

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 an important 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', for instance in the 'scorpan' framework of inferring soil information (McBratney et al., 2003). How this important variable is classified, however, will vary greatly depending on the the available data, the soil classification sytem 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 (FAO, 2006)...(HIER kommt die Beschreibung wie bei der FAO und in Österreich/Tirol das Ausgangsmaterial eingeteilt wird)

Hier vielleicht Juilleret und so fr die wichtigkeit des ausgangsmaterials. Herbst zitat??

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20 Situation in the Alps bezüglich boden und geologie wäre auch noch in-
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
25 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
30 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
35 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
40 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 ap-
45 plied 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
50 on the variability of contour lines along transects, which they correlate with caribou forage availability. Regarding field methods, they calculate micro-topographic diversity by analysing the horizontal distance of a chain laid on the ground in their study plots. Riley et al. (1999) proposed the topo-graphic ruggedness index (TRI), which compares the elevation of a central
55 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
60 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
65 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 of bedrock.
70 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.

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
75 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)
80 surveys, called 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.

85 The next step is to perform a morphometric characterisation of the geological units. Applying a data mining approach based on a forward stepwise feature selection with a SVM classifier, 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
90 units.

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

95 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.,
100 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
105 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,
110 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 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
115 well as the study area is represented by the the Mitterberg, a ridge of Per-
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
120 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 com-
mentary to the new geologic map of Eppan (Avanzini et al., 2006). The
125 paleovalley of Überetsch is described by Scholz et al. (2005) as a complex
system of gravelly lateral moraines and large kame terraces, the result of the
'Kalern lobe', a Pleniglacial tongue of the Etsch valley glacier. Additionally,
eroded remainders of debris flows that were deposited against the recessing

130 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-
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-
135 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
with an elevation difference of approximately 400 m. The steep slopes of the
Mendola-Roèn-Ridge are dominated by various Dolomite units, with inter-
140 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
in locally flatter areas by till.

The study area comprises two map sheets of the new geologic map of Italy,
145 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,
150 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 15 SGUs described in Table 1, that
allow for comparison with the parent material units described and identified
155 by the soil surveyors in the field.

2.1.2. Soils

Overview of soils in study area.

Soil profile data.

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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. *general methodology*

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-Pseudogley	Stagnosol, 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-enriched 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 podzolization.
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).

	AD	CD	CSR	DC	GD	IMS	ISR	MrD	MxD	SB	SC	SD	SGT	SSR	TG
AD		1.96	0.00	2.19	1.37	0.23	0.00	2.29	1.01	0.53	0.01	1.18	31.49	0.02	1.05
CD			0.12	1.63	0.89	0.26	0.00	0.06	0.93	0.54	0.05	0.37	0.59	0.00	1.18
CSR				1.10	0.00	0.00	0.51	0.00	0.12	0.06	0.57	3.89	0.07	0.47	2.06
DC					0.23	0.05	0.07	0.58	1.62	0.88	0.79	2.41	0.72	0.15	3.05
GD						0.20	0.00	0.00	0.31	0.03	0.00	0.03	0.27	0.00	0.24
IMS							0.00	0.00	0.05	0.06	0.00	0.03	0.09	0.00	0.09
ISR								0.00	0.00	0.00	0.10	0.40	0.00	0.00	0.04
MrD									0.02	0.11	0.05	0.05	0.17	0.00	0.01
MxD										0.25	0.14	0.25	0.93	0.01	0.82
SB											0.94	10.18	2.03	0.41	4.14
SC												0.90	0.12	0.09	0.73
SD													0.79	0.77	3.80
SGT														0.12	0.70
SSR															0.20
TG															

Table 3: Length in kilometers of the borders of adjacent SGUs

*3.1. Geomorphometric analysis of geologic map units**3.2. 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.

A typical example is...

4.1.2. *Nomenclatural differences and overlapping classes*

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

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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*

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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?*

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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...

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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References

Avanzini, M., Bargossi, G., Borsato, A., Castiglioni, G., Cucato, M., Morelli, C., Prosser, G., Sapelza, A., 2006. Erläuterungen zur geologischen Karten von Italien im Maßstab 1:50000 Blatt 026 Eppan. Technical Report. Agenzia per la protezione dell'ambiente e per i servizi tecnici.

205

Beasom, S.L., Wiggers, E.P., Giardino, J.R., 1983. A technique for assessing land surface ruggedness. The Journal of Wildlife Management 47, 1163–1166. doi:10.2307/3808184.

210

- Böhner, J., Antonić, O., 2009. Chapter 8 land-surface parameters specific to topo-climatology, in: Hengl, T., Reuter, H.I. (Eds.), *Geomorphometry Concepts, Software, Applications*. Elsevier. volume 33 of *Developments in Soil Science*, pp. 195 – 226. URL: <http://www.sciencedirect.com/science/article/pii/S0166248108000081>, doi:[http://dx.doi.org/10.1016/S0166-2481\(08\)00008-1](http://dx.doi.org/10.1016/S0166-2481(08)00008-1).
215
- Brevik, E.C., Miller, B.A., 2015. The use of soil surveys to aid in geologic mapping with an emphasis on the eastern and midwestern united states. *Soil Horizons* 56. URL: <http://dx.doi.org/10.2136/sh15-01-0001>, doi:10.2136/sh15-01-0001.
220
- Coblentz, D., Pabian, F., Prasad, L., 2014. Quantitative geomorphometrics for terrain characterization. *International Journal of Geosciences* 5, 247–266. URL: <http://dx.doi.org/10.4236/ijg.2014.53026>.
- FAO, 2006. Guidelines for soil description. Food and Agricultural Organisation of the United Nations. Rome.
225
- Gallant, J.C., Wilson, J.P., 2000. *Terrain Analysis - Principles and Applications*. John Wiley & Sons, Inc.. chapter Primary Topographic Attributes. pp. 51–85.
- Grohmann, C.H., Smith, M.J., Riccomini, C., 2010. Multiscale analysis of topographic surface roughness in the midland valley, scotland. *IEEE Transactions on Geoscience and Remote Sensing PP*, 1 – 14. doi:10.1109/TGRS.2010.2053546.
230
- Hobson, R.D., 1972. *Spatial analysis in geomorphology*. Harper and Row, New York. chapter Surface roughness in topography: quantitative approach. pp. 221–245.
235
- Jenny, H., 1941. *Factors of Soil Formation - A System of Quantitative Pedology*. Dover Publications, Inc. New York.
- Kilian, W., 2015. schlüssel zur Bestimmung der Böden Österreichs. volume 81. 2 ed., Österr. Bodenkundl. Ges.
240
- Marchi, L., Dalla Fontana, G., 2005. Gis morphometric indicators for the analysis of sediment dynamics in mountain basins. *Environmental Geology*

- 48, 218–228. URL: <http://dx.doi.org/10.1007/s00254-005-1292-4>, doi:10.1007/s00254-005-1292-4.
- 245 McBratney, A.B., Santosb, M.M., Minasny, B., 2003. On digital soil mapping. *Geoderma* 117, 3 – 52.
- Nellemann, C., Thomsen, M.G., 1994. Terrain ruggedness and caribou forage availability during snowmelt on the arctic coastal plain, alaska. *Arctic* 47, 361–367. URL: <http://www.jstor.org/stable/40511597>.
- 250 Nestroy, O., Aust, G., Blum, W., Englisch, M., Hager, H., Herzberger, E., Kilian, W., Nelhiebel, P., G. Ortner and, E.P., und J. Wagner, A.P.W.S., 2011. Systematische gliederung der bden sterreichs. sterreichische boden-systematik 2000 in der revidierten fassung von 2011. *Mitt. sterr. Bodenkdl. Ges.* 79.
- 255 Olaya, V., 2009. Chapter 6 basic land-surface parameters, in: Hengl, T., Reuter, H.I. (Eds.), *Geomorphometry Concepts, Software, Applications*. Elsevier. volume 33 of *Developments in Soil Science*, pp. 141 – 169. URL: <http://www.sciencedirect.com/science/article/pii/S0166248108000068>, doi:[http://dx.doi.org/10.1016/S0166-2481\(08\)](http://dx.doi.org/10.1016/S0166-2481(08)00006-8)
260 00006-8.
- Riley, S.J., DeGloria, S.D., Elliot, R., 1999. A terrain ruggedness index that quantifies topographic heterogeneity. *Intermountain Journal of Sciences* 5, 23 – 27.
- Sappington, J.M., Longshore, K.M., Thompson, D.B., 2007. Quantifying
265 landscape ruggedness for animal habitat analysis: A case study using bighorn sheep in the mojave desert. *Journal of Wildlife Management* 75. URL: <http://dx.doi.org/10.2193/2005-723>, doi:10.2193/2005-723.
- Scholz, H., Bestle, K.H., Willerich, S., 2005. Quartärgeologische untersuchungen im überetsch. *Geo.Alp* 2, 1–23.