



Development of a New Approach for a Digital, Cartographic Rock and Relief Representation

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Received: 5 October 2023 / Accepted: 23 January 2024 / Published online: 16 February 2024
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Abstract

This paper presents a new approach to digital rock and relief representation. A prerequisite for the method was its applicability for different scales and thus different resolutions of the underlying terrain models. A further requirement was its suitability for different rock types. It must also take into account the rock surfaces that have become ice-free due to glacier retreat and be easy to integrate into the map in the event of an update. The relief representation follows the principle that the terrain should be reproduced as naturally as possible to provide the map user with the best possible orientation in the terrain. The approach requires a very good knowledge of the terrain as well as a certain artistic talent to achieve an appealing, natural color scheme. Through the process of color manipulation from the four-color set, it is also possible, in addition to the summer representation from the data collected with remote sensing methods, to generate winter representations for e.g. ski tourers. The use of established, automatic procedures considerably reduces the workload for the cartographer and also enables simple integration of corrections and changes to the landscape, e.g. due to glacial retreat and landslides, and can be applied to large map series due to its reproducibility.

Keywords High mountain cartography · Map production · Remote sensing · GIS · Rock representation

Entwicklung eines neuen Ansatzes für eine digitale, kartographische Fels- und Reliefdarstellung

Zusammenfassung

In diesem Beitrag wird ein neuer Ansatz für die digitale Fels- und Reliefdarstellung vorgestellt. Voraussetzung für die Methode war ihre Anwendbarkeit für verschiedene Maßstäbe und damit unterschiedliche Auflösungen der zugrunde liegenden Geländemodelle. Eine weitere Anforderung war die Eignung für unterschiedliche Gesteinsarten. Sie muss auch die durch Gletscherrückgang eisfrei gewordenen Felsflächen berücksichtigen und im Falle einer Aktualisierung leicht in die Karte zu integrieren sein. Die Reliefdarstellung folgt dem Grundsatz, dass das Gelände so natürlich wie möglich nachgebildet werden soll, um dem Kartennutzer die bestmögliche Orientierung im Gelände zu ermöglichen. Der Ansatz erfordert eine sehr gute Kenntnis des Geländes sowie eine gewisse künstlerische Begabung. Durch den Prozess der Farbmanipulation aus dem Vierfarbsatz ist es möglich, neben der Sommerdarstellung aus den mit Fernerkundungsmethoden erhobenen Daten auch Winterdarstellungen für z.B. Skitourengeher zu erzeugen. Durch die Verwendung etablierter, automatischer Verfahren wird der Arbeitsaufwand für den Kartographen erheblich reduziert und ermöglicht zudem eine einfache Integration von Korrekturen und Veränderungen der Landschaft z.B. durch Gletscherrückgang und Massenbewegungen und ist durch seine Reproduzierbarkeit auf große Kartenwerke anwendbar.

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1 Introduction

One of the most fundamental duties of maps is to provide a sense of location, helping to identify the placement of objects in physical space. In mountainous regions,

orientation is particularly challenging for the reader of topographical or tourist maps, because manmade reference points such as roads or buildings are rare or absent. In addition, correct localisation and navigation can be crucial for survival in high mountain terrain. The representation of this terrain plays a major role in map creation (Farmakis-Serebryakova and Hurni 2020) and the relief and rock depiction presented in the following follows the principle already established in the 1930s by Fritz Ebster, who regarded a map as a "vivid picture of the drawn terrain that is as true to nature as possible" (Ebster 1935). Kennelly and Stewart (2014) also emphasize the visualization of landforms as a key goal of terrain mapping to provide the map user with the best possible orientation in the field.

Today, digital relief shading has the potential to produce quicker and even better results than in the analogue era, if applied properly (Räber et al. 2009). As far as rock representation is concerned, high mountain cartography is more concerned with digitally implementing the previous methods (Grünwald 2015; Geisthövel 2017), rather than seeking new ways of representation. Manual rock representation causes great effort and thus high costs, which is no longer justifiable for map projects today (Dahinden and Hurni 2007). Hurni et al. (2001) give an overview of the historic development of cliff drawing and introduce a fully digital, semi-automatic method. A recent literature collection of terrain representations based on elevation models was provided by Kennelly et al. (2021), they emphasize the importance of the reproducibility of published maps.

The following method of both rock and relief representation breaks with previous methods and represents a new approach to display both relief and rock.

It can be shown that a substantial production effort as for example for the trekking map of the Brenta Group (Buchroithner and Himpel 2010) or for the map "Mount Kenya" (Heller et al. 2017) of the German Alpine Club (DAV) is no longer necessary for the actualization of a map series due to the multitude of freely available highly accurate basic data. In this context, the presented approach aims at reducing the data acquisition in the field to a minimum. Fridolin Becker put it aptly in his article "Art in Cartography": "to convert the image of nature as purely as possible into the image, do not insert anything extraneous or omit anything essential" (Becker 1910). This guideline considerably reduces the workload for the cartographer, although the manual effort is still high compared to (fully) automatic methods.

The overall goal of this contribution is to improve terrain representation towards an easier and more intuitive interpretability by combining high-resolution terrain models with natural coloring. Furthermore, our approach is designed to enable a simple and easy integration of corrections and changes in the landscape, e.g. due to glacier retreat and

rockfall into the GIS and the derived map by a straightforward use of GIS and remote sensing methods. The methodology also follows Manfred Buchroithner's call to provide the user with "a mountain map of adequate quality and sufficient data" (Buchroithner 2012). Both quality and detail are achieved by using the highest resolution of digital terrain models. In this way, we combine their richness in detail with the easy recognition of an orthophoto map, without aiming at a photorealistic representation.

2 Data Sources

Today, terrain and surface models in high spatial resolution are offered free of charge and for general use by the authorities of the countries bordering the Alps. These terrain models, collected by laser scanning campaigns, with a resolution range of 2 m and better, are excellently suited for the method presented and enable a detailed reproduction of the complex, high alpine treasure trove of landforms. This allows an application of the method of rock and relief representation presented in the following paper overall scale ranges, from 1:10,000 to 1:100,000. In the high mountains of South America or Asia, terrain models with 30 m resolution and better, for the Himalaya for example the High Mountain Asia elevation model with 8 m resolution, are freely available to cartography today. These products are sufficient for the application in map scales of 1:50,000 and smaller. Thus, the basic requirements for the production of topographic maps from digital terrain models are given in many high mountains around the globe.

In addition to high-resolution terrain models, high-resolution, up-to-date orthophotos are also offered in the European Alps by the surveying authorities of the respective country. They are needed to define the type of land cover or to map point and line features. In other parts of the world, data from the European satellite system Sentinel-2 are used to map land cover. This sensor is preferred because it provides multitemporal coverage, which is especially beneficial in areas with constant high cloud cover or cast shadows (Schröder 2020). If the resolution of Sentinel-2 is insufficient, for example when delineating small glaciers (Prinz et al. 2018), the consultation of other datasets such as World Imagery can additionally be of help.

3 Selection of the Test Areas

To develop and refine the approach, four maps with varying scales and in different geological settings were created:

- Cima Tosa (Trentino/ Italy) 1:15.000 in the Southern limestone Alps

- Birkkarspitze in the Karwendel (Tyrol/Austria) 1:25.000 in the Northern Limestone Alps
- Biz Buin (Vorarlberg/Austria; Grisons/Switzerland) 1:25.000 in igneous and metamorphic rocks (granite and gneiss).
- Annapurna Himal (Nepal and Tibet) 1:100.000 on the Himalaya main ridge in crystalline metamorphic rocks.

The test areas were chosen to cover different scale ranges as well as different geological conditions. In addition, these areas are subject to large changes due to glacier retreat in recent years. Cima Tosa, in particular, has lost ice in the summit area in recent years. In addition to the glacier wastage, Piz Buin is threatened by a major rockfall in the area of the Buinlücke, making corrections to the existing maps necessary here. Furthermore, for the Silvretta area, both a summer and a winter representation, e.g. for ski tourers, were created. The map "Annapurna Himal" was selected because with a map scale of 1:100,000 it is borderline for a topographic high mountain map and it was created with a digital terrain model of lower resolution.

4 Methods of Relief and Rock Representation

4.1 Relief Representation

As the relief depiction is the essential element of representation, shading is of particular importance (Farmakis-Serebryakova and Hurni 2020). A workflow for the relief representation has been developed and is schematically depicted in Fig. 1. In the first step, the landcover (Fig. 2A) was depicted from orthophotos or satellite data automatically using a supervised classification approach with subsequent manual correction. Since the delineation of debris-covered glaciers is difficult using only aerial or satellite imagery, a combined approach was used with the support of high-resolution terrain models (Paul et al. 2004; Quincey et al. 2014; Bolch et al. 2007). In particular, the terrain model supports the recognition of small forms such as rock and scree cover or moraines. The land cover layer is classified into alpine meadows, forest, rock, scree and glacier surfaces. Further differentiation, as used for example by the German Alpine Club, was dispensed with. The land cover layer is used in the next step to vary the shading according to the natural coloring. The next step is to prepare the digital terrain models. This includes the reprojection of the models into the UTM projection, if necessary, the mosaicking of the data and then the derivation of the shading. The shading was generated from two different illumination directions from the terrain models (Fig. 2B, C). In addition to the classic illumination direction from north-west, these were a nadir illumination

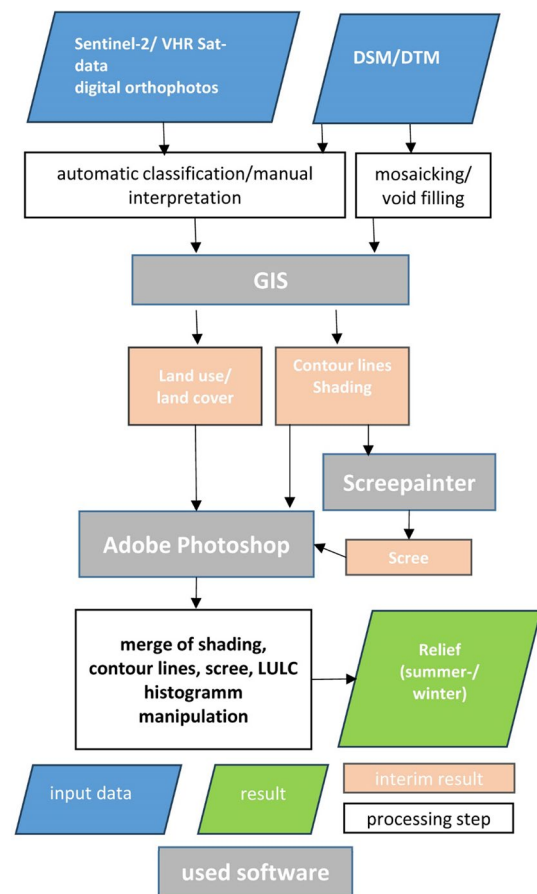


Fig. 1 Schematic representation of the relief rendering workflow

and, when appropriate, an illumination from south-east to emphasize shaded areas (Fig. 2). The combination of oblique light and slope shading has the advantage that contrast is retained in areas where light is strongly deflected (Fig. 2D).

For the final relief display, the land cover layer is merged with the combined shading in Adobe Photoshop. The land cover layer is used to mask the shadings to vary them accordingly in their color values by means of the histogram manipulation procedure in the four-color set (Winkler 1984). For this step, the process described in the patent specification nr. 379,112 "Process for producing a different-colored or multicolored image from an original with only one color tone" was implemented digitally. Adobe Photoshop was used as the tool here. In this step, the single-channel black-and-white relief is converted into a four-channel image in CMYK. The land use/land cover layer is required in this step to mask the relief (shading). The color of the masked areas is then changed by histogram manipulation to create the desired color impression (forest in green, glacier surfaces in a shade of blue, etc., see Fig. 3). Once the colour values have been defined, this work step can be standardized and thus reproduced and is suitable for larger map series.

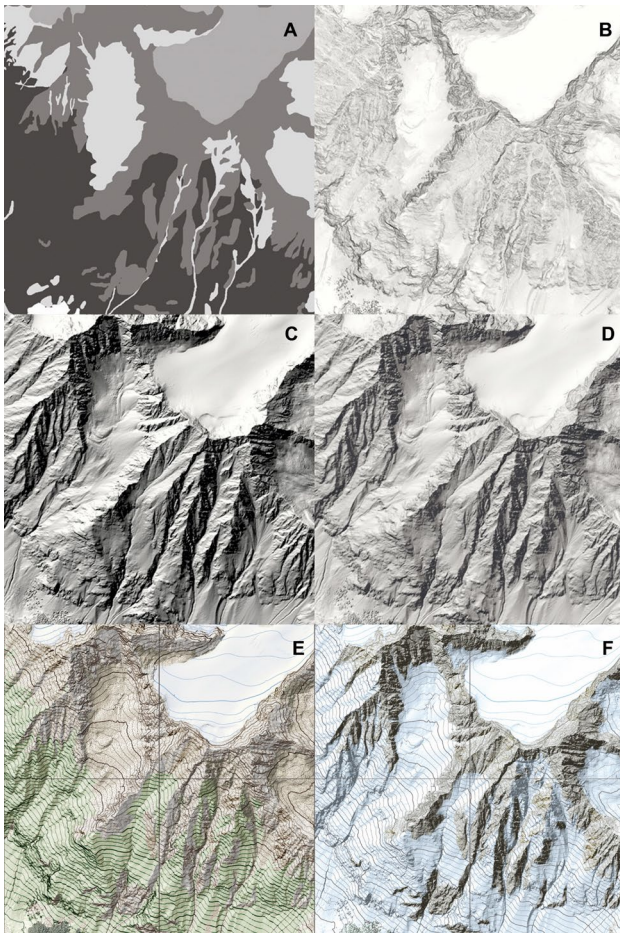


Fig. 2 The different layers in the scale 1:25.000 on the map example "Stubai": **A** Landuse/Landcover layer, **B** Slope shading, **C** Hillshading in nadir illumination, **D** Combination of slope shading and north-west illumination, **E** summer relief, **F** winter representation

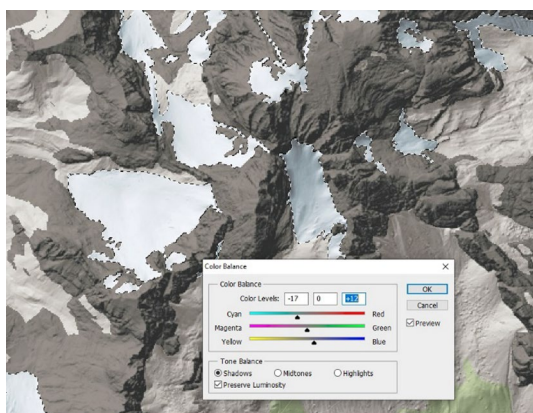


Fig. 3 Masking of the glacier surfaces using the LULC layer as a mask for the color manipulation step in Adobe Photoshop

The advantages of this method are the possibility to assign arbitrary colors to the relief, as well as in the modulation of the coloring according to the illumination. Furthermore, the contrast in the shadow areas can be emphasized. The overall impression of the relief thus appears more three-dimensional and results in an intensification of the relief impression. In this respect, the approach follows the Swiss style relief shading methodology, which modulates the relief according to illumination (Jenny and Hurni 2006). The process also makes it possible to create color gradients. Clear demarcations that do not or only rarely occur in nature, e.g. between scree and alpine mats, can also be reproduced very well in this way. Using the highest resolution terrain models and appropriate color selection, the overall impression of the topographic map comes closest to that of a pictorial dash map. This is best illustrated in the map section "Cima Tosa" (Fig. 4), where an attempt was made to recreate the natural coloring in rock and scree, as well as in the vegetation. The glacier surfaces appear in a brilliant white, with a slight shading into bluish-turquoise.

Since the terrain should be represented as true to nature as possible, this applies not only to the color scheme but also to the texture through the vegetation cover. If available, digital surface models (and not digital terrain models, where vegetation has been removed) were used for the generation of the shaded areas, since the surface model retains the surface structure and texturing of the vegetation and thus reproduces a vegetation cover that appears more realistic. The map "Furgler" (Fig. 5) is an example for such a near-natural coloring and texturing of the vegetation.

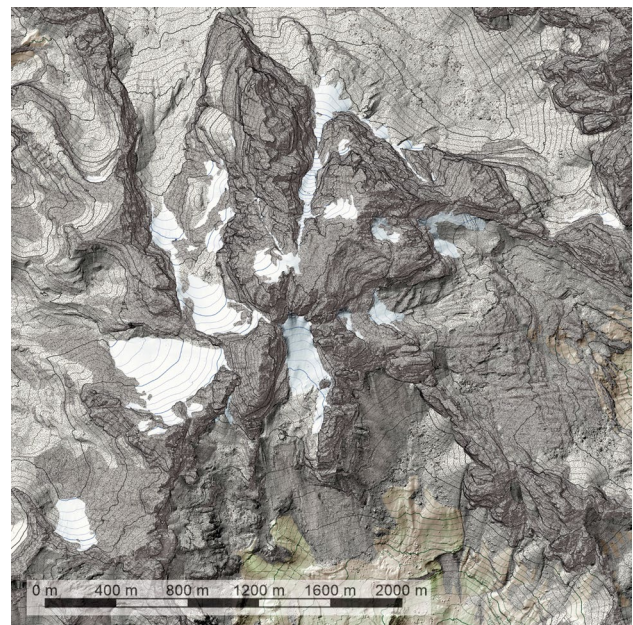


Fig. 4 Subset of the relief of the map "Cima Tosa" (Scale 1:15.000)

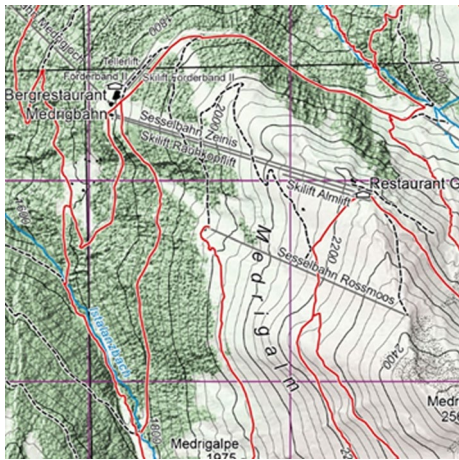


Fig. 5 Subset of the map "Furgler" in 1:25.000 with forest texture

In this respect, the process can also be described as electronic image generation to produce a perfected representation of the landscape.

The method not only allows the manipulation of the overall coloration of a map sheet but can also be used to manipulate individual areas within a map sheet or to emphasize low-contrast areas, especially those areas that are strongly facing towards or away from the light.

In the example of the "Cima Tosa" map, the supplementary rock representation was deliberately omitted because the high resolution of the laser scanning model in conjunction with the large map scale of 1:15,000 render the relief, in particular the rock areas, sufficiently well. Together with the color design, this creates a map image that is almost similar to an aerial photograph, or rather, the boundaries between the map and the aerial photograph become blurred.

The scree representation is realized via the freeware Screepainter, as this tool allows the modulation of the point

size via shading. This modulation further enhances the impression of relief. In addition, Screepainter enables the display of gully lines and the marking of areas with larger boulders. The tool also allows you to modulate the point size and shape as well as the density of the generated scree points (Jenny and Hutzler 2010). The scree layer created in this way is added to the relief in Adobe Photoshop.

If the coloring of the vegetation classes alpine meadows and forest as well as scree is adapted to the coloring of the glacier areas, the impression of a winter map is created (Fig. 2F). This makes the method also suitable for the creation of ski touring maps (Fig. 6).

Another element of the relief-supporting factors are contour lines (Hurni 2010). In the present approach, the contour lines were gridded and embedded in the shading (Fig. 7). Through the process of histogram manipulation, the contour lines are varied in the same way as the shading and in this way, they strengthen the color and lighting impression.

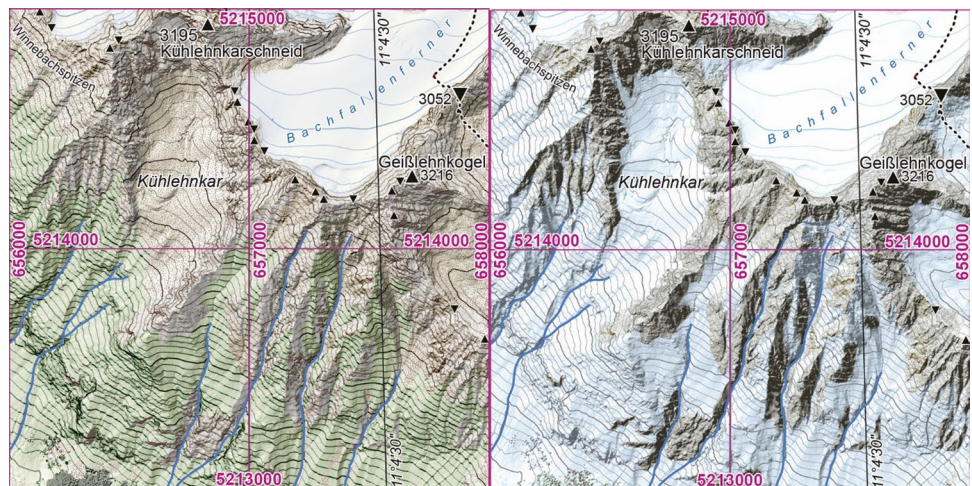
4.2 Rock Representation

The method presented has already been successfully tested and applied to a number of maps in alpine and extra-alpine areas in the scale range of 1:10,000–1:100,000. The maps include the sheets of the Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung (ARGE) "Annapurna Himal" in 1:100.000, "Annapurna Basecamp" in 1:50.000, "Dhaulagiri Himal" in 1:50.000, the map "0/2 Mount Everest – Solu Khumbu" as a new co-production of the Deutscher Alpenverein (DAV) and ARGE, as well as of currently more than 20 map sheets in the Alps, which are distributed digitally under the label "Bildkartographie".

The demand for the presented method of rock and relief representation can be defined as follows:

- Preservation of the elevation curves on the rock surfaces

Fig. 6 Section of the map "Stuibai" in summer (left) and winter representation (right) in map scale 1:25.000



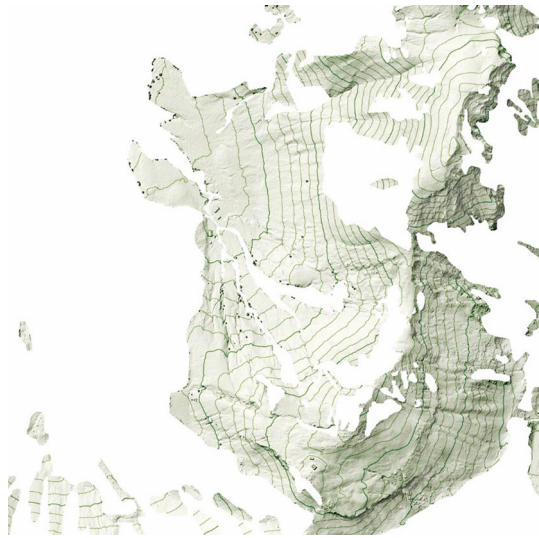


Fig. 7 Example for the visualization of contour lines, here on alpine meadows. The contour lines are rendered in shades of green according to the background

- Conservation of the shading in rocky areas as much as possible
- Readability of the surface structure in steep light and shaded areas
- Reproduction of the natural coloration of the rock areas
- Easy integration of natural changes e.g. due to glacier retreat, rockfalls
- Easy integration of new base data, especially digital terrain models
- Applicability in rugged terrain
- Applicability in different geological and morphological conditions
- Applicability for different scales and also different resolutions of base data (terrain models)

The approach presented follows Arnberger's principle "The photogrammetric contour plan should be preserved everywhere (even in rock) as an inviolable geometric framework of cartographic terrain representation" (Arnberger 1970). This rock representation method can thus be classified as a "geometrically bound" method since it is both subordinate to the contour map and geometrically accurately rendered. The method is thus reminiscent of the approach of Shelton (1985), who produced nature-like maps as early as the mid-twentieth century. He was particularly of the opinion that the signatures on the map should clearly remind us of nature and therefore a legend was superfluous (Shelton 1985), cited in (Patterson and Kelso 2004).

Two methods were developed for the rock representation. For high-resolution digital terrain models with a resolution of up to 2 m, a method was developed that best reproduces the relief energy and plasticity of these high-resolution terrain models. To do this, shading is first generated from the terrain model as previously described and the contour lines are rasterized. Depending on the intensity of the gradation, the contour lines are enhanced (in shadow) or attenuated (in light). Then, the rasterized contour lines and the shading are combined (Fig. 8).

For lower-resolution digital terrain models, a rock signature was developed and implemented using digital cartophotolithographic tools, such as Adobe Photoshop. Since these terrain models show less relief details, this procedure must be supported manually (Fig. 9). The editing is done with a digital graphics tablet. For this purpose, signatures for different rock types were developed in a graphics program, e.g. Adobe Photoshop. This activity requires the cartographer to have artistic skill as well as a keen understanding of the terrain being rendered. The rock signature was chosen in such a way that both pure rock sections and rock with scree overlays can be depicted. With the method of color manipulation presented in the following chapter, the coloring of the

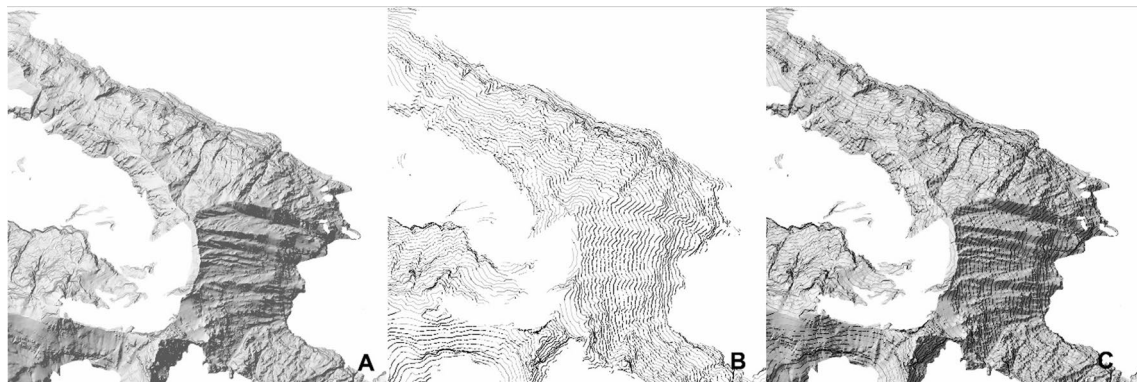


Fig. 8 Rock representation of the map example "Birkkarspitze. **A** Shading: combination of 3D elevation model in cartographic illumination and surface model, colour density adjustment according to

geological nature, **B** rasterized contour lines separated in light and shadow, **C** rock as a combination of shading and rasterized contour lines

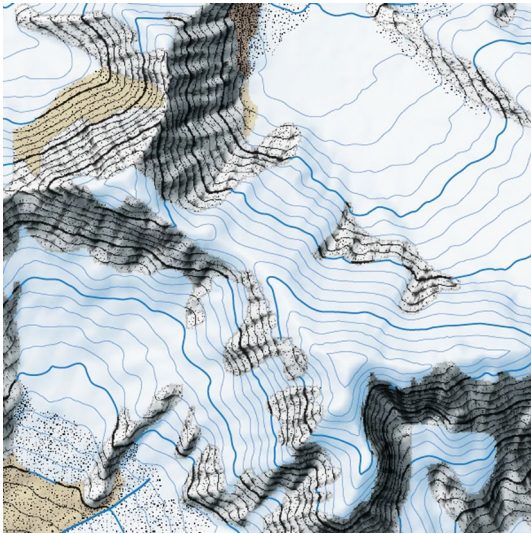


Fig. 9 Rock representation of the map example "Annapurna Himal" in 1:100.000 based on ALOSWorld3D 30 m data

rock sections can be controlled, also with regard to different colors within a map sheet.

The method of rock representation presented in the following is not done as a line or line-based hatching representation as it is used for example in Austria or Switzerland (Jenny et al. 2011), but supports the relief in the rock area in color and form. As a result, it is not sharply delineated from the adjacent areas, but allows for smooth transitions to the surroundings.

The rock drawing should support the terrain model represented in the shading and not appear as an additional signature in the relief. In this way, the contour lines are completely preserved as a relief-forming element.

4.3 Survey to Assess the Quality of the New Approach

To test how the new display is received by map users, an online survey was conducted. The survey contained five questions about maps created with the new method, partly in comparison to traditional map representations and two further general questions on the significance of content in topographic maps. Participants were also asked about their age, gender, type of sport and map-reading experience. The interviewees were not selected at random, but for the most part had a connection to maps or mountaineering. The majority of the 21–29 age group are students of the "Geovisual Design—Geomatics" bachelor's programme at the University of Applied Sciences in Munich. The older participants are mainly mountain guides and members of the German Alpine Club.

79 participants took part in the survey, of which 49 (62%) were male and 30 (38%) females. Of the participants, 4 were under 20 years old, 39 were 21–29 years old, 24 were between 30 and 49 years old and 10 were over 50 years old. Of the participants, 23 (29%) participants stated that they had many years of experience with maps 41 (52%) were "comfortable with maps and could use them to find their way around", 15 (19%) participants classified themselves as beginners or not comfortable with them.

The vast majority use topographic maps for hiking (71/90%), followed by ski touring (22/28%), mountain biking (17/22%), mountaineering (17/22%) and snowshoeing (7/9%).

5 Results and Discussion

Due to the high degree of automation, the integration of updated data sets, both from new terrain models and from land cover layers, is significantly facilitated and reduces the effort of map updates.

The color scheme, which is as close to nature as possible, as well as the use of high-resolution terrain models and intensive shading derived from them create a realistic map image, which simplifies the interpretation for the user. Figure 10 shows, in comparison with an orthophoto and a detail of a DAV map, how close the cartographic representation comes to nature in color and texture. In contrast to the orthophoto, the shadow areas are rendered with sufficient texture and information. Likewise, the retention of contour lines in the rock facilitates orientation in the terrain. The modulation of the color values in the light and shadow areas supports the relief impression without having a significant effect on the readability in shadowed areas. In contrast to the classic rock representation in the form of ridge lines, hachures or hair-lines, the rock representation does not appear to be superimposed on the terrain but integrated into the surroundings.

The technique of color manipulation also makes it possible to create winter representations (Fig. 6). Unlike other so-called snow sport maps, which simply supplement topographic maps with information such as ski and snowshoe routes, the topographic map maintains the impression of a winter map.

The entire process of relief and rock representation is further designed to work independently from the base data used for different scales and regions.

However, the approach requires the cartographer to have a very good knowledge of the terrain to be represented as well as the appropriate artistic talent to display the terrain as true to nature as possible. Unlike automatic methods of cartographic rock representation, the cartographer is thus able to emphasize small forms and special features of the terrain.

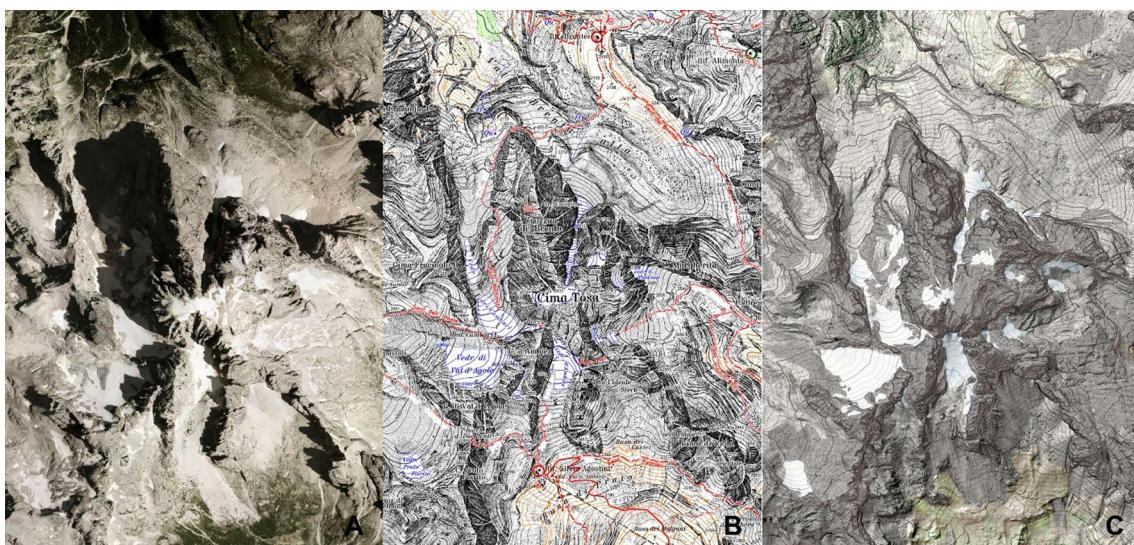


Fig. 10 Comparison with an orthophoto (A) Source: Autonomous Province of Trento <https://siat.provincia.tn.it/stem/>, the map “Brenta Group” in 1:25.000 of the German Alpine Club (© Alpenvereinskartographie, B) and the relief of map example “Cima Tosa” (C) in 1:10.000

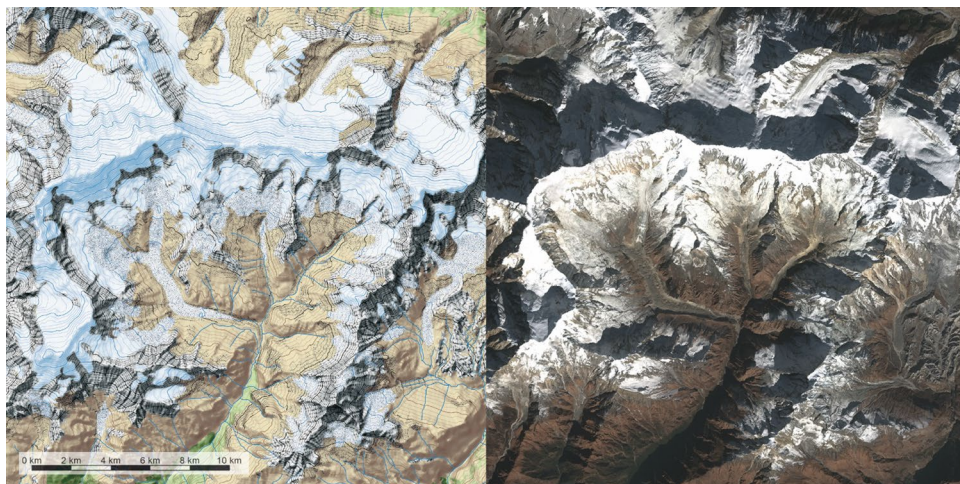
The following example (Fig. 11) of the ARGE-map “Annapurna Himal” in 1:100.000 shows the applicability of the methods of rock representation and color design also for extra-alpine areas with basic data of lower resolution. In the example, the colours of the land cover classes were strongly lightened to ensure readability.

We are convinced that the presented approach can help to lead high mountain cartography into a digital age, where the biggest challenge is not only the acquisition of accurate terrain data, especially in remote areas but their naturalistic cartographic representation. This is achieved by bringing together classical cartolithographic methods in digital implementation in combination with proven methods of remote sensing data acquisition.

In the online survey, map users were also asked what criteria are important to them when buying a map. 72 (91%) stated that the terrain had to be easy to interpret, 54 (68%) stated that the map had to be up to date, 49 (62%) maps must be available on smartphone/GPS, and 30 (38%) voted for an appealing map layout. When asked about the most important point here, 46 (58%) opted for easy interpretation, followed by 20 (25%) for up-to-dateness, 10 (13%) for availability on smartphones/GPS and 2 (3%) for the appealing map layout.

In comparison with a conventional topographical map (section of an Alpine Club map), users should decide which map section is easier for them to read or interpret in terms of terrain (steepness, type of ground: ice, rock, scree, alpine mats)?

Fig. 11 Section of the map “Annapurna Himal” (ARGE 2020) on the left, compared with ESA Sentinel-2 (2022)



Here, 65 (82%) opted for our approach and 14 (18%) for the conventional map.

When asked which map section comes closest to an aerial photo/orthophoto or best represents the terrain, the respective numbers were 57 (72%) and 22 (28%).

When asked to choose a map for a high-altitude tour, 54 (68%) opted for our map and 25 (32%) for the Alpine Club map.

When comparing the winter map to a conventional (summer) map with additional information for winter sports enthusiasts, 48 (61%) prefer the winter layout, 16 (20%) participants could not judge this and 15 (19%) participants judged saw no advantages in the winterly display.

The participants also had the opportunity to make a brief comment on the new presentation method. Of the predominantly positive feedback, 8 (10%) of participants rated the map as clear, 16(20%) praised the realistic representation and 3 (9%) praised the easy recognizability of the contour lines.

6 Conclusions

We propose a new approach for rock and relief representation. Based on its semi-automatic nature, it is time-saving in comparison to more manual methods, but also requires some knowledge of high mountain terrain as well as artistic skills. The perception of the resulting topographic maps was tested by a survey of potential users, yielding mainly positive results. The free availability of high-resolution terrain models for the alpine region for use in large-scale maps as well as the availability of terrain models with resolutions greater than 10 m for use in maps at a scale of 1:50,000 simplifies the cartographer's work. This is supported and achieved in particular by the use of automatic and semi-automatic working methods. The use of high-resolution terrain models significantly increases the richness of detail and the clarity of the terrain. The evaluation of the survey results clearly showed the users' demand for a more detailed and vivid representation of the terrain. The combination of high, detailed resolution of the terrain and near-natural coloring meets this demand. In summary, it can be said that the new method added value for the map users, particularly with regard to the interpretability of the terrain. Since a large proportion of the participants cited the ease of interpretation of a map and the topicality of high mountain maps as criteria, it can be stated that this point should be given even greater consideration in the future when creating new high mountain maps.

Acknowledgements In particular, we would like to take this opportunity to thank Mr. Herbert Winkler, who has provided us with advice and support concerning high mountain cartography. Without him, the further development of high mountain cartography in this form would not have been possible. Furthermore, we would like to thank the

colleagues of the German Alpine Association for providing the map section "Brenta Group". This work was financially supported by the Munich University of Applied Sciences HM and the German Research Foundation (DFG) through the 'Open Access Publishing' program.

Funding Open Access funding enabled and organized by Projekt DEAL. Munich University of Applied Sciences.

Data availability The image data and examples can be requested from the author.

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