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).

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 geomorphologic 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

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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. Hier vielleicth Juilleret mit seinem vereinheitlichendem system, und so fr die wichtigkeit des ausgansgsmaterials. Herbst zitat??

A number of studies have compared the information from soil surveys with geologic maps. HERE SOME LITERATURE. 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. Similarily 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 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. Coblentz 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.

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 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. 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 seperating 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 theses 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 aim 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 were 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-Kaltern, 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 the Mitterberg, a ridge of Permic 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 investigated 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 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 commentary 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 'Kaltern 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 contains a number of valleys carved into the gravels by fossil meltwater. At the eastern and western borders of the Pleistocene sediments, outcrops of Permic 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 with an elevation difference of approximately 400 m. The steep slopes of the Mendola-Roèn-Ridge are dominated by various Dolomite units, with intermittent layers of sand and siltstones. Except for the very steep Dolomite walls of the ridge, the rarely occurring outcrops of these formations are surrounded 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 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 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.

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.

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).

data base 3: . 42 aus Forstdatenbank 227 von WLM

Overview of soils in study area.

2.1.3. Digital elevation data

2.2. Methods

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.

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
glaciolacustrine 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
lodgement till	LT	compacted sub-glacial sediment	15.8
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	10.1

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.

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

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

3. Results

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

	AD	CBD	CD	CSR	DC	GLD	IMS	ISR	LD	LT	MrD	MxD	SB	SD	SSR	TG
AD	7	0	0	0	4	0	1	0	0	1	0	0	0	0	0	0
CBD	0	4	0	0	0	0	0	0	1	0	0	0	1	3	0	0
CD	0	0	3	1	3	0	0	0	0	0	0	1	1	0	0	0
CSR	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	1
DC	0	0	0	0	5	0	0	0	0	0	0	0	0	1	0	0
GLD	1	0	0	0	0	5	0	0	0	1	2	0	2	0	0	0
IMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ISR	0	0	1	7	2	0	0	0	0	0	0	0	1	4	2	3
LD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MrD	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MxD	0	0	0	1	0	0	0	0	0	2	0	0	2	0	1	3
SB	0	0	0	0	0	0	0	0	2	0	0	0	14	4	0	0
SD	1	8	1	13	20	0	0	3	0	1	0	6	3	55	3	8
SSR	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0
TG	3	2	0	12	2	2	0	0	0	40	1	1	24	15	1	48

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

3.2. Geomorphometric analysis of geologic map units

3.3. Distribution of soils with regard to geologic units

4. Discussion

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

4.1.1. 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 considered for mapping. Miller and Lee Burras (2015) note that

	CBD	CD	CSR	DC	GLD	IMS	ISR	LD	LT	MrD	MxD	SB	SD	SSR	TG
AD	0.2	21.1	0.0	23.6	14.8	2.5	0.0	1.2	33.9	22.2	10.9	5.7	12.7	0.2	11.3
CBD		0.5	6.1	8.5	0.0	0.0	1.1	0.9	1.3	0.5	1.5	10.1	9.7	0.9	7.8
CD			1.3	17.6	10.7	2.8	0.0	0.6	18.4	0.7	10.0	5.8	4.0	0.0	12.7
CSR				11.8	0.0	0.0	5.5	0.8	1.5	0.0	1.3	0.6	40.7	5.0	21.6
DC					2.5	0.6	0.7	2.4	7.7	5.9	17.4	9.3	25.6	1.6	32.9
GLD						2.2	0.0	0.2	3.5	0.8	3.4	0.4	0.5	0.0	3.5
IMS							0.0	0.0	0.1	0.0	0.6	0.7	0.4	0.0	1.0
ISR								0.2	0.0	0.0	0.0	0.0	4.3	0.0	0.4
LD									0.0	0.0	0.1	1.4	3.7	0.5	4.2
LT										1.8	10.0	21.8	8.5	1.3	7.8
MrD											0.2	1.2	0.6	0.0	0.1
MxD												2.7	2.7	0.1	9.5
SB													109.3	4.4	45.6
SD														8.3	41.9
SSR															4.2

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

the resulting maps of the two sciences try to communicate different aspects. While geology refers to geologican matierals and general landform regions, soil science is concerned more with soil properties with regard to land use and management decisions.

A typical example is...

4.1.2. Nomenclatural differences and overlaping classes

4.2. Pedologic interpretation of terrain parameters that best seperate the geological units

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

4.4. 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 hgih geomorphodynamics. Similarily, 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 aggreement was lower for areas with complicated geologic histories.

4.4.1. *High relief areas and multilayering*

Are there thresholds regarding terrain parameters?

4.4.2. *thin cover layers of till - an essential new parentmaterial unit?*

4.4.3. *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...

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

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