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From geological to soil parent material maps - a random forest-supported analysis of geological map units and topography to support soil survey in South Tyrol

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Abstract

Parent material is an important factor of soil formation and consequently plays a dominant role in both traditional field soil survey and digital soil mapping. The emergence of a new generation of geological maps at high spatial and thematic resolution in South Tyrol raises the question of how to effectively incorporate these into soil mapping efforts. By comparing the units of these geological maps with the parent material description of soil pits, we evaluate to what extent these can be used as soil parent material maps. Random forest classification and feature selection are applied to highlight those terrain parameters that 1) best distinguish between the different surficial geology units, 2) separate soil profile sites with different soil parent material, and 3) can be used together with the geologic map to train a classifier to model the distribution of soil parent material in the study area. The main issue detected by analysing the differences between the geologic map units and the soil parent material information is the dominant role of till, which acts as soil parent material for a large number of soils located on different geologic map units. While slope debris is another class with a low producer's reliability, the issues concerning its misclassification are connected to fuzzy categorical transitions between soil parent material classes. Terrain parameters characterizing surface roughness, specifically a combination of vector ruggedness measure (VRM) and topographic roughness index (TRI), i / ii

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situation and

were identified as being best suited to join the geological map units in modeling soil parent material and indicate areas where till as soil parent material should be expected. By evaluating these results together with the distribution of soil types, a geologic-topographic characterisation is performed for each geological map units, with the aim of highlighting specific combinations of geological unit and its topographical situations which should be in the center of future detailed soil surveys.

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Keywords: geologic map, soil parent material, digital soil mapping, surface roughness, random forest classification, Alpine environment

soil survey ?

1. 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). 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 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 (Phillips and Lorz, 2008). In this context, it is indicated also 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. In their study which models the carbonate-free depth of soils in Switzerland,

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Fracek and Mosimann (2013) attribute a large part of the modelling error to discrepancies between the map units of geologic maps and the actual soil parent material, highlighting the importance of this specific environmental variable in soil modelling. How this important variable is classified, however, will vary greatly depending on 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). 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 Services of the Autonomous Province of Bolzano - South Tyrol as well as North Tyrol (Englisch and Kilian, 1999; Amt der Tiroler Landesregierung, Abteilung Forstplanung, unpublished), this 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 deposits, but also the more recent deposits which are 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.

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A number of studies have compared the information from soil surveys with geologic maps. Juilleret et al. (2012) for instance compared C horizon data from soil profiles with parent material as derived from a geologic map, concluding that surficial geologic ~~maps~~ can be improved with available soil profile data. They also highlight the necessity of improved communication and exchange between the two sciences. Miller and Lee Burras (2015) compared surficial geology maps produced by a Geological Survey with comparable maps produced using Soil Survey maps of higher spatial resolution, reporting an agreement of 81%. In their review covering the subject of improving geologic maps with soil maps, Brevik and Miller (2015) argue that information from both mapping approaches should be integrated, but always

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X auch Gletschernähe hier schon erwähnen – zeitlich zu fassen under consideration of the limitations and differences between the disciplines. Whereas most of the previously mentioned studies analyse the possibility of using soil survey information, which generally comes at a higher spatial resolution, for mapping surficial geology, the aim of the presented study is to analyse the application of detailed geologic maps as parent material maps, highlighting those geologic units of the study area where the derivation of soil parent material from geology is not as straightforward as assumed.

A second 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. Beasom et al. (1983) and Nellemann and Thomsen (1994) applied contour line analysis as a way of characterizing terrain ruggedness. Grid-cell based roughness measures were proposed as the topographic roughness index (TRI) by Riley et al. (1999) or the vector ruggedness measure (VRM) by Sappington et al. (2007), who expanded on the work of Hobson (1972). Similar approaches based on eigenvalue rations of an orientation matrix were proposed for application in geology for instance by Woodcock (1977) and Coblentz et al.

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The objective of the presented study is to evaluate how to make best use of available high (both spatial and thematic) resolution geologic and topographic information for soil survey. This is of special interest as, while the quaternary deposits were often neglected in older geologic surveys or aggregated in a single unit, the new generation of geologic maps created within the CARG (Geologic and geothematic cartography of Italy) framework exhibit high detail regarding these surficial deposits. ? The study area in the Überetsch/Oltradige region of the Autonomous Province Bolzano – South Tyrol was therefore chosen due to the availability of detailed geologic maps, but also the diversity of soil forming factors, especially geology and topography. to ? 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 surficial geology map units, each of these is characterised with regard to topography and soil. We emphasize those units which are often confused or show overlap, and should therefore be surveyed with greater detail and in consideration of relevant topographic information. ? effort The main aim of the random forest classification is to identify the topographic characteristics of the parent material and geologic units in order to facilitate future detailed soil surveys, and not necessarily to improve the geological map with regard to its application as a parent material map. ? muß das gesagt werden?

2. Study area and data

2.1. 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 hill slope on the orographic right of the Etsch River. The western border of the study area is the steep slope of the Mendola-Roèn-Ridge (max. 2116 m.a.s.l.), whereas the eastern border of the Überetsch as well as the study area is represented by the the Mitterberg, a