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A new guideline for geological maps with QGIS

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Abstract

Being able to create digital geological maps has become a basic requirement for the skillset of today's geologists. QGIS is a geographical information system that receives increasing popularity due to its user-friendliness and the fact that it is an open access software. This contribution provides an update and extension to a previously published software guideline that gives a stepwise explanation on how to create a geological map with QGIS. The article serves as a brief overview of the guideline through an illustrated example. The guideline itself is published as a supplement to this paper. Within six sections, the guideline explains how to create a geological map with QGIS: 1. Introduction, 2. Download and installation, 3. Basemaps, 4. Map drawing, 5. Plugins, 6. Layouts. The aim is to instruct geologists who are completely inexperienced with digital map creation as well as provide specific information for more advanced users. In general, providing software guidelines for the geological community is an important step towards increasing geologists' digital proficiency and to keep up with today's fast paced developments in digitalization.

1. Introduction

In recent decades, the application of digital technology in geosciences has experienced a remarkable surge, both in practical and academic contexts. Digital mapping has historically been linked to advances in computing power, software and widespread availability and affordability of both. For example, the first considerations on mapping automatization (albeit in a broader, geographical context) stem from the 1950s (Tobler, 1959). However, truly digital (i.e. "paper-less") mapping in the field only became a practical approach in the 1990s to early 2000s with the advent of adequate portable devices (e.g. Briner et al., 1999). Regardless of whether the starting point is a hand-drawn map and field notes or digital field recordings, digital mapping requires a structured workflow. This imposes additional skill requirements on the modern geologist, but greatly increases the overall quality of the final product.

Finished geological maps for use in the academic and the applied world must be supplied in a digital format, preferably generated with a geographical information system (GIS). Most universities that provide geology studies today also offer courses on GIS based mapping, either as part of a wider geoinformatics education (e.g., the University of Innsbruck, Austria) or as dedicated field courses (e.g. UC Riverside, USA). However, there is still a need for additional and openly available guidelines on how to produce a digital geological map. Many universities' GIS courses are not compulsory in the relevant curricula and thus do not reach the entirety of students (e.g. the University of Vienna, Austria). Furthermore, university GIS courses are often aimed at a broader student body (including geography and meteorology students) and do not necessarily cover the specifics of geological mapping, especially on the undergraduate level. In addition, these courses seem to mostly use proprietary software (e.g. ArcGIS). Geologists whose university education dates back some time may not have had the chance to take a course in digital mapping altogether as these classes were not yet part of the curriculum. Lastly, the authors experience from the field of applied geology shows that many companies still produce maps with inadequate programs (e.g. computer aided design (CAD) programs). This highlights both an insufficient knowledge of today's open-source GIS possibilities as well as the economic threshold that is associated with some proprietary GIS programs.

QGIS is an open source, freely available GIS software that is licensed under the GNU General Public License. It provides an ever-increasing number of tools to create, edit and visualize geospatial data that is supported by a community of volunteers and different institutions (QGIS Development Team, 2023). Due to that, the popularity of QGIS has rapidly risen over the past years and is also increasingly popular for geoscientific applications from beginner to professional levels (Bartolini et al., 2013; Muenchow et al., 2017; Fang et al., 2020; Lemenkova, 2020; Penasa et al., 2020; Titti et al., 2022)

With this background, we introduce a guideline on the creation of geological maps with the open-source program QGIS. We build on the experience gained from an earlier guideline "Geological Maps with QGIS 3.X" by Erharter (2018) (see also Erharter and Palzer-Khomenko, 2018), which provides likewise provides a step by step explanation on how a digital geological map can be created with the freely available software QGIS. By the time of this writing, this earlier guideline has reached more than 11000 "reads" on the platform "Researchgate" within approximately four years. While "Researchgate reads" are not a commonly used metric to measure the impact of publications, we still see it as a valid parameter for the engagement rate of the community with a publication and it therefore shows that software guidelines such as the one presented here answer to a demand of the worldwide geological community and contribute to geologists digital proficiency. Even though the "Researchgate reads" demonstrate the impact of such a work, the reader is encouraged to cite this work if the provided guideline is used for their own scientific studies.

Other tutorials on the use of QGIS for geological map creation such as Lorscheid (2013) or Mohsen Alshaghdari (2017) exist, as well as comprehensive compilations of tutorials for QGIS without specific reference to geological topics (e.g. Gandhi, 2023). With around three bigger updates per year, QGIS is further developed rapidly and thus guidelines may become outdated after some years. The present work presents an up-to-date tutorial on creating geological maps with QGIS and is the first of such tutorials to include new features such as 3D map layouts.

2. Basic steps of digital geological map creation

The basic steps of creating a digital geological map are: i) data acquisition in the field, taking into account the overall investigation goal and desired map content; ii) transferring field data into a coherent data structure for mapping; iii) preparing basemaps on which the new map can be built; iv) adding own content to the map, i.e., map drawing; v) optional: creating additional map content such as cross sections and stereonets; vi) compiling the whole content in a publishable layout. The guideline published as supplementary material to this paper follows that overall structure. Nevertheless, the individual steps shall be briefly elaborated in the following section:

i) While the field data acquisition is not directly part of the map creation, it is generally advisable to follow an overall approach of systematic and digital data acquisition (e.g. by using digital outcrop protocols (Brodaric, 2004; Clegg et al., 2006; Dey and Ghosh, 2008; Horner et al., 2016; Allmendinger et al., 2017; Muir and Vaughan, 2017)). This ensures that data is acquired consistently, no information is overlooked and vastly eases the transfer from field data to the computer by sparing one from hours of digitizing handwritten protocols. Despite the digital data acquisition, making a plan for the map before one goes into the field and to continuously update this plan with incoming observations is highly recommended.

ii) Before the digital map creation can begin, it is recommended that the field observations are stored in a consistent file and folder structure if this is not already provided by the digital outcrop protocol. The geological map will follow a hierarchical structure (Bichler et al., 2018), where layers of information overlap each other and this structure should correspond to the overall data management of the project.

iii) Basemaps are usually added to a map before the own content is added to provide a proper "mapping background" and eventually enhance the map with third party content. These base maps can comprise orthophotos, digital elevation models and their derivatives (e.g. hillshades or slope maps) or other thematic maps. Basemaps can have different datatypes such as content from the internet (e.g., web map services) or raster data.

iv) Map drawing is the act of adding one's own content to the map and can follow different strategies. Adding geometrical elements (points, lines, polygons) directly to the map is a straightforward approach that might work well in many simple cases but poses the risk of creating topological inconsistencies in the map. The method "map drawing with contacts" is an alternative approach where one only draws the contacts as lines on the map and then intersects them with each other to automatically create polygons. This has the advantage of creating topologically flawless maps and is also more robust towards potentially necessary updates of the map, e.g., if a lithological contact needs to be changed.

v) Many geological maps are enhanced with additional information such as cross sections or stereonets of orientation data. Highly use case specific content like this is usually created with software outside of the GIS environment or with plugins and modules.

vi) The last step of map creation is usually to compile everything in a publishable, informative, and visually appealing layout. Just as the digital map creation should be considered while field data is acquired, the final layout should be considered during the digital map creation.

Producing a publishable map can come with considerable efforts and even require changes to the map itself, if, for example, problems with the maps legend are discovered at a late stage.

The guideline presented in the supplementary material guides the reader through the basic steps listed above (except the first step, as detailed instructions on geological field work are outside the scope of this work). We present solutions to frequently encountered problems and caveats; however, is essential to clarify that the outlined procedure for creating a geological map using QGIS is not the exclusive or definitive method. While we consider it to be an efficient and reliable approach, alternative techniques may also be suitable. Moreover, it is crucial to note that the guideline does not pursue specific geological research objectives, and the authors do not assert the absolute accuracy of the presented geological data.

Additionally, it is pertinent to acknowledge that the instructions provided in this guideline go beyond QGIS alone. The principles and methodologies discussed herein can be extrapolated to other software platforms, including but not limited to ArcGIS and similar tools. By adopting this broader perspective, we strive to offer a comprehensive understanding of the geological map creation process, applicable across various software environments.

3. Revised guideline for geological maps with QGIS

The development of QGIS is driven by a vibrant community resulting in frequent updates and changes. Since the writing of the previous guideline by Erharter (2018), several new capabilities have been added. This paper accounts for this evolution by presenting a revised and extended version of the guideline in the supplementary material: it covers newer QGIS versions but also contains more topics such as state of the art strategies of geological map drawing, the geoprocessing toolbox of QGIS, geopackages vs. shapefiles, plugins or 3D map layouts. Additionally, the guideline is now built around a "real world" example of a geological map (part of the official Geological Map 1 : 50.000 Holzgau of the Geological Survey of Austria (Gruber et al., 2022)). The entire map sheet is located in the North-Western part of Tyrol (Austria), most entirely in the Northern Calcareous Alps and also covers a part of neighboring Bavaria (Germany). Figure 1 shows the final geological map that is produced through-

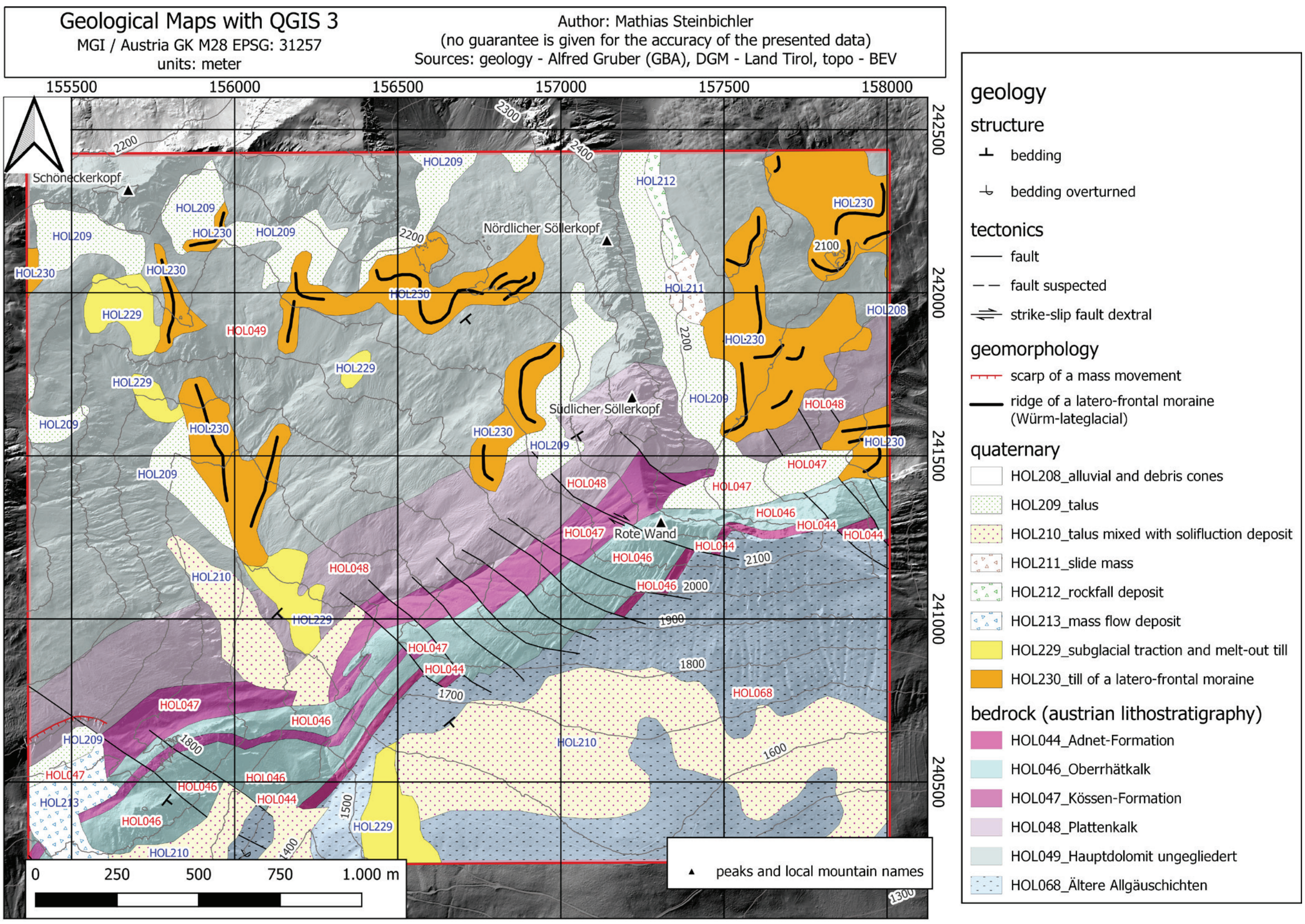

Figure 1: The final geological map that is produced throughout the QGIS guideline that is in the online supplement to this paper with the data provided in the link.

out the guideline in the online supplement to this paper for geological maps with QGIS. The supplementary data to reproduce the map that is created within the guideline is available under the following link:

https://repository.tugraz.at/records/57kxm-w5t95?token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6Ijk0MDQ2NjRiLTM2OGQtNGVlMC1iNWZmLTA5N2M5YWFkNzNlZSIsImRhdGEiOnt9LCJyYW5kb20iOiI1YTJhNzJiM2Q5MjRhOTc3ZTliODA1NjhlMTNjOTI5YSJ9.AUAmv39oYNv-v6hO3A5538p234Q3J3fgvp0X1kg6BXoE5a_8P2K6rYfzlH-EY67RBibkjPYkc6K_Zr6GS9WGBA

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