

# Joint analysis of geological map units and topography to support soil survey - lessons from a case study in South Tyrol OR From geological to soil parent material maps - a random forest-supported analysis of geological map units and topography in South Tyrol

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## Abstract

*Keywords:*

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## 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)) 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

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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 thickness; they are often multi-layered and exposed to recent morphodynamics, 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 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 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 system used, the specific mapping guidelines applied, and most importantly the particular geologic and geomorphological setting of the investigated area. In 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 material 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 sedimentary 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 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 importance 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  
60 to highlight those geologic units of the study area where the soil parent ma-  
terial cannot be simply derived from the detailed geologic map. McBratney  
et al. (2003) list some examples of DSM studies which use geologic maps as  
environmental variables.

Situation in the Alps bezüglich boden und geologie wäre auch noch in-  
65 teressant

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  
70 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.  
75 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  
80 vary strongly within a map unit. To characterise parent material units,  
especially with regard to topographic, and as a result, soil, variability, an in-  
termediate 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  
85 to computing roughness indices on raster grids. Geology, geomorphology as  
well as habitat modelling and wildlife management have been the main sci-  
entific research areas in which such investigations were performed on land  
surfaces. Hobson (1972) presented three different roughness values and ap-  
plied them to field measurements, correlating them to rock type. In another  
90 early study aimed at quantifying roughness, Beasom et al. (1983) presented  
the land surface ruggedness index, which is based on the total length of con-  
tour lines per area. Similarly analysing topographic maps, Nellesmann 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 microtopographic 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 decorrelate 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 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 (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 representing 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.

*Intention and aims.* The objective of this study is to evaluate how to make best use of available geologic and topographic information (with emphasis on terrain roughness measures) for soils survey. By applying random forest classification and feature selection, we investigate which terrain parameters, with emphasis on roughness measures, are best suited to produce a parent material map based on an available geological maps as well as topography. Additionally, the same method is applied to distinguish terrain parameters that, for each soil parent material class, best separate those profile site points that are correctly classified in the geological map from those of the same class that are misclassified. Based on this analysis and a similar investigation into characteristic terrain parameters of the geological map units, each of these is characterised with regard to topography and soil and we highlight those

130 units were there is often dissent between soil parent material as mapped by  
the soil surveyor and the geologic units mapped by geologists. The main aim  
of the random forest classification is not necessarily to improve the geological  
map with regard to its application as a parent material map, but foremost to  
135 identify the topographic characteristics of the parent material units in order  
to facilitate future, more detailed surveys.

## 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  
140 of Bolzano - South Tyrol, and extends in the north to the debris fan of An-  
drian 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 the Mitterberg, a ridge of Per-  
145 mic 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  
Etsch valley is dominantly apple orchards and vineyards, whereas the slope  
of the Mendola-Roèn-Ridge and the hilly outcrops of Vulcanites are covered  
150 by forests. Pastures are located mainly on till covering the flat areas of the  
Mendola-Roèn-Ridge.

#### 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  
155 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  
'Kalern 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  
160 recent debris flow deposits, often composed of mainly limestone and dolomite  
fragment. The vale bottom itself is filled with Pleistocene sediments and con-  
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

165 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  
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  
170 walls of the ridge, the rarely occurring outcrops of these formations are sur-  
rounded and mostly covered by Pleistocene and Holocene slope debris, and  
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  
175 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  
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  
180 study.

As means for simplification of the analysis and data harmonisation, the  
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.

185 *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  
190 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  
195 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  
200 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.

205 *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  
210 classification was performed following Kilian (2015).

*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)

*Overview of soils in study area.*

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, Regosol, Umbrisol	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).

### 2.1.3. Digital elevation data

## 2.2. Methods

### 2.2.1. General workflow

In a first step we analyse how well the geologic units of the high resolution geologic map correspond to the parent 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 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 geological units. To better understand the topographic characteristics of a geologic unit, a data mining approach using random forest classification is performed. By applying a forward stepwise feature selection as well as the



analysis of the parameter 'mean decrease accuracy', which quantifies the importance of a variable in the prediction procedure, we then identify which terrain parameters best separate parent materials units as well as geological map 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. An emphasis is set on the roughness measures, as they are deemed best suited to enhance the geologic map, as the geological units already implicitly contain information with regard to regional and local terrain parameters. 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.

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

### *2.2.3. Random Forest classification*

Random Forest classifications was performed for several applications in the course of this study:

- To expand the geological map to a parent material map by model parent material based on the profile site descriptions, the topography of their location and the information provided by the new geologic map with its detailed information with regard to surficial geology

- To investigate which terrain parameters are best suited to discriminate for each SGU those points that were correctly classified to a parent material class by the geological map from those where this information differed to the parent material identified by the field surveyors.
- To analyze which terrain parameters best distinguish between adjacent soil parent material classes as identified by the soil surveyors during field survey
- To identify the terrain parameters that best separate and consequently characterise the SGUs as described by the geological map

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.

We can use the information on the confusion between certain classes implicitly contained in the sample point data, as well as the relative height information contained in the geologic map units. Consequently, roughness measure are sufficient to improve the parent material map.

### 3. Results and discussion

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

A comparison of the soil parent material class identified in the field survey and the SGU from the geological map for the same position shows that while these match for 186 of the profile sites, leading to an overall accuracy, or correct classification rate, of 49%, there is a high number of misclassifications. A first view at the confusion matrix (Table 3) indicates that a considerable amount of these misclassifications involve the classes till and slope deposits.

	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 parent material based on geologic map data and topography

Regional-scale terrain parameters and relative elevations were not identified as important predictor variables. One reason for this is that this information is implicitly accounted for by the geologic map, as the various SGU classes are also closely linked to certain relative elevations, especially the

300 vertical distance to channel base level, due to overall geologic structure of the  
study area. Roughness: TRI can be strongly related to slope.

### 3.3. *Geologic-topographic characterisation of the predominant SGUs*

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  
305 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.

#### 3.3.1. *Alluvial deposits*

The SGU alluvial deposits occupies 16.3 km, amounting to 14.9 % of  
310 the study area. It incorporates alluvial deposits in the paleovalley but also  
in the Etsch valley, with soil profile points limited to the former. The  
alluvial deposits share very long borders with the SGUs till in general, debris  
cones, mire deposits and colluvial deposits, due to its bifurcated vertical  
transection of the study area. Long borders can therefore also be found with  
315 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  
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  
320 producer's reliability and the latter as an error of commission.

An investigation of the soil profile sites that were identified by surveyors  
as having alluvial deposits as parent material but are located on a differ-  
ent unit on the geological map, shows that these are characterized by con-  
sistently higher fischer k values, whereas slope shows less clear thresholds.  
325 Addressing the confusion of alluvial deposits with till, the random forest in-  
vestigation shows the besides obvious channel-level related terrain parameters,  
which well separate the units, convexity contributes strongly to distinguish-  
ing between alluvial deposits and till on the geologic map, with the former  
characterised by lower values concentrating around 0.42. It must however  
330 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 situated  
in the paleovalley of the Überetsch. The same investigation, but performed  
from the viewpoint of the surveyor (i.e. using the field data points and their  
parent material information), identifies a very local (small window size) ver-  
335 sion of the TRI as best suited to distinguish between the two parent mate-

rial groups, with AD interestingly characterised by higher values indicating higher ruggedness. The separation of the profilesites of the parent material classes AD and debris cones, the second most common confusion for AD, is less clear than for AD and TG. High resolution roughness values are less important than in the case of till, with texture computed with 50m grid cell size being the most decisive parameter. A comparison of the geological map units' topography also highlights the importance of this roughness parameter, which is surpassed only the regional terrain parameter catchment slope, computed at the same low DTM resolution. The choice of these parameters seem closely linked to the transitional landscape position of debris cones, situated between the steep slopes of the Mendola-Roèn-Ridge and the flatter valley bottoms.

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 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 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. Additionally, the soil types Kalklehm-Rendzina and Pararendzina were encountered, both characterised by organic horizons on more or less unweathered parent material, indicating that alluvial deposits were also identified at places lacking the stable conditions necessary for the development of a B-horizon as presented by the alluvial deposits unit of the geological map. So while the alluvial deposits unit is characterised on the geological map by the lowest mean slope aside from mire deposits, the soil data as well as the topographic analysis, indicate it is nevertheless necessary for future surveys to also investigate the less typical, rougher and sloping areas at the border or in proximity of alluvial deposit units.

### 3.3.2. Siliceous bedrock

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 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 attempting the use of the geological map as a parent material map. While the 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 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 every second soil profile located on the SGU siliceous bedrock. Further parent materials identified on the SB unit include mixed and slope deposits, as well 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 contain almost only siliceous material from bedrock units at higher elevations in the catchment or underneath the debris cover layer. Additionally, the soils 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 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 geologist'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.

The random forest-based analysis of how to topographically separate the profile sites with siliceous bedrock as parent material that are situated on the SB unit of the geological map from those with the same parent material but on different SGUs showed that the latter group is situated in areas with

lower convexity (computed with the 10 m DTM). Regarding roughness parameters, the vector ruggedness measure based on the 2.5 m grid and a large search window of approx. 130 m performed best. Soil profiles that evolved from siliceous bedrock and are also located on the SGU SB are characterised by higher vector ruggedness values. Given the strong confusion with the unit till in general, as well as the fact the these two units share a long border, it is of interest to examine the topographical differences between points that are attributed to one of these two parent material units. The TRI at a window size of approx. 100 m leads the terrain parameters with a 5-fold cross-validated classification error of approx. 15 %. The minimum curvature based on the 10 m grid performs best from the group of local terrain parameters. In general, soil profile sites with SB as parent material are consequently characterised by rougher topography (increased TRI values) and slightly positive minimal curvature values when compared with data points were till was identified as parent material. This is well in line with increased distribution of this parent material on convex, ridge-like structures in the SGU siliceous bedrock. As Table 3 shows, confusion with slope deposits is present from both the user's and the producer's point of view. The random forest-based data mining shows that, regarding the parent material as indicated by the surveyors, the terrain parameters that are most characteristic of the difference between the two units are

### 3.3.3. *Till in general*

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 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, 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 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 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 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*

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 sedimentary rock and debris cones, the first three units greatly influencing the distribution of components in the slope debris units. When comparing the 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 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 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, especially during field survey. Contrary to most other SGUs (with the exception of CBD, LD and MxD), this unit itself does not provide information regarding



485 the mineralogy of its component, which can only partially be derived through  
interpretation of its location in the catchment and the uphill geologic situ-  
ation. 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*

490 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  
495 its layers that span from north to south of the study area. Slope debris units  
often occupy locations downslope of the CSR units, accounting for the long  
border length of 40 km with this unit. The fuzzy transition from weathered  
bedrock to slope debris is a major issue also for this SGU. The confusion  
matrix representing the comparison of the parent material as indicated by the  
500 geologic map and the parent material identified in field survey (Table 3) shows  
that, consequently, this is the unit responsible for the most misclassification,  
contributing to the very low user's accuracy of this SGU. Additionally, due to  
its intermittent layering with ISR, it is not surprising that this unit was found  
to be the parent material for 7 investigated soil profiles in the calcareous  
505 sedimentary rock unit. The producer's reliability is slightly better, however,  
all in all only five of the soil profiles were attributed the parent material  
unit calcareous sedimentary rock, of which two were in fact situated on the  
SGU slope debris. This again accentuates the problem with differentiating  
these two units when adjacent, as one is often the result of weathering, and  
510 gravitational transport, of the other unit. Similarly to the other bedrock  
units in the study area, till was reported also in this unit as the soil parent  
material at 12 sites, accounting for a third of the soil profile locations on  
this SGU and highlighting the necessity to expect thin layers of till in areas  
mapped as bedrock.

### 515 3.3.6. *Debris cones*

The unit debris cones are located west of the center of the paleovalley,  
between the slope debris of the Mendola-Roèn-Ridge slope in the west, which  
are often the source area of these deposits, and the till deposited in the  
paleovalley in the east. Other units with which long borders exist are mixed,  
520 colluvial, and alluvial deposits. The number of profile sites is comparably

small with 36 profile sites, considering that the unit occupies almost 13% of the study area. A reason is that a large part of the debris cones are covered by settlements. Although the soil surveyors noted debris cones as parent material for only 5 soil profile sites, it must be considered that 20 of the misclassified parent materials on the debris cones unit were identified as slope debris. Given the long mutual border and the fact that the source of the debris cones material is mainly the slope debris and the calcareous bedrock units which themselves are the origin of the slope debris, this misclassification may seem acceptable. In fact, it rather points out a difference in the point of view of the soil and the geologic surveyors, where the first are interested in the material and the latter more in the landform presented by the debris cones unit. The remaining misclassifications are all with units that border this SGU, or, in the case of intermediate sedimentary rock, are located in the source region of the the debris cones.

*3.3.7. Intermediate sedimentary rock and siliceous sedimentary rock*

*3.3.8. MxD, LD, CD*

*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 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. 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...

Regarding glacial deposits, the soil or forestry surveyors seldom differentiate between lodgement till and other glacial deposits, only when a decisively 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

with regard to this aspect. The geologic map on the other hand also contains 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  
560 surveyor if it features additional information with regard to the mineralogic content of the different constituents of the moraine.

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 geological units*

  
565

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*

  
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### *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  
575 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*

  
580

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  
585 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.

590 3.7.3. *Is the morphodynamic background of deposits a necessary distinctive attribute from a pedological point of view?*

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

#### 4. Conclusion

595 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  
600 of field work, involving soil pits and auguring, on units identified as highly variable and uncertain regarding soils. This information can be additionally helpful for devising future sampling procedures and also for consideration when attempting to regionalise point information.

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	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

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