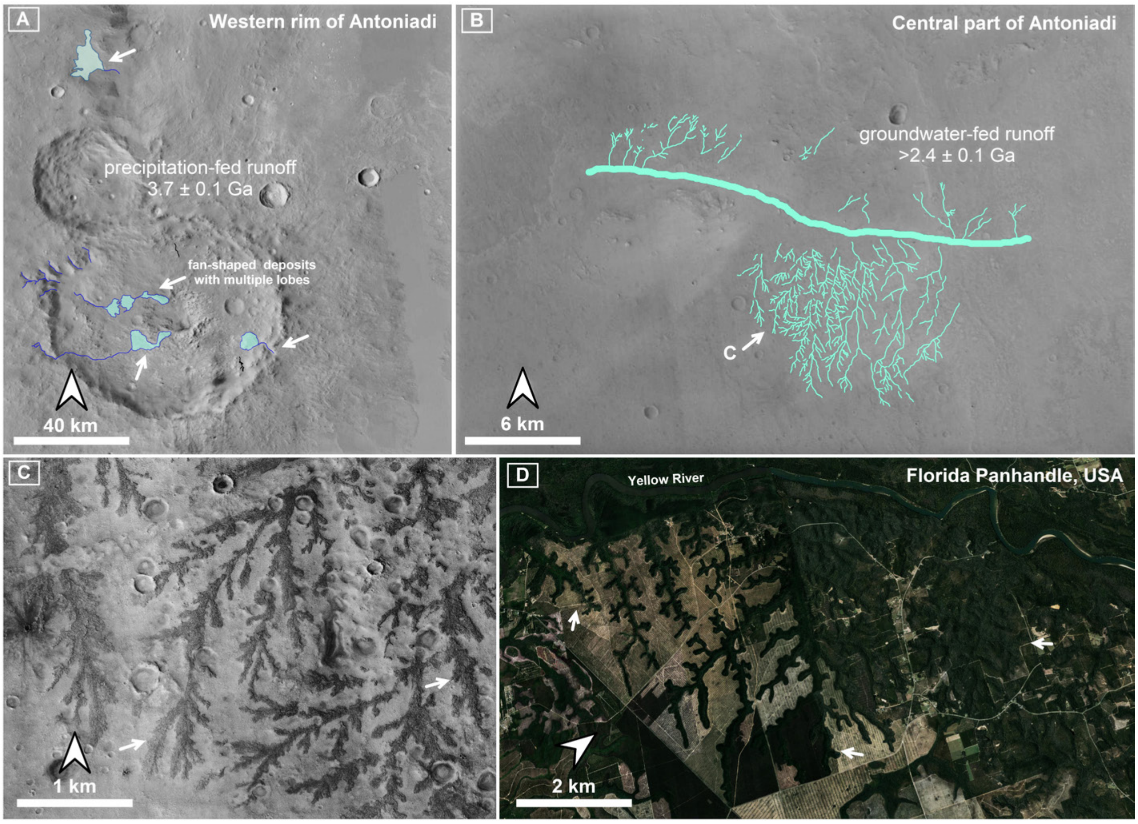

Figure 1: (A) CTX mosaic shows the distribution of the valley networks (blue) and the fan-shaped deposits (light blue) on landforms at the western rim of Antoniadi. (B) CTX mosaic showing the short, stubby, branched ridges in central Antoniadi. These ridges record former streams that drained into a main trunk that debouched into low-relief terrain. (C) HiRISE image shows a portion of the short and stubby branches (ESP_012435_2015). (D) Satellite image of a drainage network on Earth that is similar to the example in Antoniadi (image credit: Google Earth; 30°34›0.48»N, 84°51›30.48»W).

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P 10.1
Millennial scale denudation of the steep Eiger headwalls through thermo-cryogenic pre-conditioned rock fall

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Denudation of steep, alpine rockwalls is driven by rock fall processes of various sizes and magnitudes. These rockwalls are sensitive to temperature changes because thermo-cryogenic processes weaken the bedrock through fracturing, which preconditions the occurrence of rock fall. However, it is still unclear how and at which rate the fracturing of rock from cryogenic processes impacts the denudation processes operating on these steep rockwalls. Here, we present data on long-term rockwall denudation rates at the Eiger from concentrations of cosmogenic ^{36}Cl and ^{10}Be along bedrock depth profiles (Mair et al., 2019). We link these with the local bedrock fabric and the reconstructed temperature conditions at the cosmogenic nuclide study sites. We then estimate the probability of bedrock for failure (Mair et al., 2020) through the employment of a theoretical frost cracking model. Results indicate that denudation rates are low in the higher region of the NW rockwall, in contrast to both the lower part of the NW rockwall and the SE face, where rates are high, despite similar bedrock fabric conditions. Furthermore, the cosmogenic nuclide inventory allows to infer rock fall events on a small scale as main denudation agent. Additionally, the frost cracking model predicts a difference in cracking intensity from ice segregation where the inferred efficiency is low in the higher region of the NW rockwall, but relatively high in the lower section of the NW wall and on the SE rock face of the Eiger. Throughout the last millennium, temperature conditions for all studied sites have been similar to the present. These data thus suggest the occurrence of large contrasts in microclimate between the NW and SE walls of the Eiger, conditioned by locally varying insolation. These would explain the relatively low denudation rates in the upper part of the NW rockwall and the rapid denudation in the SW face and in the lower part of the NW rock face.

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