

Joint analysis of geological map units and topography to support soil survey - lessons from a case study in South Tyrol

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Abstract

Keywords:

1. Introduction

general introduction. Geologic maps have always been an important aid in soil survey as parent material is a decisive factor in soil formation (Jenny, 1941). The importance of this relationship is highlighted by the fact that, vice versa, soil maps have themselves been applied to support and improve geologic mapping (Brevik and Miller, 2015).

Geologic maps have always been an important aid in soil survey as parent material is a decisive factor in soil formation (Jenny, 1941). The importance of this relationship is highlighted by the fact that, vice versa, soil maps have themselves been applied to support and improve geologic mapping (Brevik and Miller, 2015). Providing both the physical structure and the chemical composition of the mineral constituents, parent material plays a fundamental role regarding the direction as well as speed of soil evolution. This is particularly the case in young soils (e.g. Schaetzl et al. 2000 welches paper ist das?) such as those predominantly found in the Alps (Geitner et al., 2017). Thus, in order to understand the spatial pattern of soils in the Alps, it is essential to identify the types and origins of parent materials, which are, at least in the lower and medium elevations of the Alpine environment, dominated by quaternary unconsolidated sediments. These deposits vary considerably in

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20 thickness; they are often multilayered and exposed to recent morphodynam-
 ics, all of which control soil horizon development and properties (e.g. Philips
 and Lorz 2008). In this context, it is indicated to include characteristics of
 the subsolum as often as possible, mainly in order to make soil information
 more suitable for a wide range of environmental issues, as discussed in detail
 25 by Juilleret et al. (2016). Consequently, geological maps at various scales
 have been used as an environmental variable in digital soil mapping (DSM),
 representing the soil forming factor parent material, or simply 'p'. In their
 study which presents the 'scorpan' framework of inferring soil information,
 McBratney et al. (2003) present a table of studies applying DSM, which also
 30 indicates in which of these studies the parent material was involved as an
 independent variable. How this important variable is classified, however, will
 vary greatly depending on the the available data, the soil classification sys-
 tem used, the specific mapping guidelines applied, and most importantly the
 particular geologic and geomorphologic setting of the investigated area. In
 35 its guidelines for soil description, the Food and Agriculture Organization of
 the United Nations promotes a hierarchical system for describing lithologies
 that constitute the soil parent material, based on the major classes igneous
 rock, metamorphic rock, consolidated and unconsolidated sedimentary rock
 (FAO, 2006). KA5? While the lithologies regarding bedrock as parent mate-
 40 rial are similar to the types in the classification system used by the surveyors
 employed by the Forestry service, the latter system is closely adapted to the
 Alpine environment. Specifically, the major class of unconsolidated sedimen-
 tary rocks has a far greater number of types in order to satisfy the demands
 posed by the diversity of the glacial, but also the more recent deposits, driven
 45 mainly by the high relief present in Alpine regions.

While such an adaptation of the classes and types of soil parent material
 to the given circumstances is certainly necessary, communication between
 soil scientists regarding soil parent materials and comparability is hindered
 by the multitude of classifications. Juilleret et al. (2016), who stress the im-
 50 portance of describing the subsolum in soil survey, propose a morphogenetic
 procedure for characterising and classifying subsolum material applying a
 structure similar to that of the WRB.

Herbst zitat fr bedeutung der Schrfte der Geologischen Karte fr die genauigkeit
 von DSM??

55 A number of studies have compared the information from soil surveys
 with geologic maps. HERE SOME MORE LITERATURE, like Miller and
 Lee Burras (2015), Juilleret(2012), Brevik and Miller (2015). While most of

the previously mentioned studies analyse the possibility of using soil survey information for mapping surficial geology, the aim of the presented study is to highlight those geologic units of the study area where the soil parent material cannot be simply derived from the detailed geologic map.

Situation in the Alps bezüglich boden und geologie wäre auch noch interessant

McBratney et al. (2003) list some examples of DSM studies which use geologic maps as environmental variables.

A second, immensely important soil forming factor is topography or relief. It is considered in traditional soil survey, for instance by mapping landscape position and local slope and curvature (FAO, 2006), and also DSM, where the representing variables implemented in a given model can be chosen from a wide set of available parameters. Examples of such terrain parameters can be found, amongst others, in Böhner and Antonić (2009), Gallant and Wilson (2000) and Olaya (2009). Regarding the geomorphometric characterisation of geologic or soil parent material units, a number of considerations have to be taken into account when choosing which parameter groups to investigate. While regional parameters well describe the, hydrologically relevant, relative position in the landscape, they, as well as absolute and relative height-related parameters, are strongly correlated to the underlying geological structure of a given region. Local parameters such as slope and curvature are often used to infer soil properties and give insight into local dynamics, but may also vary strongly within a map unit. To characterise parent material units, especially with regard to topographic, and as a result, soil, variability, an intermediate terrain parameter describing a unit's land surface is of particular interest. Researchers have long investigated ways to quantify the roughness or ruggedness of terrain, from the analysis of field data and topographic maps to computing roughness indices on raster grids. Geology, geomorphology as well as habitat modelling and wildlife management have been the main scientific research areas in which such investigations were performed on land surfaces. Hobson (1972) presented three different roughness values and applied them to field measurements, correlating them to rock type. In another early study aimed at quantifying roughness, Beasom et al. (1983) presented the land surface ruggedness index, which is based on the total length of contour lines per area. Similarly analysing topographic maps, Nellemann and Thomsen (1994) describe the calculation of a terrain ruggedness index based on the variability of contour lines along transects, which they correlate with caribou forage availability. Regarding field methods, they calculate microto-

pographic diversity by analysing the horizontal distance of a chain laid on the ground in their study plots. Riley et al. (1999) proposed the topographic ruggedness index (TRI), which compares the elevation of a central pixel to the elevations of cells within a given search window. In an attempt to decor-
100 relate roughness from slope, Sappington et al. (2007) expanded on the work of Hobson (1972) to introduce vector ruggedness measure (VRM), which is calculated based on the orientation of vectors normal to the surface in a given area. (Grohmann et al., 2010) analysed several roughness measures at different resolutions and window sizes with regard to their ability to depict terrain
105 features. They highlight the ability of VRM to detect fine-scale roughness features and attribute low roughness values to steep but smooth slopes, but also acknowledge its inability to delimit slope breaks and identify regional relief. The Melton ruggedness index, which relates the elevation difference of a basin to the drainage area, was applied by Marchi and Dalla Fontana
110 (2005) to investigate sediment transport, however compared to VRM it is more of a measure of general relief than roughness. Similar to VRM, roughness measures based on eigenvalue ratios of an orientation matrix have been used in geology to describe land surfaces, especially bedrock fabric. Coblenz et al. (2014) combined such a roughness measures with parameters represent-
115 ing the drainage network of the investigated geologic units to create terrain characterisation types to distinguish various lithologies, with emphasis on discriminating soft and hard rock areas.

overview of intention and aims. In a first step we analyse how well the geologic units of the high resolution geologic map correspond to the parent
120 material identified by the soil surveyor, thus evaluating the performance and reliability of geologic maps to support soil survey in South Tyrol. This requires generalisation of the geologic units into surficial geology units (SGUs) that can be compared to the parent material units used in the soil (or forestry) surveys. The result is a confusion matrix that shows to which extent geologic
125 units are in accordance with the parent material mapped by the surveyor. We highlight those units that are often confused or show overlap, and which should consequently be surveyed with greater detail and in consideration of relevant topographic information.

The next step is to perform a morphometric characterisation of the geologic units. To better understand the topographic characteristics of a
130 geologic unit, a data mining approach using random forest classification is performed. Application of a forward stepwise feature selection as well as

the analysis of the parameter 'mean decrease Gini', which quantifies the importance of a variable in the prediction procedure, we then identify which terrain parameters best separate geologic units and discuss how they can be related to and interpreted with regard to soil formation and the distribution of soil units. This data mining procedure was applied to several groups of terrain parameters. One group included all computed terrain parameters, while other groups focus either on local or regional terrain parameters, or parameters related to surface roughness. In this study, this analysis is presented only for the areawise most relevant geologic units, and the focus is on separating those units which share common borders.

The connection between the two important soil forming factors, parent material and topography, on the one hand, and soil as the result of these factors on the other, is then investigated by analysing the diversity and distribution of soils for each geologic unit. This is performed from two points of view: the soil type distribution is done for profile sites per geologic unit, but also per parent material unit as attributed by the soil surveyor. This gives insight into how the surveyors' soil landscape model relates specific parent material units to specific soil types, especially when applying a morphologic-genetic classification such as the Austrian soil classification (Nestroy et al., 2011). The synthesis of this information then leads to a geologic-topographic characterisation (GTC) that describes each geologic unit.

The objective of this study is to evaluate how to make best use of available geologic and topographic information for soils survey. Hence each geologic unit is characterised with regard to topography and soil and we highlight those units where there is often dissent between soil parent material as mapped by the soil surveyor and the geologic units mapped by geologists.

2. Material and Methods

2.1. Study area and data

General description. The study area includes the wide vale of Eppan-Kalern, the Überetsch, located just south-west of Bozen in the Autonomous Province of Bolzano - South Tyrol, and extends in the north to the debris fan of Andrian in the Etsch Valley and the adjacent hillslope on the orographic right of the Etsch River. The western border of the study area is the steep slope of the Mendola-Roèn-Ridge, whereas the eastern border of the Überetsch as well as the study area is represented by the Mitterberg, a ridge of Permian Vulcanites from which steep slopes descend to the Etsch Valley (approx.

200 m a.s.l.). The Kalterer Lake represents the southern limits of the investi-
gated area. The land use of the paleovalley and its debris cones as well as the
170 Etsch valley is dominantly apple orchards and vineyards, whereas the slope
of the Mendola-Roèn-Ridge and the hilly outcrops of Vulcanites are covered
by forests. Pastures are located mainly on till covering the flat areas of the
Mendola-Roèn-Ridge.

175 2.1.1. *Surficial Geology*

A detailed description of the geologic situation can be found in the com-
mentary to the new geologic map of Eppan (Avanzini et al., 2006). The
paleovalley of Überetsch is described by Scholz et al. (2005) as a complex
system of gravelly lateral moraines and large kame terraces, the result if the
180 'Kalterner lobe', a Pleniglacial tongue of the Etsch valley glacier. Additionally,
eroded remainders of debris flows that were deposited against the recessing
glacier can be found along the slopes of the Mendola-Roèn-Ridge, as well as
recent debris flow deposits, often composed of mainly limestone and dolomite
fragment. The vale bottom itself is filled with Pleistocene sediments and con-
185 tains a number of valleys carved into the gravels by fossil meltwater. At the
eastern and western borders of the Pleistocene sediments, outcrops of Per-
mic igneous Rhyolite and Lapilli-Tuff are responsible for a hilly relief, most
prominently at the eastern border of the study area where the Überetsch is
separated from the Etsch valley by a steep slope down from the Mitterberg
190 with an elevation difference of approximately 400 m. The steep slopes of the
Mendola-Roèn-Ridge are dominated by various Dolomite units, with inter-
mittent layers of sand and siltstones. Except for the very steep Dolomite
walls of the ridge, the rarely occurring outcrops of these formations are sur-
rounded and mostly covered by Pleistocene and Holocene slope debris, and
195 in locally flatter areas by till.

The study area comprises two map sheets of the new geologic map of Italy,
sheet Eppan, which covers the northern and major part of the area, as well as
sheet Mezzo-Lombardo in the southern part. The sheets were published at a
scale of 1 : 50,000 in 2007 and 2012, respectively. Mapping was performed at a
200 scale of 1 : 10,000, this information was kindly provided by the Department of
Geology and Building Material Tests of the Autonomous Province Bolzano,
South Tyrol, in shapefile format and used for the analysis performed in this
study.

As means for simplification of the analysis and data harmonisation, the
205 geologic map units were generalised to the 16 SGUs described in Table 1, that

allow for comparison with the parent material units described and identified by the soil surveyors in the field.

| SGU | Abbrev. | short description | % area |
|---------------------------------|---------|-----------------------------------------------------------------|--------|
| alluvial deposits | AD | Holocene and Pleistocene deposits of silt, sand and gravels | 14.9 |
| coarse blocky debris | CBD | Holocene and Pleistocene blocky deposits of mass movements | 1.8 |
| colluvial deposits | CD | footslope deposits | 2.4 |
| calcareous sedimentary rock | CSR | limestones and dolomites | 8.4 |
| debris cones | DC | Holocene conic deposits from debris flows and torrents | 12.7 |
| glacio- and lacustrine deposits | GLD | (fine) sand deposits (with dropstones) | 2.5 |
| ice-marginal sediments | IMS | clast-supported gravels | 0.2 |
| intermediate sedimentary rock | ISR | silt- and sandstones | 0.2 |
| landslide deposits | LD | large landslide deposits | 1.2 |
| mire deposits | MrD | Holocene and Pleistocene silt and peat deposits | 3.3 |
| mixed deposits | MxD | Pleistocene deposits from debris flows, torrents and avalanches | 2.1 |
| siliceous bedrock | SB | rhyolite and rhyodazite tuffs and ignimbrites | 13.0 |
| slope debris | SD | Holocene and Pleistocene debris on slopes | 10.3 |
| siliceous sedimentary rock | SSR | sandstones and siltstones | 1.1 |
| till in general | TG | undifferentiated glacial sediment | 25.9 |

Table 1: Table of the generalised parent material geounits with abbreviations and short description. Additionally, the proportion of the study area covered by each geounit is given. Anthropogene deposits and water bodies are not included in the analysis.

2.1.2. Soils

soil classification. The soil classification scheme applied in this study is the Austrian system (Nestroy et al., 2011), as most of the soil profile descriptions available for this study apply this system and it is generally recommendable to use local systems for large-scale mapping. Additionally, not all available soil profile data, especially those from points investigated only with augering, included sufficient information for deriving the reference soil group according to the World Reference Base for soil resources (IUSS Working Group WRB, 2015). Table 2 gives an overview of which reference soil groups are correlated to the relevant soil types in the Austrian classification. Classification of the soil profiles was performed at the subtype level, a basic overview of the Austrian soil classification system can be found in Baruck et al. (2016).

data base 1: soil survey of agricultural areas in the Überetsch/Oltradige region. From 1993-1995 a soil survey of the farmlands in the region Überetsch was conducted (Thalheimer, 2006). Soil types were classified according to Soil Taxonomy, resulting in a soil map with 18 different soil series. 58 detailed soil pit descriptions were incorporated into the presented study, all located either in vineyards or apple orchards. Using the horizon descriptions, chemical properties as well as photographs of the pit face, theses soil profiles were reclassified applying the Austrian System.

230 *data base 2: soil survey 'ReBo - Terrain Classification of ALS Data to support Digital Soil Mapping'.* During this project which was funded by the Autonomous Province Bolzano - South Tyrol and had the aim to investigate optimal cooperation between soil survey and terrain classification, 55 soil pit profiles were described in the presented studies area of interest. Soil classification was performed following Kilian (2015).

235 *data base 3: data base of the Forestry Service of the Autonomous Province Bolzano - South Tyrol.* 42 pit descriptions from the Forestry Service data set

data base 4. 227 auger observations (WLM)

| soil type | possible WRB group | short description | soil class |
|-----------------------|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------|--------------------------|
| Grobmaterial-Rohboden | Leptosol, Regosol, Histosol | same as Feinmaterial-Rohboden but with more than 40 V.-% coarse fraction | Terrestrische Rohböden |
| Feinmaterial-Rohboden | Leptosol, Regosol, Histosol, Arenosol | only initial soil formation (Ai horizon) on parent material with less than 40 V.-% coarse fraction. | Terrestrische Rohböden |
| Rendzina | Leptosols, Histosols | with organic horizon on calcareous bedrock. | Terrestrische Humusböden |
| Kalklehm-Rendzina | Leptosol | soils with a loamy organic horizon on calcareous bedrock. | Terrestrische Humusböden |
| Pararendzina | Leptosol, Regosol, Umbrisol, Histosol | with organic horizon on carbonatic siliceous bedrock. | Terrestrische Humusböden |
| Ranker | Leptosol, Umbrisol, Regosol | with organic horizon on siliceous bedrock. | Terrestrische Humusböden |
| Braunerde | Cambisol, Fluvisol, Luvisol, Umbrisol, Regosol | with brown B-horizon owing to weathering and re-formation of clay minerals. | Braunerden |
| Parabraunerde | Luvisol, Albiluvisol, Cambisol | with eluvial horizon over clay-enriched B-horizon. | Braunerden |
| Semipodsol | Podzol, Regosol | characterized by moderate podzolization. | Podsole |
| Kalkbraunlehm | Cambisol, Luvisol | with a yellow- to redbrown cohesive B-horizon on calcareous bedrock, often fossil soils. | Kalklehme |
| Farb-Substratboden | Regosol, Alisol, Ferralsol, Luvisol, Nitisol, Arenosol | strong influence of color of parent material, overprinting horizon differentiation. | Substratböden |
| Textur-Substratboden | Regosol, Arenosol, Vertisol | strong influence of texture of parent material, overprinting horizon differentiation. | Substratböden |
| Kolluvisol | Anthrosol | developed from fine soil material relocated by (often human-induced) erosion. | Umgelagerte Böden |
| Rigolboden | Anthrosol | influenced by deep, homogenizing human cultivation. | Umgelagerte Böden |
| Haftnsse-Pseudogley | Stagnosol, Planosol | influenced by shallow, capillary stagnation phases. | Pseudogleye |

Table 2: Table relating the Austrian soil types to WRB reference groups along with a simplified description, based on Kilian (2015).

Overview of soils in study area.

2.1.3. Digital elevation data

2.2. Methods

240 2.2.1. *Terrain parameters with emphasis on roughness measures*
(Riley et al., 1999)

2.2.2. Random Forest classification

random sampling of points for terrain analysis.

245 Considering the confusion matrices and the accuracy measures calculated,
this was performed as if the field observations described by the surveyors had
been planned to validate the use of the geologic map as a map of soil parent
material.

3. Results and discussion

3.1. Comparison of soil parent material at soil profile sites with geologic map units

The overall accuracy, or correct classification rate of this comparison is 49%.

| | AD | CBD | CD | CSR | DC | GLD | IMS | ISR | LD | MrD | MxD | SB | SD | SSR | TG |
|-----|----|-----|----|-----|----|-----|-----|-----|----|-----|-----|----|----|-----|----|
| AD | 7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 |
| CBD | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 2 |
| CD | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| CSR | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 7 | 0 | 0 | 1 | 0 | 13 | 0 | 12 |
| DC | 4 | 0 | 3 | 0 | 5 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 20 | 0 | 2 |
| GLD | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| IMS | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ISR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| LD | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| MrD | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| MxD | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 1 |
| SB | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 2 | 14 | 3 | 1 | 24 |
| SD | 0 | 3 | 0 | 2 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 55 | 0 | 15 |
| SSR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 3 | 3 | 1 |
| TG | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 3 | 0 | 1 | 5 | 0 | 9 | 0 | 88 |

Table 3: Tabular comparison of parent material geounits as observed by soil surveyor (columns) and in the geologic map (rows).

3.2. Random forest classification of SGUs based on topography

A random forest classifier was trained on 100 random points per SGU and then applied to predict the membership of 200 different randomly selected points per unit. A stepwise forward feature selection procedure with all available terrain parameters except for absolute heights showed that after 7 parameters were selected, additional parameters did not significantly improve the correct classification rate of 75 %. The terrain derivatives selected by the random forest classifier are channel network base level, which on its own correctly predicts 66 % of the SGUs of the validation points, and slope, Texture, catchment area, VerticalDistanceToChannelNetwork and convexity, as well as the channel network base level calculated at a coarser resolution.

As was to be expected due to the geological structure of the research area,
 265 terrain parameters based on relative elevations, as well as regional terrain pa-
 rameters such as catchment area can well distinguish between some SGUs.
 An investigation based on applying only local terrain parameters in the ran-
 dom forest classification showed that the parameters profile, cross-sectional
 and total curvature, together with convexity as well as slope computed at
 270 two different window sizes, lead to a correct classification rate of 49 %. Using
 only the terrain parameters related to surface roughness, a correct classifi-
 cation rate of only 45 % was achieved with a combination of the predictor
 variables TRI (res=2.5 m, ws=60 m), texture at two grid cell sizes(res=50 m
 and 2.5 m?) as well as VRM and vector strength based on the 2.5 m DTM
 275 and a window size of approx. 150 m. The importance measures of a classi-
 fication using all available roughness measures also highlight the Texture at
 50 m grid cell size and a neighborhood of 10 cells to be the most influential
 variable, followed by the TRI at various search windows.

| | CBD | CD | CSR | DC | GLD | IMS | ISR | LD | MrD | MxD | SB | SD | SSR | TG |
|-----|-----|------|-----|------|------|-----|-----|-----|------|------|------|-------|-----|------|
| AD | 0.2 | 21.1 | 0.0 | 23.6 | 14.8 | 2.5 | 0.0 | 1.2 | 22.2 | 10.9 | 5.7 | 12.7 | 0.2 | 45.2 |
| CBD | | 0.5 | 6.1 | 8.5 | 0.0 | 0.0 | 1.1 | 0.9 | 0.5 | 1.5 | 10.1 | 9.7 | 0.9 | 9.1 |
| CD | | | 1.3 | 17.6 | 10.7 | 2.8 | 0.0 | 0.6 | 0.7 | 10.0 | 5.8 | 4.0 | 0.0 | 31.1 |
| CSR | | | | 11.8 | 0.0 | 0.0 | 5.5 | 0.8 | 0.0 | 1.3 | 0.6 | 40.7 | 5.0 | 23.1 |
| DC | | | | | 2.5 | 0.6 | 0.7 | 2.4 | 5.9 | 17.4 | 9.3 | 25.6 | 1.6 | 40.6 |
| GLD | | | | | | 2.2 | 0.0 | 0.2 | 0.8 | 3.4 | 0.4 | 0.5 | 0.0 | 7 |
| IMS | | | | | | | 0.0 | 0.0 | 0.0 | 0.6 | 0.7 | 0.4 | 0.0 | 1.1 |
| ISR | | | | | | | | 0.2 | 0.0 | 0.0 | 0.0 | 4.3 | 0.0 | 0.4 |
| LD | | | | | | | | | 0.0 | 0.1 | 1.4 | 3.7 | 0.5 | 4.2 |
| MrD | | | | | | | | | | 0.2 | 1.2 | 0.6 | 0.0 | 1.9 |
| MxD | | | | | | | | | | | 2.7 | 2.7 | 0.1 | 19.5 |
| SB | | | | | | | | | | | | 109.3 | 4.4 | 67.4 |
| SD | | | | | | | | | | | | | 8.3 | 50.4 |
| SSR | | | | | | | | | | | | | | 5.5 |

Table 4: Length in kilometers of the borders of adjacent SGUs

3.3. Geologic-topographic characterisation of the predominant SGUs

280 Through synthesis of results of the comparison of the soil point data
 and the geologic map, the random forest analysis of terrain parameters as
 well as the distribution of soil types in the study area, a geologic-topographic

characterisation of the SGUs is performed. Only those units with substantial areal extent and sufficient soil profile points are described in detail.

285 *3.3.1. Alluvial deposits*

The SGU alluvial deposits occupies 16.3 km, amounting to 14.9 % of the study area. It incorporates alluvial deposits in the paleovalley but also in the Etsch valley, with to soil profile points limited to the former. The alluvial deposits share very long borders with the SGUs till in general, debris
290 cones, mire deposits and colluvial deposits, due to its bifurcated vertical transection of the study area. Long borders can therefore also be found with the units glaciolacustrine deposits, mixed deposits, slope debris and till in general. There is agreement between the geological map and the soil profile description in 7 (54%) of the 13 profiles for which the soil surveyors identified
295 this SGU as the soil parent material. Some confusion with the SGUs debris cones and till in general can be observed, the former from the viewpoint of producer's reliability and the latter as an error of commission.

When attempting to characterise and predict the SGUs based on the 7 best terrain parameters, the SGUs with which the most confusion occurs are
300 mire deposits, colluvial deposits, debris cones and to a lesser degree till in general, which all have common borders with the alluvial deposits. Most other SGUs can be separated from alluvial deposits based on relative elevation measures such as channel network base level or catchment area. Applying only local terrain parameters to distinguish alluvial from colluvial deposits, the
305 random forest classifier identifies slope computed at a window size of 27.5 m as the most adequate predictor variable due to the slightly steeper slopes of the latter unit, leading to to correct identification in 71 % of the sample points, performing better than regional parameters such as catchment slope or LS factor (approx. 65 %) or vector ruggedness from group of roughness-
310 related terrain parameters. Separating alluvial from mire deposits showed similar results, though a combination of slope and maximum curvature is able to correctly identify 83 % of the sample points when only analysing these two SGUs, as mire deposits are found in flatter regions with slightly smaller curvature values. Regarding roughness measures, a combination of
315 TRI, VRM and texture performs slightly better with a correct classification rate of 75 % of the points, compared to 67 % when distinguishing between alluvial and colluvial deposits with a combination of three roughness measures. Profile curvature and the closely related parameter convexity are determined to be the local terrain parameter than best characterises the difference be-

320 tween the topography of the SGUs alluvial deposits and till. (Hier muss noch
an der Analyse gearbeitet werden da bisher Grundmoräne getrennt betrachtet
wurde)

Of the 11 soil profile or auger points located on areas covered by alluvial
deposits according to the reclassified geological map, the soil type Braunerde
325 is predominant, with some occasional anthrosols. These brown soils are to be
expected as the more or less pronounced stability of the flat alluvial deposits
have allowed a certain degree of pedogenetic processes to occur. The Rigosols
on the other hand are typical for the vineyards and orchards commonly found
on alluvial deposits in the region, where landscape as well as soil have seen
330 strong anthropogenic influence. The distribution of the soil types of the
profile points identified to have alluvial deposits as parent material by the
surveyors is comparable regarding the dominance of brown soils. Addition-
ally, the soil types Kalklehm-Rendzina and Pararendzina were encountered,
both characterised by organic horizons on more or less unweathered parent
335 material, indicating that alluvial deposits were also identified at places lack-
ing the stable conditions necessary for the development of a B-horizon as
presented by the alluvial deposits unit of the geological map. It must how-
ever be considered that the SGU in the study area also incorporates parts
of the wide Etsch valley floor, whereas the soil profile points are mostly sit-
340 uated in the paleovalley of the Überetsch. So while the alluvial deposits
unit is characterised by the lowest mean slope aside from mire deposits, it is
nevertheless necessary for future surveys to also investigate the less typical,
more sloping areas at the border or in proximity of alluvial deposit units.

3.3.2. *Siliceous bedrock*

345 The SGU siliceous bedrock in the study area is characterised by outcrops
of rhyolitic ignimbrite in the Überetsch paleovalley, for instance forming the
Mitterberg which separates the paleovalley from the current Etsch valley. It
represents 13 % of the study area, and shares a long border with the SGU till
in general, but also the units coarse blocky debris and debris cones. Shorter
350 borders exist with almost all other SGU, especially mixed deposits and slope
deposits. Regarding the comparison of the unit on the geological map with
the parent material as reported by the surveyors, there is an interesting
discrepancy between user's accuracy and producer's reliability when at-
tempting the use of the geological map as a parent material map. While the
355 parent material of only 14 of the 49 profile sites located on siliceous bedrock
according to the geological map was identified as siliceous bedrock by the

360 surveyors, 70 % of all soil pits with this parent material were actually on the
 correct unit of the geological map. This means that when investigating soils
 on siliceous bedrock, the probability that they are encountered in the unit
 SB is higher than for other units, however it is similarly probable to encounter
 other parent materials in this unit. The greatest confusion occurred with the
 unit till in general, which was found to be the parent material of almost ev-
 ery second soil profile located on the SGU siliceous bedrock. Further parent
 materials identified on the SB unit include mixed and slope deposits, as well
 365 as glaciolacustrine deposits (Table 3). Confusion with slope debris or mixed
 deposits is understandable due to the often fuzzy transition from weathered
 bedrock to slope debris, or the fact that mixed deposits may very well con-
 tain almost only siliceous material from bedrock units at higher elevations in
 the catchment or underneath the debris cover layer. Additionally, the soils
 370 resulting from such parent material must not necessarily be very different to
 that on siliceous bedrock. Till, as a parent material, is a different case, as the
 material may be derived from catchments with a very different geology and
 the grain distribution is not comparable to that of slope debris or siliceous
 bedrock. When evaluating the misclassification of the parent materials till
 375 and siliceous bedrock, it is essential to consider different mapping procedures.
 Furthermore, the parent material layer must not necessarily be very thick.
 So, whereas the soil surveyor is particularly interested in the parent material,
 i.e. the material which through pedogenic processes and weathering slowly
 becomes the solum, no matter the thickness of this specific layer, the geolo-
 380 gist's main concern is the underlying material, and may consider cover layers
 of till only once their thickness reaches a certain threshold, for instance 1 m
 as conveyed by the surveyors of the geologic survey of South Tyrol. Given the
 strong confusion with till in general, as well as the fact that these two units
 share a long border, it is of interest to examine the topographical differences
 385 these units on the geological map. When modeling the distribution of SGUs
 in the study area based on the mentioned 7 terrain parameters, the siliceous
 bedrock unit

3.3.3. *Till in general*

390 The unit till in general comprises lodgement and subglacial till, as well
 as other, undifferentiated till materials. It is found in the paleovalley as well
 as on flat terraces of the Mendola-Roèn-Ridge. Covering more than 25
 % of the study area, it is the most common SGU on the geological map,
 sharing borders with every single SGU, the longest, each with a length of at

least 30 km, being those with the SGUs alluvial deposits, colluvial deposits,
395 debris cones, siliceous bedrock and slope deposits. According to the geologic
map, 109 of the soil data points are located on the SGU till in general,
accounting for 29% of the points. In 88 of these locations, the surveyors
agreed with regard to the parent material being till, leading to a user's
accuracy of 80%. The majority of the other soil data points on this SGU were
400 attributed the parent materials slope deposits or mixed deposits, with some
intermediary sedimentary rocks also identified as parent material. While the
user's accuracy for till is the best amongst the SGUs, the producer's reliability
is not comparable, as the surveyors also identified till as the parent material
at 63 further locations on different SGUs. The relative majority of these
405 locations are found on the unit siliceous bedrock, already discussed above,
but a large number of soil profiles with this parent material were also located
on the units calcareous sedimentary rock and slope debris. Furthermore, till
was identified as the parent material of soils on the units SSR, MxD, MrD,
GLD, DC, CBD and AD. An important takeaway point from these results
410 is that, at least in this study area, while the SGU unit till in general is a
good indicator for where to reliably encounter soils evolved from till, it is of
great importance to expect this parent material also on various other SGUs.
Terrain analysis

3.3.4. *Slope debris*

415 Slope debris, as a SGU of the geologic map, occupies 10% of the study
area. Its by far longest border is shared with the unit siliceous bedrock,
other important borders are with the units till in general, calcareous sedi-
mentary rock and debris cones, the first three units greatly influencing the
distribution of components in the slope debris units. When comparing the
420 parent material of soil profile sites with the SGUs, the slope debris unit
has slightly better user's accuracy than producer's reliability, as surveyors
established slope debris as the parent material of 55 of the 84 profile points
on this SGU, but also for 69 soil data points on other SGUs. Similar to the
SGU siliceous bedrock, the most confusion regarding parent material on the
425 SGU slope debris occurred with the unit till in general, which was identified
at 15 soil profiles. As is the case with the SB unit, some of this confusion may
be attributed to thin layers or punctual deposits of till. Considering slope
debris, another important aspect is that the debris in question may very well
be composed of till material that has been transported gravitationally. The
430 same explanations may hold for other parent materials which were identified

on the slope debris unit, especially for the bedrock units SB, ISR and CSR. While some isolated outcrops are possible, the most likely cause is that the constituents of the slope debris are so dominated by transported material of one of these bedrock classes, that the surveyors determine this unit as the parent material of the examined soil profile. On the other hand, misclassifications between the units coarse blocky debris and slope deposits can be attributed to the fuzzy border between these units, ultimately linked to the grain size distribution, and the subjective interpretation thereof. Contrary to most other SGUs (with the exception of CBD, LD and MxD), this unit itself does not provide information regarding the mineralogy of its component, which can only partially be derived through interpretation of its location in the catchment and the uphill geologic situation. Consequently, this unit is much better described by its topography than its material, as the latter may be highly diverse.

3.3.5. *Calcareous sedimentary rock*

The calcareous sedimentary rocks in the study area are predominantly responsible for the steep walls of the upper elevations of the Mendola-Roèn-Ridge (Dolomite and limestone), but also represent some thin layers in lower parts of that slope, interchanging with intermediate and siliceous sedimentary rock layers. Despite covering only 8.4% of the area, it has long borders due to its layers that span from north to south of the study area. Debris slope units often occupy locations downslope of the CSR units, accounting for the long border length of 40 km with this unit. The confusion matrix representing the comparison of the parent material as indicated by the geologic map and the parent material identified in field survey (Table 3) shows

Due to its intermittent layering with ISR, is not surprising that this unit was found to be the parent material for 7 investigated soil profiles in the calcareous sedimentary rock unit.

As a consequence, the most misclassification occurs with the slope deposit unit. The fuzzy border between weathered bedrock and slope debris is a major issue also for this SGU.

3.3.6. *Debris cones*

3.3.7. *Intermediate sedimentary rock and siliceous sedimentary rock*

3.3.8. *MxD, LD, CD*

465 3.3.9. *GLD, IMS, MrD*

3.4. *Differences between geologic survey and parent material from profile site descriptions*

3.4.1. *Differences with regard to mapping purpose*

Between the two different frameworks of mapping, geology on the one
470 hand and soil on the other, it is important to acknowledge the main focus
of attention of each branch of research. There may exist a difference with
regard to how pronounced a certain feature or characteristic must be in
order to be considered for mapping. Miller and Lee Burras (2015) note that
the resulting maps of the two sciences try to communicate different aspects.
475 While geology refers to geologic materials and general landform regions, soil
science is concerned more with soil properties with regard to land use and
management decisions.

A typical example is the unit landslide debris, which seems only of interest
to the mappers with focus on geology, whereas the soil surveyor...

480 Regarding glacial deposits, the soil or forestry surveyors seldom differen-
tiated between lodgement till and other glacial deposits, only when an deci-
sively higher clay content was determined. On the other hand, the chemical
properties, especially with regard to acidic properties of the tillic material
are of much more interest to the soil surveyors who further differentiate till
485 with regard to this aspect. The geologic map on the other hand also con-
tains information with regard to the age and the geologic system(synthem)
to which certain moraines belong, whereas this is only of interest to the soil
surveyor if it features additional information with regard to the mineralogic
content of the different constituents of the moraine.

490 Geologist only map regolith cover layers thicker than approximately 1 m.

3.4.2. *Nomenclatural differences and overlapping classes*

Congalton

3.5. *Pedologic interpretation of terrain parameters that best separate the ge-
ological units*

495 Do the points surveyed as moraine have different terrain parameters from
those mapped as moraine on the geologic map.

3.6. *Distribution of soil types with regard to geologic unit as well as parent material unit*

3.7. *Influence of the Alpine environment on interpretability of geologic units as parent material units*

Heung et al. (2014) note that while traditional geologic maps focusing on bed rock are a valuable input for DSM when the residual materials form the soil parent material, but less so in areas distinguished by glaciation and high geomorphodynamics. Similarly, in their comparison of surficial geology maps derived from Soil Survey maps on the one hand and the Geologic Survey on the other, Miller and Lee Burras (2015) point out that the level of agreement was lower for areas with complicated geologic histories.

3.7.1. *High relief areas and multilayering*

Are there thresholds regarding terrain parameters?

3.7.2. *thin cover layers of till - an essential new parent material unit?*

Why is important to differentiate till and slope debris? While there may exist situations where the slope debris is composed of till material, the general difference is that soils from slope debris can be understood with knowledge of local geology and that they may not be so different from soils higher up in the catchment that evolved from bedrock, whereas till can consist of chemically very different components.

3.7.3. *Is the morphodynamic background of deposits a necessary distinctive attribute from a pedological point of view?*

In the study area, mixed deposits from mass movement and torrents have the same components as till or hillside debris, which themselves are often the same...

4. Conclusion

We propose that future surveys focus increasingly on these units with greater uncertainty with regard to soil parent material to strengthen understanding of the pedologic relevance of these units. By performing a GTC prior to future detailed field soil surveys, the surveyor can make best use of available information and concentrate the time and money consuming task of field work, involving soil pits and auguring, on units identified as highly variable and uncertain regarding soils. This information can be additionally

530 helpful for devising future sampling procedures and also for consideration
when attempting to regionalise point information.

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