11TH MOUNTAIN CARTOGRAPHY WORKSHOP

PROCEEDINGS

MAY 21-25, 2018
HVAR, CROATIA

Venue:
Hotels Pharos (rooms) and
Amfora (conference) in the City of Hvar

Organizers:
ICA Commission on Mountain Cartography
Faculty of Geodesy, University of Zagreb

Conference topics:
Topographic Mapping
Automation in Mountain Cartography
Relief Presentation
Mapping for Recreation
Mapping of Caves, Islands, and Oceans
Mapping Glaciers
Mountain Safety
Education and Storytelling
Visualization in Mountain Cartography

www.mountaincartography.org
science.geof.unizg.hr/cmc2018

Mapping for Outdoor Activities in Mountains

Proceedings of the 11th ICA Mountain Cartography Workshop

May 21 – 25, 2018, Hvar, Croatia

Workshop Organisation

University of Zagreb
Faculty of Geodesy
Zagreb, Croatia

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Cover:

View of Sv. Nikola, highest point of Island of Hvar at 628 m above sea, with participants of the workshop
(photo by Dušan Petrovič)

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Foreword

Since 1998 ICA Mountain Cartography Workshops have traditionally been held in the mountains, sometimes at elevations above 1000 meters. But with the 11th workshop in May 2018, we moved the venue to sea level, meeting on Hvar, an island off the Dalmatian coast. Here, the rocky landscape, high cliffs, peaks rising to 600 meters, steep ravines, and isolated islets with deeply indented coves reminded us that Hvar Island is in fact the top of a submerged mountain ridge, part of the Dinaric Range. The beautiful setting—white limestone rocks contrasting with blue sky and the even deeper blues of the Adriatic Sea—provided inspiration for the 44 participants from 13 countries attending the workshop. The workshop theme was "Mapping for Outdoor Activities in Mountains."

The 34 presentations found in this publication showcase the diversity of mountain cartography—from the summit of Mount Everest to the bottom of the oceans—and with many places in between. Topics include automation, recreation, caves, volcanoes, islands, relief presentation, glaciers, mountain safety, education, and visualization. Given that cartography is a graphical field, illustrations are abundant throughout. Twelve presentations are reviewed papers and ten are extended abstracts. The remaining twelve, which were published as reviewed papers elsewhere in scientific journals, are included in this volume only as short abstracts. We strongly believe that the articles offered in these pages will spur readers to further conduct research and professional activities in the field of mountain cartography.

As the commission chairs, we wish to thank the participants and contributors who have made this publication possible. Speaking for ourselves and all workshop participants, we would like to thank Dražen Tutić, Faculty of Geodesy, University of Zagreb, for preparing this valuable publication and also for hosting a well-organized workshop together with Milo Tadić, Matjaž Štanfel and Ana Kuveždić Divjak.

Dušan Petrovič, Chair, ICA Commission on Mountain Cartography

Ljubljana, Slovenia

Tom Patterson, Co-Chair, ICA Commission on Mountain Cartography

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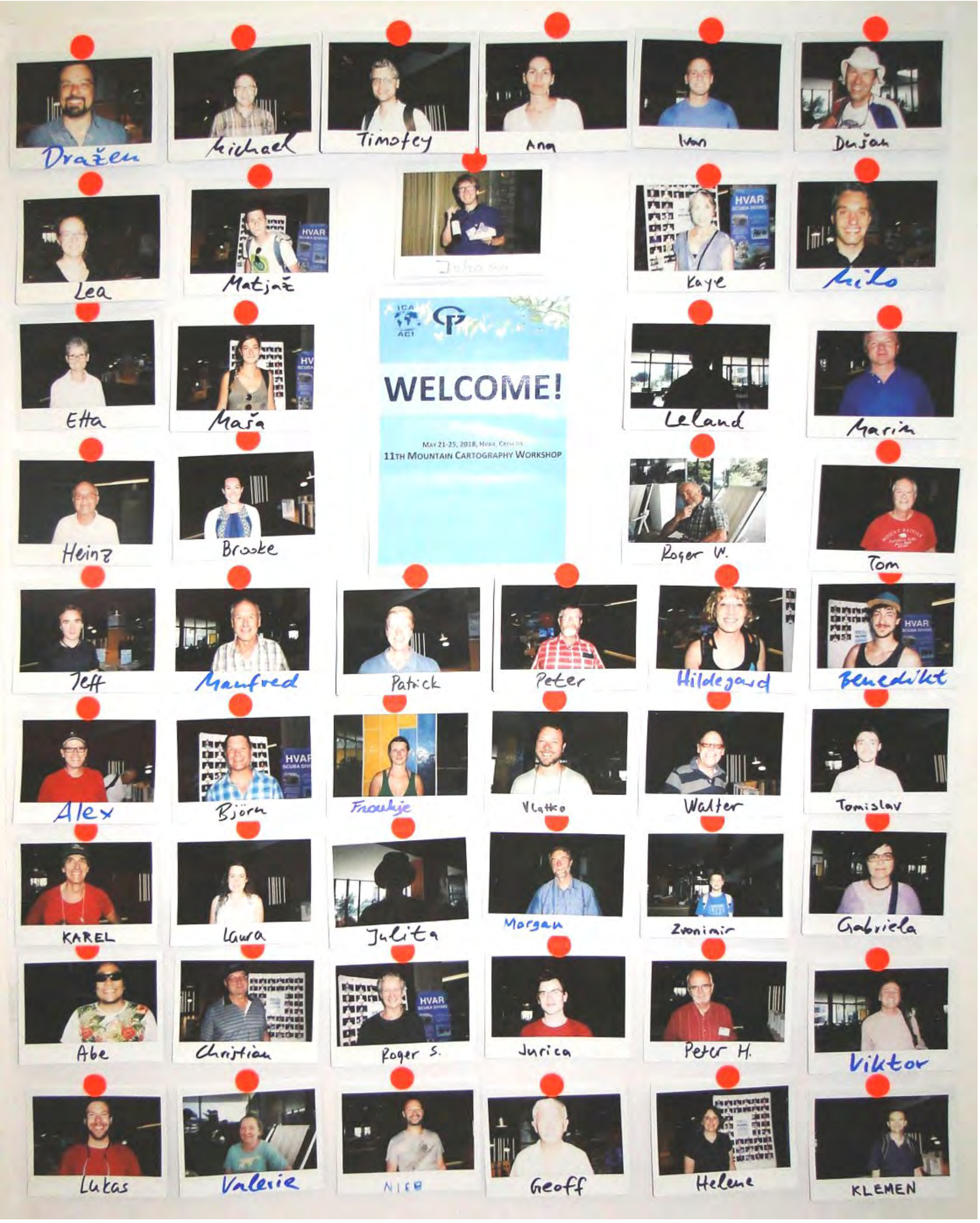
June 2019



People who made the workshop happen. Thank you all!

Welcome

At the 10th ICA Mountain Cartography Workshop held in April 2016 in Berchtesgaden, Germany, we were asked by ICA Commission on Mountain Cartography (CMC) chair Dušan Petrovič, could we make a change and organize workshop at Croatian seaside, e.g. Island of Hvar. We took the challenge, explored the opportunities and found that it could be a good place for 11th workshop. Hvar is not a big mountain and mountains are traditional places of CMC workshops. On Hvar, as one of Croatian famous tourist places, snow is considered as miracle, it has warm Mediterranean climate and highest point of 628 m above sea level. All that required that we had to design a different experience of the place. Hvar is not only about tourism, it has great nature and tradition, so we tried to bring some of these experiences closer to participants of workshop.

Workshop goals are to define the topics of mountain cartography further, to promote the methods and knowledge of mountain cartography and to demonstrate and discuss state of the art issues on practical and theoretical mountain cartography. The overall theme of this year's workshop was "Mapping for Outdoor Activities in Mountains" with the idea to address local issues in the field of mountain cartography. Two days of the workshop featured 34 presentations divided into nine sessions with following topics: Mapping Mountains, Automation, Recreation, Caves, Volcanoes, Islands, and Oceans, Relief Presentation, Glaciers, Mountain Safety, Education, and Visualization. The workshop was attended by 44 participants from the USA, Canada, New Zealand, Russia, Austria, Switzerland, Romania, Norway, U.K., Germany, Philippines, Slovenia, and Croatia.

Sveti Nikola (628 m), the top of Island of Hvar

Dušan, Milo, Matjaž and me visited Hvar in October 2017 with aim to visit on foot what we will offer to participants. It was clear that Hvar is so much more than just a tourist attraction. Hiking throughout the island reveals hidden places, unique blendings of human activities and nature, history and modern life. It was time to create a complete program and organize everything in a way that participants can experience and feel good on Island of Hvar. Milo was in charge of hotel, reservations, financies and overall structure of workshop. Matjaž was in charge for outdoor activities. For that they deserve special thanks. Big thanks to all members of organizing and scientific committee, all of them contributed substaintially to the success of the workshop. And finally, thanks to all who participated.

Four participants—Maša Arnež (Slovenia), Lukas Neugebauer and Benedikt Hajek (Austria), and Tomislav Jogun (Croatia)—were able to attend thanks to ICA scholarships for young scientists or professionals in cartography and GIScience. Thanks to this scholarships, these gifted young scientists were able to present their work at the workshop.

The Workshop began on Monday evening with welcoming remarks from the local organizer, Dražen Tutić and the commission chair, Dušan Petrovič. The program continued with welcome dinner. Next two days were reserved for presentations. Each day started with a keynote presentation, first by Alex Tait from National Geographic Society with a talk titled "Mount Everest: What is left to Map?" and second by Tom Patterson

Vrboska

from U.S. National Park Service with a talk titled "Designing 3D Terrain Maps". On Wednesday the Commission had a meeting where Dušan Petrovič delivered current agenda and issues of CMC.

On Tuesday evening participants enjoyed a mountain trivia contest prepared by Tom Patterson. Thursday was a day for outdoor activities. In the first part, participants had an option for hiking to Sveti Nikola peak or walk to nearby Hvar Observatory where astronomer Jaša Čalogović, from Faculty of Geodesy, gave a presentation of observations of the Sun that are conducted on this observatory. In the afternoon, the boat tour around Pakleni Islands offered swimming opportunity, views of the city of Hvar from seaside as well as the famous beaches which attract many tourists. The day concluded with a gala dinner. Friday was a final day for most of the participants, and after a wrap up and closing session, they departed Hvar. For those who stayed on the island, organization team prepared hiking tour from Velo Grablje to Milna and back to Hvar, and for the evening a wine tasting in village Vrboska.

More information on the workshop can be found on CMC website (http://science.geof.unizg.hr/cmc2108).

Next, 12th Mountain Cartography Workshop will be held in Snow Mountain Ranch, Colorado, USA, from April 14–18, 2020.

Dražen Tutić
Local Organising Committee
Zagreb, June 2019

Group Photos

Participants of the 11th ICA Mountain Cartography Workshop held at the Hotel Amfora, Hvar, Croatia (photo by Milo Tadic)

Winners of ICA scholarships for young scientists or professionals in cartography and GIScience (left to right: Dušan Petrovič, **Maša Arnež, Benedikt Hajek, Lucas Nuegebauer, Tomislav Jogun**, Tom Patterson) (photo by Ana Kuveždić Divjak)

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Abstracts

Mapping The Mountain

The Mapping of Mount Ruapehu

Geoff AITKEN
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Abstract. Ruapehu is arguably the most mapped mountain in New Zealand. In 1887, the first 'comprehensive' map covering Mt Ruapehu, and adjacent Ngauruhoe and Tongariro, was published to support a proposal for our first national park. Subsequent mapping, utilising contemporary cartographic developments (in the widest sense), has continuously redefined our knowledge of the mountain's geography and geomorphology, and encouraged its use for recreation by city dwellers. As an active volcano, some features have changed dramatically—some with devastating consequences. The cartographic presentation of basic mapping, recreational mapping and scientific documentation, is presented as a record and compared, as cartographic visualisation and technologies have developed over 130 years.

Keywords: *mountain mapping, cartography, history, Ruapehu, New Zealand*

1 Geography

Mount Ruapehu has been the ski playground for all the North Island since about 1913. It is four to five hours drive from either Auckland or Wellington. Skiers from both refer to it as '**The Mountain**' – as in, *"We are going to the mountain for the weekend"*.

The central North Island plateau has been created by volcanism over 350,000 years and earlier eruptions are evident around the massive Taupō caldera, the Rotorua thermal areas, and further north, the active volcano at White Island.

The ongoing activity of this stratovolcano does not deter the skiers and climbers from taking advantage of the opportunities that the elevation of Ruapehu offers.

2 Volcanism

Ruapehu, the largest active volcano in New Zealand, is the highest point on the North Island and has three major peaks: Tahurangi (2,797m), Te Heuheu (2,755m), and Paretetaitonga (2,751m). The 150m deep, active crater lake between the peaks fills with snow melt between major eruptions which occur about every 50 years. The lake temperature normally varies between 15-45 °C.

The 1945 eruption emptied Crater Lake and dammed the outlet with lava, tephra and tephra debris. The crater slowly refilled with water, until on 24 December 1953 the dam collapsed causing a lahar in the Whangaehu River which destroyed a railway bridge causing the loss of 151 lives.

There were significant eruptions in 1995 and 1996. On 18 March 2007, another dam composed of tephra only, which had been holding back the Crater Lake burst, sending a lahar down the mountain. An estimated 1.4 million cubic metres of mud, rock, and water travelled down the Whangaehu river. Highways were

closed temporarily but no one was hurt despite the lahar being twice as severe as the one in 1953.

There are fourteen seismic instruments and nine GPS units on the mountain or in the vicinity. The robustness of the natural structures containing the Crater Lake concern scientists, Department of Conservation (DOC) staff, and recreation managers, and are continually monitored. Although the basic shape of the mountain is unchanged over recent history, the 14 'glaciers' have shrunk considerably.

The intrinsic dangers on the mountain, in areas sometimes crowded with 10,000 skiers, has necessitated a comprehensive hazard assessment and the development and implementation of comprehensive risk mitigation plans (Keys 1996, Keys and Green 2008).

3 Historical Maps 1887 to 1963

In 1887, a remarkable map was produced to illustrate the proposed Tongariro National Park which resulted from land set aside by Paramount Chief Te Heuheu Tukino IV and the 'Crown', the colonial government. The map (at 1:126 720 scale) not only shows the context of the proposed park but records the state of geographical knowledge using a rarely seen graphic technique (Aitken 2014).

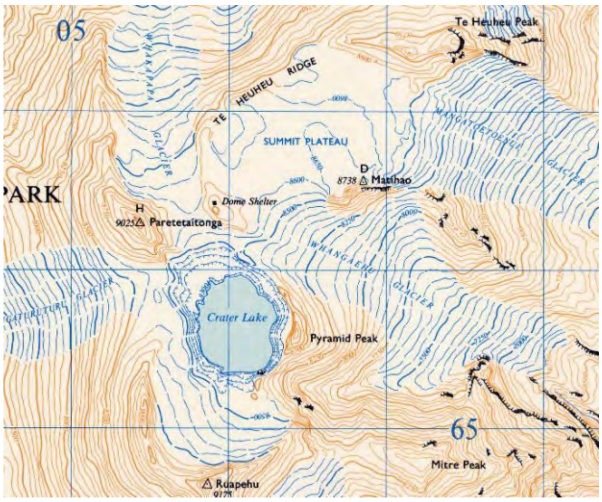
The five maps published in 1909, 1917 (2), 1924, and 1927, highlighted in red on Appendix 1, have used the same skeletal base information with minor updates, the biggest of which, in 1927, is the addition of the extended Park boundary which is similar to today's boundary. This edition has many 'land cover' notes, and tracks over mountainous terrain that are shown similarly to the main roads. (!)

A chronological list of published maps is in Appendix 1, and selected map extracts in Appendix 2.

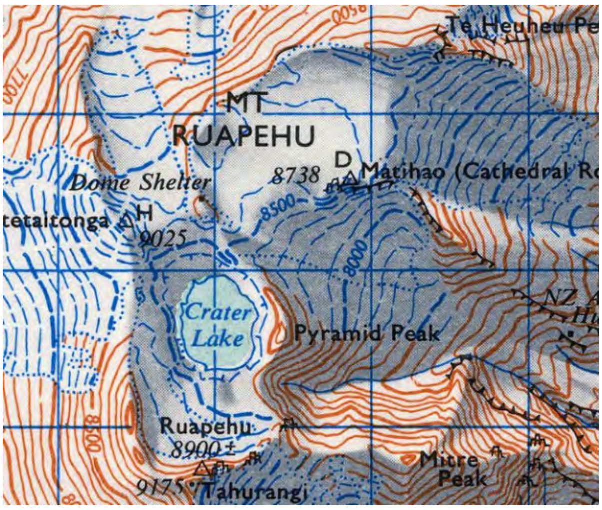
4 National Topographic Mapping

The recreational and scientific mapping of Mount Ruapehu has been based on the national topographic mapping series.

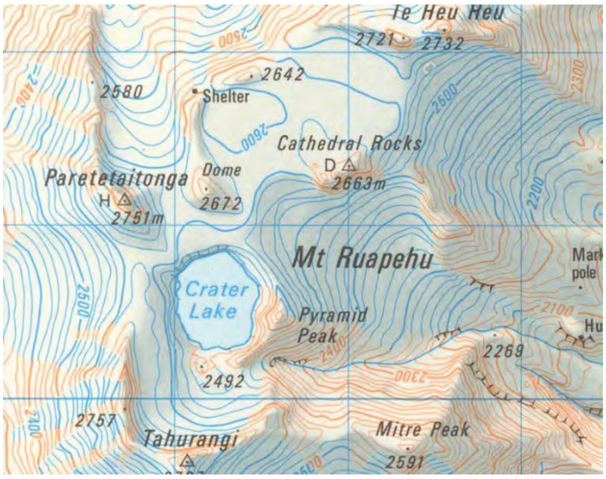
Before 1963, maps of Mount Ruapehu were based on cadastral surveys and sketch mapping. This changed when aerial photography, photogrammetry, and cartographic scribing were introduced and became standard contributors to national mapping. First, in 1963, was a map at 1:25 000 scale with fifty foot contours. This mapping was later incorporated into the first mile-to-an-inch map of the area in 1966 with 100ft contours). This mapping remained the best available until 1982 when it was superseded by 1:50 000 mapping from new photography and published on the recently adopted New Zealand Map Grid Projection. (Jupp 2011). The 1982 mapping has been the definitive source of contours for Mount Ruapehu until their redefinition 35 years later by Horizons Regional Council in 2017.



1963 - NZMS2 N122/1: Photography flown on 17 November 1957 at a nominal scale of 1:44 000. Mapped on a Wild A6 stereoplotter at 1:15 840.
Published 1:25 000 with 50ft contours. Second edition published in 1964.



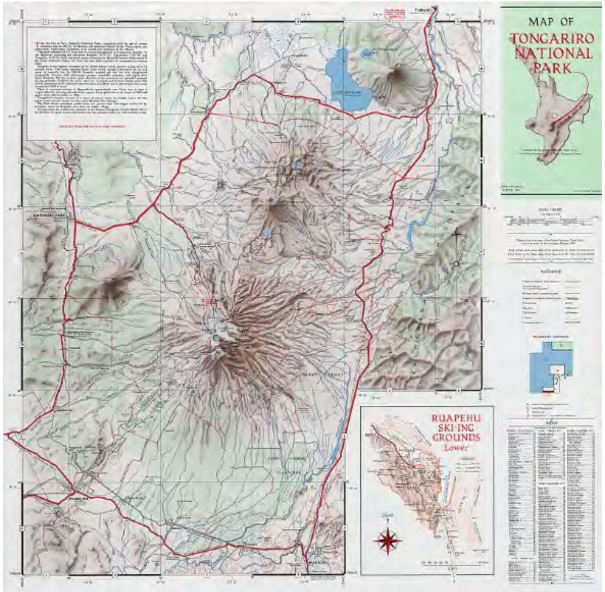
1966 - NZMS1 N122: This sheet was mapped from a range of aerial photography covering a period of 14 years, including the photography used to map the NZMS2 above. Topoplots were produced at 1:15 840, which was the standard mapping scale. This was the best available mapping until 1982.
Published 1:63 360 with 100ft contours. Second edition 1971, reprinted 1985.



1982 - NZMS260 T20: New mapping was produced at 1:25000 from aerial photography flown on 3 Jan 1975. Essentially, this mapping is still in use.
Published 1:50 000 with 20m contours. Monochrome topoplots at 1:25 000 were also available. Further editions were published in 1994 and 1997.
2009 - Topo50 BJ34: Part of the new metric series on the newly adopted NZTM projection. Same data as NZMS260 sheet T20, but with minor updates (tracks, bridges, huts etc.) over the previous eight years. No updates were made to contours.
Published 1:50 000 with 20m contours. Paper and digital editions.

5 National Park Mapping

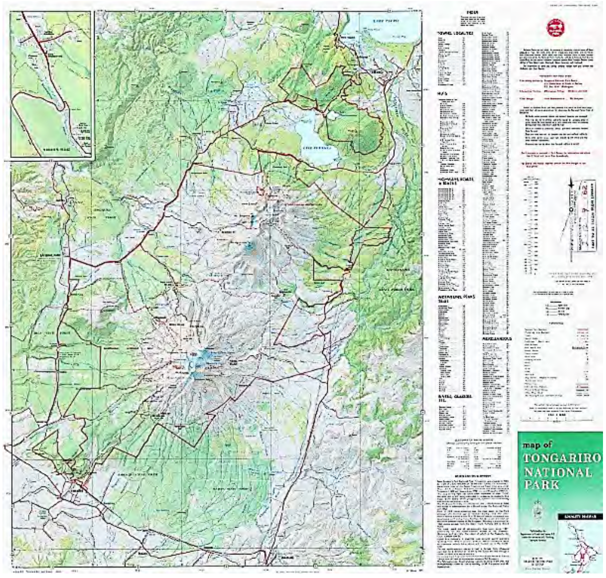
Mount Ruapehu is the highest volcano in Tongariro National Park. Since it was first gazetted in 1883, maps have been made available for both the administration of the Park and for recreational users. As better base mapping became available, and Lands and Survey (L&S) became more capable technically, and political motivation increased, L&S produced and published increasingly useful maps of National Parks. At that time, all national parks were administered by L&S, so the inspiration, compilation, and creation of this series was all in-house.



The first real 'Park Map' of Ruapehu was **NZMS150 Tongariro National Park**, published in 1958 with further editions in 1963, 1969, and 1973. This hand drawn map was at a scale of 1:80 000 with descriptive text on the reverse. The first edition featured a hand drawn relief shading in a striking brown colour with 250-foot contours on the eastern side of Ruapehu. These contours were created by plane table supplemented by aerial photographs. An enlargement of the lower Whakapapa ski slopes helped identify the positions of the 30-odd ski lodges.

Publication marked a huge step forward in visualisation and execution.

The second edition in 1963 used the same drawings but changed the relief to a neutral grey to reduce conflict with other map components. Reference is made on the map to NZMS221 Ruapehu Ski Fields and NZMS186 Walks in the Chateau Area, which were separate publications. The 1969 and 1973 editions were very similar in content and presentation. No effort was made to incorporate the larger scale map data that became available in 1966. The editions of this map are highlighted in Appendix 1 in green.

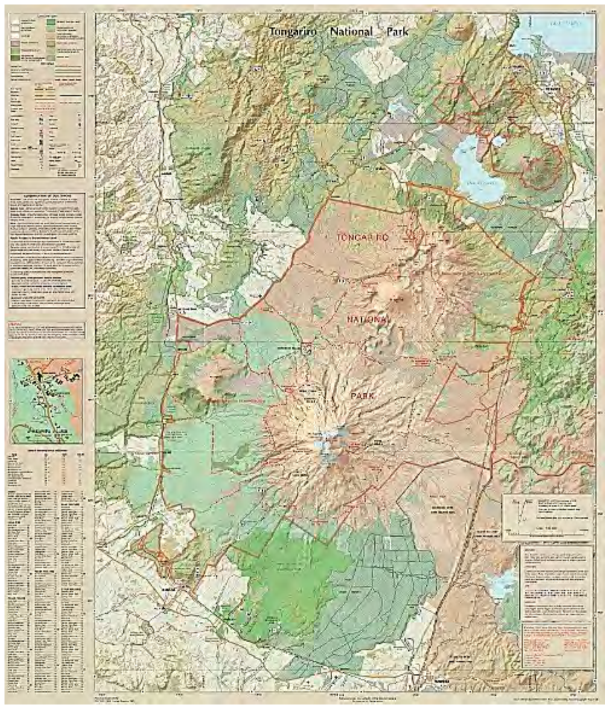


With the availability of mile-to-an-inch mapping, a more comprehensive map was developed to match increased public demand. **NZMS273-4 Tongariro National Park** was published in 1975 utilising scribing, stripping-film letter-type, and screen tints to produce a more sophisticated appearance. Again, a neutral grey relief was employed, this time supplemented by fifty metre contours. The reverse included a 1:20 000 map with 20 metre contours of the top of Ruapehu including all three ski fields. Also included on the reverse were extensive notes on huts and tracks, and an index to names featured on the enlargement.

Between 1975 and 2004 eight editions were published of this map. In 1988, the fourth edition sold 8362 copies clearly indicating its success as a public document. The 1980 and 1985 editions were almost identical in content and appearance to the 1975 edition, but in 1987 the contour interval was reduced to 40m on the main map and the scale of the ski fields enlargement increased to 1:12 500 with 20m contours. This larger scale effectively replaced the NZMS221 Ruapehu Ski Fields map which was last published in 1969. Duotone photographs were introduced on the reverse as illustrations.

In 1987 L&S was split, with the mapping functions being part of a more commercially oriented Department of Survey and Land Information (DoSLI).

The 2000 and 2004 editions of **NZMS273-4 Tongariro National Park** were different. The main map introduced twelve land cover categories to aid botanical interpretation and the reverse of the map included smaller insets of the top of Ruapehu and the Tongariro Alpine Crossing, a comprehensive text, and many coloured photographs. Maps of the ski fields were no longer required.

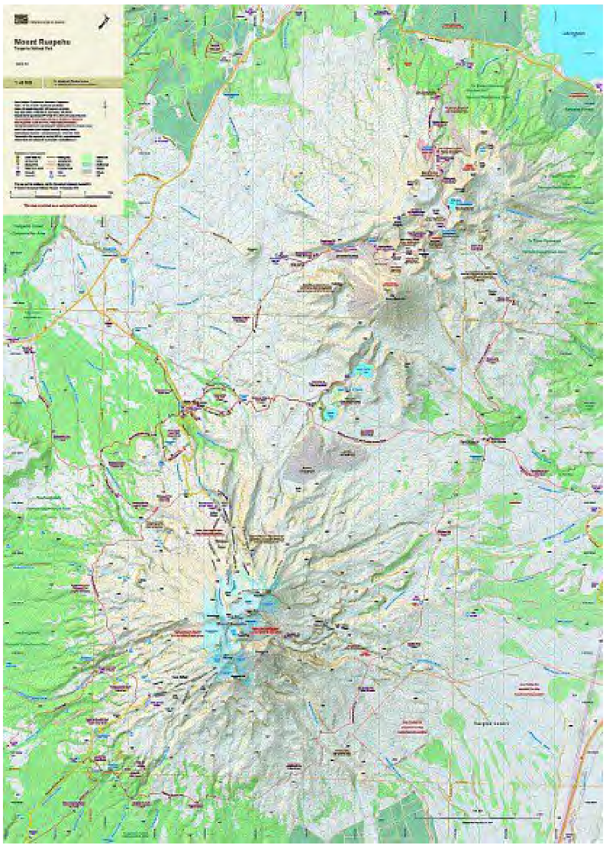


The politically directed reorganisation of government departments in 1996 led to the demise of DoSLI as a centre of cartographic excellence and forced the Department of Conservation to subcontract the production cartography of national park mapping to private companies. The 2000 edition to of the Tongariro National Park map was produced by Terralink and the 2004 edition by GeoSmart. The editions of this map are highlighted in Appendix 1 in orange.

6 The Commercial Era

Following its experience with DOC's Tongariro National Park map in 2000, and using staff that were previously employed on this work within DoSLI, Terralink published its own **Ruapehu and Tongariro Recreation Areas** map in 2002, followed by a second edition in 2004. This double-sided map showed recreational thematic information on a 1:50 000 topographic base. Some copies were printed on a synthetic paper.

In 2004 NewTopo began publishing mountain maps.



An early focus was on the Tongariro National Park with four overlapping maps at scales of 1:30 000, 1:40 000, and 1:60 000. NewTopo's map of Mount Ruapehu was first published to mark the 8th Mountain Cartography Workshop at Taurewa in 2012. All four maps sell very well indicating a real need and appreciation by the public. The base data for all four maps was derived from the original NZMS260 topographic mapping (1982) updated by whatever information is publicly available and consultation with DOC staff.

In 2013 Craig Potton Publishing published a suite of maps of DOC's 'Great Walks' with cartography by Geographx. This included a map of the Tongariro Circuit which also covered the Ruapehu Round the Mountain Track. An overview of the Tongariro National Park on an orthographic oblique projection was printed on the back.

In preparation for the 4th edition of the Mount Ruapehu map, NewTopo decided to add a composite image of the top of Ruapehu to the back of the map at 1:10 000 scale. Andrew Steffert of Horizons Regional Council provided invaluable assistance. Both summer and winter images were available. The summer image was chosen to encourage people to safely climb to the Crater Lake, or beyond to the peaks...

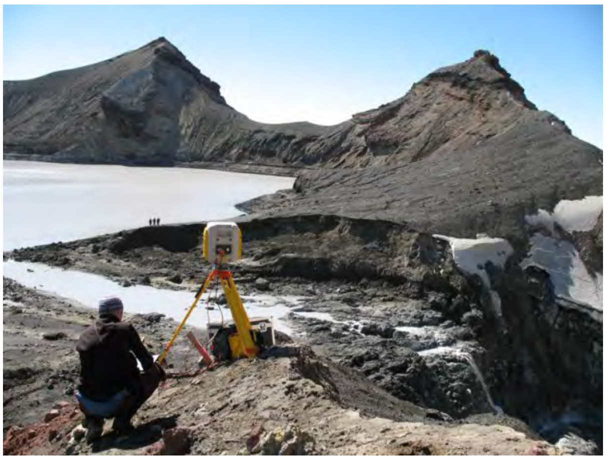
7 Visualisation and Presentation

Throughout the 130 years, the available information has been well presented by exploiting the technologies of the time. Innovation is evident in the blotchy art technique in 1887, the formal hachures of 1917, the bold relief shading of 1958, and the relatively subtle representations since 1982. Most maps have been strictly topographic though recreation-oriented editions added thematic information and text notes to the face of the map. The exception was the short-lived 2000 and 2004 editions of the Tongariro National Park map which included land cover categories.

8 Afterword

8.1 Physical Change

Although the main structure of the mountain is unchanged, the Crater Lake outlet, which is the beginning of the Whangaehu River, has changed several times. Volcanic eruptions have resulted in varying lake levels causing lahars that have caused significant flooding down the Whangaehu Valley in the past. The current outlet is over a lip of 'solid' rock and may provide a fixed lake level over the next few years.



8.2 Future Mapping

The mountain is now quite naked as the snow and ice has melted away. The top is now scientifically monitored to give warning of volcanic events and subsequent lahars which could threaten life and infrastructure. The published mapping for recreation and administration of the National Park can be expected to be maintained, adding to the continuum recorded here.

Acknowledgements

Dr. Harry Keys, DOC. Contributions to feature names. Checking volcanology text.

Chris Kinzett, LINZ (now retired). Assistance with historical photogrammetric facts.

Graeme Jupp, LINZ. Terralink background, history, and loan of the Ruapehu and Tongariro Recreation Areas map.

Andrew Steffert, Horizons Regional Council. Creation of the image mosaic and contours for the1:10 000 image on the back of the 2018 edition of NewTopo's Mount Ruapehu.

Image Sources

Maps: Map extracts are either from the Cartographic and Geospatial Resources Repository of Auckland University or the Alexander Turnbull Library, National Library of New Zealand.

Photos: P1 - Mount Ruapehu GNS Science, www.gns.org.nz.
P5 - Crater Lake outlet. Reece Gardner

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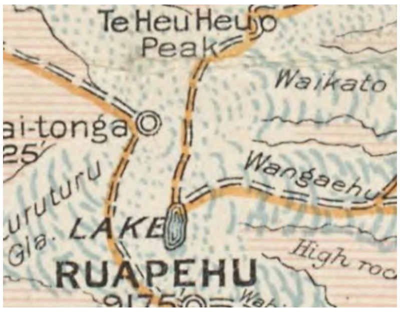
Appendix 1 Mapping Timeline for Mapping the Mountain

1887	**Proposed Tongariro National Park**	1:126 720					
1909	**Tongariro National Park**	1:95 040					
1911	**Sketch Plan of Ruapehu, etc.**	1:126 720					
1917	**Tongariro National Park**						
1917	**NZMS54 Tongariro NP**	Front: 1:126 720		Back: Enlargements of Ruapehu, Ngauruhoe, Tongariro.			
1924	**Tongariro National Park**	1:126 720		No enlargements on back.			
1927	**NZMS54 Tongariro NP**			No enlargements on back.			
1935	**Ruapehu Survey District**	1:63 360					
1958	**NZMS150 Tongariro NP**	Front:	1:80 000	pt.250ft	Back:	Text	
1963	**NZMS150 Tongariro NP**	Front:	pt.250ft		Back:	Text	
1963	NZMS2 N122-1	1:25 000	50ft	***New mapping from 1:15 840 photogrammetry***			
1963	**NZMS221 Ruapehu Ski Fields**	1:10 000	50ft				
1964	**NZMS2 N122-1**	1:25 000	50ft				
1966	NZMS1 N122	1:63 360	100ft	***New mapping from 1:15 840 photogrammetry***			
1969	**NZMS221 Ruapehu Ski Fields**	1:12 500	100ft				
1969	**NZMS150 Tongariro NP**	Front: 1:80 000		250ft	Back:	Text	
1971	**NZMS1 N122**	1:63 360	100ft				
1973	**NZMS150 Tongariro NP**	Front: 1:80 000		250ft	Back:	Text	
1982	**NZMS260 T20**	1:50 000	20m	***New mapping from 1:25 000 photogram.*** 8500ptd			
1985	**NZMS1 N122**	1:63 360	100ft	1971 edition reprinted 1985 for continuity of coverage.			
1994	**NZMS260 T20**	1:50 000	20m	2678ptd			
1997	**NZMS260 T20**	1:50 000	20m	6975ptd			
1975	**NZMS273-04 Tongariro**	Front: 1:80 000	50m	Back:	1:20 000	20m	text
1980	**NZMS273-04 Tongariro**	Front: 1:80 000	50m	Back:	1:20 000	20m	text
1985	**NZMS273-04 Tongariro**	Front: 1:80 000	50m	Back:	1:20 000	20m	text
1987	**NZMS273-04 Tongariro**	Front: 1:80 000	40m	Back:	1:12 500	20m	text, photos. 8362 sales 1988
1991	**NZMS273-04 Tongariro**	Front: 1:80 000	40m	Back:	1:12 500	20m	text, photos.
1996	**NZMS273-04 Tongariro**	Front: 1:80 000	40m	Back:	Insets: 1:40 000		text, photos, land cover
2000	**NZMS273-04 Tongariro**	Front: 1:80 000	40m	Back:	Insets: 1:50 000		text, photos, land cover
2002	**Ruapehu and Tongariro**	Front: 1:50 000	20m	Back:	1:50 000	20m	[Terralink]
2004	**NZMS273-04 Tongariro**	Front: 1:80 000	40m	Back:	insets: 1:50 000 and 1:25 000, text, photos.		
2004	**Ruapehu and Tongariro**	Front: 1:50 000	20m	Back:	1:50 000	20m	[Terralink]
2009	**Ruapehu Round the Mountain**	1:60 000	20m				[NewTopo]
2009	**Topo50 BJ34**	1:50 000	20m	***Derived from earlier 50K mapping***			[LINZ]
2012	**Mount Ruapehu**	1:40 000	20m				[NewTopo]
2013	**Ruapehu Round the Mountain**	1:60 000	20m				[NewTopo]
2013	**Tongariro Circuit**	Front: 1:40 000	20m	Back: Perspective projection of TNP.			[Geographx]
2014	**Mount Ruapehu**	1:40 000	20m				[NewTopo]
2016	**Ruapehu Round the Mountain**	1:60 000	20m				[NewTopo]
2016	**Mount Ruapehu**	1:40 000	20m				[NewTopo]
2018	**Mount Ruapehu**	1:40 000	20m				[NewTopo]

Appendix 2 Historical Mapping Sequence

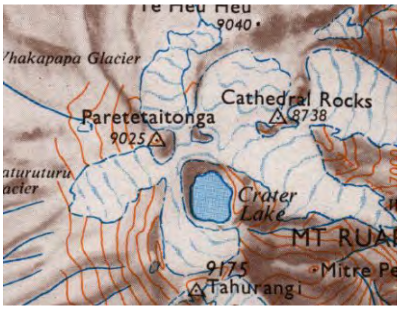
Year and scale of publication. New topographic base mapping shown in red.

1887

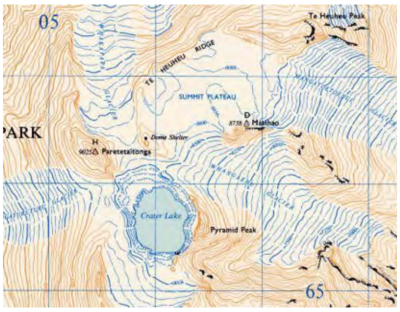


1909

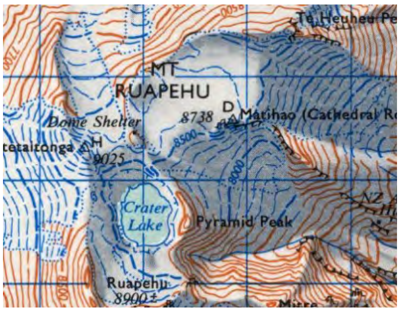
1917



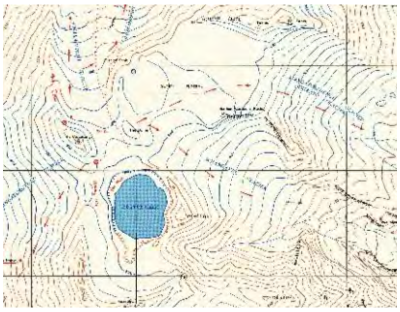
1958 1:80 000

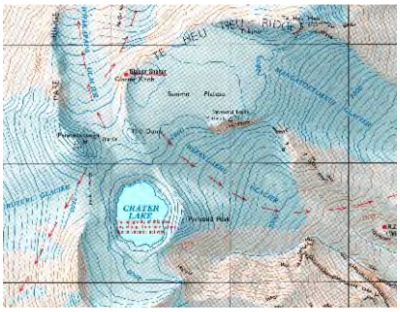


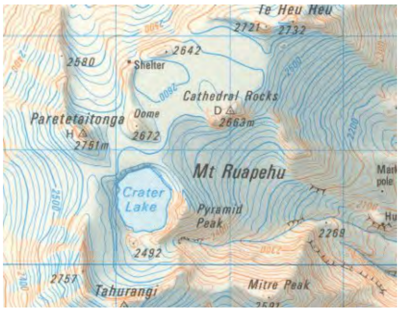
1963 1:25 000



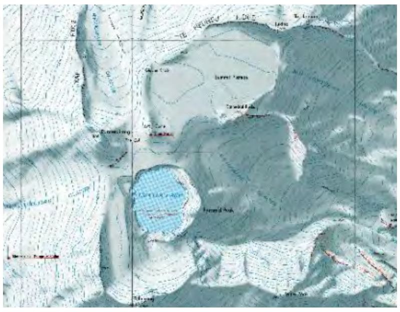
1966 1:63 360

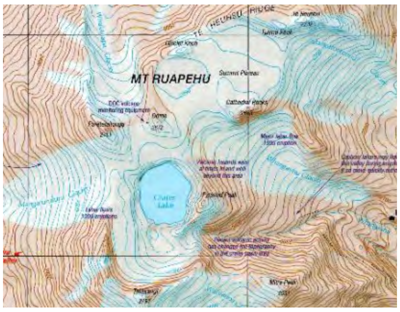

1969 1:12 500


1975 1:20 000

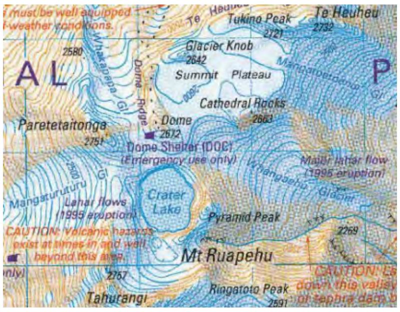


1982 1:50 000

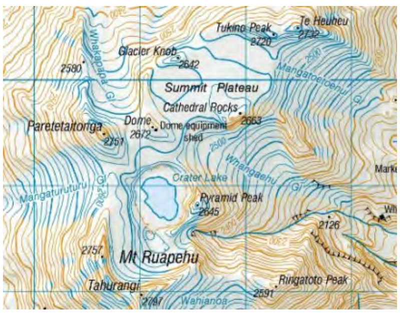

1987 1:12 500



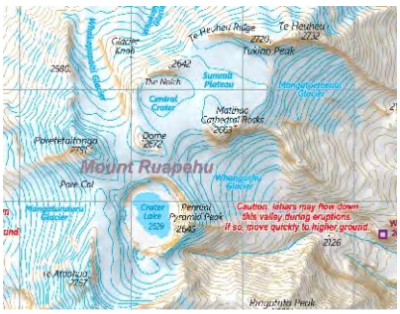
2004 1:50 000



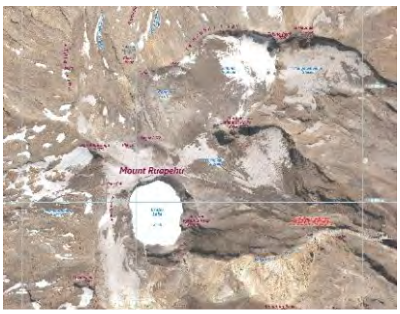
2004T 1:50 000



2009 1:50 000



2012 1:40 000


2016 1:10 000

The Art and Science of Creating a Shaded Relief Globe

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Abstract. Creating a shaded relief globe of the earth showing the continents, the isles of the sea and the depths of the oceans has been both challenging and rewarding personally as a cartographer. There has been the learning process of using the open source software QGIS, combined with Adobe Illustrator and Photoshop. The first major component or working process from using digital technology is to create and print gores to be applied on a sphere or globe. The second component is to create a handmade globe or sphere with centuries old materials and methods using papier-mâché and plaster of Paris. The third component is the application of each individual gore on the plaster of Paris surface of the sphere in perfect alignment from pole to pole. The fourth and alternative step is to hand color the gores using water-soluble color pencils, water color paints and brushes. And the finally stage is the application of a clear protective coating and mounting the completed globe on its polar axis of 23.5 degrees. The art and science of creating a shaded relief globe is a work in progress.

Keywords: *globes, Martin Behaim, Vincenzo Coronelli, digital elevation model (DEM), bathymetry, hypsometric coloring*

With the help of skilled artisans in Nuremberg, Germany, Martin Behaim created what is now the oldest surviving terrestrial globe dating back to the year 1492. Representation of the mountains began as symbols in the shape of molehills transitioning into shadow hachuring during the early centuries of globe making. However, the depicted known world had suddenly become obsolete with the voyage of Christopher Columbus to the New World, and subsequent discoveries.

Exploration, advancements in navigation, and the invention of new printing methods brought forward the Golden Age of Cartography, moving from the Middle Ages into the Reformation, Renaissance, and the Age of Enlightenment.

Figure 1: The Erdapfel terrestrial globe produced by Martin Behaim from 1490–1492 (Martin Behaim – Student Globe on iron stand – Greaves & Thomas, Globe Makers)

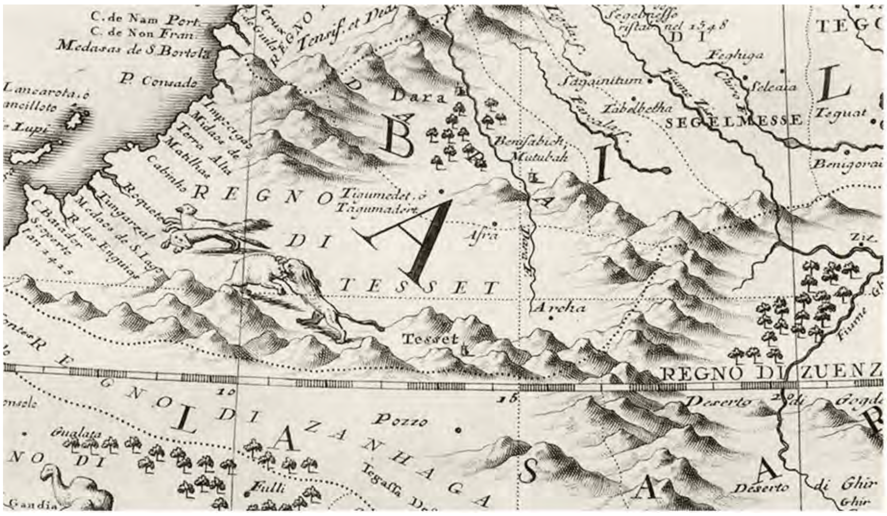

Figure 2: Vincenzo Coronelli gore made in 1688. (David RumseyMap Collection www.davidrumsey.com)

For example, Vincenzo Coronelli's terrestrial globes included hachures with variations of size and shapes of mountain symbols with the light projected from the top left and shadows placed on the lower right-hand side. Google Earth has now partially replaced the physical globe with a computer rendered Earth as a three-dimensional globe using satellite imagery and digital elevation models. We have advanced in five hundred years from creating hand-made terrestrial spheres to handling terabytes of digital data.

Cartography is defined as the art and science of making maps. Combining the art of traditional skills and the science of digital technology, these two worlds are brought together to create a physical terrestrial globe. Creating a globe is modeling the earth showing the continents, the isles of the sea and the depths of the oceans. A shaded relief globe can be created by using the open source software QGIS, commercial Adobe Illustrator and Photoshop. These became the main digital tools in the creative cartographic process. Suddenly the reality of using GIS software has also become the prime option in order to integrate historical maps with geospatial data.

Bringing together the Digital Elevation Model (DEM) data, bathymetric data and the use of hypsometric coloring yields a representation of the physical relief of the earth's surface and the ocean floor. Research for the history of globe making came with the purchase of books in English, French and German. Books written by the cartographers Eduard Imhof (Switzerland) and Erik Arnberger (Austria) became essential reading.

The William C. Wonders Map Collection at the University of Alberta has about 8,000 maps of the former Soviet Union. This is where I discovered mint condition prints of gores for making a globe in the USSR depicting world geology.

Maps of the former Soviet Union have become a fascination for me, and notably their use of hypsometric coloring to portray mountain peaks and the depths of the oceans.

But what about QGIS and the art and science of creating a shaded relief globe? Let us explore what I have been able to learn to so far. Being free to focus on QGIS

Figure 3: USSR World Geology globe gores.

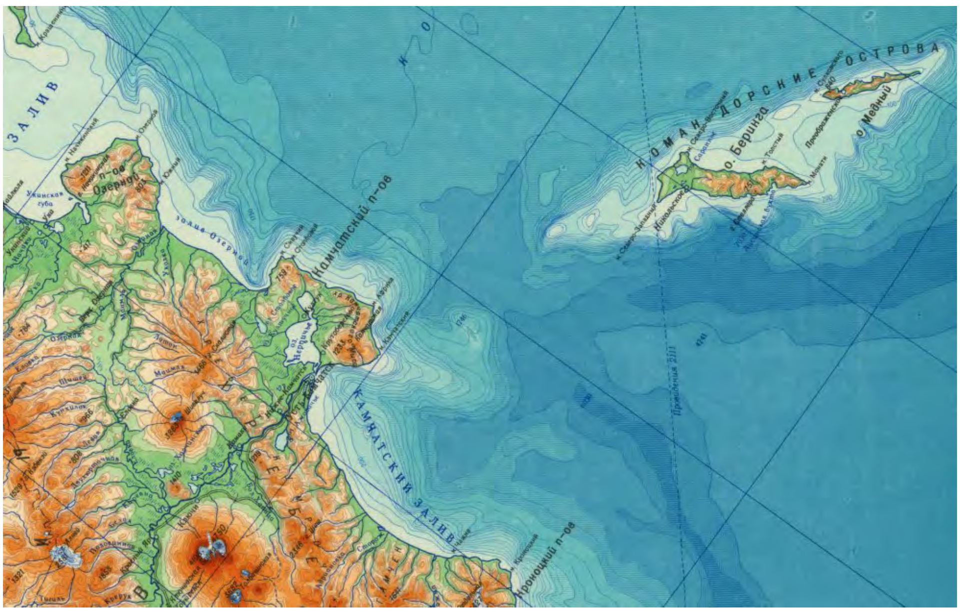

Figure 4: USSR relief map detail using hypsometric coloring.

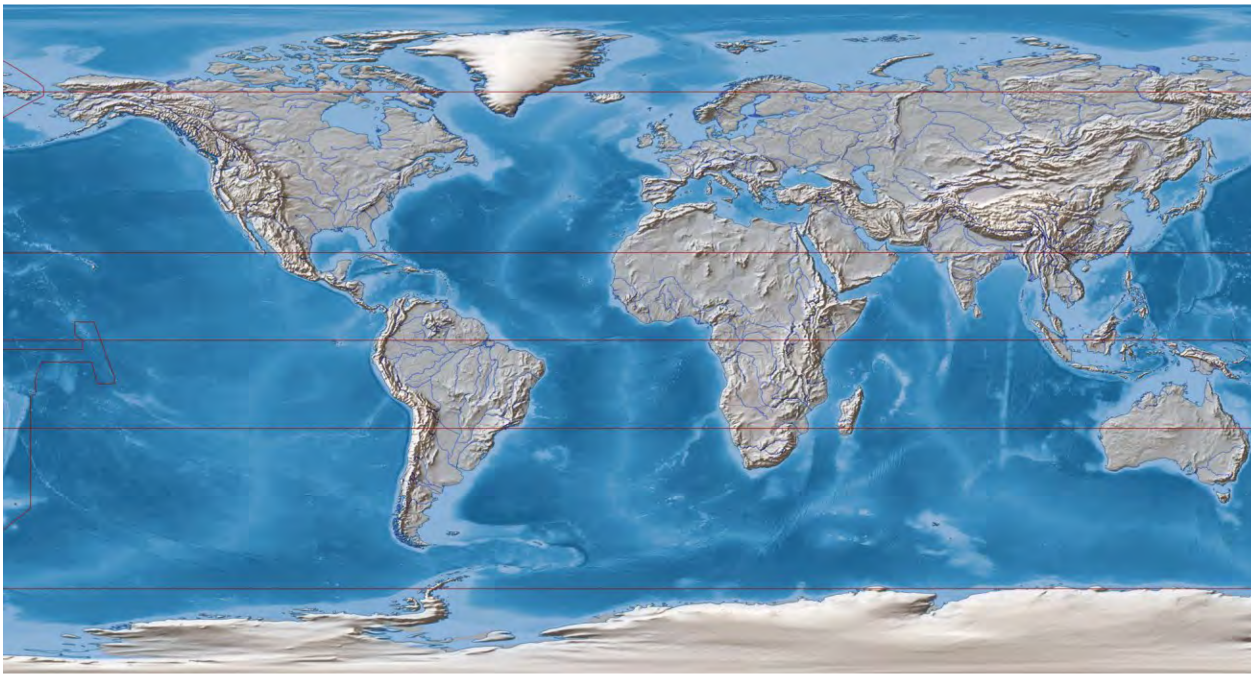

Figure 5: The ETOPO1 Ice Global Relief Model from NOAA and the 1:50 million DEM data from Natural Earth combined together.

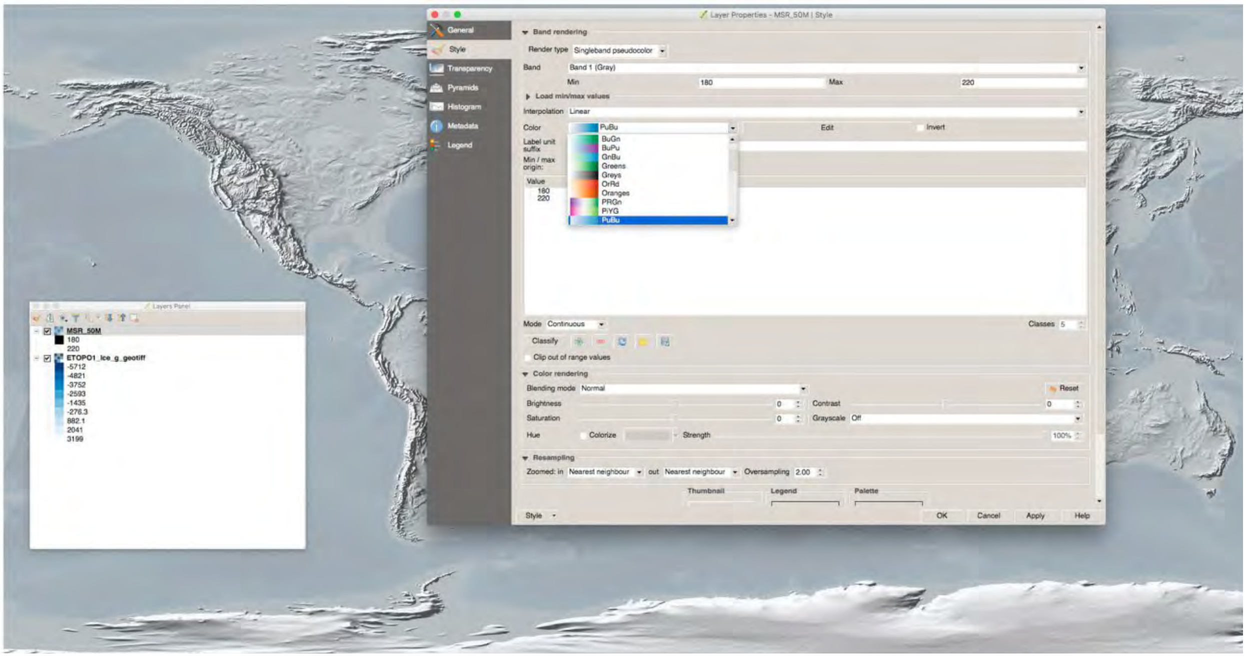

Figure 6: Colour Ramp Palette and Pseudo-color within QGIS.

for globe making occurred only two days before traveling to Europe to attend the 11th Mountain Cartography Workshop in Hvar, Croatia, 2018. This delay was caused by a pressing mapping project deadline prior to attending the workshop.

The following steps were implemented in QGIS in order to create a globe:

Generalization of lines (coastline)
Colour ramp palette (pseudo-colors)
Gores (with shaded relief)

The ETOPO1 Ice Global Relief Model from NOAA and the 1:50 million DEM data from Natural Earth were utilized.

Dražen Tutić, of the University of Zagreb, Faculty of Geodesy, Croatia, created a tool or plugin for the Generalization of Lines in QGIS. Generalization has always been a challenge in cartography and more so in the GIS world. With the help of Tutić's creative knowledge in QGIS, I began to learn the processes that can be found in QGIS.

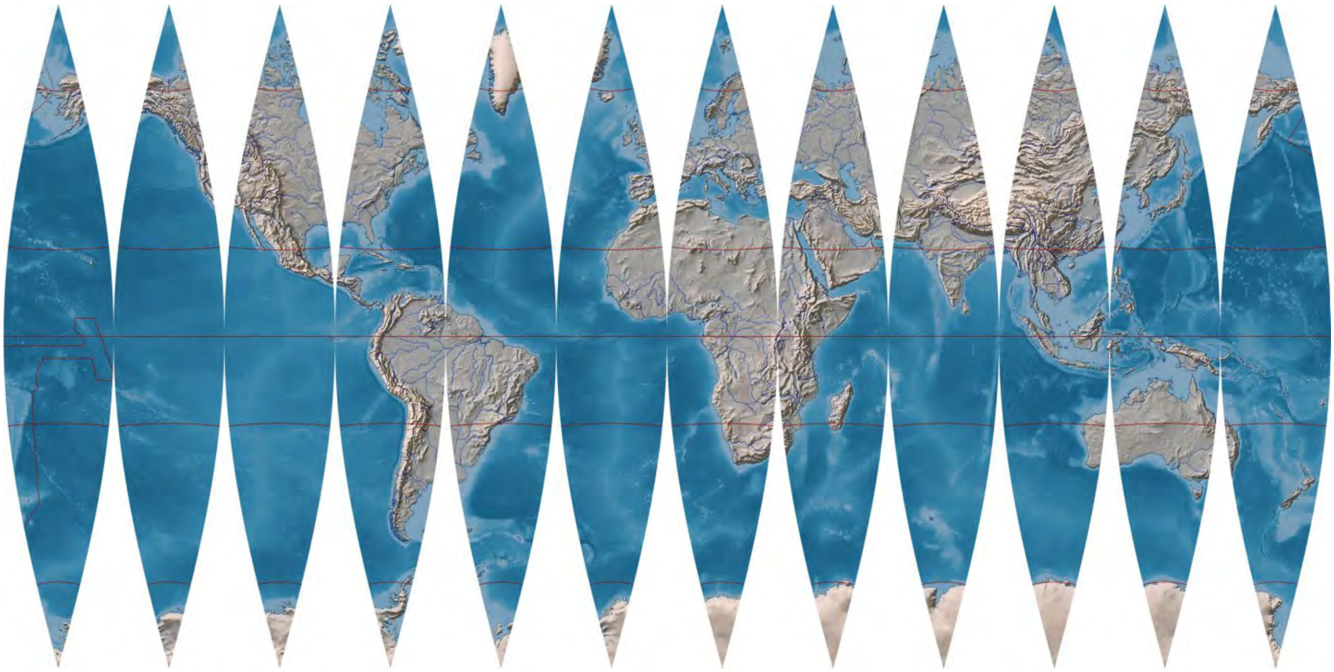

Figure 7: Shaded relief World Map with 12 gores created using Photoshop plugin Flexify 2 by Flaming Pear.

Prior to using QGIS, I used the Photoshop plugin Flexify 2 by Flaming Pear to create the gores. The finished shaded relief map from QGIS was a high-resolution image imported into Flexify. Various methods of globe making were experimented with, following historical research and consulting with various globe makers and historians in Europe. The application of the hand cut gores onto a papier-mâché and plaster of Paris globes or spheres became an arduous learning experience.

An apprenticeship with a professional globe maker requires at least a year.

The Mountain Cartography Workshop takes place every two years and by the next workshop in 2020, I hope that the end result will be a shaded relief globe: a satisfactory globe that would be noteworthy to display before fellow cartographers. It is not a spinning earth in virtual reality, but a shaded relief globe with printed gores: a globe representing the earth, mounted and rotating on its polar axis of 23.5 degrees. But for now, my globe making project is a work in progress.

After studying the history of globe making in Europe, it was decided that two wooden spheres would be made (17.78cm & 25.4cm in diameter) by a local wood turner. The purpose for this was to create a negative mold from the wooden sphere.

A gypsum - cement mold was made with the help of a good friend Wayne Jeanotte and his Wayne's Workshop. The mold is to be used for making two hemispheres of papier-mâché and plaster of Paris. The two hemispheres are then glued together forming a sphere on a central shaft or polar axis to which the gores are adhered. The caps that cover the poles of the globe are called "calottes" which means a plain skull cap.

Figure 8: A gypsum - cement mold created as a negative mold from a wooden sphere made by a wood turner.

Returning to hypsometric coloring in globe making, not all creative cartography has to be done in the world of digital computers. Hand painting a globe is an art and science. This artistic method is used by the few remaining globe makers in the world. I have returned to the traditional world of being creative with human hands, just as cartographers such as Eduard Imhof, used their hands to be creative in cartography in the past. As a youth in the 1960s my Aunt Edith gave me coloring pencils made in Switzerland. Recently, I have purchased a set of Caran d'Ache, Swiss-made water-soluble color pencils.

This will be most useful in the creative process in the near future of my globe making endeavors.

Creating a traditional hand-made globe combined with digital technology is no easy task to perform.

This has become a work in progress project well after the Mountain Cartography Workshop in Hvar, Croatia 2018.

I quote the following inspiring words. *"No matter how old we become, we can acquire knowledge and use it. We can gather wisdom and profit from it. We can grow and progress and improve – and, in the process, strengthen the lives of those within our circle of influence."* Gordon B. Hinckley – *"Standing for Something"* 2000.

And in conclusion here are the words of a famous New Zealander and mountain climber. *"It is not the mountain we conquer, but ourselves"* Edmund Hillary.

Acknowledgements

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Stew Bremner, The Wood Turner, Spruce Grove, Alberta, Canada

James Bissell-Thomas, Greaves & Thomas Globe Makers, Ryde – Isle of Wight, United Kingdom.

Chris Adam, Lander and May Globe Makers, Cowes – Isle of Wight , United Kingdom

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Mapping the Mountains and Glaciers of South Georgia

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Abstract. It had been 14 years since publication of the last comprehensive map of South Georgia and there was great need for new data and a new map of the region. A double-sided map showing South Georgia at 1:200 000 scale and the Shackleton Crossing route at 1:40 000 and 1:25 000 scales was produced to fulfil the requirement. The data production required specialised knowledge of data availability and mapping in the Polar Regions; some of the data still have known errors and limitations, but the data were a large improvement on what was previously available. The new map has been very successful since its publication in 2017. The map has already had its first re-print and the addition of the reverse Shackleton Crossing map gathered interest from a wide-ranging audience. The map will be updated and edited as and when needed, with the availability in accurate data hopefully ever-increasing.

Keywords: *South Georgia, map production, topographic mapping, glacier change, digital elevation model, rock extraction*

1 Introduction

South Georgia is a remote island 170 km in length and between 2 and 40 km wide, lying 1700 km south-east from the tip of South America in the South Atlantic Ocean (Figure 1). It is a mountainous island and the highest peak is Mount Paget, near the centre of the island, at 2934 m. More than half of the island is permanently ice covered and it is has numerous ocean-terminating glaciers, with glacial plumes providing nutrients to the surrounding ocean. South Georgia is part of British Overseas Territory and is managed by the Government of South Georgia and South Sandwich Islands. There are two permanently occupied research stations, King Edward Point and Bird Island, both of which are operated by British Antarctic Survey (BAS). South Georgia has a history of whaling and sealing and there are seven disused whaling stations still on the island, in varying states of disrepair. The island is also known for the Shackleton Crossing; Ernest Shackleton and his men made the first crossing of the island in 1916 after having their boat crushed in sea ice in the Weddell Sea. It is of global significance today for its wildlife and position in the Southern Ocean ecosystem; it is home to around five million seals and 65 million pairs of breeding birds and the surrounding seas are of vital importance for migrating whales and fish. The government manage sustainable fisheries and one of the world's largest Marine Protected Areas (MPAs), surrounding the island, was designated in 2012. Tourism is another important activity on South Georgia and cruise ships and landing permits are strictly managed by the government.

The first complete map of South Georgia was produced in 1958 and was based on triangulation surveys and overland mountaineering travel. The island has no airstrip and it is over 1300 km from the nearest other air facilities on the Falkland Islands, meaning that there has never been a systematic aerial photography survey.

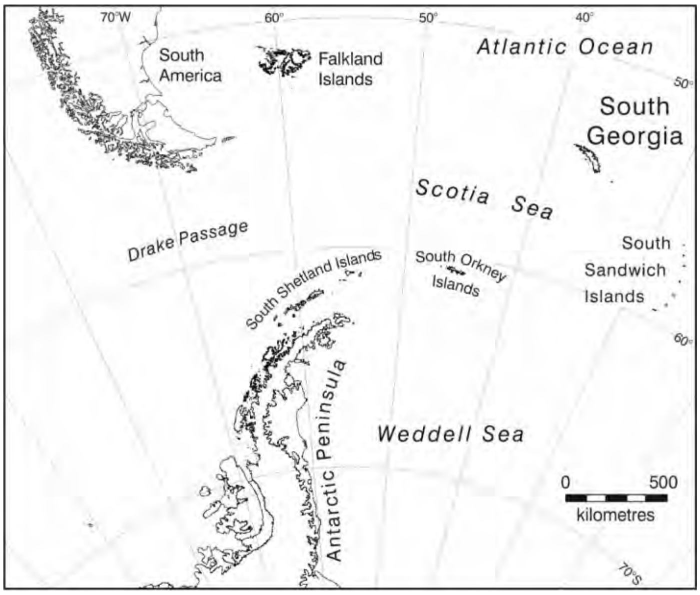

Figure 1: Location of South Georgia at 54°30' S and 36°30' W in the South Atlantic Ocean.

Small areas have been photographed from helicopters operating from ships, but before the satellite era it was extremely difficult to survey and map. The next map after 1958 was published by British Antarctic Survey in 2004 at 1:200,000 scale and was based largely on a 2003 Landsat 7 image. Since that time there has been significant change around South Georgia, with Neumayer Glacier having retreated by over 6 km, for example. Many new bays, coves and islands have also been formed, and a new, more detailed and more up-to-date map was needed for managing activity on the island, including scientific and tourist visitors. The new map is double-sided and includes detailed mapping of the Shackleton Crossing route on the reverse. Many people attempt this route every year and, although it is known to be dangerous, there has never been a map of the route. This paper will mainly cover the methods and results for the South Georgia map and not the reverse Shackleton Crossing map.

2 Data Sources and Methods

2.1 Digital Elevation Model

A new Digital Elevation Model (DEM) was needed to produce contours and a hillshade for the new map. Some automatically produced DEMs work well on high-contrast surfaces such as rock and some work well over ice (Fretwell et al., 2013), but no single product works well over both surface types and it was therefore known that we would have to use multiple sources for the DEM. The resources available to use were the ASTER Global Digital Elevation Model (GDEM) v2 with data collected between 2000 and 2010 available at 1 arc second cell size, Shuttle Radar Topography Mission (SRTM) DEM data at 2 arc second by 1 arc second cell size collected in 2000, and five high-resolution (2-5 m) DEMs created in-house at BAS through rigorous photogrammetry between 1998 and 2017. All of the data processing was performed in ArcMap 10.4.1.

GDEM is available for the whole of South Georgia and initial examination of the data showed significant areas of low quality data over areas of ice and snow. We used the quality assessment file available with each DEM file to remove areas of 'low' quality data – this file represents the stacking number, the number of independent DEMs which have been used to create the elevation value of each pixel, and areas with low numbers are considered lower quality. There is not an exact cut-off point between low and good quality data and some experimenting was required to find a suitable cut-off point to use when removing data. The result of this was a DEM covering the whole region, with holes where the low-quality data had been removed. A polygon was created around the remaining GDEM areas and a buffer of 200 m was made around these polygons. SRTM data at 2 arc second by 1 arc second spatial resolution was used to fill the remaining empty areas not covered by GDEM or the polygon buffer. The result of this was GDEM data covering most of South Georgia, small empty areas where the buffer polygon area was present, and SRTM data filling the holes. These two data sources were then merged together using the Topo to Raster tool in ArcMap at 20 m resolution and using the

WGS84 / South Georgia Lambert Conformal Conic projection. The buffer between the two data sources acted to ensure there were no sudden steps in the elevation when they were merged together.

The five high-resolution photogrammetric DEMs available to use were of higher quality and spatial resolution than the GDEM/SRTM DEM just created. The DEMs were of varying resolution (2-5 m) and so they were downsampled and mosaicked together at 20 m resolution, to match the resolution of the newly created DEM. Buffer polygons were again created around these areas at varying distances. A distance of 200 m was used in general, but where there had been large changes in elevation due to glacier retreat and drops in elevation, a larger buffer of between 400 and 800 m was used. The difference in elevation was due to the different acquisition dates and the difference in quality between the data sources. These buffer polygons were then used to erase areas of the GDEM/SRTM DEM, leaving two main datasets which needed merging together (Figure 2). The GDEM/SRTM and the higher resolution areas were both converted to points and then merged together using the Topo to Raster tool in ArcMap. The resultant DEM was a seamless DEM of the whole of South Georgia at 20 m resolution.

2.2 Hillshade

Although every care had been taken to produce a DEM of the highest possible quality from the data sources available, when a hillshade was produced using the Hillshade tool in ArcMap, there were still many areas that contained artefacts. SRTM data is sometimes noisy, and resulted in a 'bumpy' looking hillshade over large flat areas of ice. In order to remove some of this noise, the Focal Statistics tool was implemented on the DEM to smooth some of the erroneous noise. A hillshade was then created using the Hillshade tool in ArcMap, with a Z or exaggeration factor of 1.2. This factor was chosen to slightly exaggerate some of the terrain for cartographic effect, but to keep it as natural looking as possible. The resultant hillshade was then manually edited in Adobe Photoshop to smooth any remaining artefacts of the lower quality source data.

2.3 Contours

Contours were generated at 100 m intervals and smoothed slightly using the Smooth Line tool in ArcMap, with the Bezier Interpolation smoothing algorithm. There were some clear errors in the contours. In places, contours were left dangling in areas where glaciers had retreated significantly since the acquisition date of the source DEM data. Although the coastline had been used as a break-line when producing the DEM, it had not resolved all of these issues. A few more areas had errors where the contours generated from the DEM did not match known spot heights. This was due to low quality GDEM data on steep, shadowy slopes. In order to overcome both of these problems, approximate contours were added to the contour shapefile using knowledge of the terrain and following the typical shape of glaciers.

2.4 Ice-free Areas

A dataset showing the location of rock outcrop, moraine and ice was required for the map and this was produced by following the method of Burton-Johnson et

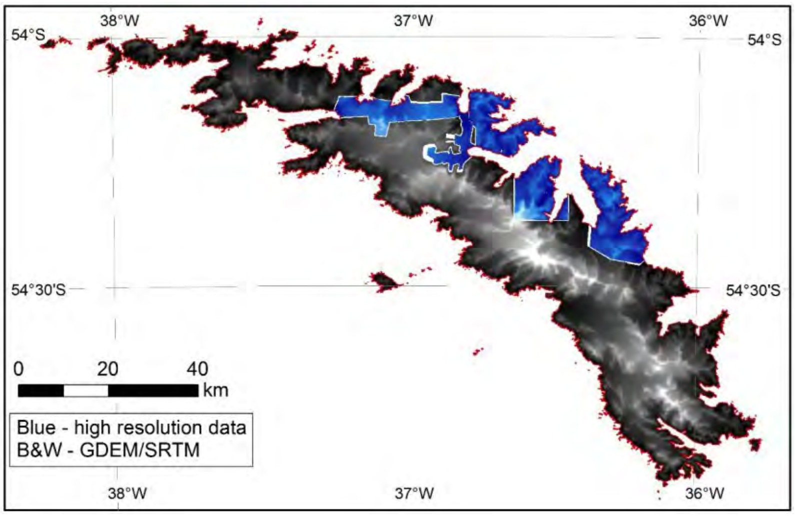

Figure 2: The two main datasets used to create the seamless DEM of South Georgia. The empty buffer areas can be seen in between the datasets, ensuring that they merged together without large steps.

al. (2016), which classifies satellite imagery to extract these features. The Normalized Difference Snow Index (NDSI) is commonly used for mapping snow extent (Dozier, 1989). However, this method is less successful in high-latitude areas, where there are shaded areas caused by low sun angles (Burton-Johnson et al., 2016). The method from Burton-Johnson et al. (2016) uses the NDSI but adapts it to work more accurately at higher latitudes by combining separate algorithms that divide the image into many different spectral components. This method was used on an almost entirely cloud-free Landsat 8 image of South Georgia from 22nd February 2016. The threshold for distinguishing rock from ice is not a set number and this took some work to find the best level for this particular Landsat image, but once this was set then the method, in general, worked fairly well.

The main problem was distinguishing rock from moraine, a limitation acknowledged by Burton-Johnson et al. (2016), but not seen as a large problem for their work due to limited moraine in Antarctica. Another limitation of the method is the pixel size of the Landsat image – 30 m; the resultant output was also 30 m pixel size. Both of these limitations resulted in some manual editing of the output being necessary. The 30 m pixel size was not a large problem over most of the area and was suitable for the 1:200 000 scale map but it did cause a problem around the coastline, and the data was edited to fit the coastline so that we did not have overhanging areas, or small empty gaps in between the rock and coastline. The moraine/rock distinction needed more work to manually refine the moraine areas.

2.5 Bathymetry

Bathymetry for the map was produced from a 100 m DEM from Hogg et al. (2016); this DEM was smoothed and reclassified to produce a polygon shapefile required for the map. There were a few errors with the dataset, with many headlands appearing to be in water deeper than 100 or 200 m, likely due to interpolation across data gaps in the DEM. These errors were fixed manually edited to avoid portraying obvious faults on the map.

2.6 The Shackleton Crossing Map

This paper focuses predominantly on the whole-island South Georgia side of the map, but a few details of data and methods for the reverse Shackleton Crossing map are given here. All data for this side were produced from Very High Resolution (VHR) satellite images obtained from DigitalGlobe. Contours, hillshade and spot heights were constructed from a DEM that was created by rigorous photogrammetry on stereo-pairs of VHR images. The extent of rock, ice and blue-ice areas were manually digitised from the VHR images. A cross-section of the route was also created from the DEM by extracting an elevation profile in ArcMap.

3 Map Production

The majority of work for the map was carried out in ArcMap, including making a splined label shapefile for place names. The data and layout was then transferred to CorelDRAW Graphic Design software where the final editing was completed. BAS has a general style for published maps, which was followed for this map. The page size was 1000 x 890 mm, the map scale was 1:200 000 and the datum and projection used was WGS84 / South Georgia Lambert Conformal Conic. The surface (rock, ice, moraine) layer was overlaid onto the hillshade with a 50% transparency applied, allowing the hillshade to be seen. An extract of the map can be seen in Figure 3 where it is possible to see the splined labels, the semi-transparent surface layer, and an example of the approximate contours shown as a dashed line at the front of Nordenskjöld Glacier, one of the glaciers which had retreated and left dangling contours. The map was printed by Dennis Maps in Somerset, UK on weather-resistant paper with a hard, card cover for the folded versions, using a KBA 162a large format printing press.

4 Map Reach

The map is now available for sale in many map stores in both the UK and further afield, including Stanfords in London. Over 1500 copies have been sold since July 2017 (as of July 2018) and the map release was featured on the BBC news website as well as on BBC Radio Wales' morning show, with the presenter being a big fan of the Shackleton Crossing story. All of the data from both sides of the map are available to view, query and download from the South Georgia GIS (www.sg-gis.gov.gs) and there has been a lot of interest in this newly updated data.

Figure 3: An extract of the South Georgia 1:200 000 scale map with King Edward Point Research Station shown in King Edward Cove.

Acknowledgements

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Mountain Maps in the New 2017 Edition Swiss World Atlas

Concept, Content, and Added Value

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Abstract. The new edition of the printed Swiss World Atlas was published in June 2017. This school atlas is the most used atlas in Swiss secondary schools (grades 7 – 13). Since the last edition in 2010, the atlas was completely restructured, revised, and updated with a contemporary design. Map formats are now standardised and the layout is more appealing. The atlas content has been supplemented with new sections, including a comprehensive introductory chapter that covers topics such as geo information, map projections, map types and structure, and map use competencies. Maps and thematic topics are listed in a clearly structured table of contents. In addition, extensive geographic name and subject indices make for easy atlas navigation. The 256-page book is completed by a fold-out general key and an attractive overview of countries showcasing their national flags. Among the 430 maps and illustrations in the new Swiss World Atlas, there are numerous new and revised mountain maps. This paper focuses on four newly designed mountain maps to illustrate the diversity of this map type and their content, concept and special characteristics. The map examples include the Bernina Mountains (Switzerland), Mount Kilimanjaro (Kenia/Tanzania), the Hawaiian Archipelago (USA), and Mount Everest (Nepal/China). Besides topography, the following thematic aspects are highlighted: touristic activities, climatic factors, vegetation aspects, socio-cultural or economic structures, temporal development of human actions and their impacts. Finally, the added value of these thematic combinations for teaching purposes is discussed.

Keywords: *mountain map, school atlas, geo information, secondary school level*

1 Introduction

1.1 The New Edition 2017 of the Swiss World Atlas

Since 1910, the Swiss World Atlas is the most used printed atlas in Swiss schools at the secondary school level (7th through 13th grade) (Swiss World Atlas 2017). It has been published in accordance with the geographic education needs set by the Swiss Conference of Cantonal Ministers of Education (EDK). The other participating institutions are the Institute of Cartography and Geoinformation at ETH Zurich for the editorial work, and the Lehrmittelverlag Zurich for the marketing and distribution.

The new Swiss World Atlas was published in June 2017 (Fig. 1). It provides a map collection dealing with different kinds of physical-geographic features and social-economic phenomena for Switzerland and Europe, other countries, continents, large regions, and the

Figure 1: The new edition 2017 of the Swiss World Atlas, published in the three official Swiss national languages German, French, and Italian.

world. Based on an exemplary approach, over 430 maps and illustrations of different geographic extent, scale, and thematic content are available in the atlas. The new edition of the atlas is available in the three official Swiss national languages German, French and Italian.

1.2 Concept and Changes

The conceptualization of the new Swiss World Atlas 2017 was partially constrained by the previous edition in 2010. These constraints dictated the number of pages, the paper format and, at a technical level, reliance on the same printing process with six special atlas colours. In many other respects, the 2017 edition has been completely redesigned, restructured, and updated.

For the didactic concept, the new curriculum for secondary schools and the framework curriculum of the Swiss Conference of Cantonal Ministers of Education (EDK) for elementary schools had to be considered (EDK 2018). The skills-oriented approach for these curricula is explicitly apparent in the new introductory chapter (see below).

The Swiss World Atlas has been updated with a new contemporary design. For example, the general layout has been made more appealing by using a new colour scheme in red, white, brown and grey. In addition, significantly more white space was included in the page margins and between maps or paragraphs. The new design of the front cover with a red globe on a white background is certainly the most recognisable element of this 'face-lifting'.

The 256-page book exhibits a modified atlas structure, a revised map sequence, and new atlas parts. It has been supplemented with a clearer table of contents page and topic list, as well as more comprehensive name and subject indices. New features include navigation aids, such as globes with overlaid map frames and side tabs, a fold-out general key, and a country overview (organised by continent and illustrated with national flags).

The completely new introduction is a highlight of the newly added content (Fig. 2). Taking up 14 pages, it explains the principles of spatial geo-information or cartography, and encourages a skills-oriented approach to working with maps. Specific topics covered in

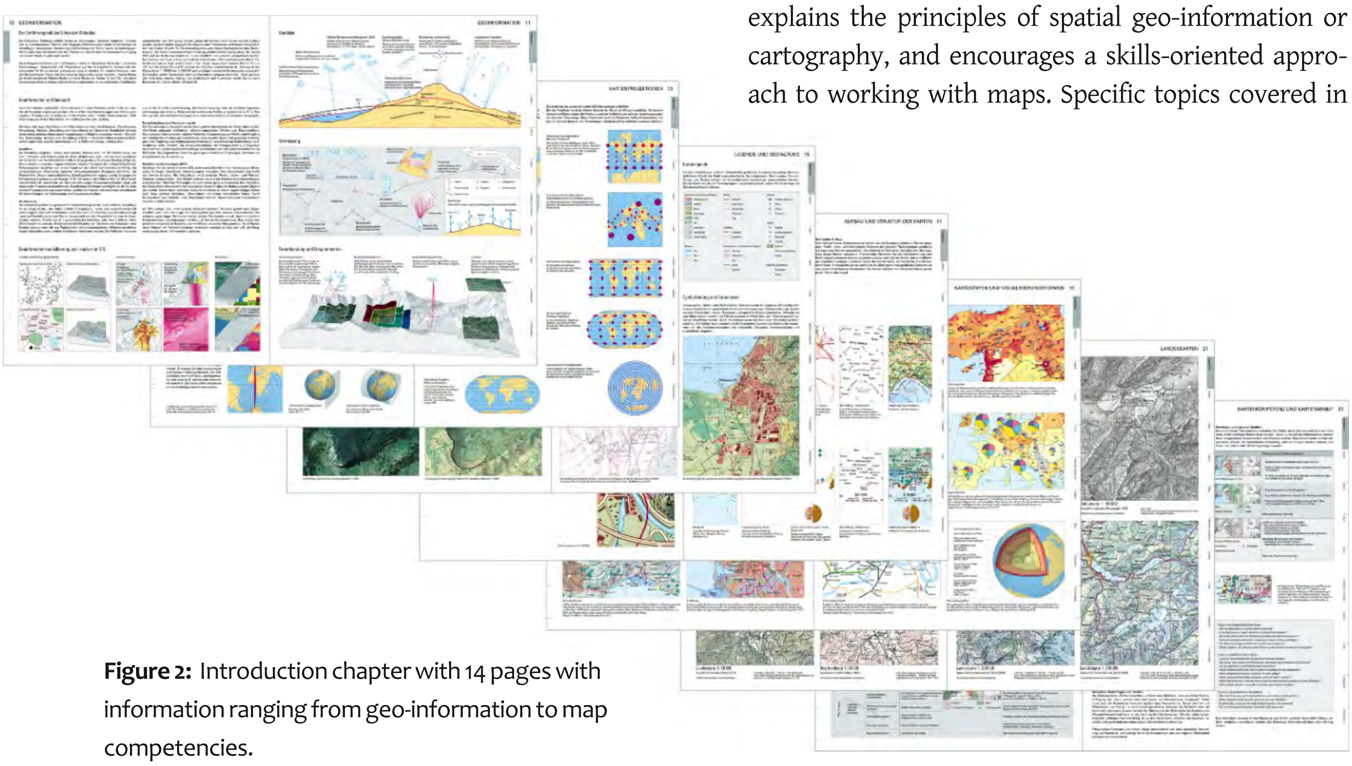

Figure 2: Introduction chapter with 14 pages with information ranging from geo-information to map competencies.

this chapter include geo-information, map projection, map key, map design, map scale, map generalization, map structure and content, map types and cartographic representations, the Swiss national map series, and map competencies and handling.

The maps in the Swiss World Atlas 2017 have also been updated, supplemented, and graphically revised. The atlas offers a global picture of our planet, featuring over 430 maps and images. The atlas also allows readers to make connections between different topics. Uniformly designed overview maps displaying the topography, political structure, and economic status of countries, major regions, and continents allow users to easily compare different geographical areas. This comprehensive overall view of the world is complemented by thematic maps on climate, geology, and population density.

Furthermore, the new atlas features many more maps addressing specific topics such as environment, resources, transportation, energy, natural hazards, and conflicts. Some of the atlas' traditional relief maps have been supplemented with high-resolution satellite images of distinctive landscapes. New descriptive infographics, profiles, and perspective views have also been included to illustrate complex geographical issues.

The atlas also introduces new map design standards: The minimum map size is now a quarter page, and the map scales for the different map types are unified (both with a few exceptions). Additionally, the font Univers Next Pro is the standard map and atlas font.

More generally, a new technical workflow for the atlas was developed and standardised. This workflow begins with the introduction of GIS-based data handling for base map data, followed by semi-automated processes for data extraction (for indices and listings), standardised map and page design, and processing with graphic and layout software.

2 Mountain Maps in the Swiss World Atlas

2.1 General Characteristics of Mountain Maps

We define a mountain map as a cartographic representation that depicts and emphasises topographic features and any kind of thematic features specific to mountainous areas (Haeberling 2015). Thus, mountain maps show the diverse land forms (e.g. mountain ridges and valleys, slopes and cliffs, peaks, and saddles) as well as the typical land cover (e.g. lakes, forests, meadows and pastures, glaciers, rocky and scree areas) in a mostly rocky or hilly landscape. Additionally, a diversity of natural objects (e.g. rivers, waterfalls, springs, caves, isolated trees, or rocks) or man-made features (e.g. settlements or single houses, roads and railroads, transport lifts and cables, dams) can be represented. Such content is often available in official national maps depicting a mountainous region. However, most mountain maps are thematic maps that combine a topographic base map with other topics such as tourism, transportation, economy, vegetation, or climate. Unlimited thematic combinations are possible, as is also the case for school atlases.

2.2 Mountain Maps for Teaching Purposes

With a mountain map, students can learn to interpret relationships between terrain and geographic features (e.g. geology, vegetation types, precipitation) or processes (e.g. avalanches, rock falls, transitional grazing, and precipitation). Therefore, mountain maps with their terrain depiction in the form of hill shading, contour lines, elevation points, or hypsometric tinting are best suited to teach students map reading and how to geographically interpret the terrain. This will help teachers explain natural or anthropogenic developments and demonstrate their impacts on the regional or global biosphere or atmosphere to the students. Maps of glacier retreat as a result of climate change are a notable example of such relationships.

2.3 Mountain Maps in the Swiss World Atlas

The 2017 edition of the Swiss World Atlas contains more than 20 mountain maps, ranging from large scale (1: 50,000) to small scale (1: 3,500,000). They depict the distinctive topography of selected regions all over the world, combined with specific natural, socio-cultural, or economical topics.

Students working with these mountain maps should learn to localise and analyse selected geographic topics contained within the topography. They could also be instructed to locate and compare the presented area within other maps in the atlas.

From a technical point of view, the base data (vector or raster data) for the mountain maps were derived from different data sources, mainly from Swisstopo (2018), Natural Earth (2018), USGS (2018), and OpenStreetMap (2018). These data were pre-processed and

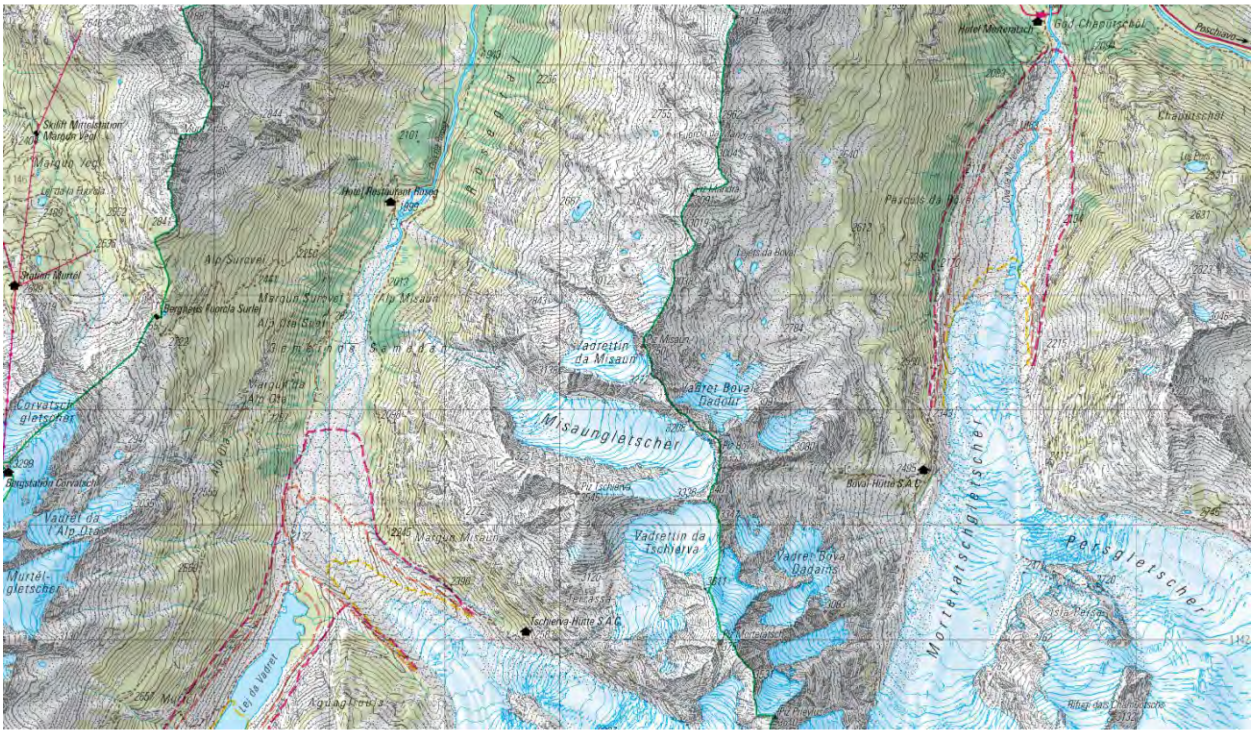

Figure 3: Reduced section of the map 'Bernina Mountains' (Swiss World Atlas 2017, p. 31).

generalised with ArcGIS 3D Analyst (Esri 2018) for generating contour lines, and with Blender (2018) and Adobe Photoshop (2018) for the hill shading. These data were then integrated and graphically designed within a standardised map file template using Adobe Illustrator (2018).

2.4 Map Examples

The following four examples of mountain maps in the Swiss World Atlas demonstrate the diversity of regions, thematic contents, didactic purposes and cartographic specifics discussed above.

2.4.1 Map Example 'Bernina Mountains'

The new mountain map of the Bernina Mountains (Switzerland) has been designed for a full page and at a scale of 1:50,000 (Fig. 3). It replaces two small maps (1/6 page each) in the 2010 edition.

Besides the total topographic situation and land cover, the new map prominently shows the retreat of all glaciers within the map extent from 1850 until 2008. Additional information on touristic infrastructure (e.g. railway station, campground, restaurants and mountain cabins) is shown that may be of interest for Swiss school classes that are planning a field trip to witness the glacier retreat along the highly popular 'Morteratsch Glacier' theme trail.

Special cartographic characteristics of this map include the grey cliff drawings and the blue glacier crevasses, both extracted from the Swiss Map Raster 50 (Swisstopo 2018), the rasterised Swiss national map LK50. A remarkable feature of this map is the bi-coloured shaded relief for the glaciated area (blue) and the non-glaciated area (grey), which was derived from the single-coloured, manually drawn shaded relief of the Swiss national map LK50 (Fig. 4).

2.4.2 Map Example 'Mount Kilimanjaro'

The small (1/6 page) mountain map of Mount Kilimanjaro (Tanzania/Kenya) in the 2010 atlas edition has been updated and enlarged to 1/4 page at a scale of 1:1,000,000 (Fig. 5). The map shows not only the popular hiking routes and touristic infrastructure, but also the agricultural land use, mineral resources and national parks of this African region. The map is supplemented with two climatic diagrams for the north and the south slopes of this volcanic massif, allowing students to recognise relationships between economic and touristic development and different climatic conditions. A cartographic highlight of this map is the analytical hill shading.

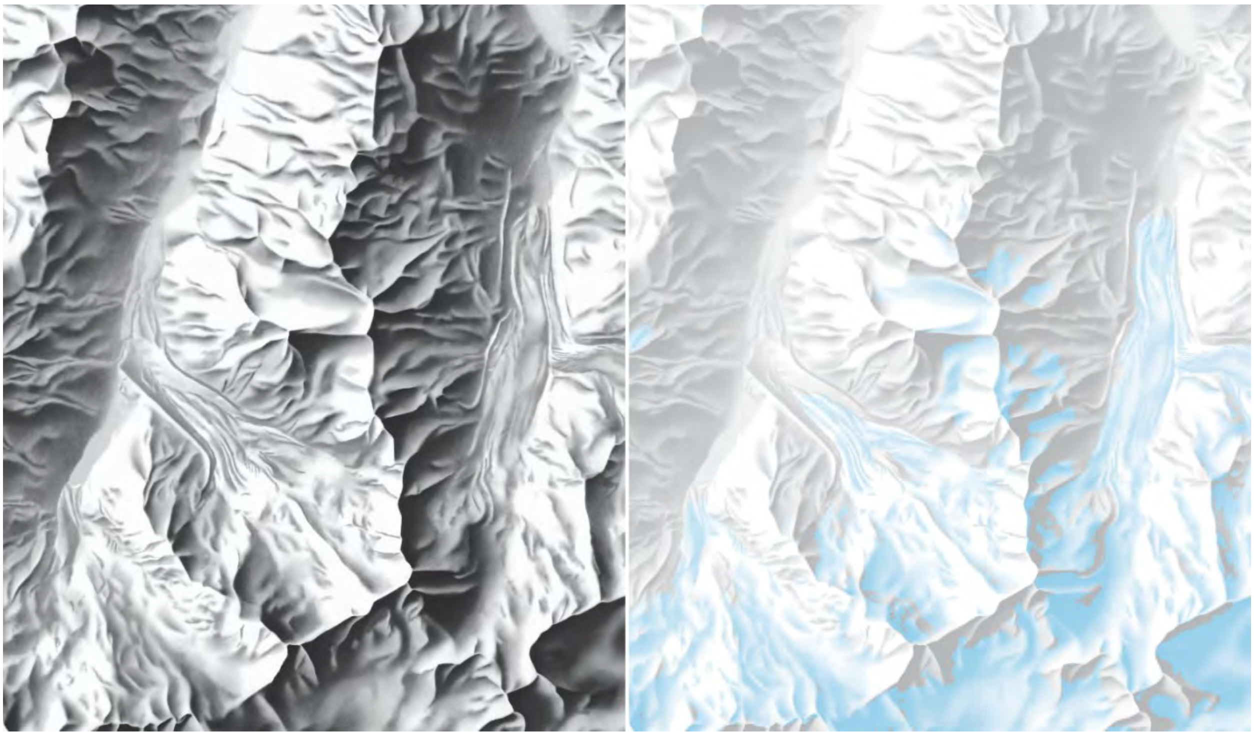

Figure 4: Hill shadings for the map 'Bernina Mountains': Original relief (left; Swisstopo 2018) and the bicoloured shaded relief (right) with glaciated area (light blue) and non-glaciated area (grey; Swiss World Atlas 2017).

2.4.3 Map Example 'Hawaiian Islands'

The 2010 atlas edition contained a small map (1/6 page, 1:10,000,000) of the Hawaiian Islands (USA), whereas the updated map in the 2017 edition fills half of a page at a scale of 1:35,000,000 (Fig. 6). The Hawaiian Islands showcase impressive topography from more than 5000 m below sea level to the 4207 m summit of Mauna Kea, the highest volcano in the archipelago. Thus, it is an ideal topographic situation to show the below- and above-sea relief with a detailed, newly-generated hill shading across the entire Hawaiian Island chain. A small-scale inset map provides information about the shift of the Hawaiian-Emperor chain and the movement of the Pacific tectonic plate. The map thus allows students to reconstruct the genesis of the different islands of Hawaiian chain, taking into account the age of each island that is shown below its name. A larger-scale map of Kilauea printed on the same atlas page illustrates volcanic activities and agricultural land use, and nine climate diagrams describe the climatic conditions around the islands. The 'Hawaiian Islands' map will help students interpret the broader context of Pacific island chains and their volcanic origins.

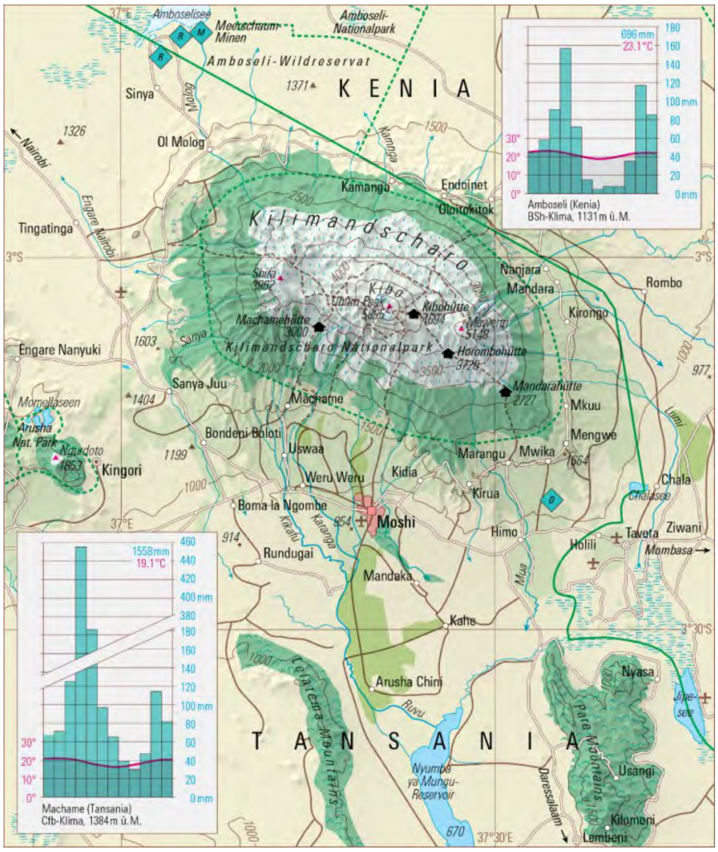

Figure 5: Map 'Mount Kilimanjaro' (Swiss World Atlas 2017, p. 119).

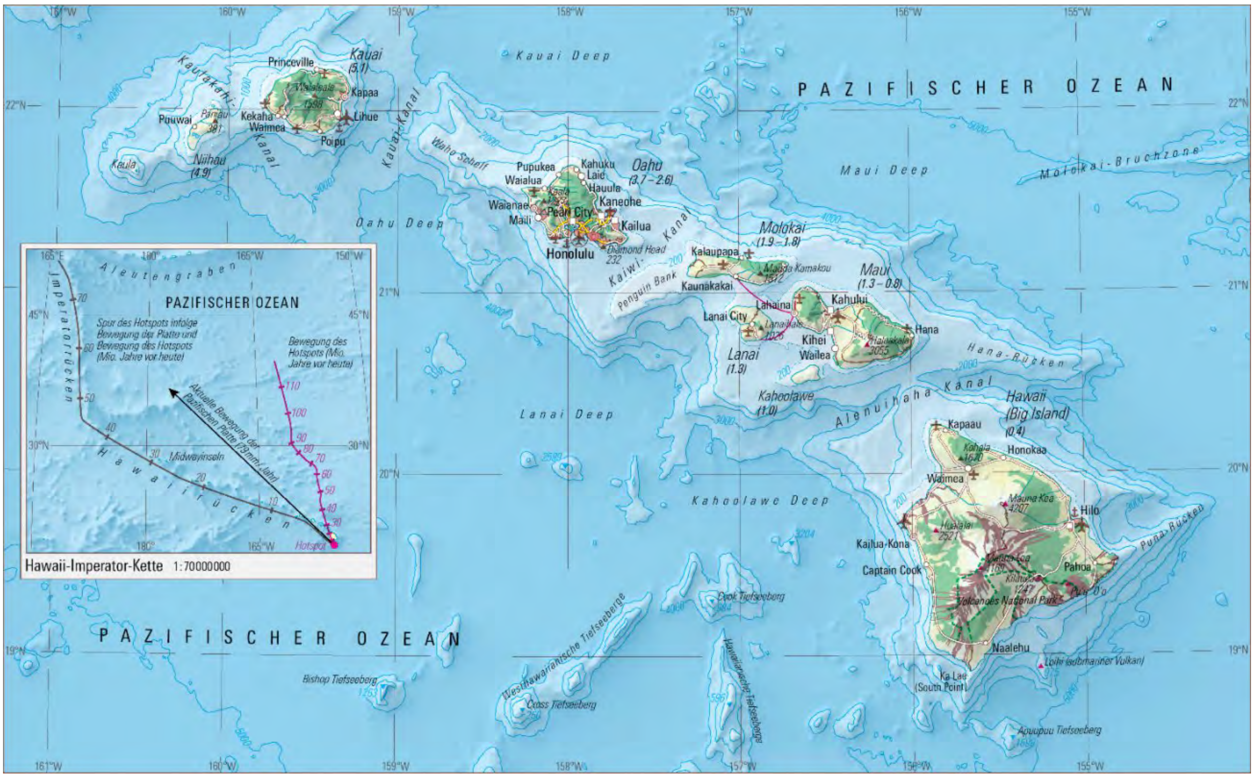

Figure 6: Reduced map 'Hawaiian Islands' (Swiss World Atlas 2017, p. 166).

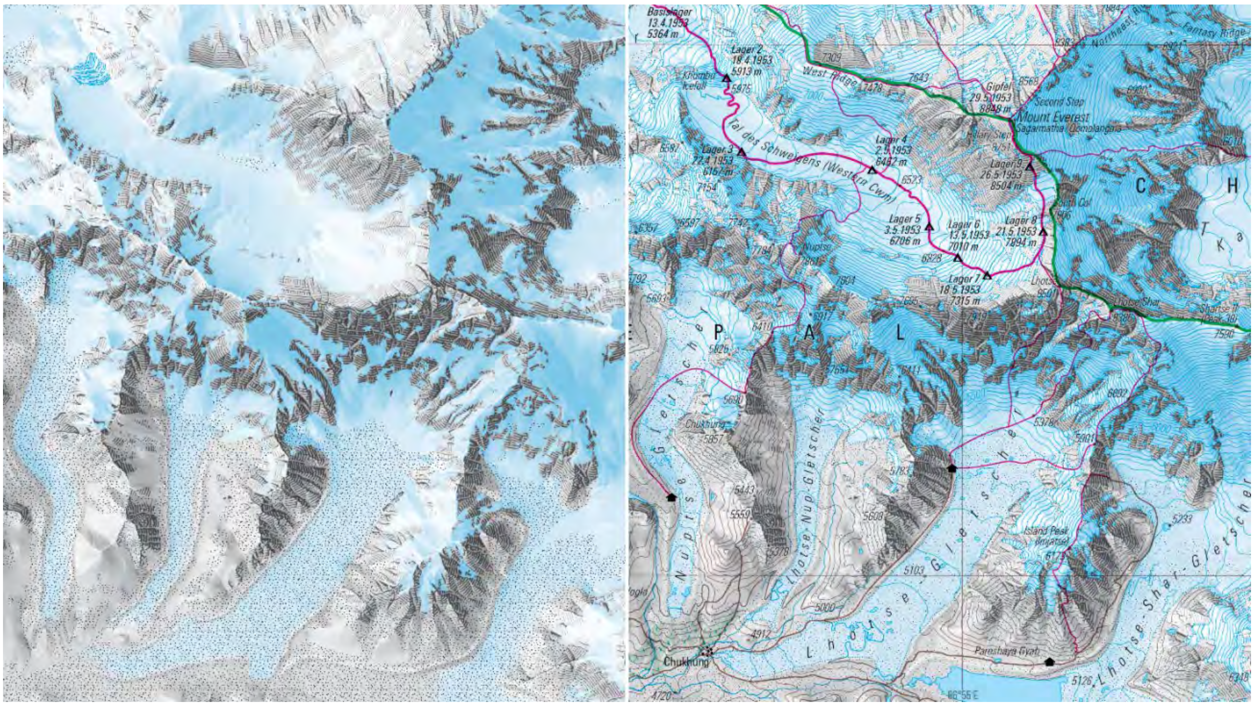

Figure 7: Reduced sections of the map 'Mount Everest'; with cliff drawings, scree symbolisation and the bicoloured hill shading (left), and the final map (right) (Swiss World Atlas 2017, p. 144).

2.4.4 Map Example 'Mount Everest'

A mountain map of Mount Everest (Nepal/China) with its environment has been an indispensable part of the Swiss World Atlas for decades. For the 2017 edition, the map has been completely revised and expanded from 1/6 page at 1:200,000 to 1/2 page at 1:100,000. The new map shows the high-alpine topographic environment in more detail (Fig. 7). Also shown are the different expedition routes (which are often mentioned in news reports), camps, and other touristic infrastructure. The map will thus allow teachers and students to discuss and recognise the problems that high touristic pressure may inflict on a very remote region.

Cartographic items of interest on this map include the automatically-generated cliff drawings and scree symbolisation in the Swiss style, developed by R. Geisthövel in his PhD thesis (2017). Another attractive cartographic design element is bi-coloured hill shading for the glaciated area (blue) and the non-glaciated area (grey), similar to the 'Bernina Mountains' map example.

3 Conclusions and Future Directions

The new 2017 edition of the printed Swiss World Atlas contains many thematic mountain maps. Some have been revised from the previous 2010 edition, others are completely new. With the diversity of depicted regions and topics, the atlas offers a set of useful and informative mountain maps for teachers and students in Swiss schools to acquire geographic knowledge and develop map interpretation skills.

Future evaluations will assess to what degree the editorial team met the intended goals for didactic and teaching purposes. So far, since the publication of the new atlas in summer 2017, our dedicated user groups have not yet provided much feedback specifically about the mountain maps. More statements from teachers about the usability and quality of the mountain maps needs to be collected. Alternatively, our evaluation methods could also include observing or testing students' map reading or geographic problem solving skills.

Since its first edition in 1910, the Swiss World Atlas has been continuously updated and revised. In this tradition, work on the next edition has already started, including some revisions of mountain maps. These changes will not only include corrections of errors in labels or numbers, but also thematic data updates and cartographic refinements (e.g. label placement).

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Topographic Maps Based on OpenStreetMap Data

Optimising Depiction of Water Streams

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Abstract. The availability of free-to-use geodata as well as the new technological possibilities of generating topographic maps have led to a shift in the cartographic workload from professionals to nonprofessionals. The new idea of Volunteered Geographic Information (VGI) has led to geodata being gathered by citizens, collected in projects such as OpenStreetMap (OSM) and eventually being made available under open data licencing. Even though the quantity of data input is comparatively high, its quality may be ambiguous. It has never been easier to generate topographic maps with global coverage than it is with this newly available and steadily growing database. Web-based maps are created via automated processes. As opposed to topographic maps from official institutions such as Swisstopo, individual elements of the map are not manually revised or edited, which may lead to different problems in depiction. The reason for this is the heterogeneity of VGI data, which complicate automated cartographic processes such as generalisation. Therefore, a new process, which allows for the generalisation of OSM data (focussing on water stream features), is introduced.

Keywords: *topographic maps, open data, OpenStreetMap, digital elevation models, water streams*

1 Introduction

Topographic maps are a useful tool for orientation and navigation in the terrain. During outdoor activities such as hiking, mountain biking and ski touring they are not only essential for planning routes, but also for risk assessment (e.g. avalanches). The requirements for accuracy and completeness of the topographic map's data are therefore comparatively high. Other than that, visualisation methods used to produce a map from geodata play an important role. Readability and comprehensibility of the map data contribute to a higher usability for the map-reader.

Examples for high quality geodata and visualisation can be found when viewing maps of the Swiss Bundesamt für Landeskartografie Swisstopo (Swisstopo 2018). These topographic maps are produced using strict quality standards. To optimise the depiction of the map, processes like the positioning of labels are placed manually. Another distinctive characteristic of the Swisstopo maps is its rock depiction. This artistic representation of a natural phenomenon in the style of Eduard Imhof adds to a highly detailed, three-dimensional overall look of the maps. While Swisstopo invests countless working hours into accurate data acquisition and optimal visualisation, other countries do not have these kinds of possibilities. In order to still produce topographic maps of these regions, Open Data is becoming a valuable source.

Today´s cartography is no longer exclusively an undertaking for specialists. Free-to-use geodata, as well as software for processing this data, can be obtained by non-professionals and hobbyists worldwide. The reason for this is the Open Data Initiative. "Open data and content can be freely used, modified, and shared by anyone for any purpose (opendef 2018)". A new method for gathering geodata exists in terms of crowd sourcing. The acquisition of geodata by volunteers is referred to as Volunteered Geographic Information (VGI) (Goodchild 2007). The most popular example for this is the Open Data project OpenStreetMap (OSM 2018), which offers a platform for users to provide and use geodata worldwide under the Open Database License (opendatacommons 2018).

Considering these developments, a shift in geodata acquisition from specialists to non-professionals can be observed (see Heipke 2010). While the VGI method can provide a comparatively high quantity of data, its quality is disputed. A discourse on quality of VGI based geodata has been carried out since the last decade, while Open Geodatabases, especially OpenStreetMap, has become more relevant. While the work of specialists such as cartographers and geodesists is based on quality standards, these standards cannot be upheld and verified by non-professionals and hobbyists.

The use of VGI based geodata for the preparation of topographic maps shows its limitation when depicting large scales (> 1:75.000). Problems in accuracy and further data processing arise. Thus, it is necessary to develop new methods of data processing and depiction dealing with the special characteristics of VGI Data.

2 Topic of Inquiry

The most comprehensive and successful VGI service at present is OpenStreetMap (OSM 2018) launched in 2004. OSM is a map data service where users can contribute, expand and revise geodata. Registered members are able to instantly add to and edit the database. In other VGI services such as the (recently closed) "Google Map Maker" (Google Map Maker 2018), edits are reviewed first (see Neis and Zielstra 2014).

In order to determine the quality of geodata, six fundamental characteristics are listed by reference to ISO/TC 2011 (see isotc211 2017). These features are further discussed by Heipke (2010) and Goodchild and Li (2012).

- Completeness: Depicts whether there are missing objects in the database. A high value in completeness states that all of the essential objects of the desired area are included in the database.
- Up-to-dateness: When was the data acquired and is it being kept up-to-date? This sign of quality needs to be particularly considered for objects which change over time (e.g. glaciers).
- Relative and absolute geometric accuracy: The precision in the positioning of an object can be subcategorized into relative and absolute geometric accuracy. Relative geometric accuracy describes the relation and distance between two objects on a map as well as their distance in reality. Absolute geometric accuracy describes the exact positioning of an object on a map in comparison to reality pertaining to a pre-defined scheme of reference (e.g. UTM) (see GITTA 2003).
- Topological correctness: Are the relationships between neighbouring objects correct? Objects can be misaligned or displaced through generalisation. This should only concern the precision of positioning of an object. When a street runs orthogonally along the left side of a river, it also needs to be depicted on the left side of the river on the map in order to allow for orientation.
- Logical consistency: Are the points, lines and areas of the depicted objects logically interconnected? The overlapping of two different kinds of land cover polygons (e.g. lake and meadow) would be a mistake, for instance. This quality is of particular importance when it comes to processing geodata. When using automated processing, logical inconsistency can lead to faulty data.
- Attribute correctness: Do the objects concur with their assigned metadata (attributes)? Furthermore, the degree of detail in attributing is essential (e.g. are water lines just declared as such, or are further subcategorizations such as rivers, streams, creeks, canals, etc. necessary?).

Attribute correctness of geodata also refers to its semantic resolution as described by Ruas and Bianchin (2002). Semantic resolution grades the level of detail of descriptive metadata. A high semantic resolution is related to a wide variety and a precise attribution of the geodata. While submitting geodata such as lines for streets and rivers or polygons for buildings, users have options to add specific tags to the data in OSM. Vandecasteele and Devillers (2015) point out inconsistencies of the attribution obtained through this method, leading to semantic heterogeneity of the VGI data.

Touya and Reimer (2015) describe the OSM data as qualitative in regions with high completeness (mostly urban regions). The level of detail of the data however has regional differences that they refer to as strongly heterogenic. As the quality of OSM data depends on the region, automated cartographic processes such as the cartographic generalisation are problematic. When setting parameters for automated processes homogenous datasets are assumed (see Touya and Reimer 2015).

An obvious case for the problem of automated generalisation is the depiction of OSM water lines. The semantic resolution of the data is insufficient and it is therefore not possible to filter the OSM water lines via its attributes. The results are poorly generalised water line depictions for different zoom levels or scales of maps. To optimise the visualisation of OSM water lines in topographic maps, a new method for enhancing its semantic resolution was developed and is presented in this article.

Alongside data for objects such as streets, rivers and buildings, topographic maps require data for depicting the terrain. Contour lines and hill shading can be derived from a Digital Elevation Model (DEM). There are many Open Data DEMs to choose from, although they differ in coverage and ground resolution. The ground resolution affects the accuracy of generated contour lines. In the case of an insufficiently low resolution, large scaled maps (> 1:75.000) with contour lines of smaller equidistance (e.g. 20m) will not only show an inaccurate but also a faulty terrain depiction. Many projects for automated topographic maps based on Open Data use DEMs that feature (nearly) global coverage. These DEMs on the other hand, offer comparatively low ground resolutions (e.g. SRTM Model: 1px = 30x30m). The combination of these DEMs particularly with OSM Data leads to problems in depiction of large scaled maps.

3 OpenTopoMap

To illustrate emerging problems in data depiction of topographic maps based on Open Data, a closer look at the OSM project OpenTopoMap is necessary.

OpenTopoMap is a free-to-use topographic map generated from OSM and SRTM elevation model data (SRTM 2018). The map style borrows from official maps and tries to obtain good readability through high contrast and well-balanced signatures (OpenTopoMap 2018). The project was founded by Stefan Erhardt and Philipp Hochreuther and is supported by the Friedrich-Alexander-University, Erlach Nürnberg.

While maps of official institutions such as the Swisstopo are manually reviewed and revised, the OpenTopoMap is generated completely through automated processes. Thus, certain problems of depiction arise that are discussed briefly below.

The positioning of labels is often suboptimal as they cover important features such as road crossings. Spot heights do not seem to align with the locations depicted by the contour lines. This is a result of the different data origins from elevation points (OSM) and contour lines (SRTM). Another consequence of different data sources are the faulty topological relations between contour lines and OSM water lines. OpenTopoMap has the option to render very high zoom levels of the map without considering the ground resolution of the underlying DEM (SRTM = max. 30m). The resolution does not hold up at these higher zoom levels as the contour lines show inaccuracy. As a result, water lines sometimes misalign with valleys depicted by the contour lines. In extreme cases, streams are shown flowing crosswise on slopes or even uphill as depicted in figure 1.

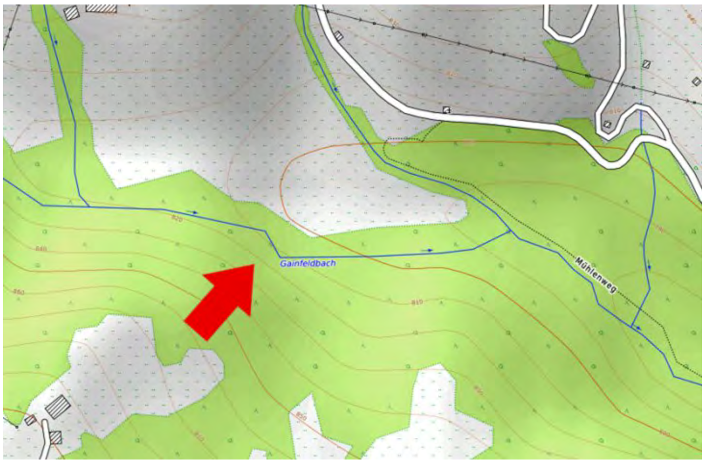

Figure 1: OpenTopoMap – faulty topological relation between contours and water lines (OpenTopoMap 2018)

Another problem related to the OSM water lines is the poor generalisation of features. The reason and a possile solution for it are discussed in the following chapter.

4 Generalisation of OSM Water Lines

A frequently occurring problem of topographic maps based on OSM data is the generalisation of the water line network. Because of low semantic resolution, especially for OSM water lines, a classification based on their attributes cannot be done. As seen in the depiction of OpenTopoMap, all water lines included in the geodata base are shown even at lower zoom levels (see fig. 2). It is therefore not possible for the map-reader to distinguish between primary and secondary water lines. The

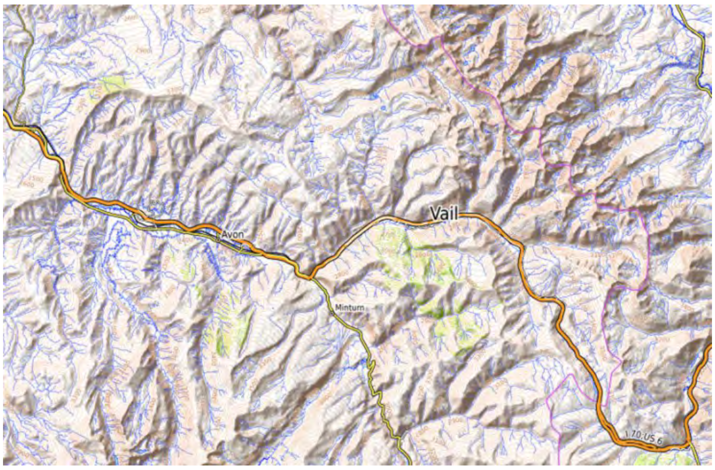

Figure 2: OpenTopoMap, water line depiction (OpenTopoMap 2018)

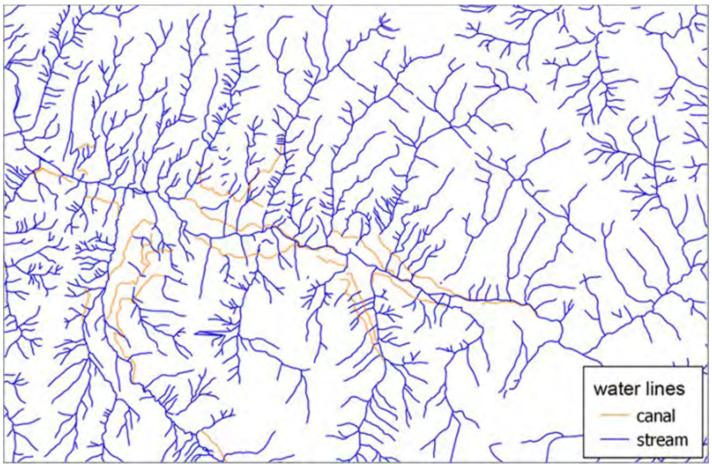

Figure 3: OSM data, water line attributes

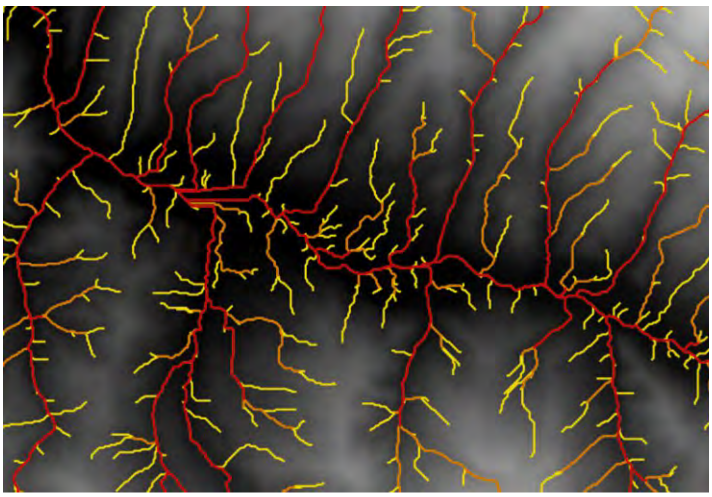

Figure 4: Channel Network based on SRTM

map is overloaded with water network information. While adding data to the OSM geodata base, users are given options to tag water lines with the specific labels: stream, canal, river and drain. Figure 2 shows the water line network of the region around Vail, Colorado (USA). In this area, users only tagged the lines with either stream or canal, while the latter tag is used much less frequently. The majority of water lines are declared as streams. To allow for an automated generalisation of the OSM water lines, the semantic resolution of the data must be enhanced. The Channel Network Method has been developed in order to establish a hierarchy of water lines. This will be further elaborated on in the following chapter.

5 Channel Network Method

The calculation of a Channel Network is a tool for the hydrological analysis of DEMs in GIS. In this process, the path that the water takes from the highest to the lowest part of the terrain is calculated. This analysis is part of the calculation of catchment areas in water systems. These catchment areas represent drainage areas and are separated by watersheds. The calculation of a Channel Network shows the flow of the drainages. They are represented as line features. Running water can only be found in these locations, which is how the discrepancy between the calculated Channel Networks and mapped water lines can be predicted.

In order to allow for the calculation of a Channel Network, the DEM needs to be pre-edited. Sinks or pits are found in the DEM, which can be traced back to naturally occurring terrain peculiarities or to faulty data (a.k.a. artefacts). These pits prevent the unobstructed realisation of hydrological analyses such as the Channel Network Analysis.

In order to correct this faulty data, an algorithm with the name "fill sinks", developed by Wang and Liu, was used on the DEM (Wang and Liu 2006). This process was conducted on the SRTM elevation model in the region of Vail (SRTM 2018).

The SRTM elevation model, which has been "filled," can then be used to calculate the Channel Network. The tool "Channel Network and drainage basins" from the SAGA-GIS library was used for this (SAGA-GIS 2018, Conrad 2003).

A parameter for threshold can be inserted for the analysis. This threshold is based on the Strahler stream

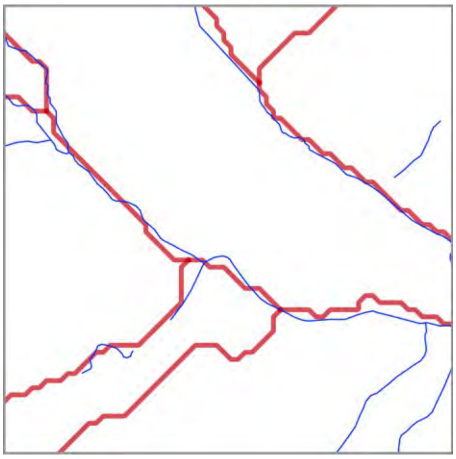

Figure 5: OSM water lines and Channel Network

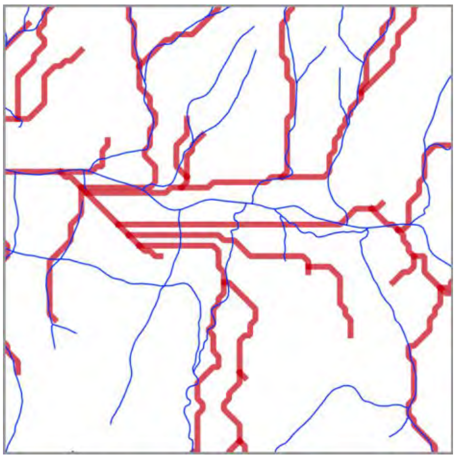

Figure 6: OSM water lines and inaccurate Channel Network

order. The minimum value is 1. A larger value confines the network to the main drainage lines, which leads to a network with a lower level of detail.

In the following example, the process is carried out using three different thresholds (4, 5 and 6). Figure 4 shows the three Channel Networks for the threshold values 4 (yellow), 5 (orange) and 6 (red). The Channels with lower thresholds include the ones with higher thresholds (4 contains 5 and 6, 5 contains 6). The classification of channels obtained through this process will be transferred to the OSM water network later on. The channels can be saved as line features in ESRI shapefile format.

To make the procedure more understandable, the following operations for channels with a threshold of 6 were substituted for all three Channel Networks.

When comparing the OSM water lines (blue) with the generated Channel Network (red) positional similarities can be observed (fig. 5). OSM water lines that coincide with lines of the channel network are selected in the next steps and a new attribute for their hierarchy (Strahler threshold number) is added.

Problems of this method occur in flat terrain, as shown in figure 6. The Channel Network generates faulty lines because of the inaccurate SRTM elevation model. The selection of OSM water lines is therefore not possible in these areas.

To select OSM water lines via Channel Network, a buffer must be generated first around the channel network lines. The buffer width is specified at 80m. The reason for this value is the low ground resolution of the SRTM elevation model (30m) that leads to greater gaps between channel network lines and OSM water lines. Specifying a buffer width lower than the gap between the two lines would result in parts of the water lines not being included in the selection. The choice of a higher buffer width guarantees the intersection between Channel Network and OSM water lines. On the other hand, it also increases the chance for faulty selections in situations where two water lines are located too close to each other.

Subsequently, a degree of coverage is chosen that states the percentage of OSM water line length, which needs to be within a buffer in order to be selected. For the following example, a degree of coverage of >60% has been chosen. Water lines which are completely or partially (more than 60%) covered by buffer polygons due to their short length are removed from the selection. A minimum length is given. In the example below, a minimum length of 600 m is given for level 6.

Table 1 shows the parameters used for the three calculated levels of generalisation.

A new attribute (Strahler number threshold 4, 5 or 6) is assigned to the selected OSM water lines for the three levels of generalisation. Generalisation is thus practicable. Figure 7 depicts the calculated levels of generalisation using an excerpt for the region of Vail.

Table 1: Parameters for Channel Network Method

Testing area: Vail DEM: SRTM (30 m)	Strahler number 6	Strahler number 5	Strahler number 4
buffer width (m)	80	60	40
degree of coverage (%)	60	60	60
minimum length (m)	600	300	0

A partially faulty choice of lines, which can be traced

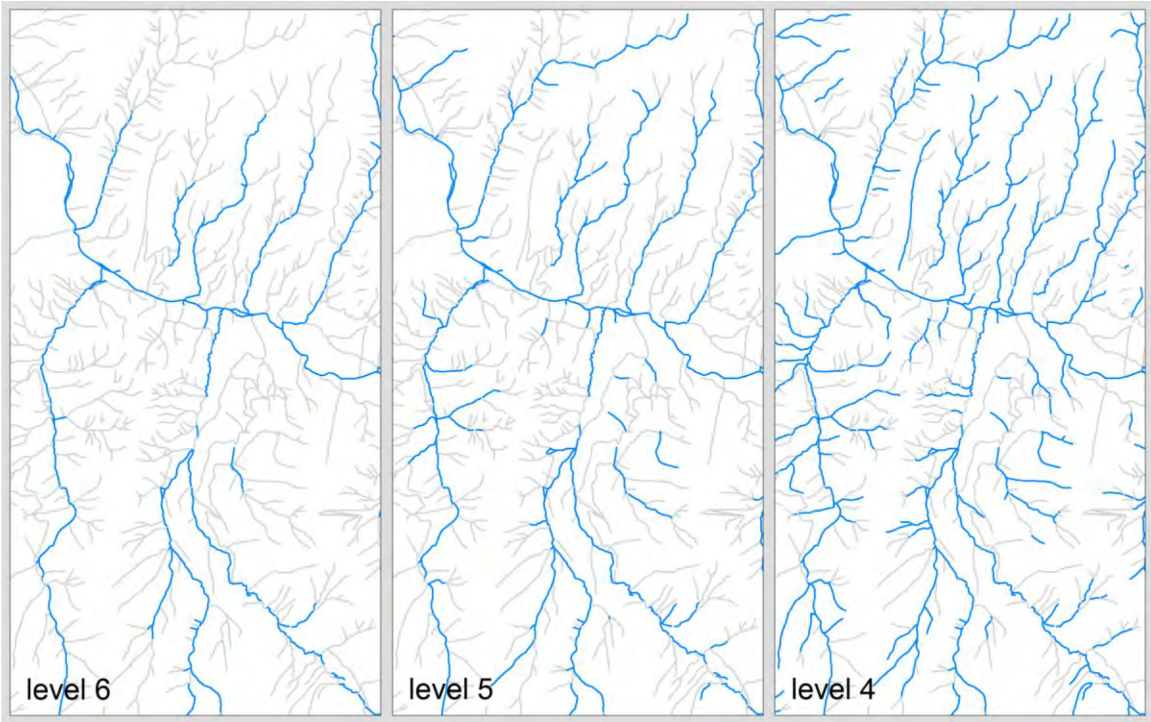

Figure 7: OSM water lines, 3 different levels of generalisation

back to the aforementioned inaccuracies of the SRTM elevation model, can be noticed. Breaks in the selected OSM water networks are a result. This problem can be solved using high resolution DEMs, where water lines and Channel Network lines show less difference in location. When using SRTM, these mistakes can be minimised by adapting the parameters discussed earlier, however, a manual verification of the choice of generalisation is recommended.

6 Summary

The usage of Open Geodata, especially VGI Data, leads to several problems in topographical depiction. The reason for this is heterogenous data quality, in particular with reference to meta-data. Automated cartographical processes such as generalisation are thus made more difficult. Generalisation is of great importance when it comes to optimising the visualisation of maps. This set of problems is also the reason why the generalisation of OSM water lines has proven to be difficult. These lines cannot be classified and refined for different scales or zoom levels because of their low semantic resolution. The Channel Network Process has been developed in order to address this problem.

This generalisation process for OSM water lines, based on the method of classification via Channel Networks, leads to partially feasible results. For this method, a drainage system (Channel Network) is calculated using a DEM. The position of the Channel Network agrees with the location of the water lines, depending on the accuracy of the DEM. Since the calculated Channel Network is based on a hierarchy, it can be transferred to the OSM water lines and thus enable a classification. This kind of classification can be used for several degrees of generalisation (meaning for several scales) by changing the parameters. Depending on the choice of the DEM, the quality of the results may vary. Channel Networks based on DEM with high ground resolution have a higher correspondence with the position of OSM water lines, which is why the process of generalisation is less prone to errors. Larger degrees of generalisation of the water lines lead to more accurate results than low degrees of generalisation.

The process can be used as a tool to classify regionally restricted water lines. Adapting the parameters to regional particularities with reference to situation and terrain can lead to better results. A manual verification of the generalised data obtained through this process is advised.

7 Outlook

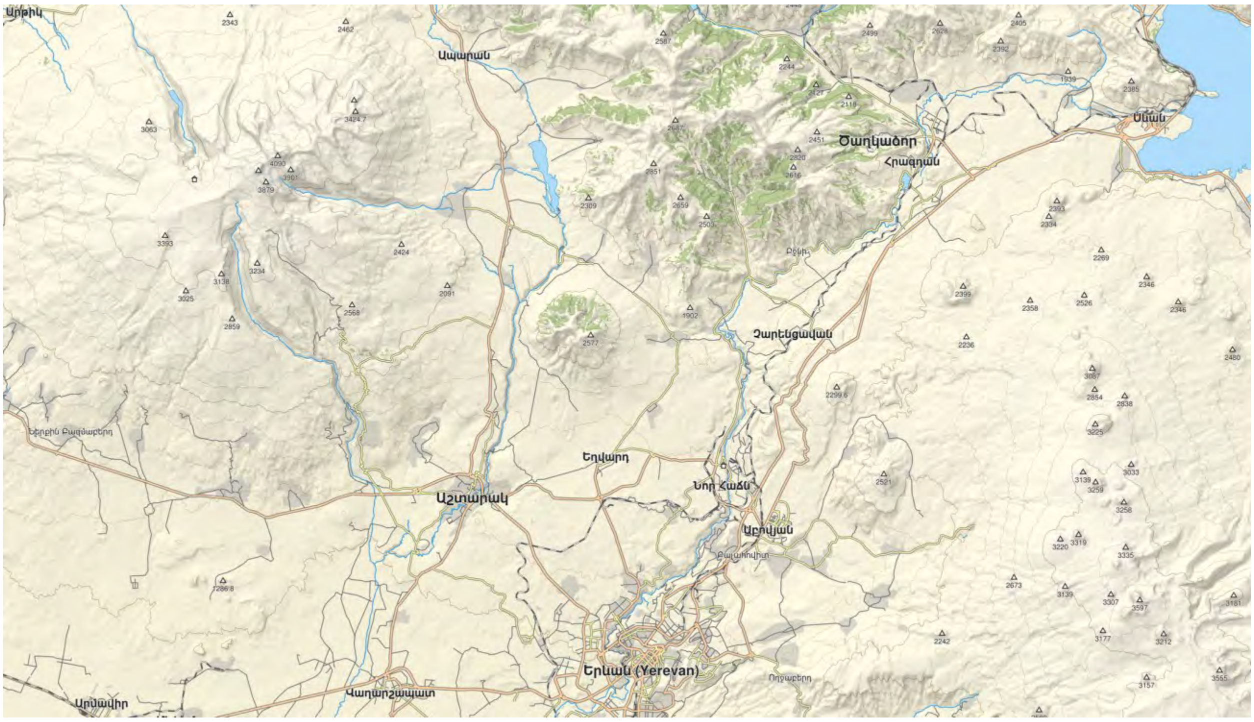

Figure 8: Topographic Map of Armenia based on OSM and SRTM data (University of Vienna 2018)

The improvement of automated processes such as generalisation requires additional focus in order to increase the quality of depiction in topographical maps based on Open Data. VGI Data, such as the one obtained from the OpenStreetMap Database, needs new methods of processing in order to optimise the production of maps. The combination of several methods leads to higher levels of quality in topographical Open Data maps. The Channel Network process can be considered a tool designed to serve this purpose.

Methods of revising VGI and Open Data help to produce improved maps for countries without access to accurate maps, which have been produced using official geodata based on high quality standards. A proof-of-concept of the described approach is currently under consideration at the University of Vienna and will try to tackle various aspects of high quality topographic mapping discussed in this article. A collaboration project that will be conducted by the working group Cartography and GIS, Department of Geography und Regional Research at the University of Vienna together with Armenian representatives will have the goal of producing a framework for a nationwide topographical map of Armenia focusing on recreational issues. It can be considered as an example for the application of this new method. OSM as well as SRTM data are used in this process. The obtained maps constitute pioneering work for the production of maps for outdoor enthusiasts such as hikers, mountain bikers or ski touring mountaineers (see fig. 8).

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Practical Strategies for Active Learning and Design Thinking in Mountain Cartography Education

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Abstract. The goal of this paper is to share practical strategies (things that a teacher can do in the classroom or through a course design) that facilitate active learning and design thinking in lecture- and laboratory-based instruction of mountain cartography. Examples are presented of instructional materials and results from student work from a recent project-based cartography class for undergraduate students. For the first eight weeks of the semester, students in the course collectively created an Atlas of US National Monuments with a focus on monuments that had been designated under the Antiquities Act. Project assignments included developing a style guide and developing layouts that combined a locator map, one or more thematic maps, and a physical geography reference map. Practical strategies for making lecture meetings more active include learning from handout-based activities, learning from sets of good examples, and learning to give and receive criticism from peers on drafts of work. Video presentations of software tutorials are discussed as a practical method for simultaneously introducing software procedures and supporting independent projects. Finally, a strategy is presented to help students describe and explain their design process through narrated slideshow presentations. This paper aims to provide practical advice for those that teach mountain cartography in academic settings and who are interested in promoting design thinking skills through creative independent work.

Keywords: *education, mountain cartography, practical*

1 Introduction

Learning to teach is similar to learning to make maps in the sense that they are both things that you learn through practice. A teacher often learns by trying things in the classroom and reflecting on reasons that some things seemed to have worked and some things did not. Here, I discuss some methods that I used for teaching an undergraduate cartography course at Middlebury College in spring 2018, including methods for making lectures more active, for teaching design thinking, and for evaluating independent student work. By sharing teaching methods and providing some reasons as to why they may have worked or how they might work better, I hope to contribute some practical tips to other instructors of cartography. While these methods emerged from a course that included modules on mountain cartography, the methods are general and likely apply to teaching cartography in general.

2 Course Structure

In Spring 2018, I offered a course called "Cartographic Design" at Middlebury College, a private liberal arts college in Vermont. Twenty-six undergraduate students enrolled in the course. We met once a week for three hours in the classroom and once a week for three hours in the computer laboratory. The semester consisted of twelve weeks of instruction. An introductory course in Geographic Information Systems was a required prerequisite, so that students began the course with a working knowledge of raster and vector datasets, geographic reference systems, and fundamental spatial operations with a GIS.

Beyond the basic goal of teaching cartography, I had two pedagogical ambitions for the course. First, I wanted to make both lectures and labs places for active learning. This meant that I wanted to avoid giving long talks with slides during lectures. It also meant that I wanted the labs to involve something more than cookbook instructions for making different kinds of maps with computer software. Second, I wanted students to learn by designing maps rather than simply learn about map design. This meant that I want to do more than treat map design as a topic that we discussed in the course. Instead, I wanted students to engage in design thinking, or the process of generating a set of possible alternatives and selecting one that works for a particular goal or reason. “Design is not finding the solution to a problem, but finding a solution to the problem” (Ervin 2008, 9).

I organized the course in three parts. For the first three weeks, the students developed a style guide that introduced basic principles of working with color, symbols, and lettering. For the next six weeks, I asked each student to select a different National Monument that had been included in the Trump Administration’s Executive Order 13792 (“Review of Designations Under the Antiquities Act”) and then design a poster that helped someone learn about the history and geography of the National Monument. At a minimum, the poster needed to include three maps: a locator map, a map of political geography inspired by the National Geographic political atlas and magazine stories, and a map of terrain that blended shaded relief with texture shading (Brown 2014; Patterson 2014) and landcover tints, inspired by National Park Service maps (Patterson 2015). Students gathered all the data for their maps, used a GIS to process the data, and then designed the maps and poster layout. For the final three weeks of the semester, I opened up that course so that students could develop a map layout about any place or theme that interested them. I did this in case students felt restricted by their National Monument and wanted to explore a new place or theme.

Figure 1: First handout that aimed to have students look at type before introducing type anatomy vocabulary.

3 Style Guide

The course’s structure aimed to provide scaffolding to help students learn to design maps. The style guide assignment was an attempt to make a complex problem (like designing original maps) easier to learn by first teaching elements of cartography before teaching how the elements interact through map design. By asking students to make a style guide first, I tried to introduce them to principles and software tools for working with type, color, and symbols outside of the context of making any one single map.

In lectures, I tried to develop an active learning environment by asking students to complete short tasks before I lectured on a topic. For most tasks, I made handouts on half-sheets of paper and asked the students to work through the handouts in pairs for 5-10 minutes before leading a short discussion with the entire class. Many tasks involved giving the students a set of elements and asking them to group the elements into subsets. For example, the very first task I gave students prompted them to organize a set of lowercase and uppercase letters into groups (Figure 1). The subsequent discussion focused on comparing and contrasting the different groups that students identified and the criteria used for making the groups. This set up a mini-lecture on type anatomy that students were perhaps primed to engage with because I was simply providing names for things they had already observed.

Similarly, another task involved organizing a set of fonts into subsets (Figure 2). In the subsequent

Figure 2: Handout to generate discussion about things to consider when choosing a font or pairing fonts.

discussion, we compared and contrasted the different groups that students had come up with and the criteria they used for grouping them. This primed the students to learn classic vocabulary (e.g. serif, sans serif) and subtle differences between fonts, like the changing appearance of lowercase "a" in regular and italic or the differences in the width of strings. This enabled a conversation about things to consider when choosing a font or when pairing different fonts as part of a map's design.

To facilitate discussions about assigned readings, I found it helpful to give students a handout that contained copies of figures from the reading with some elements of the original figure concealed. I developed this method while trying to design a handout to teach principles for label placement (Imhof 1975). After failing to find examples of maps that could both illustrate all of Imhof's principles and be reproduced legibly on small handouts, it occurred to me that I could simply reproduce his diagrams of "good" and "poor" examples with his labels of judgement erased and ask students to tell me which one was which and why (Figure 3). This proved to be an effective way to help students see Imhof's judgements as following his key principles (legibility, graphic association, non-disturbing, spatial situation, class and hierarchy), rather than as a long list of seemingly arbitrary rules.

In lab meetings, activities illustrated how to work with specific software tools for type, color, graphic variables, etc., that we had discussed in lecture meetings. Each activity contributed items to the style guide (Figure 4). For example, one task prompted students to choose a published map and describe the color model for the map's palette. This provided an opportunity to introduce basic tools for working with color in Adobe Illustrator while introducing more general strategies for mixing CMYK (Brewer 2016, 147-149). Other tasks included identifying fonts used in example maps, identifying minimum perceptual differences in pecked and cased lines, creating color illustrations for Munsell's theory of color (Cleland et al. 1921), and illustrating Imhof's principles for label placement (Imhof 1975).

4 Poster Project

After the first three weeks, students began to develop maps for their poster. In lectures, group activities shifted to two different kinds of map critiques. The first involved bringing in paper copies of maps that I thought represented "good examples" and taping them

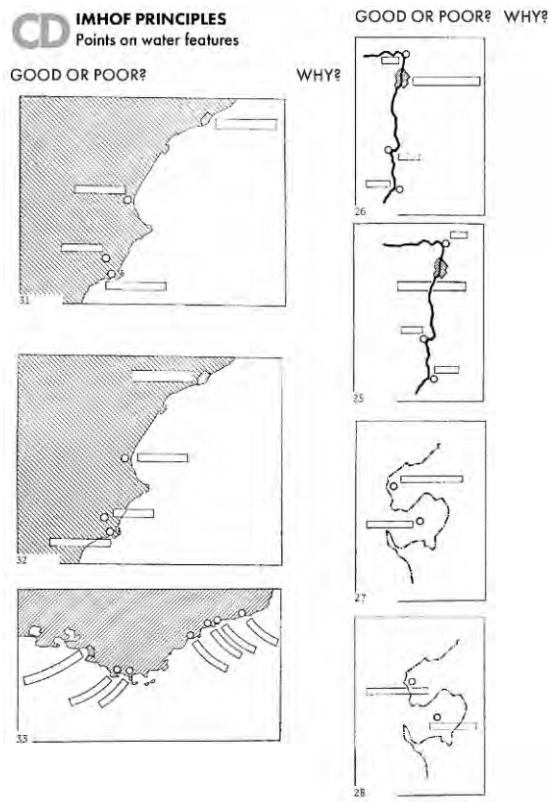


Figure 3: For handouts to discuss Imhof's principles for label positioning, I hid his judgement labels.

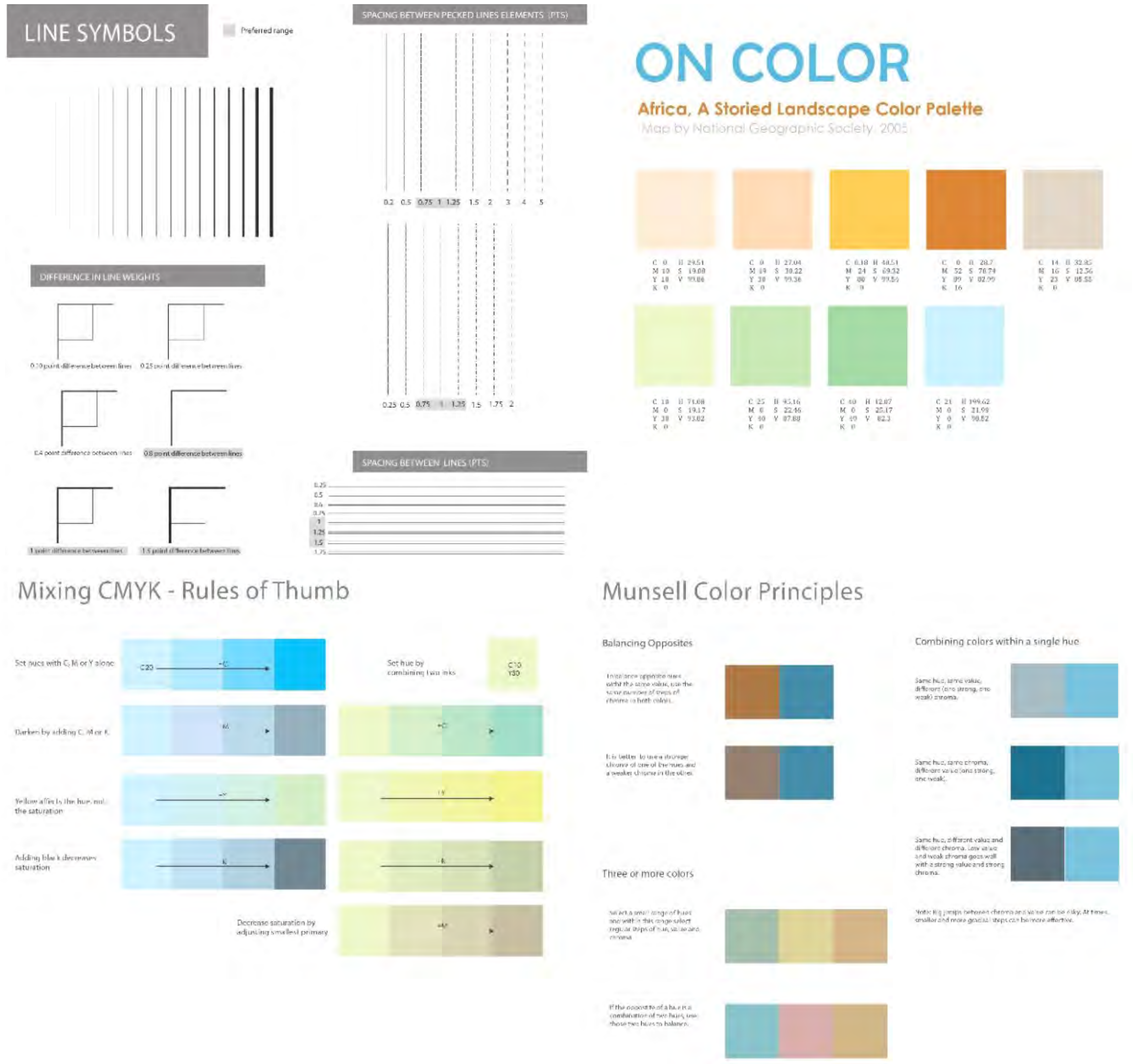


Figure 4: Two spreads from Style Guide by Vanessa Dikuyama '18.

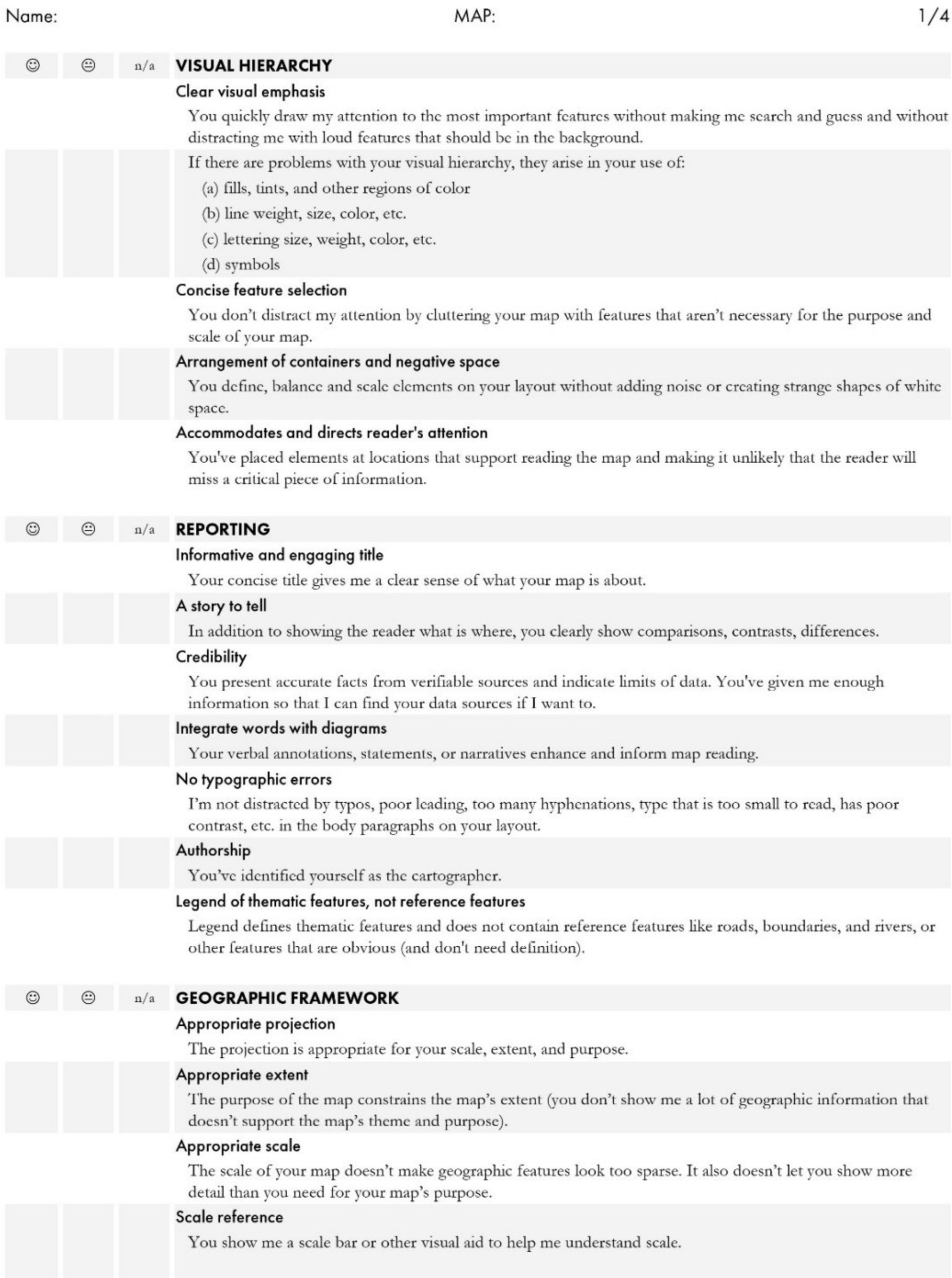
up to the walls, making a sort of pop-up map gallery. I asked students to move around the room in pairs and talk to each other about the maps. This was most productive when students received prompts to discuss. ("What's the first thing you notice about this map?" "What are some patterns you see in the use of type?" "Please describe this map's palette.") After 20-30 minutes, we convened together as a group and discussed what they had seen.

The second strategy involved having the students critique each other's work. In the peer crits, we broke into three groups, where students in one group taped their map to the wall and stood by it. Students in the other two groups formed pairs and had 5-10 minutes to talk to each student about their map. I encouraged the reviewers to follow a simple format: first look at the map for at least a minute before you say anything, then point out something that you like and ask the author about it, then tell the cartographer what distracts or confuses you and ask them about it. I repeatedly asked students to focus on conveying what they think works or does not work, but encouraged them to avoid giving specific advice regarding changes to the map. I did this for two reasons. First, I wanted the discussion to focus on why something worked or did not work to encourage students to articulate principles and their contexts. Second, I wanted to avoid situations where students frustrated each other if they followed a peer's advice that did not wind up working. After the peer crits, I gave students several days to incorporate feedback and make changes to their map before submitting it for a grade.

Technical instruction during the project phase introduced new methods and workflows in ArcGIS and the Adobe Creative Suite. Students gathered data from many sources, including Earth Explorer, the National Map, the National Park Service IRMA, the BLM Navigator, the USGS National Boundaries Dataset, Department of Interior Data Repository, and other sources. In addition, I introduced advanced methods in shaded relief (Patterson 2015) and workflows for moving from ArcGIS to Photoshop.

5 Evaluating Student Work

There were two major challenges for evaluating student work in the course. First, each student in the course turned in a different map, so I needed a framework that could allow me to evaluate 26 different individual maps with both consistency and efficiency. Second, I wanted to give the students feedback not just on the product of their design but their process of designing it.


Name: MAP: 1/4

☺ 😐 n/a **VISUAL HIERARCHY**

Clear visual emphasis
You quickly draw my attention to the most important features without making me search and guess and without distracting me with loud features that should be in the background.

If there are problems with your visual hierarchy, they arise in your use of:
(a) fills, tints, and other regions of color
(b) line weight, size, color, etc.
(c) lettering size, weight, color, etc.
(d) symbols

Concise feature selection
You don't distract my attention by cluttering your map with features that aren't necessary for the purpose and scale of your map.

Arrangement of containers and negative space
You define, balance and scale elements on your layout without adding noise or creating strange shapes of white space.

Accommodates and directs reader's attention
You've placed elements at locations that support reading the map and making it unlikely that the reader will miss a critical piece of information.

☺ 😐 n/a **REPORTING**

Informative and engaging title
Your concise title gives me a clear sense of what your map is about.

A story to tell
In addition to showing the reader what is where, you clearly show comparisons, contrasts, differences.

Credibility
You present accurate facts from verifiable sources and indicate limits of data. You've given me enough information so that I can find your data sources if I want to.

Integrate words with diagrams
Your verbal annotations, statements, or narratives enhance and inform map reading.

No typographic errors
I'm not distracted by typos, poor leading, too many hyphenations, type that is too small to read, has poor contrast, etc. in the body paragraphs on your layout.

Authorship
You've identified yourself as the cartographer.

Legend of thematic features, not reference features
Legend defines thematic features and does not contain reference features like roads, boundaries, and rivers, or other features that are obvious (and don't need definition).

☺ 😐 n/a **GEOGRAPHIC FRAMEWORK**

Appropriate projection
The projection is appropriate for your scale, extent, and purpose.

Appropriate extent
The purpose of the map constrains the map's extent (you don't show me a lot of geographic information that doesn't support the map's theme and purpose).

Appropriate scale
The scale of your map doesn't make geographic features look too sparse. It also doesn't let you show more detail than you need for your map's purpose.

Scale reference
You show me a scale bar or other visual aid to help me understand scale.

Figure 5: First two sections of map evaluation checklist

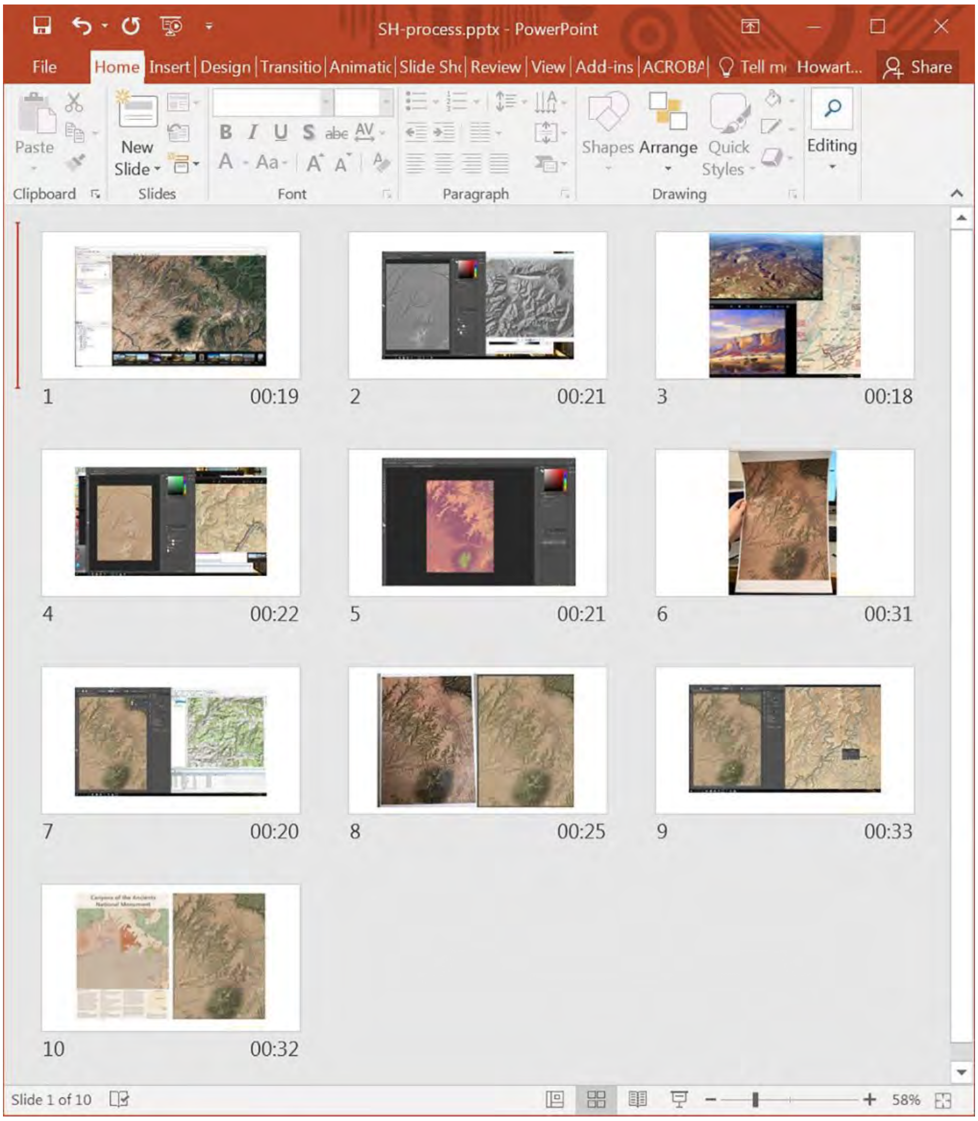


Figure 6: Description of design process in ten slides with 20 seconds or less of explanation per slide by Sarah Howard '19

To evaluate maps, I developed a simple checklist for map design. Figure 5 shows the first two sections. The checklist aimed to convey what I think works, what doesn't work, and the reasons that things work or not. I arranged the criteria under the following categories: visual hierarchy, reporting, geographic framework, fills, linework, lettering, topography, and symbols.

To document their design process, students were required to describe the decisions they made while working on their map in a short, narrative slide presentation (10 slides, 20 seconds per slide). The slide presentations combined screen shots and audio narration of their process for making the map (Figure 6). In my feedback, I focused on four general aspects of the student's design process. First, how did they define the goals and constraints for their map? In general, I was looking for some explanation as to why students had chosen the scale and extent of the map, the elements to include in the composition, and some sense of the relative importance of these elements and the visual hierarchy they map should convey. The main question here concerned the degree to which students expressed awareness for the audience, the geography of their study site, the context of the map, their purpose as a mapmaker, and the limits of the available data. Second, how did they plan their steps? Did they make a simple sketch or a list of goals or somehow step away from the GIS and graphics software while conceiving the layout? Did their workflow force them to "do over" a lot of previous work because they made a particular decision too late in the process? In general, I tried to help students see how decisions could affect other decisions and develop strategies for sequencing workflows efficiently. Third, how did they justify their decisions? For example, did they point to a good example, or refer to a cartographic principle, or did they offer only a personal opinion or no reason at all? In this regard, I found that teaching design was similar to teaching academic writing and the use of evidence when making an argument. Fourth, how did they reflect on their decisions to decide if their design was working? For example, did they print out drafts so they could see their work in the medium and scale of their eventual product? Did they solicit someone else's opinion, or incorporate feedback from one of our class crits? My goal here was to encourage students to consider design to be something like a hypothesis that they should seek to test rather than presume true.

6 Conclusion

A number of the methods from this course were successful in the sense that I plan to continue improving on them in the future. In general, the efforts to make lectures more active through small group tasks and critiques were successful with one caveat. In the pop-up map galleries, I found that students needed help focusing their criticisms so that they didn't just fall back on their personal and subjective opinions. Prompts helped connect discussions to cartographic principles and good examples, rather than personal feelings or beliefs.

The main cautionary advice that I offer other instructors interested in project-based approaches to teaching cartography concerns the need for scaffolding when teaching design. Few students had difficulty with the locator map project, because they were largely applying elements from the style guide to their own project and because the data were readily accessible through Natural Earth. Many students had difficulty with the other two maps, particularly the third map depicting terrain, and this likely stemmed from two issues. First, the style guide had not introduced them to elements of mountain cartography and it was difficult for students to simultaneously acquire new methods and apply them to independent work. Second, finding data was difficult and time-consuming because there wasn't a single central source, like Natural Earth, that all the students could use for their chosen scale.

The framework for guiding independent projects discussed above was helpful for creating an environment where students could learn from each other. The map projects were similar in purpose but different in place. This created two pleasant outcomes. First, it allowed us to compare how physical geography (glaciated mountains in Maine versus Montana versus the erosion of the Colorado Plateau versus the Basin and Range, etc) and basic constraints of cartography (map scale and extent) affected methods in mountain cartography. Second, it helped create an environment where students could learn from each other outside of the designated lecture and lab meetings with an instructor, because students worked on tasks that were analogous but not identical. With better scaffolding and a smaller class size to facilitate individual mentoring, this is a promising framework for learning mountain cartography in the constraints of an undergraduate classroom.

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Geodetic Hiking Portal

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Abstract. There are 75 trigonometric points (pillars) of the 1st order in the territory of the Republic of Croatia, which are primarily of interest to geodesists. However, because most of these pillars are on the summits of mountains, they are also of interest to hikers. This paper describes the Geodetic Hiking Portal. The portal is a supplement to the newly suggested Geodetic hiking tour. It contains reliable spatial and attribute data on the trigonometrical pillars of the 1st order (checkpoints of the tour) with descriptions and illustrations of their access routes.

Keywords: *geodesy, trigonometrical points, hiking web portal*

1 Introduction

st organized mountaineering association in Croatia dates back to 1874 with the foundation of Hrvatsko planinarsko družtvo (Croatian Mountaineering Company) (URL 1). It later became Hrvatski planinarski savez (Croatian Mountaineering Association). Croatia also has a long tradition of maintaining mountain tours for hiking[1]. The main tour is the Croatian Mountain Tour. It is the successor of the Croatian mountain transversal Along the Croatian Mountains (URL 3). There are also many local tours maintained by regional mountaineering associations. Many mountain tours attract hikers and other visitors to traverse the summits and visit nearby areas.

Throughout Croatia there is a series of points located mostly on the summits of mountains. Geodetic pillars and pyramids are built on these points. These points are trigonometrical points of the 1st order, which were established to support the former and current official coordinate reference system of Croatia. Individually and as a collection, they are of interest only to geodesists. These points date a few centuries back, to the Austro-Hungarian era. However, because most of them are on scenic summits with open vistas, their locations are also of interest to hikers. To make these points better known to the general public and to point out their importance to laymen, the Geodetic Hiking Tour is proposed. The checkpoints of the Geodetic Hiking Tour are the trigonometrical points of the 1st order on the territory of Croatia.

2 Overview of the History of the Trigonometrical Network of the 1st order

The network of trigonometric points of the 1st order in Croatia consists of 75 pillars. Average distance between the points is approximately 30 km and they are the basis

[1] A hiking tour is a collection of hiking destinations connected in a meaningful manner. Completing the tour is rewarded by the mountaineering asociation responsible for the tour.A tour can be a trail, a network of trails, a collection of unconnected points or a hiking competition without specific points, but with other requirements. Passing of checkpoints is confirmed by a stamp in a personal hiking log or by a photo of the hiker next to the checkpoint. The hiker that fufills the requirements of the tour ir rewarded with a pin or a written acknowledgment (URL 2) .

Figure 1: Trigonometrical point Bjelolasica

of the coordinate reference frame. Most of the pillars were built during surveys conducted by the Austro-Hungarian empire of the Croatian territory; others were built during surveys by Yugoslavia. First topographic mapping of the Habsburg Monarchy, and thus of the territory of Croatia, was the First Military Survey, i.e. the Josef Survey (Čolić et al.). It started in 1764 and lasted until 1787. The result were 4,096 pages of topographic maps. During the survey, no trigonometric network was established so the maps can't be mutually connected. With the demand for more accurate maps, the Austrian Empire established Astronomic-Trigonometric Department of the Austrian Army. This Department conducted the first triangulation survey, astronomical measurements to determine the coordinates of points, measurements of gravity and detailed topographic measurements. The Second Military Survey, i.e. the Franz Survey started in 1807 and ended in 1869. The year 1869 saw the beginning of the Third Military Survey, i.e. the Franz-Joseph Survey. During this survey a geodetic frame was developed. Trigonometic points from previous surveys were used, but their coordinates were determined anew. This was also the first survey that used the metric system. The survey ended in 1887. The Fourth Military Survey, i.e. the Precise Survey started in 1896 and ended unfinished in 1916. The trigonometrical network of this survey was later used as the trigonometrical network of lower orders for the territory of Croatia. Some of the pillars were destroyed early on, and even more during the First World War (Čolić 1994).

During the State of SHS and Kingdom of Yugoslavia, there were no fundamental geodetic measurements or topografic surveys. After the Second World War, there were triangulation measurements, levelling, and topographic surveys. Part of the trigonometrical network of the 1st order on the territories of Croatia, Slovenia, Bosnia and Herzegovina, and Montenegro are the trigonometrical pillars of the Austro-Hungarian survey. The network on the territory of Croatia was reconstructed since 1946 (Peterca and Čolović 1987). There were many problems with the post-war trigonometrical network. After the 1946-1949 surveys, the accuracy of the network was increased by converting it into a geodetic-astronomical network. Some of the pillars were rebuilt. Some basis measurements were completed and Laplace points were determined, where the astronomical measurements took place. Angles in some of the triangles were measured again. Finally, it was determined to re-measure the whole network. In the early 1970s, however, almost all geodetic measuremnts were terminated. The lenghtly triangulation measurements were never processed, nor accessible to civil geodetic organisations and scientists. After independence in 1991, the Republic of Croatia cannot produce topographic maps because all of the printing originals were

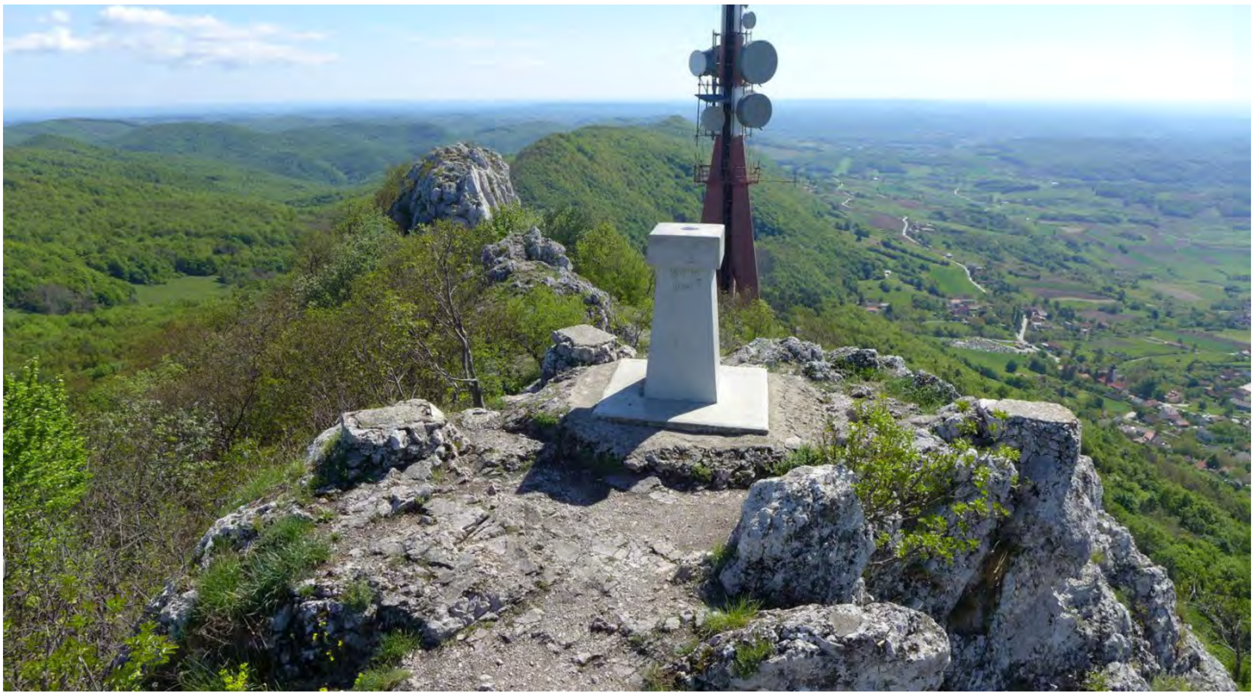

Figure 2: Trigonometrical point Kalnik

in Belgrade. Aerial photography began in the mid-1990s with the purpose of creating new topographic maps using modern digital technologies. GPS measurements began at the same time at selected trigonometrical points of the 1st order as a part of the EUREF international project. That made Croatia part of the European Reference Frame. Measurements were continued with the CRODYN geodynamic project. New GNSS campaigns were a part of the EUREF-CRODYN projects, but also of the CROREF project for geodynamic research of the Adriatic Sea and for the control of the permanent points of the GNSS network of Croatia (Špoljarić et al. 2010).

3 Geodetic Hiking Tour

Although most of the trig points are on the summits of hills and mountains, some are in lowlands, and some are in towns and settlements. As they are mostly on the summits, they are of great interest for hikers. Trigonometrical points are mostly pillars and pyramids, while the ones in settlements are mostly church towers with an eccentric point nearby. Out of the 75 trigonometrical points, a few of them are overgrown with forest or shrubs, e.g. Privis and Koševac. Most of the points have open horizons, e.g. Bjelolasica (Figure 1) and Kalnik (Figure 2), which was crutial when their location was chosen. Twenty nine checkpoints with attractive locations are on the Croatian Mountain Tour, which is the main and the most popular hiking tour in Croatia.

To popularise the points and to connect them into a hiking network, establishment of the Geodetic Hiking Tour is proposed. Checkpoints on the Tour are the trigonometrical points of the 1st order. The first idea of the tour was developed and suggested by Professor Špoljarić, but the realization of the Tour began last year with the development of its online sites, by visiting the pillars, and collecting their spatial and attribute data. Geodetic Hiking Portal (URL4) and the e-Log of the Geodetic Hiking Tour (URL5) were developed as a support for hikers who would visit the Geodetic Hiking Tour. The Portal serves as a database of the checkpoints. It was developed by J. Jagetić. E-Log is a place where users can log their visits to checkpoints, which was developed by G. Tomac. In April of this year, the Geodetic Hiking Tour was presented to the Commission on Mountain Trails of the Croatian Mountaineering Association, the main Croatian mountaineering and hiking organization.

4 Geodetic Hiking Portal

Spatial data and attributes of the trigonometrical points were collected for the effectuation of the Geodetic Hiking Tour. Some of the data were obtained by searching the archives of former surveys. Archives of

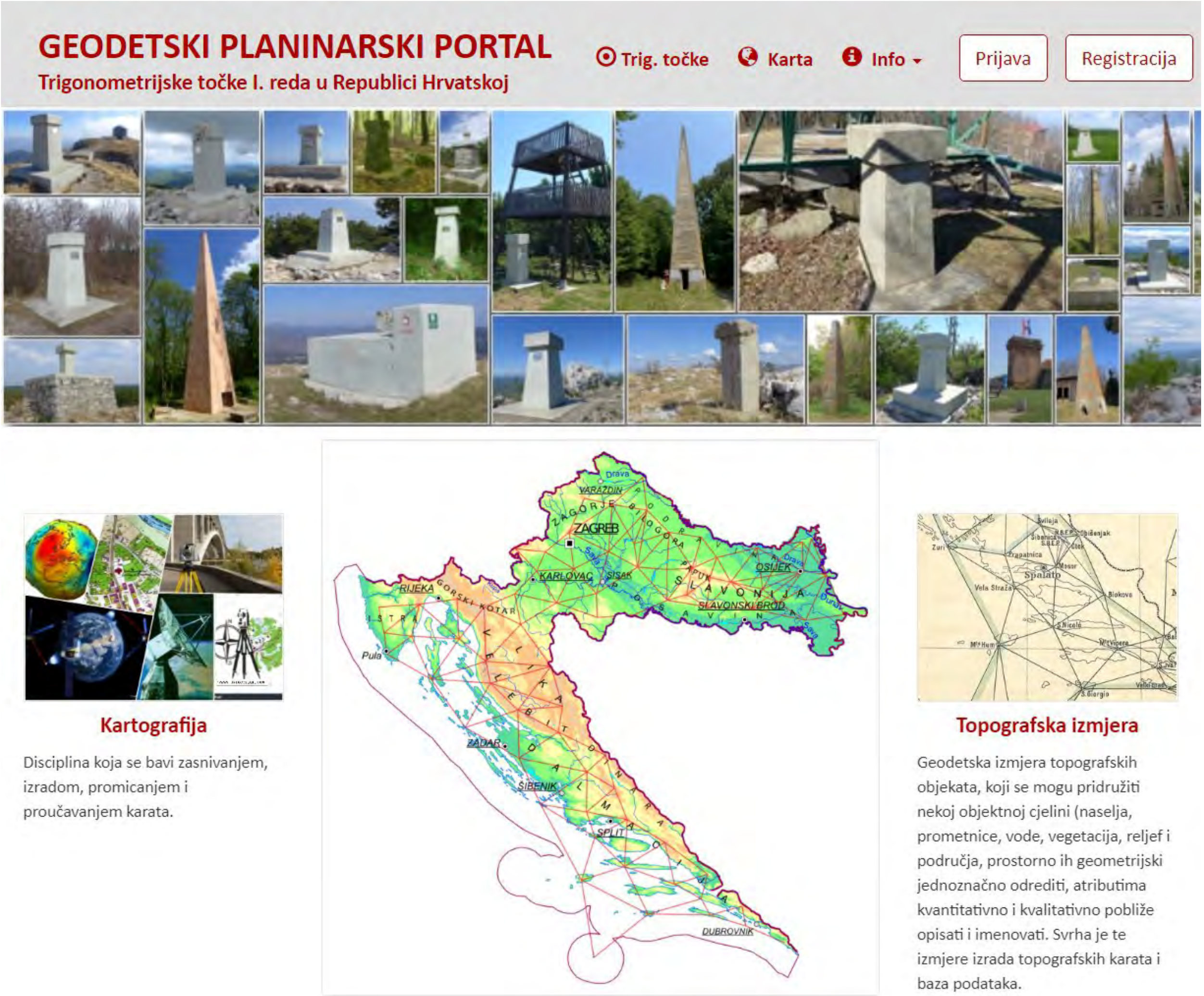

Figure 3: Homepage of the Geodetic Hiking Portal (URL 4).

Austro-Hungarian surveys were found as were the data sheets from Yugoslavian surveys. Another source were data sheets of points from the Croatian GPS Campaign obtained from the State Geodetic Administration. Data about those points that are a part of the Croatian Mountain Tour were obtained on the web pages of the Croatian Mountaineering Association.

Some of the data were collected in the field by visiting the trigonometrical points. GNSS tracks were recorded using a handheld GNSS device. Access routes by car and on foot were recorded. Photographs were taken along the track as well as at the summit. Access routes are described to help other hikers to get to the trigonometrical points, along with the photographs and GNSS traces.

The collected data were joined, edited, standardized, and finally published on the Geodetic Hiking Portal (URL3) (Figure 3). It serves as the database of the Geodetic Hiking Tour and provides the user with useful information for the preparation of hikes to the checkpoints. In the development of the Geodetic Hiking Portal, several open source technologies were used. PostgreSQL was used in the development of the database. To add spatial data, the PostGIS extension of the PostgreSQL was used. Web framework Django was used to develop the back-end of the portal, which was written in the Python programming language. HTML, CSS and JavaScript were used to create the front-end of the portal. For easier editing, Bootstrap library was used. To add and edit maps on the portal, Leaflet, a JavaScript library, was used.

The portal contains spatial data and attributes of trigonometric points. Each point has its own page, which is accessible either through the table that lists every point, or through the interactive map that contains every point. It was not necessary to create each individual page for every point; a template was made using Django framework and it is filled with the data from

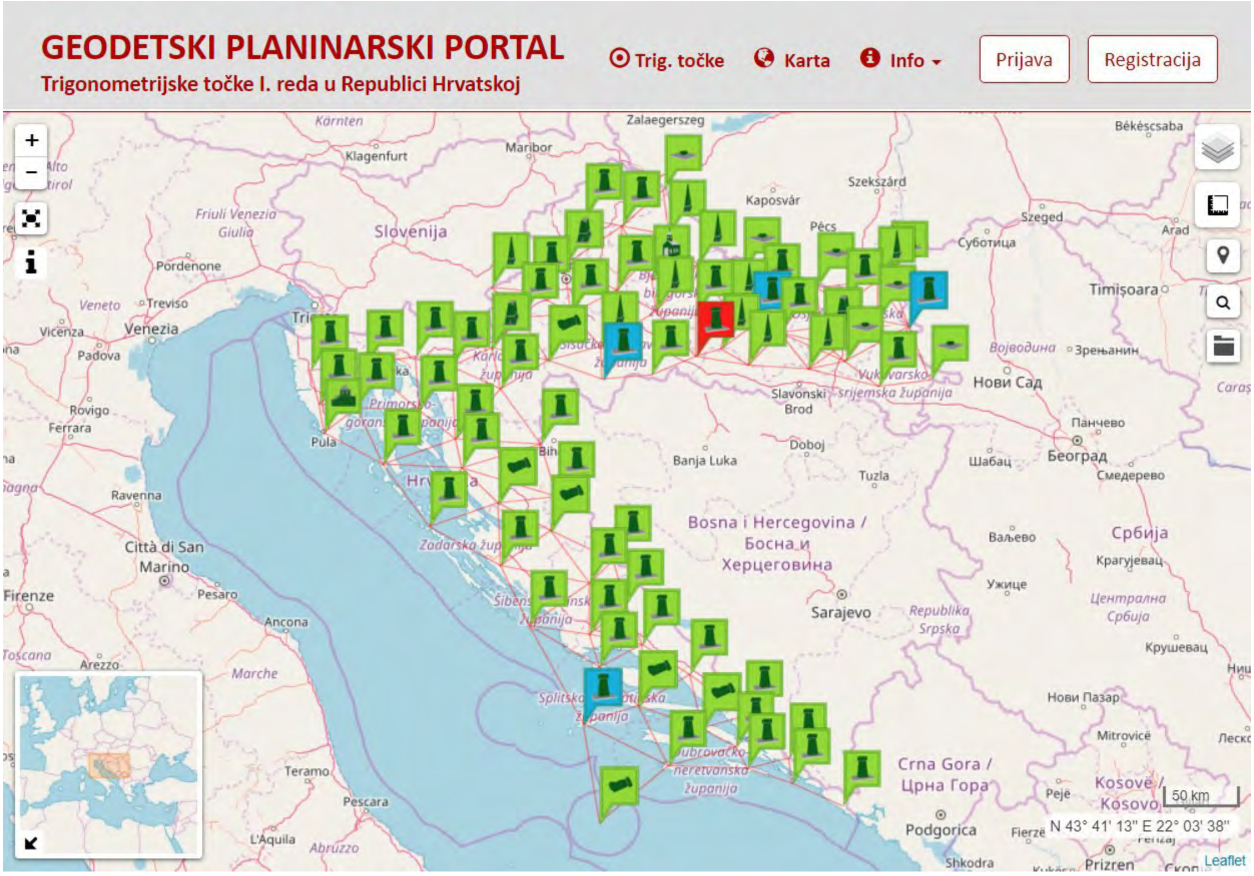

Figure 4: Interactive map on the Geodetic Hiking Portal

the database. Each page contains the collected data on that point. There is a photo and the description of the way a point is marked, an interactive map with access routes, geometric data, as well as geodetic and hiking attribute data. It also contains the descriptions of access routes, along with photographs of them, their length and duration, and a GNSS track in gpx format that can be downloaded and put into a GNSS device.

A major part of the portal is the interactive map created using the Leaflet library. (Figure 4) It displays the network of the trigonometrical points of the 1st order and the lines of sights between the points. There is also the collected GNSS trail data that can be directly downloaded from the map, and the elevation profile of the tracks can be displayed. Users can add their own GNSS tracks to be displayed on the map. The content can be filtered to show only the points in a specified region, only specific ways of marking, or points at a certain elevation.

The Geodetic Hiking Portal also contains additional information to inform users about geodesy and its related disciplines, such as cartography, photogrammetry, and geomatics. There is also a historical overview of the trigonometrical surveys with the topographic maps that were the result of the First, Second, and Third Military Survey.

5 Conclusion

Development of the database with spatial and attribute data of trigonometrical points of the 1st order created a new source of information on points of the coordinate reference frame. The historical and contemporaty data on their development covers the history of geodesy in Croatia. The portal also promotes the State Geodetic Administration, geodetic profession, and its heritage. It is an opportunity to educate hikers, cyclists, and other visitors on geodesy. The main and the most attractive hiking tour in Croatia has in total 152 checkpoints. Out of 75 geodetic pillars and pyramids, only 26 of them are the checkpoints on the Croatian Mountain Tour, so 49 of them were previously unknown to the general public.

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Denali and the Alaska Range

Mapping North America's Highest Peak

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Abstract. Denali, the highest peak in North America, and the sprawling Alaska Range pose a unique cartographic challenge. Inspired by Heinrich Berann's stunning artistry, the Denali and the Alaska Range panorama mimics aspects of Berann's distinct style with natural-color images derived from high-resolution satellite imagery draped over obliquely rendered relief. The bird's-eye view emphasizes the grandeur of Denali while connecting with the reader on a more intimate level. Three-dimensional panoramic mapping can bring many landscapes to life, but its application should be approached conservatively. As panoramic mapping grows in popularity, great works of artists such as Berann can be a valuable reference for cartographers.

Keywords: *Denali, shaded relief, panorama, relief representation*

1 Introduction

Denali, one of the world's most prominent and isolated peaks, is part of the narrow and formidable Alaska Range stretching 400 miles (650km) from southcentral Alaska to the southern border of Canada's Yukon Territory. At 20,310 feet (6,190 meters), it is the tallest peak in North America. If measuring from the base of Denali on land–rather than from sea level–to its highest point, Denali surpasses Mt. Everest as the tallest mountain in the world. The towering, vast, and mountainous terrain poses a unique cartographic challenge. This paper examines the motivation, innovative techniques, and design decisions behind the panoramic map of Denali and the Alaska Range (Figure 1).

Until 2015, Denali was officially named Mount McKinley, a name suggested by a prospector in 1896 in honor of then presidential candidate William McKinley, who later became the 25th president of the United States. In 1975, the Alaska Board of Geographic Names changed the name to Denali–meaning "the great one" in the native Koyukon Athabascan language–but a request from the Alaska state legislature to the U.S. Board on Geographic Names to follow suit was blocked by a congressman from Ohio, McKinley's home state. Ahead of a presidential visit to Alaska in 2015, the Obama Administration and then U.S. Secretary of the Interior Sally Jewel announced the name Denali would be restored in recognition of the traditions of Alaska Natives and the strong support of the Alaskan people. In addition to the renaming of Denali back to its traditional native name, a passion for relief representation, and a desire to test the limits of panoramic mapping techniques in a topographically complex alpine landscape motivated the creation of this map.

Serving as inspiration for the design of the Denali and the Alaska Range panorama was the work of renowned Austrian painter and panoramist Heinrich Berann. During his prolific 50-year career, Berann painted more than 500 panoramas (Patterson, 2000). His final panorama, published in 1994, was Denali (Figure 2).

Berann skillfully blended artistic ingenuity with natural realism to invite the reader to experience a landscape

Figure 1: Denali and the Alaska Range by Brooke E. Marston, 2016.

Figure 2: Denali panoramic map by Heinrich Berann published in 1994 (source: Patterson, 2000).

in a more intuitive manner. Using large arcing horizons, delicate and ethereal cloudscapes, background haze, and plan oblique relief to give the impression of front-to-back depth in his panoramas (Jenny and Patterson, 2007), Berann transcended the boundary between art and cartography. Since the publication of Berann's Denali panorama, panoramas of Denali have been scarce. Berann's unique ability to visualize a landscape in a way that immediately appeals to and invokes the imagination of the average person inspired this map, one of the few panoramic maps of Denali produced in more than two decades.

2 Cartographic Methods and Production

The rugged expansiveness of the Alaska Range is difficult to illustrate comprehensively with standard two-dimensional planimetric mapping techniques. Using a three-dimensional panoramic perspective for Denali played to one of this cartographic technique's greatest strengths: capturing the grandness of Denali and the Alaska Range in one continuous view. One of most effective uses of three-dimensional relief is at smaller scales in dramatic terrain dominated by tall, solitary peaks (Jenny and Patterson, 2007). In this regard, Denali and the Alaska Range were well-suited for panoramic representation. As cartographer Erwin Raisz once said, plan oblique is a method that "makes mountains look like mountains" (Raisz, 1948). The bird's-eye-view emphasizes the sheer size of the mountains while maintaining a closeness with the reader.

Because weather in Alaska is highly variable and unpredictable, finding high-resolution satellite imagery with minimal cloud coverage was a challenge. In a stroke of luck, cloud-free Landsat 8 30-meter resolution satellite imagery from June 2015 was available from Libra, a browser for open Landsat 8 satellite imagery (Libra, 2015). Landsat 8, an American satellite launched in February 2013 by NASA in collaboration with the U.S. Geological Survey, collects imagery for nine shortwave bands and two longwave thermal bands (Figure 3).

Using the Landsat 8 Photoshop Tutorial by Tom Patterson as a guide, the Landsat 8 imagery downloaded from Libra was processed in Adobe Photoshop CS6 to create a natural color image for the Denali panorama. Because Landsat 8 bands 4, 3, and 2 correspond to the red, green, and blue portions of the visible spectrum, merging these bands as RGB channels in Photoshop produced an image that approximated Earth's natural colors (Figure 4a). However, in a 4-3-2 natural color

Band	Description	Resolution (m)
1	Ultra blue	30
2	Blue	30
3	Green	30
4	Red	30
5	Near Infrared	30
6	Shortwave Infrared	30
7	Shortwave Infrared	30
8	Panchromatic	15
9	Cirrus clouds	30
10*	Thermal Infrared	30
11*	Thermal Infrared	30

*Acquired at 100 meter resolution, but resampled to 30 meter.

(a)

LC80700162015166LGN00_B1.TIF
LC80700162015166LGN00_B2.TIF
LC80700162015166LGN00_B3.TIF
LC80700162015166LGN00_B4.TIF
LC80700162015166LGN00_B5.TIF
LC80700162015166LGN00_B6.TIF
LC80700162015166LGN00_B7.TIF
LC80700162015166LGN00_B8.TIF
LC80700162015166LGN00_B9.TIF
LC80700162015166LGN00_B10.TIF
LC80700162015166LGN00_B11.TIF
LC80700162015166LGN00_BQA.TIF
LC80700162015166LGN00_MTL.txt

(b)

Figure 3: (a) Landsat 8 band descriptions (source: landsat.usgs.gov); (b) decompressed file structure for June 2015 Landsat 8 imagery for Denali downloaded from Libra.

image, forests often appear a dingy brown or gray. To enhance the green hue for forest, a second image was made by merging Landsat 8 bands 7, 5, and 3 (Figure 4b). Combining and altering the blending modes of the 7-5-3 and 4-3-2 images until the forests are an appropriate green created a composite RGB blended image that more closely emulates what people see in their everyday lives (Figure 4c). Landsat 8 Band 8 was used to apply panchromatic sharpening–a remote sensing technique to enhance the resolution of 30-meter Landsat 8 imagery–to the composite RGB blended image. Adjusting levels and curves of the composite RGB blended image produced a suitable natural color image (Figure 4d) to overlay on a relief rendering.

Natural Scene Designer Pro 6.0 was used to render a three-dimensional panoramic terrain model from a 5-meter digital elevation model. Once an appropriate panoramic viewpoint was selected, the natural color image was draped over the terrain model and a panorama TIFF image was rendered (Figure 5a). A distance mask–a grayscale image in which shades of gray are based on distance from the viewpoint origin–was also rendered in Natural Scene Designer (Figure 5b).

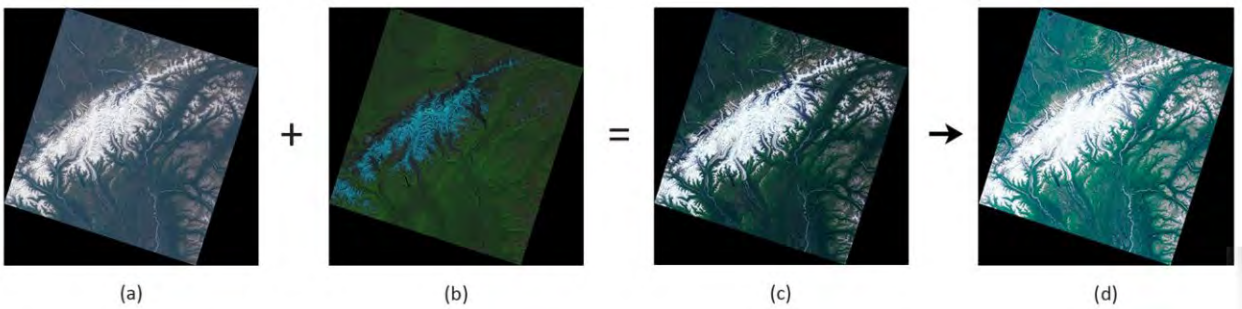

Figure 4: (a) 4-3-2 image; (b) 7-5-3 image; (c) composite RGB blended image; (d) composite RGB blended image with panchromatic sharpening and Photoshop adjustments applied.

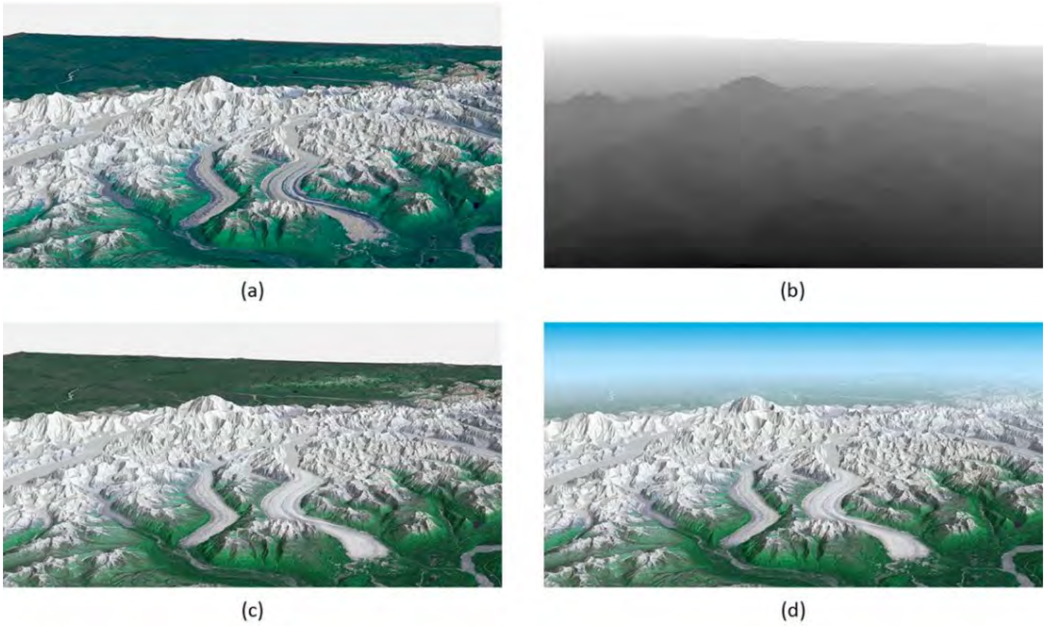

Figure 5: (a) Natural color image overlaid on plan oblique relief; (b) distance mask; (c) selective coloring and lighting effects applied to natural color image; (d) distance mask creates a background haze by fading the background into a sky gradient.

In Photoshop, the panorama TIFF was modified with level, hue, and curve adjustments for selective coloring and lighting effects (Figure 5c). The distance mask created a background haze by fading and blending the background into a blue-brown linear gradient imitating the sky (Figure 5d). The final stage of production, adding labels to the map, was done in Adobe Illustrator CS6 (Figure 1).

3 Design

Many individual design decisions went into the Denali and the Alaska Range map. One of the most significant design decisions was also one of the first: determining the panorama's point of view. The Alaska Range arcs east to west along a crescent shape across south central Alaska. The origin of the viewpoint for the panorama, southeast of the Denali Massif, was carefully selected after trying several different locations to feature Denali majestically in the center of the map (Figure 6). With this viewpoint, the Kahiltna, Tokostina, Ruth, and Eldridge Glaciers direct the reader's vision from lowlands in the foreground, up the span of the glaciers to their nexus at the base of Denali.

When it came to painting panoramic landscapes, Berann took artistic license with the precise location and position of features, often selectively rotating or rearranging mountains to avoid obstructing or obscuring certain features. However, this panoramic map depicts a more realistic landscape truer to the geography of the Alaska Range. Except for subtle panoramic relief in the foreground, and a slight vertical exaggeration, major landscape features have not been altered. One of the disadvantages of using vertical exaggeration combined with three-dimensional relief in this landscape is the exaggeration of already rugged mountains that can result in a noisy, spiking effect which may be distracting to some readers. An example of this are the very rugged mountains east of Mooses Tooth. A possible solution would be to render a separate patch of that area with terrain smoothing, or adjust the light source to be higher and more to the south to diminish the shadows slightly.

Color selection was another important design consideration. Denali is located in a circumpolar boreal deciduous forest, known as the "emerald halo," characterized by bright green foliage in springtime. Berann's panorama, reminiscent of a landscape painting, utilized bright, saturated colors. To achieve a similar effect, bright green vegetation was used in the lowlands to reflect vivid spring tones. High-elevation peaks were rendered in soft grays, whites, and blues, evoking a wintery chill. The striking contrast between these color palettes and the bird's-eye-view perspective transports the reader into the jagged and cold landscape. The Denali panorama portrays the massive scale and grandeur of this dramatic and harsh wilderness from the perspective of a soaring bald eagle.

4 Conclusion

The Denali and the Alaska Range map has been well-received by cartographic and science communities alike. Designing this map tested the advantages and limitations of perspective, orientation, and vertical exaggeration in a dramatic wilderness landscape defined by extensive mountain glaciers and tundra, narrow canyons, and broad braided river valleys. The panoramic view shows landforms more realistically in a side view, creating an illustrative quality that appeals to many readers by portraying the landscape much how they see it in their everyday lives. Today's three-dimensional relief rendering software applications have made producing panoramic maps faster, less expensive, and more accessible to a larger audience; however, not all landscapes benefit from a panoramic depiction and its use should be implemented judiciously. Disadvantages of panoramic mapping include partially obscured or occluded terrain features, the shortening of the back slopes of steep mountains, ineffectiveness at larger scales, and the exaggerated spiking effect in craggier mountainous areas. Although new technology lessens the necessity that cartographers possess specialized manual artistic skills, the success of a panoramic map continues to rely heavily on individual design decisions. As cartography evolves in new directions and panoramic mapping gains in popularity, great works of artists such as Heinrich Berann serve as inspiration and a guiding force forward in the digital age of three-dimensional relief representation.

Acknowledgements

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Figure 6: Approximate location of the panorama viewpoint.

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Topographic Maps and Weather Information for Avalanche Prevention in Remote Mountainous Areas Utilizing a Collaborative-Participatory Approach

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Abstract. Avalanche prevention is a key factor for the safety of winter sports enthusiasts. Danger assessment is hereby the basis and is used for in field decision support. Making such decision-making aids available to the public poses however major challenges for avalanche warning. Both the potential and the variable avalanche danger, as well as their complex interconnectivity must be considered. The potential avalanche danger is strongly connected to the terrain's relief; hence, high quality topographic maps support the detection of these areas. On the other side, appropriate weather data is necessary to estimate and predict the variable avalanche danger. However, the quality of communication decides whether this avalanche related information can be understood to prevent avalanche incidents or not and be utilized for decision support. To address these issues professional avalanche warning is currently being mainly pursued worldwide by official services in regions facing high winter tourism. However, as this approach cannot or only with great difficulty be implemented in remote mountainous areas due to resource constraints, it remains questionable how regions can be supplied with avalanche-relevant information. One possibility is to pursue a collaborative-participatory approach in which sustainability, free availability of all information and targeted applicability are given high priority. To meet these demands, an open system based on open data and crowd sourcing approaches is desirable. In this contribution, the comparison between the data bases of official avalanche warning services and crowd sourcing based participatory methods will be discussed. Furthermore, the conceptual implementation of these approaches and methods is presented.

Keywords: *topographic mapping, avalanche prevention, remote mountainous areas, collaborative approach*

1 Introduction

Tourism is nowadays a global phenomenon. Especially winter tourism is increasing worldwide not only in regions equipped with high-tech infrastructure such as ski lifts and cable cars, but also in snow-covered remote mountainous areas that are very often sought for their beauty and wildness. Tourists from abroad as well as locals discover new territories for winter sports. Backcountry skiing/snowboarding or snowshoeing are just some of the ways to explore such new terrain.

With increasing winter tourism, the threat of natural hazards to humans is constantly rising. In snow-covered mountainous environments, avalanches are one of the main hazards that endanger humans and their property (VICKERS et al. 2017). In order to avoid or reduce serious damage and casualties, avalanche prevention is essential. Regions facing high-industrialized winter tourism very often pursue avalanche prevention in collaboration with official avalanche warning services. In contrast, remote mountainous areas with sparse population and low infrastructure, but with tourism on the rise, deal with serious challenges to prevent avalanche incidents.

Armenia is a perfect example of a country with high diversity of nature and terrain as well as developing tourism in which to investigate potential strategies and policies of avalanche prevention. In the winter season, snow-covered volcanoes are becoming increasingly popular for skiing tourism, however winter sports enthusiasts in Armenia still have to deal with poor infrastructure and scarcely available information on terrain and current snow conditions. In this regard, only limited efforts are currently being undertaken to manage safety in the Armenian mountains according to avalanche prevention guidance.

In the past, people avoided mountaineering or skiing snow covered mountains, so avalanches were no threat in Armenia. Now, as winter tourism is emerging, the first causalities are being registered such as the one on 28th January 2018 on Mount Araler. (ARMALP 2018). Both, the lack of risk management related to avalanche danger prevention and increasing winter tourism are responsible for the incident on Mount Araler. Subsequently, avalanche danger assessment and risk management in Armenia's mountains are currently only being established on individual initiatives.

Due to the fact that not every winter tourist has expertise in avalanche risk prevention, strategies to develop an avalanche warning service infrastructure for Armenia should be pursued. Essential and feasible steps must therefore be taken to provide a basic framework for avalanche prevention in remote mountainous areas, like in Armenia. This framework is discussed and evaluated in the following sections.

2 Avalanche Warning – Information Pyramid

Avalanche prevention is nothing new in mountainous regions, especially when dealing with intensive winter tourism. Technical infrastructure and in particular acquiring and processing information on the current avalanche situation are crucial for the success of avalanche prevention (MAIR 1999). The safety of winter sports enthusiasts according to avalanche danger is supported by a so-called "avalanche warning" that is commonly communicated by official regional or national avalanche warning services.

As an example for an internationally well-organized, functional and professional avalanche warning service, we will next discuss the structures and strategies of the service of Tyrol, Austria. The avalanche warning service Tyrol was founded in 1960 and since then has been investing knowledge and labour into improving its avalanche warning (MAIR, NAIRZ 2010). The service's goal is to contribute to the avalanche prevention accomplished by publishing a daily danger assessment about the current avalanche situation for defined geographic regions. This so-called "avalanche bulletin" provides all information needed to support the decision-making process in the field. Ever since the Tyrolian Avalanche Warning Service became a member of the EAWS (European Avalanche Warning Services), the avalanche bulletin is part of the standardized structure based on the information pyramid (ARGE – Lawinenwarndienste Österreich 2015).

The uniform structure of the avalanche bulletin follows the information pyramid adopted by European countries, and thus guarantees an appropriate communication of decisive information. On top of the pyramid, a number stands for the avalanche danger scale standardized by the EAWS (ARGE – Lawinenwarndienste Österreich 2015). This number classifies the current avalanche danger that is an aggregate of distinct and complex information; hence, beginners profit from this danger scale. Besides this number, a danger scale map and symbols that refer to particularly dangerous areas, serve as further information. Advanced winter sports enthusiasts are able to locate the avalanche danger applied to the map's scale. Information on how the current avalanche situation evolved are of interest for experts. Detailed snowpack and weather information and the latest avalanche patterns provide a deeper insight into the avalanche danger assessment (MAIR, NAIRZ 2015).

The structure of the information pyramid poses the relevant questions WHAT, WHERE and WHY that subsequently must be answered by the avalanche bulletin (ARGE – Lawinenwarndienste Österreich 2015). Different users ranging from unexperienced winter sports enthusiasts to experts address these questions in order to communicate relevant information to a broader audience. It must be said that the quality of the avalanche bulletin published by the avalanche warning service

Tyrol relies on a large amount of technical, financial and human resources, on a well-built infrastructure and many years of experience of avalanche warning and scientific work (MAIR, NAIRZ 2010). The avalanche warning service Tyrol and its avalanche bulletin have undergone continuous improvements and efforts in communicating avalanche danger efficiently. It is currently regarded as one of the cutting-edge institutions worldwide pursuing professional avalanche warning (NEUGEBAUER, KRIZ 2017).

3 Variable and Potential Avalanche Danger

It is questionable whether expensive infrastructure and approved methods for risk management that are used in highly frequented touristic regions, can achieve the same results for similar settings in remote areas such as in Armenia. Therefore, using an alternative approach must be the solution. The goal is to offer avalanche warning assessments that fit the needs of remote regions in an appropriate way.

In this contribution the two factors of weather and terrain are considered as relevant. They are responsible for the snow pack's structure and stability. Consequently, only these two factors will be considered relevant to understanding avalanche danger. Changes to these quantities lead to a general avalanche danger. Both quantities vary in different dimensions; hence the weather differs over time and the terrain alters over space. Analytically separated into time and space the general avalanche danger is divided into a variable and a potential component. The variable avalanche danger changes over time and is influenced by the weather. In contrast, the potential avalanche danger fluctuates over space and is affected by the terrain. To estimate the variable avalanche danger automatically-generated recurrent meteorological data are needed. However, the potential avalanche danger can be determined by a single visualisation of the terrain of a certain region. In order to assess the general avalanche danger, information of both quantities are necessary and must be collected, stored, processed, visualized and communicated.

4 Levels of Information

In Europe, a professional avalanche bulletin is produced by collecting and evaluating data based on the standards defined by the European Avalanche Warning Service. The result in the form of a bulletin thus contributes efficiently to prevent avalanche incidents in European mountains (BUSER et al. 1985). In remote mountainous areas, such as in Armenia, the possibility of producing an avalanche bulletin to European quality standards is limited, however. In remote mountainous regions, the required resources and knowledge to achieve this goal are simply not available. A minimum requirement list of necessary information to make an avalanche warning possible is therefore desirable the first step. Such an appropriate list is currently being discussed following the principles of the information pyramid developed by the European Avalanche Warning Services (ARGE – Lawinenwarndienste Österreich 2015). The proclaimed five Levels of Information consist of the following categories:

1. Raw Weather Data
2. Raw Weather Data and Raw Terrain Data
3. Weather Charts and Topographic Maps
4. Thematic Maps
5. Avalanche Bulletin

This list distinguishes five Levels of Information, which represents the required information range from minimum to maximum. Therefore, each Level of Information can be used for different target groups. The gained information by level for each target group is inversely proportional to the needed resources to make an avalanche danger assessment.

Level 1: Raw Weather Data

The absolute minimum of necessary information in order to assess the avalanche danger is in theory raw weather data. However additional knowledge about specific terrain features and the complex context of avalanche awareness are required. The fact that raw weather data is difficult to interpret makes information at Level 1 for an avalanche danger assessment problematic and somtimes unsuitable.

Level 2: Raw Weather Data and Raw Terrain Data

If the information is extended by addition of raw terrain data, theoretically both, the variable and the potential avalanche danger can be estimated. Nevertheless, raw data such as meteorological measurements or topographic terrain data such as DEMs (digital elevation models), are hard to use in the field for decision-making. The importance of having knowledge about avalanche awareness in combination with the ability to interpret raw weather and terrain data, makes the information provided at Level 2 mainly usable only by experts, for example, in the fields of avalanche science, cartography or meteorology.

Level 3: Weather Charts and Topographic Maps

Information at Level 3 is not only meant to serve domain experts, but also to assist the advanced non-professional mountain sports enthusiasts. Consequently, the raw data at Level 2 must be transformed into a readable form. Weather charts and topographic maps give information about the variable and the potential avalanche danger; however, knowledge about avalanche awareness is still required.

Level 4: Thematic Maps

Complex avalanche danger can be illustrated in thematic maps at Level 4. Underlined slope gradient and aspect classes point out the potential avalanche danger on a topographic map. The ratio between the slope gradient and potential avalanche danger for example, can assist the map-reader to navigate through potentially less critical areas through a process of elimination. Real-time updated thematic maps e.g. of the current snow coverage, wind speed or temperature distribution show variations in avalanche danger unambiguously. Hence, less background knowledge about avalanche awareness is necessary to communicate information at Level 4, opposed to Level 3.

Level 5: Avalanche Bulletin

Only a small amount of background knowledge about avalanche awareness is required by the user to interpret an avalanche bulletin. The professional avalanche bulletin, as described by the aforementioned example of Tyrol, connects the variable and the potential avalanche danger through its avalanche danger scale. Thus, unexperienced winter sports enthusiasts are able to use the given information at Level 5 for making decisions in the field.

Significant background knowledge is needed for each Level of Information to estimate the avalanche danger and it decreases with each higher level in the information pyramid (see Figure 1). However, the required resources increase per level. This inversely proportional ratio between the user's expertise and the necessary resources to provide specific information is crucial for establishing the basis for an avalanche warning. In conclusion: the more resources available, the less background knowledge that the user needs.

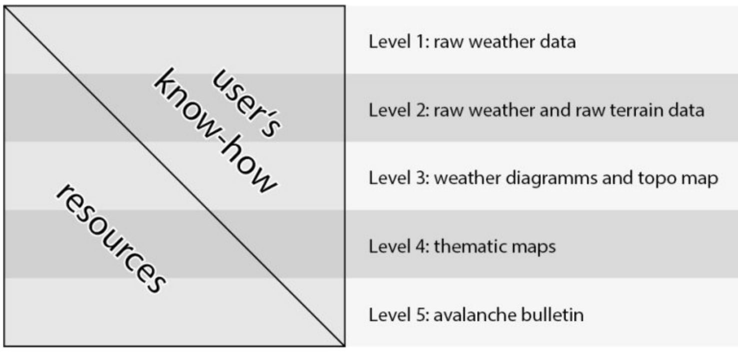

Figure 1: The user's expertise and necessary resources to provide avalanche relevant information at each level are inversely proportional.

5 Collaborative-Participatory Approach

Making resources available for avalanche warning is difficult and can be very sophisticated especially if deployed in remote mountainous regions. These resources mainly consist of variable meteorological data and terrain related geo-data, as described above within the five Levels of Information. In populated areas or in locations with developed infrastructure as in some parts of Armenia, little of these data are available, if at all. However, in order to realize a comprehensive basis for avalanche warning assessment in remote mountainous areas, an alternative approach to acquire data is necessary. A participatory approach can satisfy this assumption if the quality of data can be guaranteed. This involves a method where people as actors affected by a range of activities with a common goal play an active and influential part in the decision and acquisition process. (BERGOLD, THOMAS 2012). In other words, the actor collaborates and is not just a beneficiary, but also has the opportunity to shape the outcome. The common goal is therefore to facilitate a representative cross section of avalanche relevant information focussing on the above described meteorological and terrain related information. The people affected by this common goal are experts and winter sports enthusiasts alike, who need considerable information about the current avalanche situation in a specific area. The involvement of the affected people is realized through their participation acquiring geo-data, snow and avalanche information as well as weather data.

The current online application LAWIS (Avalanche Warning Service Information System) (LAWIS 2018) is one example of such an approach within the domain of avalanche prevention. This collaboration project was established by the University of Vienna, Department of Geography and Regional Research, Cartography and GIS, in cooperation with the Avalanche Warning Service Tyrol and exemplifies a successful realization of the aforementioned participatory approach referring to data acquisition for avalanche prevention. LAWIS communicates via an interactive topographic map portal information about the weather, snowpack and its stability, as well as facts about current and past avalanche incidents. Based on a participatory approach, everyone has the possibility to feed the system with relevant data. Consequently, the user is no longer a consumer alone, but also a participant in the production process. Volunteers participate in data acquisition at the same time as they use the gained information for their decision-making in the field. Hence, systems such as LAWIS are characterized as "bottom-up" systems.

6 Data

The basic principles of participatory data acquisition as described and exercised in LAWIS forms the basis for an avalanche warning assessment framework for remote mountainous areas. Two essential principles are crucial within this procedure. At first, the acquired data has to be applicable under the terms of the OpenData-movement. This means that data must be accessible, affordable, usable, reusable and redistributable for all. Any limitations or constraints to persons, groups or purposes are not allowed (OKFN 2018). Secondly, data acquisition must follow the VGI approach (Volunteered Geographic Information)—in other words, collected by volunteers disseminating geographic data to create user-generated content (GOODCHILD, LI 2012).

The OpenStreetMap dataset (OSM) is an example of data collected by VGI that follows the OpenData approach. This user-generated content fits to a certain extent the needs to create tailored topographic maps. If this OSM data is then combined with a DEM then avalanche-related information, such as the steepness of a slope, can be extracted from such maps. The USGS (United States Geological Survey) provides DEM datasets underlying the OpenData approach (USGS SRTM 2018). Since the participatory approach applies also for all data relevant for avalanche warning, weather and snow data are also made available under the OpenData approach. The NOAA (National Oceanic and Atmospheric Administration) for example provides free- to-use weather data (NOAA 2018) and current snow information is available via Sentinel-2 satellite data from the USGS (USGS SENTINEL-2 2018).

Despite the suitability of various datasets for the creation of a basis for an avalanche warning, there are problems and difficulties in the implementation. Due to the VGI approach of OSM data, quality differences are inevitable. NEIS and ZIELSTRA (2014), as well as MOONEY and CORCORAN (2013) point out major heterogeneity in OSM datasets between countries, especially within urban and rural areas. Hence, this data heterogeneity makes the production of topographic maps for remote mountains such as in Armenia difficult. Automatic controlling mechanisms and quality improvements (e.g. the Channel Network Method (HAJEK 2017) that reclassifies water streams for depiction improvements) do not solve the problem but can improve accuracy. In contrast to OSM data heterogeneity, weather and snow data have the problem of availability. In Armenia for example, only sixteen ground-based weather stations deliver reliable meteorological data, which is published by the NOAA (OGIMET 2018). Interpolation methods must be employed to acheive full coverage, however this again reduces the overall data reliability. Information about snow covered areas gained from Sentinel-2 satellite images is available every five days if the cloud cover does not restrict data acquisition (USGS SENTINEL-2 2018).

7 First Results

Despite difficulties and problems of data acquisition in remote mountainous regions, first attempts to create a basis for an avalanche warning have been undertaken. The University of Vienna, Department of Geography and Regional Research, Cartography and

Figure 2: Topographic map of the investigation area in Armenia, region Mount Araler, produced with OSM datasets and DEM data from the USGS (original scale 1:50.000).

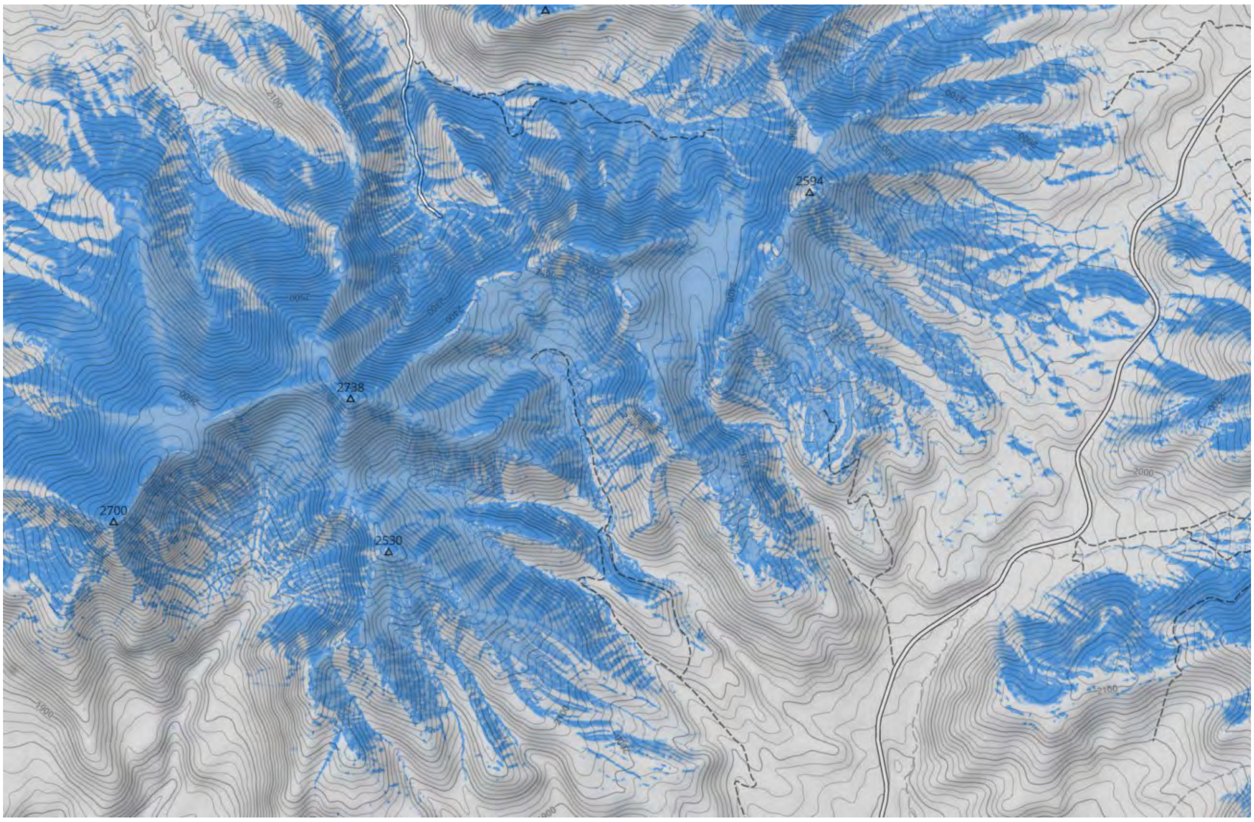

Figure 3: Current snow cover map of a region in Anatolia, Turkey, on 15th March 2016 (original scale 1:50.000); blue colour depicts areas with substantial snow coverage. Pixel resolution approx. 10m. Data extracted from Sentinel-2 dataset.

GIS, has produced a topographic map of a selected representative mountainous region in Armenia (see Figure 2). This map has been tested in the field. Despite the heterogeneity of the OSM data, particularly the depiction of contour lines (25 meter intervals) extracted from a DEM, its applicability for the detection of potential avalanche danger areas is promising.

Further tests are being conducted in similar remote mountainous regions. Snow covered mountains and volcanoes appropriate for winter tourism can be found in many different regions worldwide, such as in Turkey (region of Anatolia) where similar research is being carried out. As in Armenia, Turkey also currently lacks substantial efforts on mountain safety relating to avalanche danger. For this reason, the University of Vienna, Department of Geography and Regional Research, Cartography and GIS, produced and tested a snow cover map in the mountains of Anatolia (see Figure 3). In order to detect current snow covered areas real-time data from the Sentinel-2 satellite was used. The data was then subsequently visualised on a specially adapted large-scale topographic map. The information gained from the snow cover map was useful for tour planning. Furthermore, avalanche danger was estimated through combining the potential avalanche slopes with the current snow information.

These two examples demonstrate the applicability and usability of data communication at Level 3 and 4 of the Levels of Information using a collaborative-participatory approach for an avalanche warning. However, further investigation in respect to quality assurance and reliability of weather and snow data must be developed and carried out. The process implemented by the online portal LAWIS demonstrates a potential solution offering additional snow and avalanche data if people participate in the data collection. Winter sports enthusiasts for example can publish snow pit analysis and stability tests that provide insight into the snow structure. Observations of avalanche incidents point out potential hazard areas. This information is visualised automatically in LAWIS on top of a tailored topographic map that combines weather and snow pack information as well as referenced observations of incidents to disseminate a holistic overview on current avalanche relevant issues.

8 Conclusion

Regions with increasing winter tourism in remote mountainous areas, as in Armenia, will be more and more confronted in the near future by avalanche risk. Major efforts have yet still to be undertaken in such regions to assess and cope with avalanche hazard prevention. The question posed is how such mountainous regions due to their circumstances of being remote and lacking substantial infrastructure can supply avalanche-relevant information in an appropriate way to both experts and to the public. This contribution proposes the possibility of using a collaborative-participatory approach. Data is used under the principles of the OpenData movement and VGI in contrast to the employment of proprietary data. The OpenData and VGI approach, thus, guarantees free use, access and distribution; hence, the participation of every interested or affected person is given high priority. Due to the heterogeneity of VGI data, five Levels of Information have been developed and demonstrate an efficient workflow given the precarious relationship of data availability and their quality. Further tests still have to be undertaken to demonstrate the applicability and benefit for the tour planning as well as avalanche assessment. Combined with systems such as LAWIS additional information about the snowpack and avalanche incidents can be integrated to promote a high-level information portal that can provide a broad user group essential insight to avalanche prevention and thus even save lives.

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Designing 3D Terrain Maps

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Abstract. Nowadays, despite the ubiquity of automated 3D maps provided by technology companies such as Apple and Google, knowledge about designing 3D terrain maps is still generally lacking in the cartographic community. My talk will provide practical advice about designing obliquely-viewed 3D terrain maps for use on static computer displays or in print. The emphasis is on small-scale views of mountainous landscapes without buildings and other cultural minutiae. I will start with cautionary advice on whether to attempt 3D terrain mapping, which requires considerably more time and expense than planimetric mapping of the same area. The availability of good data, terrain that is suitable for 3D depiction, and the map purpose are all factors in this decision. Next, I will discuss scene setup. Once a digital elevation model is loaded in your 3D software, adjusting the virtual camera for direction of view, pitch, and lens focal length are key considerations. Another critical decision is whether the 3D map should include a horizon and sky, elements that take up precious space on the page and that may not be necessary. Illumination must take into account the dominant terrain structures and whether the terrain is draped with imagery containing embedded cast shadows. The amount of vertical exaggeration affects how dramatic the terrain will appear, and realistic. I will wrap up with a discussion of graphic embellishments to 3D terrain maps, all of which are performed in Adobe Photoshop. Topics include background haze and foreground shadows, sun glints on water surfaces, clouds, and horizon curvature.

Keywords: *3D, terrain, scene setup, camera settings, illumination, horizon and sky, sun glints*

1 Introduction

This article offers ideas and advice about creating obliquely viewed 3D terrain maps for use on static computer displays or as hard-copy output. I emphasize small-scale views of wide geographic areas (i.e. maps) without buildings and other minutiae of the cultural landscape. The basis for my advice is over three decades of hands-on experience making these kinds of maps.

I make custom 3D maps for a variety of media types ranging from printed brochures to trailhead signs to visitor center exhibits. No two of my maps look alike. Nor do I use standardized production techniques; audience needs vary widely from project to project and the availability of good geospatial data is hit or miss. Making 3D terrain maps requires flexibility and opportunism. Accordingly, my workflow entails a general approach rather than prescriptive procedures.

You will need multiple applications to make professional-quality 3D terrain maps. My indispensable software includes Natural Scene Designer Pro for rendering 3D scenes and Adobe Photoshop for raster compositing (and much more). I also use Adobe Illustrator in conjunction with the MAPublisher GIS plugin for vector cartography, and the Geographic Imager GIS plugin for Adobe Photoshop. Taken together these applications are expensive, but with them I can efficiently produce most types of 3D terrain maps. Although your preferred software may be different than mine, the ideas and advice that follow should be generally applicable to your workflow.

What follows are five of the ten tips for designing 3D terrain maps discussed during my keynote at the Hvar workshop. Space limitations prohibit including all of them here. However, the remaining tips are online at http://shadedrelief.com/3D_Terrain_Maps/.

2 Should You Make a 3D Map?

There are legitimate reasons for making 3D terrain maps: they look interesting, attracting the attention of readers. Oblique viewed terrain that is three-dimensional is easier for general audiences to understand compared to conventional shaded relief and certainly topographic maps packed with contour lines. They show the vertical dimension of a landscape in addition to the x, y spatial dimension (Figure 1). And it is also immensely satisfying to make 3D terrain maps.

However, despite offering real advantages, for most projects you should NOT go to the trouble of making a 3D map. These are prohibiting factors to consider:

Time – Producing a 3D terrain map takes from two to three times as long as a conventional map. You must first compile a 2D base map before rendering the elements in 3D. There are a great many design variables to account for: For example, will the terrain look better with slightly more vertical exaggeration? Designing 3D terrain maps is addictive. You can experiment for hours.

Cost – Directly related to the above.

Data – Mapping is not possible without essential data, such as DEMs and aerial imagery. Other data challenges include low resolution, poor quality, and compatibility—especially maps that straddle international borders. You can spend large amounts of time trying to enhance poor quality data and still end up with a map that looks bad.

Geography – Some terrain is not suited for 3D depiction. Such as when important features stay hidden regardless of the viewing direction. Or when the focus of the map is a boring area dominated by adjacent terrain that is more interesting. For example, on a 3D terrain map of the Coconino Plateau, Arizona, most of us would instead look at nearby Grand Canyon.

Purpose/audience – Serious backcountry users need topographic maps with contour lines (although 3D maps are useful for trip planning). If terrain is not an

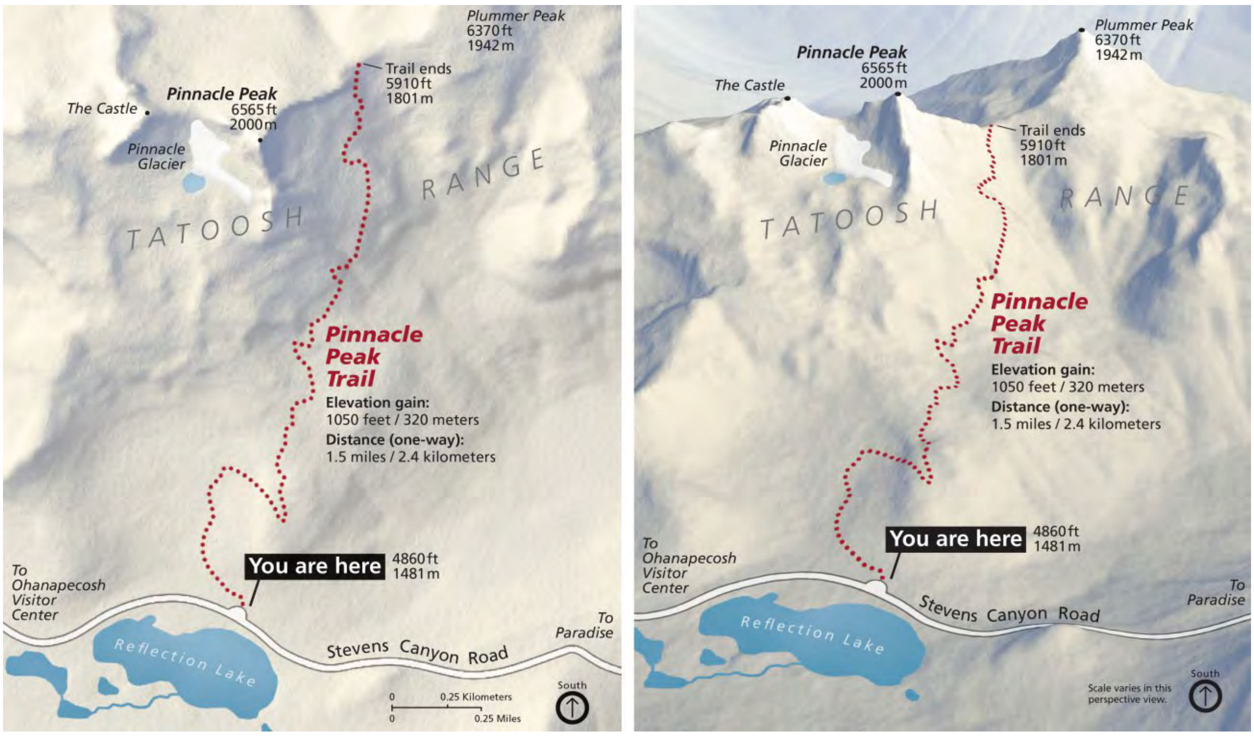

Figure 1: A 2D map (left) and 3D map (right) of Pinnacle Peak, Mount Rainier National Park, Washington, compared.

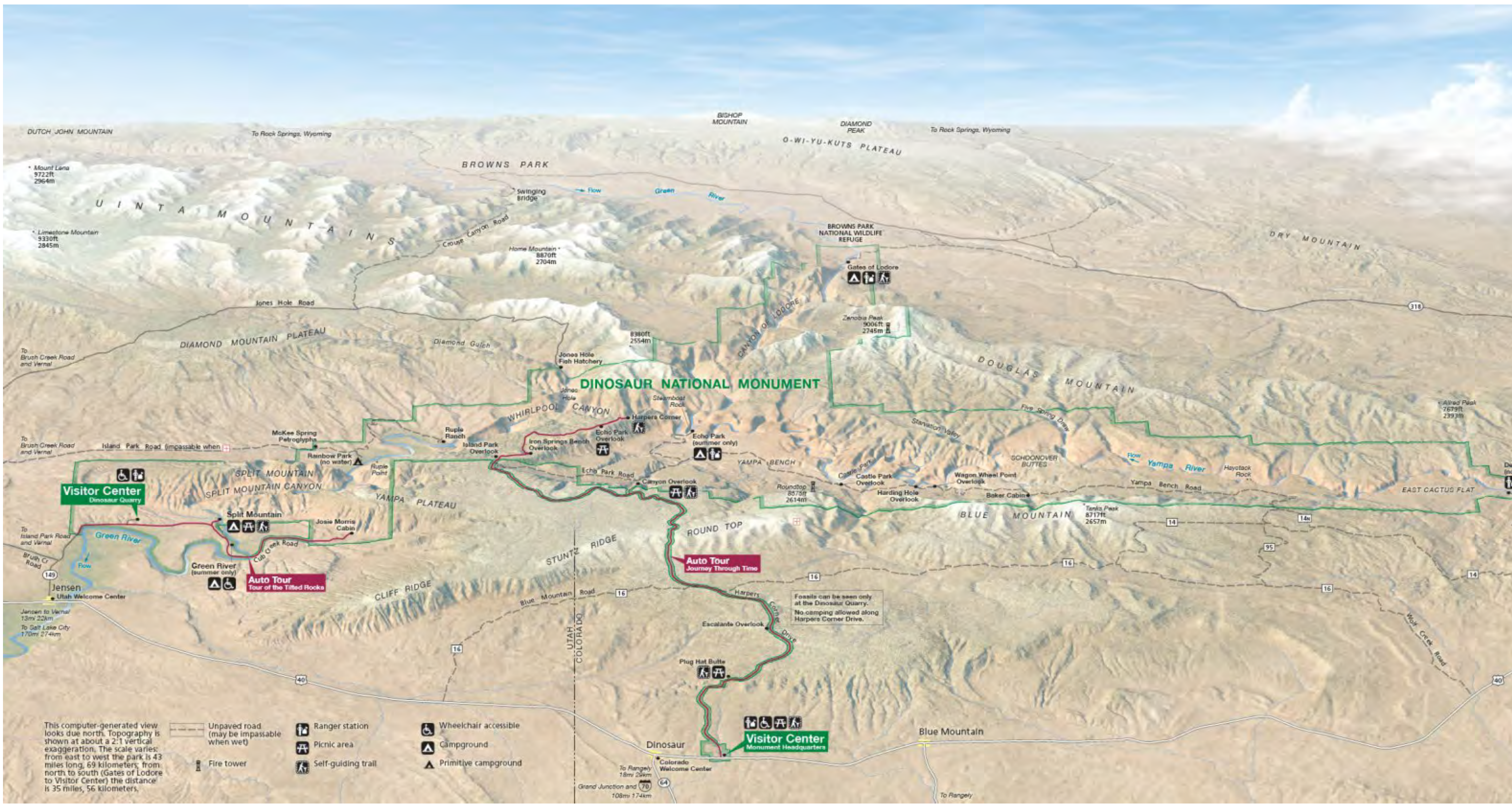

Figure 2: An inappropriate 3D map of Dinosaur National Monument, Utah and Colorado.

essential part of your map's message, going to the trouble of making a 3D map makes little sense.

Georeferencing – 3D terrain maps are pictorial products without georeferencing. On a mobile device there is no pulsing blue dot showing where you are.

Point of view – 3D terrain maps have a single point of view. Unlike a conventional map, it is not possible to navigate with a 3D map rotated 180 degrees. The mountains will appear upside down.

Foreshortening – The vertical dimension (from top to bottom on a page) of a 3D map is shorter than a conventional map of the same area because of the oblique viewing angle. The viewable area compresses. This is bad if your map must show important features in the background, or give equal emphasis to foreground and background features. Also, if your 3D terrain map must go in a layout with a portrait format, the fit can be awkward.

In the 1990s, with newfound enthusiasm for 3D digital techniques, I made a map of Dinosaur National Monument that I would come to regret (Figure 2). Among the problems: most of the map foreground was non-park land. In the middle ground, foreshortening compressed the already narrow main park area on the north-south (vertical) axis. As a consequence, the Green and Yampa rivers are mostly obscured in their deep canyons. Lastly, the sky and clouds devote too much precious map real estate to what is essentially a decorative element. Two years later for a routine reprint, I replaced the 3D map of Dinosaur National Monument with a more functional, albeit less interesting, 2D map. Lesson learned: I now wait for the right 3D mapping project to come along.

Tip 1 – Camera Direction

Selecting a direction of view is your first decision when setting up a 3D scene. All factors being equal, I prefer a camera direction looking from south to north for compatibility with conventional maps that usually are north oriented. In general, the smaller the map scale, and the less familiar the place, the more reason for selecting a north looking view. For example, many of us would not recognize, say, Ethiopia in a view looking south, but we *might* have a chance if the view looked north.

Staying on the subject of small-scale maps, rotating a scene by only 10, 20, or 30 degrees from true north (to either the east or west) can bring interest to a scene while still maintaining geographic familiarity. You often see maps in *National Geographic* magazine that do

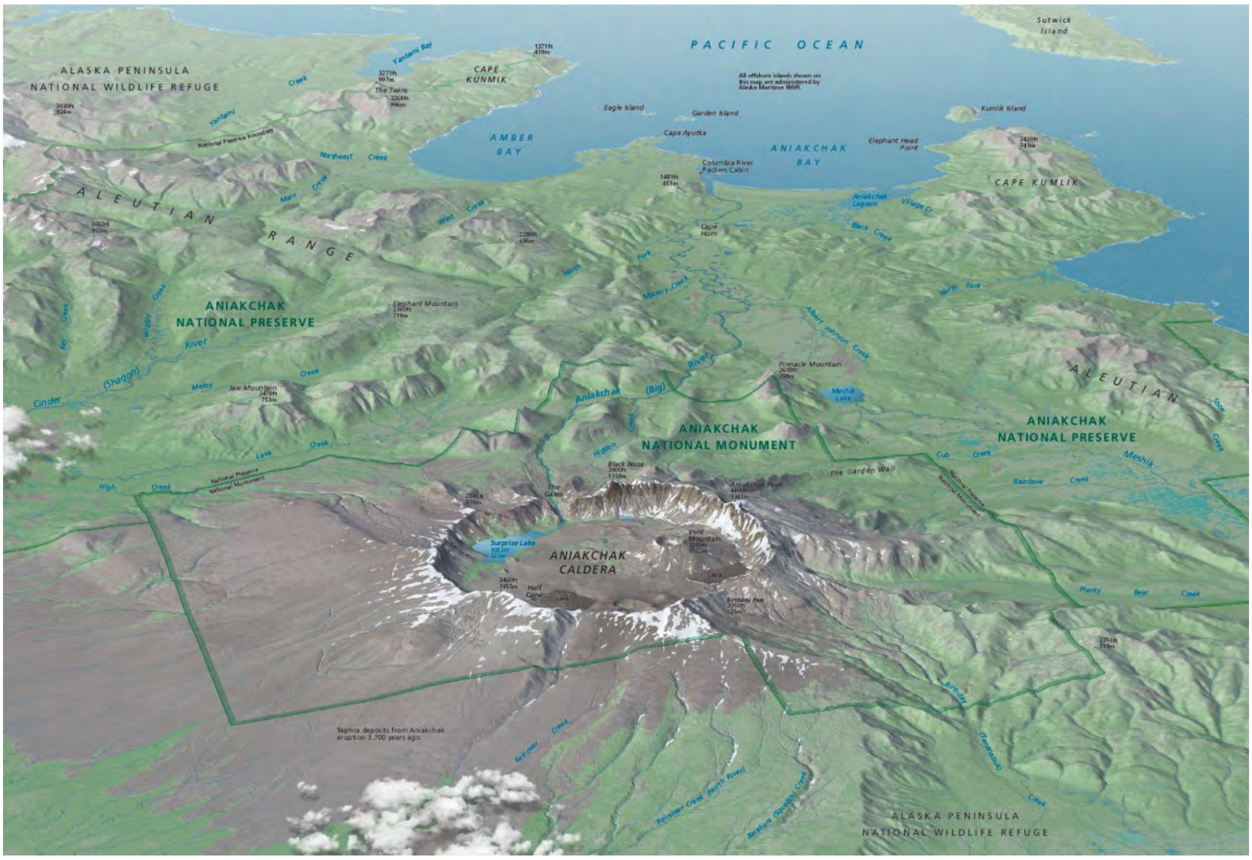

Figure 3: Aniakchak National Monument, Alaska, looking east-southeast. Although artists avoid centering the subject in a painting, it is accepted practice on 3D terrain maps.

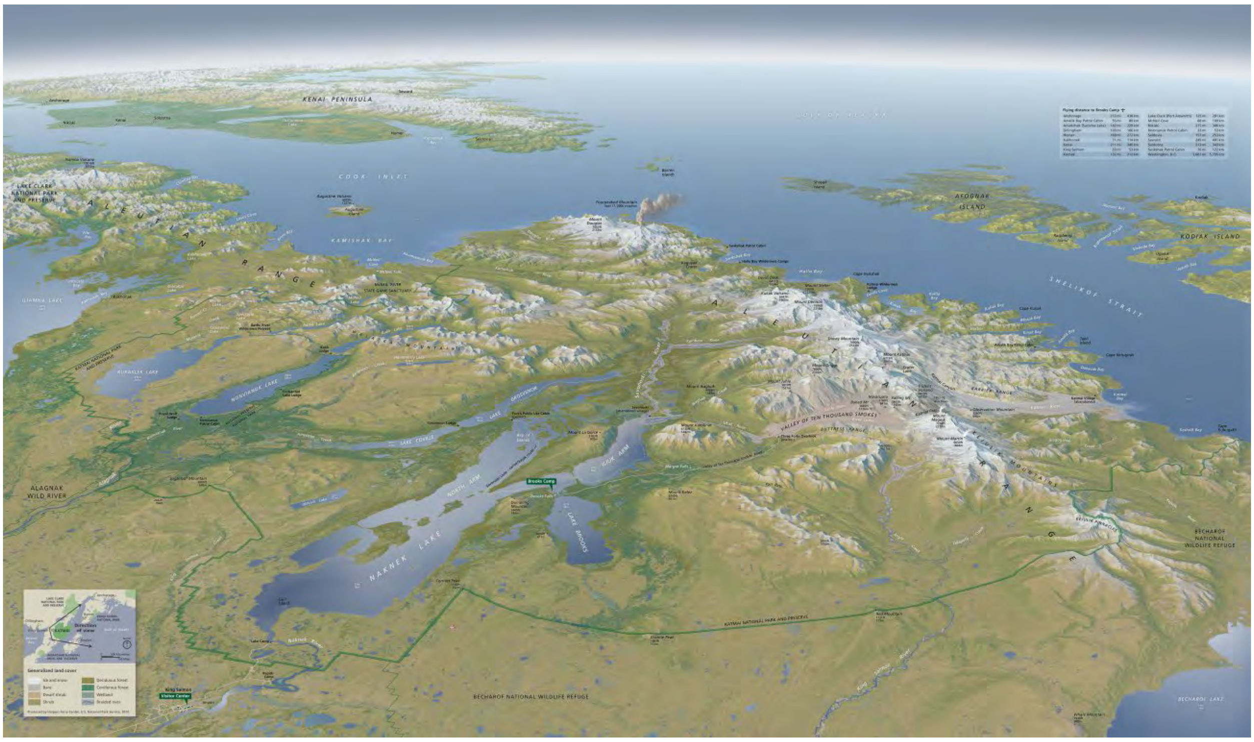

Figure 4: Katmai National Park, Alaska, looking southeast.

Figure 5: Pinnacle Peak Trail, Mount Rainier National Park, Washington.

this very successfully. Rotating the direction of view from north can give you more options when positioning a 3D map in a graphical layout, especially for geographic areas with an unusual or unbalanced shape.

Map focus is a key consideration when choosing a direction. From bottom to top on the page, 3D terrain maps have a foreground, middle ground, and background. Try to place the most important information in the upper foreground (do not crowd the bottom of the page) and middle ground. The background is for geographic context and graphic balance.

Unique terrain characteristics are a valid reason for selecting a camera direction other than north. On the map of Aniakchak National Monument (Figure 3), a southeast-looking view reveals the Aniakchak River flowing through a breach in the caldera wall to the Pacific, a route taken by river rafters, among the few visitors to this remote park.

Graphical composition is another reason for choosing a non-north view. For example, a northeast-looking view of Katmai National Park (Figure 4) takes advantage of the parallel lake and ocean coasts that are perpendicularly aligned, intersecting at an implied "X" near the center of the scene. The lake alignment is further implied by an erupting volcano plume that points through a gap in the coast toward the empty Pacific. This view direction also conveniently provided space in the lower left and upper right corners for an inset map and distance chart.

Large-scale 3D terrain maps used for site navigation are best served with a camera direction that looks in the direction of travel. The National Park Service employs site-specific views for trailhead maps. The map, sign on the ground, and person reading it is oriented in the same direction as the trail (Figure 5). Tightly cropping the map focuses attention on only those geographic features relevant to hikers.

Avoid a direction of view that looks down slope on a terrain. For example, the view from the summit of Pinnacle Peak to the trailhead at Reflection Lake, would not work as well as the opposite view looking up (Figure 5). In downhill views, because the terrain would fall away from the reader, foreshortening is severe. This limits the mappable area. Downhill views also can be disorienting. When it comes to terrain, most people are accustomed to looking up.

Most satellite images and aerial photographs are taken in mid-morning (there are fewer clouds and less haze at that hour), which places shadows on northwest-facing slopes in the northern hemisphere. On 3D terrain maps draped with satellite images, the embedded shadows interfere with views that look from north to south—slopes facing the reader will be dark

Figure 6: A 15-meter Landsat 8 image draped on a 30-meter DEM of Crater Lake, Oregon.

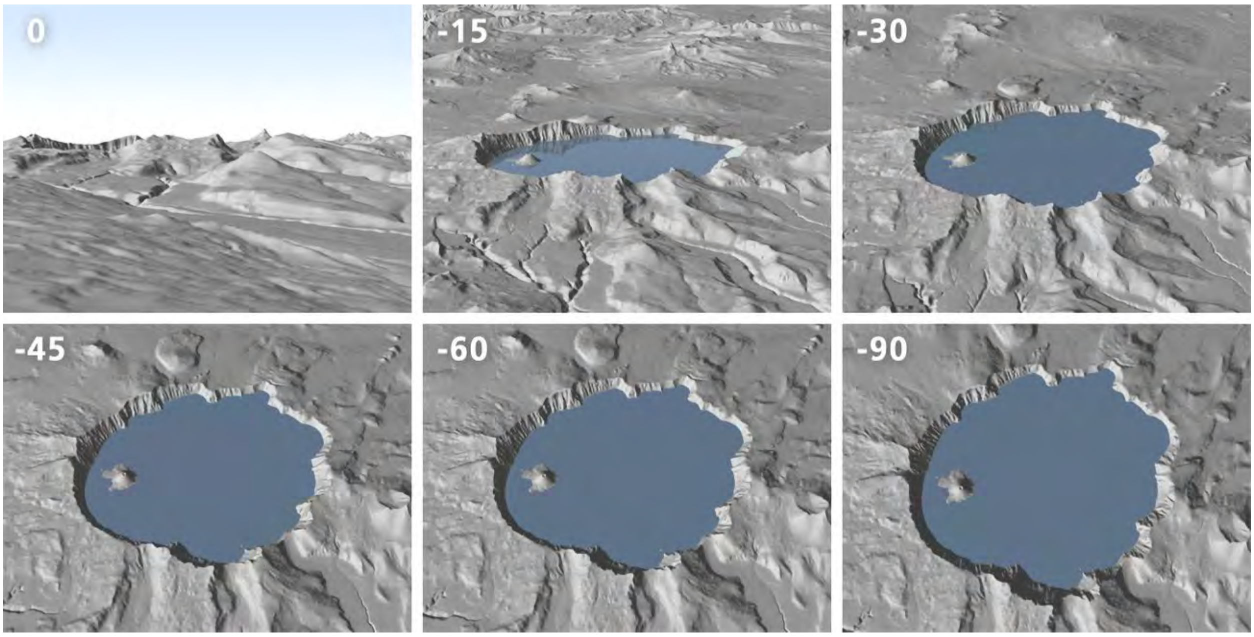

Figure 7: Camera pitch study, Crater Lake, Oregon. Shallow angles are where the action is. Changing the pitch from -15° to -30° has more noticeable influence on the view than from -60° to -90°.

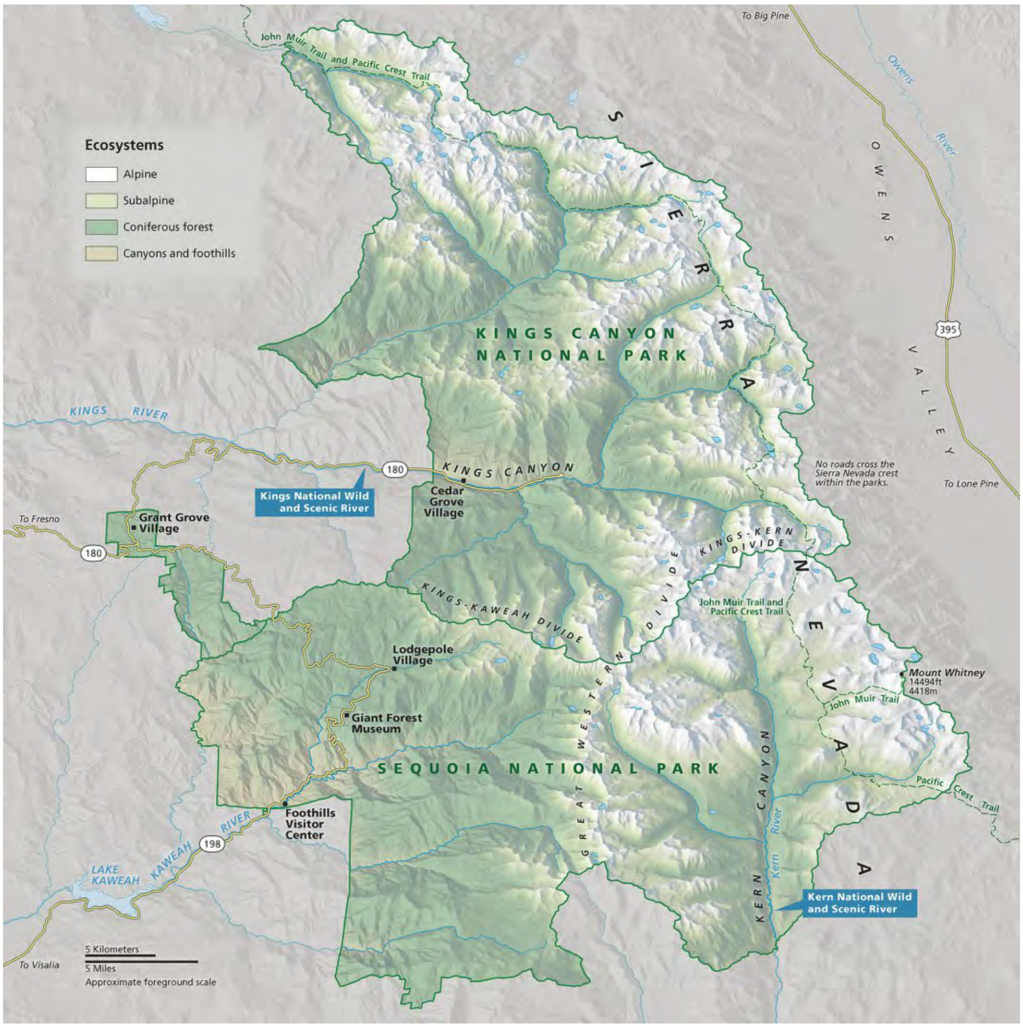

Figure 8: A high oblique view of Sequoia and Kings Canyon National Parks, California, with the camera pitch set at -46°.

and lack detail (Figure 6, top). You will instead have to use a view that looks generally from south to north (Figure 6, bottom).

Tip 2 – Camera Pitch

Viewing a place at an oblique angle from above is what fascinates us most about 3D terrain maps. In Natural Scene Designer Pro, *Pitch* controls the downward tilt of the virtual camera used to view the terrain (Figure 7). At 0° pitch the camera is horizontal. With this setting and from a low altitude, the rendered scene would look similar to what a person sees while standing on the ground. At -90° pitch the camera is vertical. With this setting and from a high altitude, the rendered scene would look indistinguishable from a conventional map. To make a 3D terrain map, the trick is finding an ideal pitch setting somewhere between these extremes.

The choice is between dramatic terrain at shallower pitches and more map-like scenes at steeper pitches. As a cartographer, my first priority is to clearly show spatial relationships on the terrain surface. At the same time, I strive to create a scene that presents the terrain with considerable drama. Increasing the terrain vertical exaggeration can compensate somewhat for steeper pitches that I prefer. Of the seven 3D terrain maps that I am currently working on, the average pitch is -37°.

Terrain characteristics often dictate camera pitch. The map of Sequoia and Kings Canyon National Parks (Figure 8) uses a steep pitch to show Kings River and Route 180 deep within Kings Canyon. At shallower pitches the river would be completely hidden. The narrowing shape of the parks from south to north was another factor. At shallower pitches the northern apex would be very far away.

The map of Maui, Hawaii (Figure 9), employs a shallow camera pitch to emphasize Haleakala (the shield volcano in the foreground) that otherwise would look inconsequential because of its gradual slopes. The protruding West Maui Mountains in the background obscure parts of the island unimportant to the map's purpose. By contrast, in the foreground, Haleakala's eroded valleys slope from summit to sea, tilting toward the reader.

Camera pitch causes foreshortening, the compression you see from foreground to background in a scene, which is sometimes useful for layout purposes. Take

Figure 9: A low oblique view of Maui, Hawaii, with the camera pitch set at -12°, which is low enough to show the horizon.

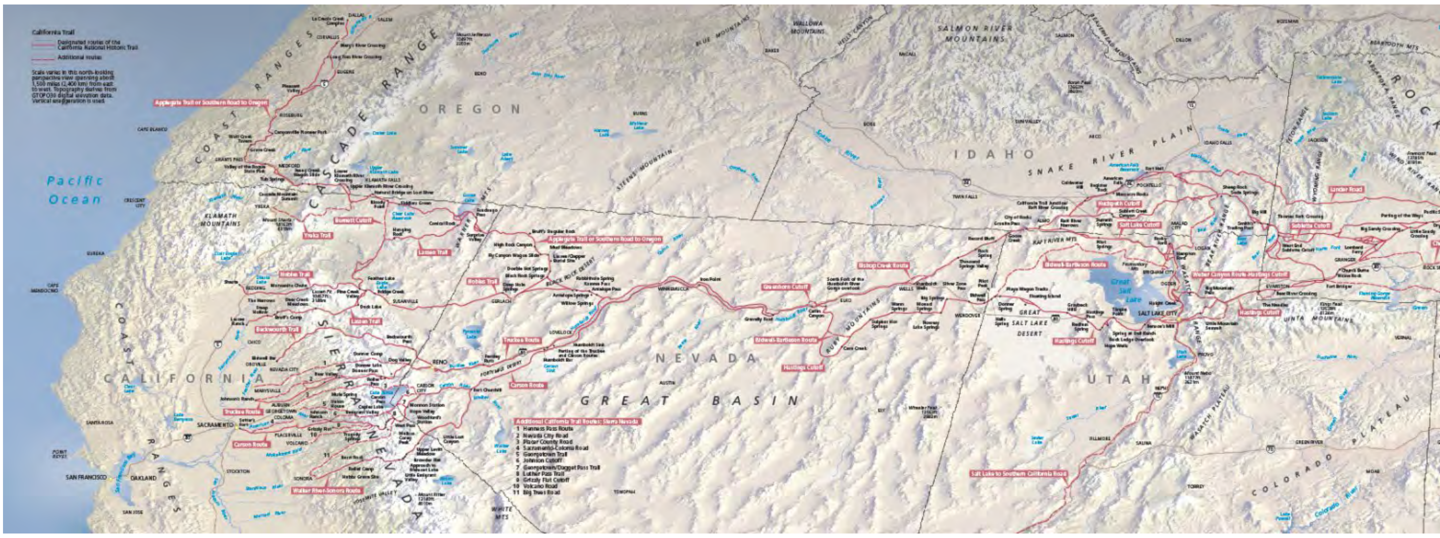

Figure 10: The California Trail.

for example the California Trail map (Figure 10). This primarily east-west trail has western branches going as far north as Salem, Oregon, and as far south as the central Sierra Nevada. Fitting the map on an A12 sheet of paper was only possible by rendering it as a 3D oblique view, which lessened the height.

Tip 3 – Camera Lens (Focal Length)

Changing this often-overlooked camera setting—in Natural Scene Designer Pro, the tendency is to stay with the default 35-millimeter lens—will greatly alter the appearance of your final map. The illustration below (Figure 11) shows a sampling of the choices available, from a very wide-angle 20-millimeter lens to a very telephoto 200-millimeter lens. Wide-angle lenses result in scenes with considerable perspective convergence; the foreground is magnified and the background pinches toward an unseen vanishing point. By contrast, telephoto lenses have less perspective convergence; the foreground and background are similar in size.

I prefer telephoto lenses to wide-angle lenses for general mapmaking. I start by setting up a scene with a 70-millimeter lens and then change the focal length as needed. Besides depicting the foreground and background more equal in size, telephoto lenses are better suited to making maps that must fit within a rectangular formatted shape (Figures 12 and 13).

Despite my preference for slightly telephoto 3D terrain maps, they are not problem free. The lack of optical perspective can result in boring scenes with little foreground to background depth. To counteract this, I will add background haze, foreground shadows, valley fog, and clouds.

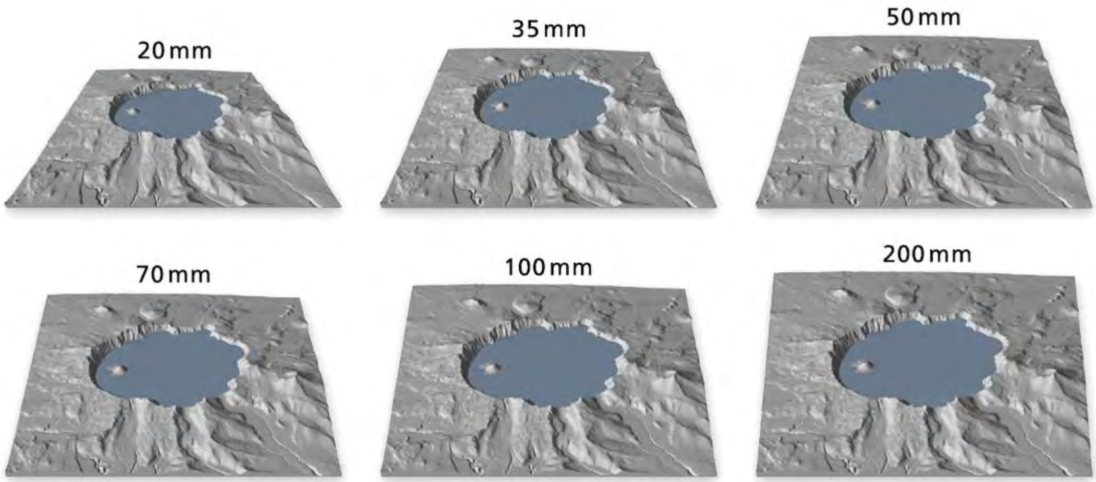

Figure 11: Camera lens study, Crater Lake, Oregon. The camera pitch is a constant -35° for all scenes.

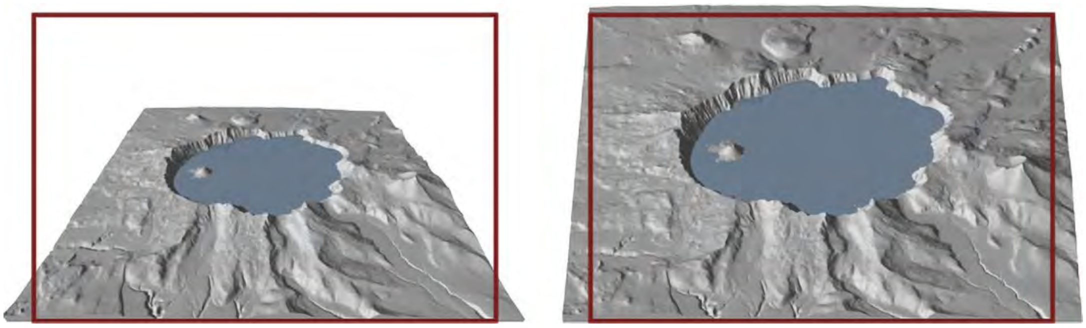

Figure 12: Map in a box: Compared to a wide-angle lens (left), the same data rendered with a telephoto lens (right) completely fills the red bounding box.

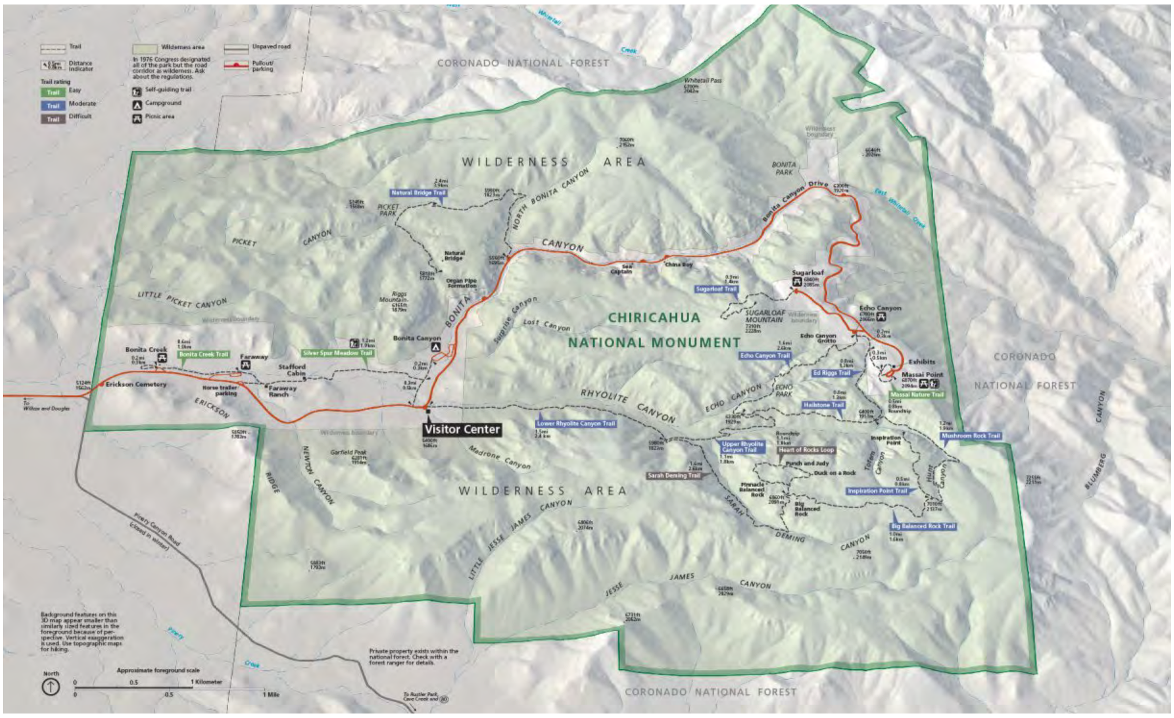

Figure 13: Chiricahua National Monument, Arizona, rendered with a telephoto camera lens and steep camera pitch. With these settings the distinctive park shape remains recognizable on the up-and-down terrain.

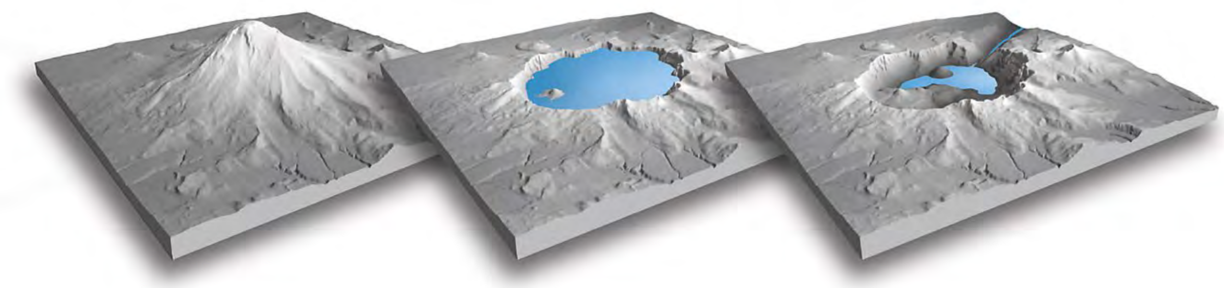

Figure 14: Crater Lake geology: (left) Ancient Mt. Mazama, a stratovolcano. (Middle) The lake today. (Right) Possible future breaching of the caldera wall.

Figure 15: The Grand Canyon of the Yellowstone by Thomas Moran. Source: Smithsonian American Art Museum.

I tend to use wide-angle-lenses for making geology block diagrams and illustrative maps with few labels and lines. For example, the Crater Lake block diagrams (Figure 14) looked more dynamic—as are geologic processes—when rendered with a wide-angle lens. Using a partial side view adds to the visual interest.

Tip 4 – Background Haze and Foreground Shadow

Thomas Moran's inspirational "The Grand Canyon of the Yellowstone" (Figure 15) was on display at the US Capitol in 1872, the same year that Congress established Yellowstone National Park. His art is relevant to 3D terrain mapping for its treatment of visual depth with light and shadows. The dark foreground tones guide your eyes to the Grand Canyon of the Yellowstone depicted with luminous colors in the middle ground. Your eyes then go to Lower Yellowstone Falls, partially obscured by mist, and eventually find three steaming geysers in the hazy background.

It is easy to apply Moran's classic painting techniques—background haze and foreground shadows—to your 3D scenes. To create background haze, first render a distance mask in Natural Scene Designer Pro, which you will find it as one of the options in the "Render" menu. The image below (Figure 16) is a distance render for a random location in North Cascades National Park. Areas closest to the virtual camera are dark and the tones get progressively lighter with distance.

The next steps are in Photoshop. Create a new layer above the terrain to which you want to apply haze, fill

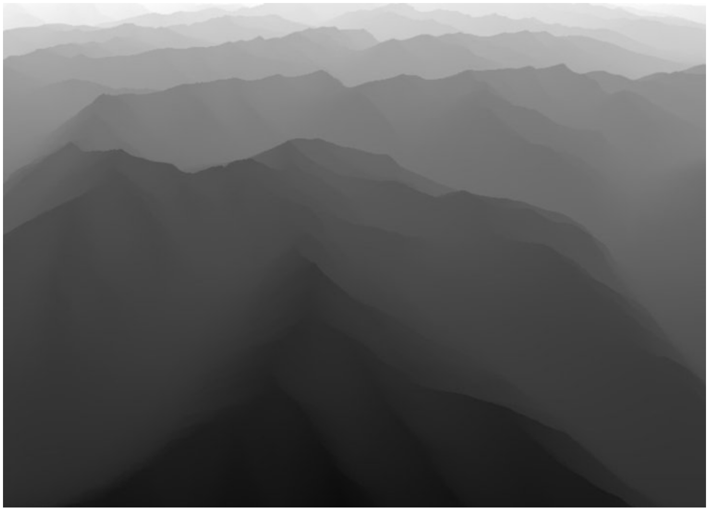

Figure 16: A distance mask of North Cascades National Park, Washington.

the layer with white or blue-white, add a layer mask, and paste the distance mask into the layer mask. Decrease the opacity of the haze layer to lessen the amount of haze. You can optionally apply a curves adjustment to the distance mask to precisely control where the haze starts in your scene.

Adding a foreground shadow works much the same way. In Photoshop, create another layer on top of your terrain, fill it with black or some other dark color, and add a layer mask. Then use the gradient tool in the layer mask to modulate the shadow intensity (tip: hold down the shift key to constrain the gradient to a vertical alignment). For most scenes, just a little darkening is all that you will need in the immediate foreground. Vary the layer opacity to control darkness.

The illustration below (Figure 17) shows background haze and foreground added to a typical mountain scene.

Using a distance mask rendered in Natural Scene Designer Pro to create haze works best with large-scale scenes viewed from a shallow angle. Rendered distance masks, however, are unnecessary for small-scale scenes viewed from high above. Instead, place a simple gradient in a Photoshop layer mask in the same manner that you used to create the foreground shadow, such as on the Bering Land Bridge below (Figure 18).

Additional Comments

- I use background haze on all 3D terrain maps, sometimes copiously. By contrast, I use a foreground shadow less often and then only sparingly.
- Although Natural Scene Designer Pro has a haze option in the Sky settings tab, I rarely use it. The built-in Natural Scene Designer haze covers too much of the foreground in the typical scenes I create from a high oblique angle. I prefer to add haze in Photoshop, which offers precise control and the ability to edit haze at later stages of map production.
- Haze and shadow gradients can appear with banding artifacts when applied over smooth water surfaces. Adding a little noise with Photoshop to the gradients can lessen this problem.
- Haze and shadows are an excellent way to give the illusion of depth to 3D scenes created with telephoto camera lenses previously discussed here.

Tip 5 – Sun Glints on Water

Those of you who have perused other pages on this site may have noticed this: water bodies on most of the example maps have sun glints—one of my favorite devices for beautifying 3D terrain maps.

Flat tones do not exist in nature and nor should they exist on even the simplest maps. Take for example the before-and-after geologic diagram of Grand Teton National Park during the ice age (Figure 19). The flat lake without sun glints suggest that the entire scene is static.

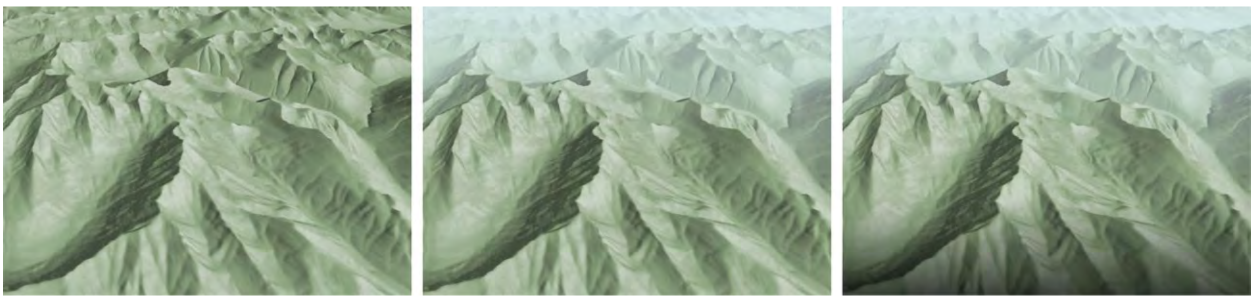

Figure 17: (left) A plain 3D terrain of North Cascades National Park, Washington. (middle) The same terrain with background haze. (right) And the terrain with a foreground shadow.

Figure 18: An unpublished draft map of Bering Land Bridge National Preserve, Alaska, with a foreground shadow and background haze made with Photoshop gradients.

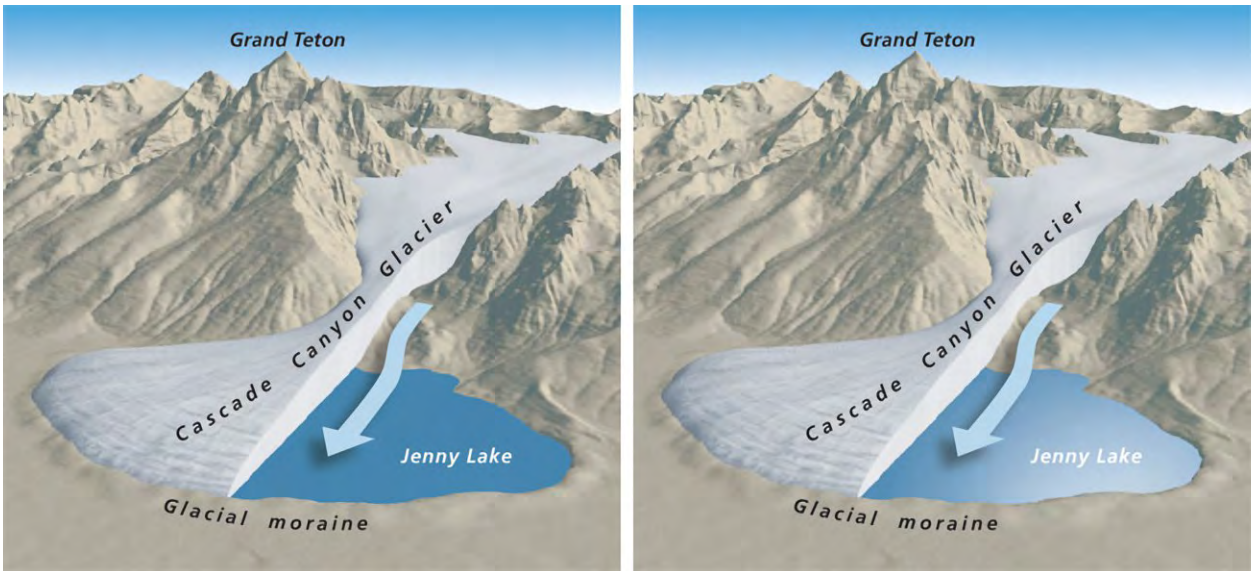

Figure 19: Jenny Lake geology diagram, Grand Teton National Park, Wyoming.

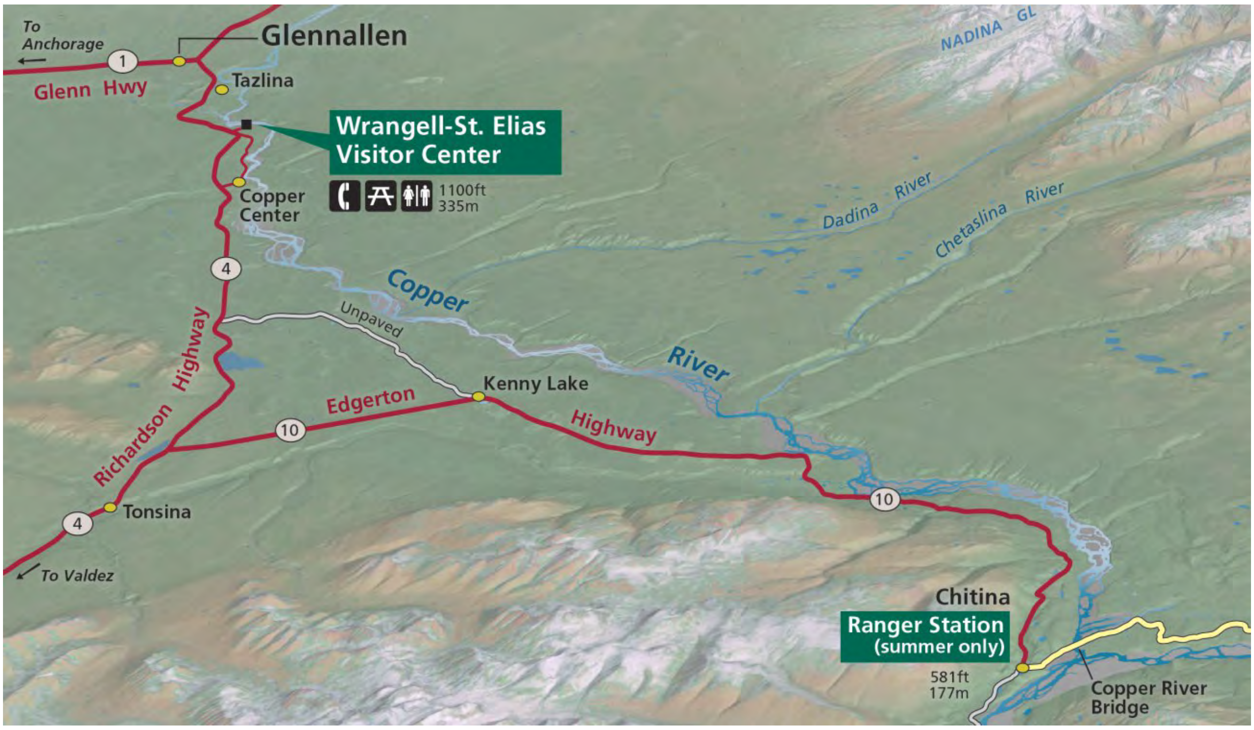

Figure 20: Wrangell-St. Elias National Park, Alaska.

But with sun glints the diagram come to life, suggesting to the reader on a subliminal level that glaciers are highly dynamic.

Procedure

Adding sun glints to water bodies could not be easier in Adobe Photoshop. First, open your 3D terrain map in Photoshop. Use the Magic Wand Tool to select water bodies. Next, create a new layer and then create a layer mask. Your selection will then become the printable area on the new layer. Select the Brush Tool and a very large, soft brush. Set the brush opacity at 10 percent. Finally, repeatedly dab on the water bodies to create the sun glints.

Comments

- If you don't like the sun glints that you initially draw, delete what is on the layer and try again. I typically have to redraw sun glints several times before I am satisfied with their size and brightness.
- There is an art to drawing sun glints on water bodies. Fewer large glints generally look better than many small glints.
- If the terrain adjacent to a water body is light, avoid drawing a sun glint there because the two will have a similar value, making the shoreline indistinct.
- Should your sun glints have banding artifacts, applying a small amount of noise to the glints will usually remove the banding (Filter/Noise/Add Noise).
- Sun glints are an excellent method for depicting flowing rivers. In the illustration below (Figure 20), sun glints suggest the continually changing course of the braided Copper River.

3 Conclusion

Designing 3D terrain maps is a complex undertaking that must take into account many variables. Because no two maps are alike, universal design solutions are often not applicable, forcing the cartographer to make decisions based primarily on the local geography, the map purpose, and their personal aesthetic preference. The tips presented here (and on http://shadedrelief.com/3D_Terrain_Maps/) provide newcomers to this field a general approach on how to start designing 3D terrain maps. Ultimately, however, designing successful 3D terrain maps also requires a large investment of time and effort.


Adriana


Mapping Mount Everest: What is Left to Map?

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Abstract. This paper describes the history of mapping Mount Everest (also known as Sagarmatha in Nepal and Chomolongma or Qomolangma Feng in Tibet). It focuses initially on the surveying and mapping efforts that first identified the location of the mountain as a major peak of the Himalaya and then as the highest mountain in the world. The history then follows the improved quality and coverage of topographic mapping from 1922 to the present day and also the depiction of the mountain in three-dimensional visualizations. A final section discusses the future mapping that could provide important new information about Mount Everest and its environs.

Keywords: *cartography, Mount Everest, Himalaya, topographic maps, 3D visualization, terrain mapping, height measurement*

1 Introduction

Mount Everest is the highest mountain in the world, as measured by elevation above sea level, and there is an extensive documentation of the history of its discovery, exploration, and ascents (see Ward 2003 and Unsworth 2000 for two of the most complete histories). Surveyors and mapmakers have been attracted to the mountain both to measure and to map in detail this iconic peak. These mapping efforts, starting in the 1920s and for many years after, were closely tied to the expeditions to Tibet and then to Nepal to summit Mount Everest.

Since the advent of aerial photography and satellite remote sensing there has been a great expansion of mapping efforts and today Everest is one of the most mapped mountains in the world. This paper evaluates how Mount Everest has been mapped throughout its history of exploration and then considers what is left to map.

There seems to be a historical trend of people becoming obsessed with this mountain: the English climber George Mallory (see Anker 1999, Davis 2011) who gave his life attempting the summit, physician-climber-historian Michael Ward (many books and articles as noted below), explorer-cartographer-scientist Bradford Washburn (Washburn 1988), and the many modern tourist-climbers who seek Everest as the ultimate summit (as tragically described in Krakauer 1997). My personal quest to know Everest started in December 2017 in Kathmandu. The Survey

Department of Nepal invited the National Geographic Society (NGS) to send a representative to a workshop about technical methodology for the new Nepali measurement of the height of Mount Everest.

In my role as The Geographer at National Geographic I attended the workshop and presented the history of the National Geographic sponsored 1990s GPS measurement and long history of NGS mapping of Mount Everest. Subsequent to the workshop, I walked the first part of the Mount Everest Basecamp trekking route from Lukla to Khumjung and was able to see the mountain in person (Figure 1). It helped inspire me to delve deeper into research on the history of mapping the mountain.

Figure 1: Mount Everest rising above the ridge of Nuptse, as seen from the trail on the way up from the Dudh Kosi River to the town of Namche Bazar (photo: Alex Tait).

2 Histories of Mapping and Naming Mount Everest

Several scholars have compiled information on the cartographic history of Mount Everest since its first known documented appearance on a map in the early 18th century. The most complete of these efforts was by Michael Ward (1994a, 1994b, 2003) with important additional contributions made by Hughes (2009, 2009/2012) and Hurni (2015). These efforts have focused on the European tradition of mapping as a process of exploration, surveying, and documentation and the recording of geographic data through a scientific process using a measured coordinate system and specific graphical symbology. In other words, cartographers created topographic maps.

The highest mountains of the eastern Himalaya, including the area of the Khumbu region which includes the Mount Everest massif, were well known to the local people of Tibet and Nepal for millennia. They were already known and indeed they had undoubtedly been recorded in graphic images prior to the earliest maps created once Europeans had begun their exploration (Schwartzburg 1994, Ward 2003). Though extant examples of Tibetan maps of Mount Everest itself have not been found, a map published in National Geographic magazine (Doig 1966), by the Tibetan artist Pasang Sherpa, shows how the Solu Khumbu region and Mount Everest would appear in the style of indigenous mapmakers (Figure 2).

These dual traditions of mapping Mount Everest point to a need to examine the multiple names for this iconic peak. For this paper, I have adopted the name in common usage in English: Mount Everest. This name is recognized in western historical and journalistic contexts and is well known in Nepal and Tibet by locals for the tourism industry. But, it is, of course, not the local name nor the earliest name for the mountain.

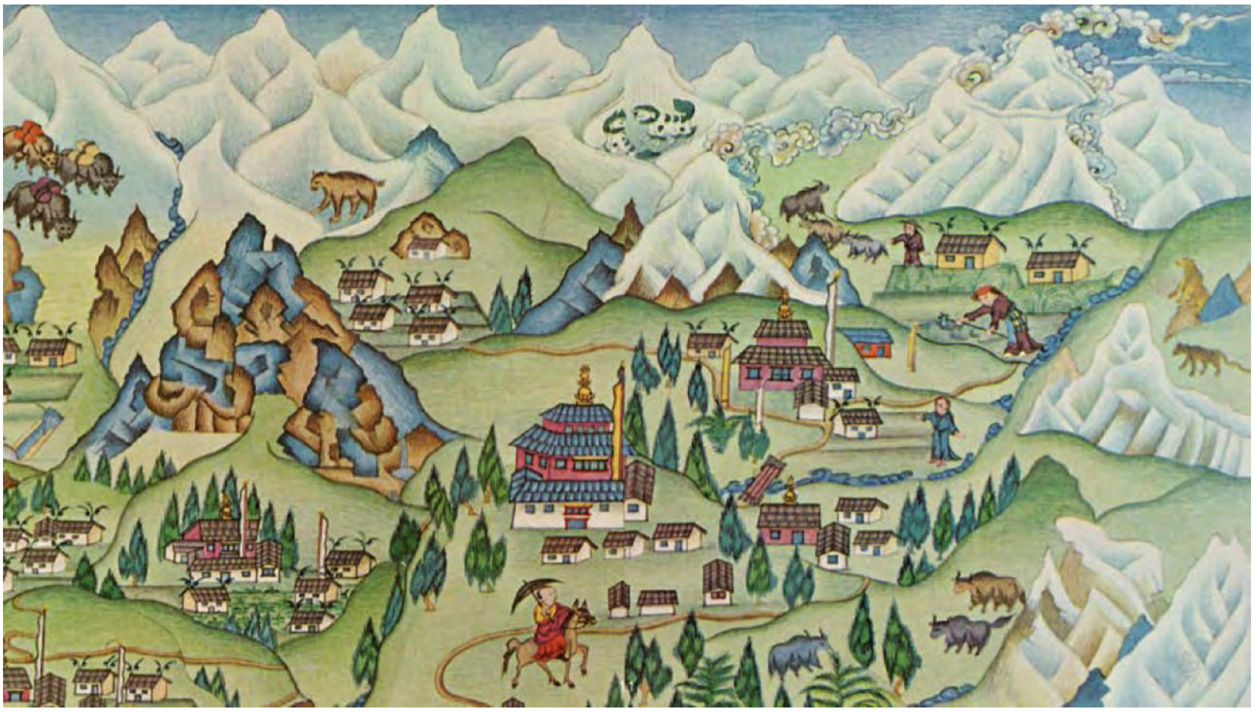

Figure 2: Solu Khumbu by Pasang Sherpa in National Geographic magazine (Doig 1966). Showing villages and mountains with Sagarmatha-Mount Everest at upper right with a snow plume.

NGA Quick GeoNames Search

geonames.nga.mil/namesgaz/gnsquicksearch.asp

GeoNames Search Results

Total Number of Names in query: 14
Total Number of Features in query: 1
Records 1 through 14

The geographic names in this database are provided for the guidance of and use by the Federal Government and for the information of the general public.
The names, variants, and associated data may not reflect the views of the United States Government on the sovereignty over geographic features.

Name (Type)	Geopolitical Entity Name (Code)	First-Order Administrative Division Name (Code)	Latitude, Longitude DMS (DD)	MGRS	Feature Designation (Code)	Display Location Using
Mount Everest (Conventional - C) Qomolangma Feng (Approved - N) China (CH) Sagarmāthā (Approved - N) Nepal (NP) Zhumulangma Feng (Approved - N) China (CH) Feng (Generic) 珠穆朗玛峰 (Non-Roman Script - NS) China (CH) 峰 (Generic) Ai-fo-lo-ssu Feng (Variant - V) Chomolongma (Variant - V) Chomo-lungma (Variant - V) Djomo-lungma (Variant - V) Everest (Variant - V) Mount Jolmo Lungma (Variant - V) Lapchi-kang (Variant - V) Sagar-Matha (Variant - V) Sheng-mu Feng (Variant - V)	China (CH), Nepal (NP)		27° 59' 18" N, 086° 55' 28" E (27.988368, 86.92454)	45RVL9258095916	mountain (MT)	Google Maps MapQuest

Figure 3: GeoNames Server entry for Mount Everest (U.S. National Geospatial-Intelligence Agency 2018).

A look at the documented names for the peak that appear in the U.S. National Geospatial- Intelligence Agency (NGA 2018) GeoNames server reveals 14 variants for this geographic feature (Figure 3). Mount Everest, as noted, has been the conventional name used in English but Sagarmatha (transliterated Nepali) and Chomolongma or Qomolangma (transliterated from Tibetan and Chinese, there are many variant spellings) are also officially recognized names.

It is clear that the local people in this area of the Tibetan Himalaya used the name Chomolongma to refer to the massive mountain that is easily observed from the plains of Tibet to the north. This name appears in the historic record on maps in the early eighteenth century (Ward 2003) and is shown in below (from the Kangxi Imperial Atlas of China, 1717). The source of the Nepali Sanskrit name Sagarmatha is less clear. While some records indicate that the term was newly coined in the 1960s others point to an earlier origin for a Nepali local name for the mountain (Ward 1997).

The origin of the name "Mount Everest" is very well documented. Andrew Waugh, Surveyor General of British India, named the peak in 1856 after his predecessor George Everest because he erroneously assumed that there was no established local name for the peak (Waugh 1857). Since the mountain is not easily seen from the south in its entirety nor does it appear as the tallest peak in this part of the Himalaya, there was speculation that a local Nepali name had not been established Also, names of more prominent peaks such as Guarisankar were misapplied to Mount Everest. Summaries of the naming of the mountain are available in Ward (1997, 2003). For brevity sake, this paper uses the name Mount Everest with full understanding that Chomolongma and Sagarmatha are equally official and are the appellations used by the local people.

3 Earliest Documentation: Putting Mount Everest on the Map

The earliest known map to show the name Chomolongma (in the approximate correct location for Mount Everest) appeared on Plate 14 (Figure 4) of The Kangxi imperial atlas of China (Atlas published in c.1721, facsimile by Fuchs 1943). The original compilation of the atlas was based on the nationwide field survey done between 1708 and 1717 by Chinese officials and Jesuits missionaries Jean Baptiste Regis and Pierre Jartoux. The name Chomolongma appears in Chinese characters in a location and configurations of rivers that indicate the arms of the Kosi River (Ahuwalia 1978).

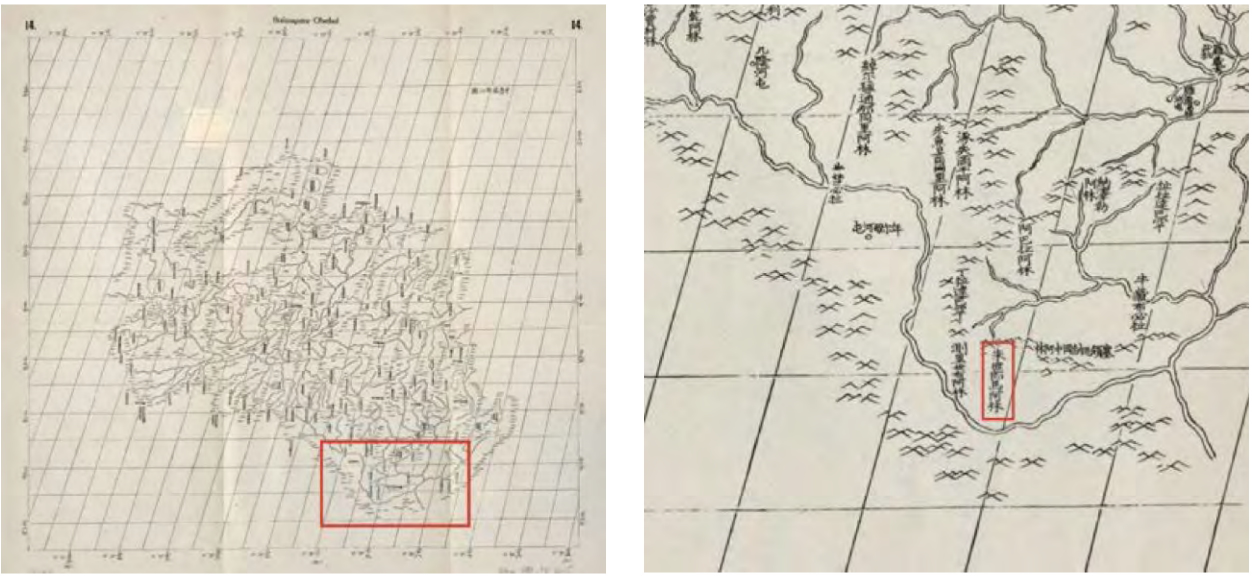

Figure 4: Plate 14, titled "Brahmaputra-Oberlauf," in the atlas titled Der Jesuiten-Atlas der Kanghsi-Zeit: China und die Aussenlaender (Fuchs 1943), 1717 [1943 fascimile].

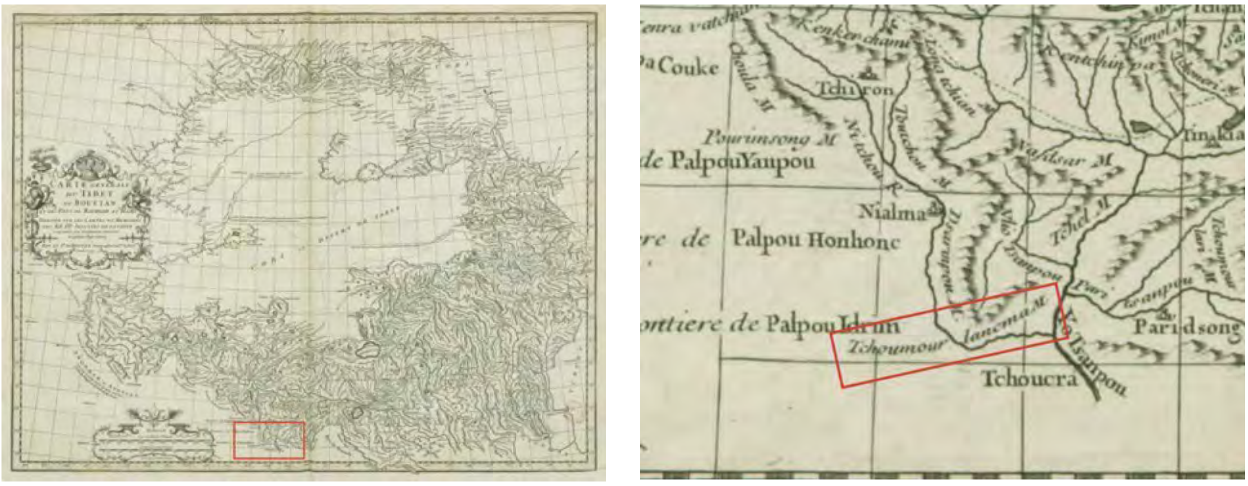

Figure 5: Carte générale du Tibet ou Bout-tan et des pays de Kashgar et Hami, Jean-Baptiste Bourguignon d'Anville, 1733.

This map was the basis for the first maps of this area of Tibet to appear in detail in a western language (Figure 5). Jean-Baptiste Bourguignon d'Anville (1733) published a map in French which included the name "Tchoumour Lancma M." applied to mountain symbology in the same location as the earlier Chinese-Jesuit map. Ward (1997) details the use of this name and its evolution and application to the mountain with current Tibetan transliteration of Chomolonga or Qomolangma.

The sightings and recording of a high mountain in the eastern Himalaya did not include any mention of this mountain being the highest in the range or the highest in the world. This was a prominent peak, known as Chomolongma, that dominated the southern mountains in this section of Tibet. It was not until the British, in the nineteenth century, began detailed mapping of the Indian subcontinent and viewing the Himalaya range from the south that there was any supposition about these mountain ranges containing the highest peak in the world.

As the British explored the ranges of the Himalaya, first Nanda Devi in northern India in the western Himalaya was thought to be the highest peak in the world, it is actually the 23rd highest mountain. Then Dhaulaghiri (seventh highest) in the central Himalaya and then Kangchenjunga (third highest) east of Everest were thought to be the highest (Waller 2004).

The Great Trigonometric Survey of India began an extensive mapping of the sub-continent, the triangulation reached to the foothills of the Himalaya but could

Figure 6: Andrew Waugh's illustration of the Survey of India's work to determine the height of Mount Everest (Waugh 1858). The work was based on surveys from 1849-1850.

not enter Nepal. The bulk of the surveying up to the foothills was the under the guidance of George Everest, Surveyor General. A surveyor on Everest's team noted a high peak north and west of Kangchengjunga and labeled it Peak XV.

Andrew Waugh took over as Surveyor General from George Everest in 1843 and continued the mapping of the distant Himalayan peaks, including Peak XV. Using stations between 108 and 118 miles away from Peak XV and a theodolite with 24-inch lens, his team conducted a careful trigonometric measurement of the height of Peak XV (see Figure 6). In 1856 Andrew Waugh proclaimed a new highest peak in the world, measured at 29,002 feet or 8840 meters (the mean of six measurements) in elevation above sea level at the Bay of Bengal and he named it Mount Everest after his predecessor (Waugh 1858).

4 Topographical Mapping

Though the work of the British Survey of India had refined the known height and location of Mount Everest and established that it was indeed the highest mountain in the world, detailed mapping of the extent and configuration of the morphology of the mountain and its environs did not begin until almost 70 years later, due to restrictions on westerners entering Nepal and Tibet.

In 1921 the British, in what would be the first of a long series of trips to Mount Everest, undertook an expedition to explore and map the approaches to and the possible routes up the mountain from the North. Cartographers at the Royal Geographic Society produced the first detailed topographic map of Mount Everest from the survey data collected by the expedition (Figure 7, Howard-Bury 1922). The knowledge and detail of the configuration of the ridges and valleys of the north side of the mountain were sketched in on a map at a scale of 1 to 50,000.

Additional British expeditions in 1922 and 1924 contributed more geographical knowledge about the Mount Everest area (Bruce 1923 and Norton 1925). A map drawn after the 1924 expedition (Figure 8), by Charles Jacot-Guillemard and cartographers at the Royal Geographical Society and the Ordnance Survey, set a new bar for detailed, and aesthetic, mapping of this high mountain area (Hurni 2015, Jenny et. al. 2014).

Detailed mapping by the RGS based on information from the British climbing expeditions greatly exceeded any topographic mapping from British teams based in India. There was, however a smaller scale topographic map produced by the Survey of India for this region, at a scale of 1:126,720 (Figure 9). The details of ridgelines, peaks, glaciers and valleys were far sketchier than the precise cartographic work done on the north side at larger scales. The reprint of this map in 2002 declares that this was the "First Published Map of Mount Everest," it must refer to its status as a dedicated topographic sheet map with complete data coverage. It certainly post- dates the RGS maps from the 1920s, not to mention the eighteenth-century maps from the Chinese imperial atlas and derivatives.

Despite a British expedition to the north side of Everest in 1933, it was not until the 1935 expedition and

Figure 7: Preliminary Map of Mount Everest, 1922, scale of 1:50000, by cartographers at the Royal Geographical Society, from photographs and sketches of the British 1921 Expedition (Howard-Bury 1922).

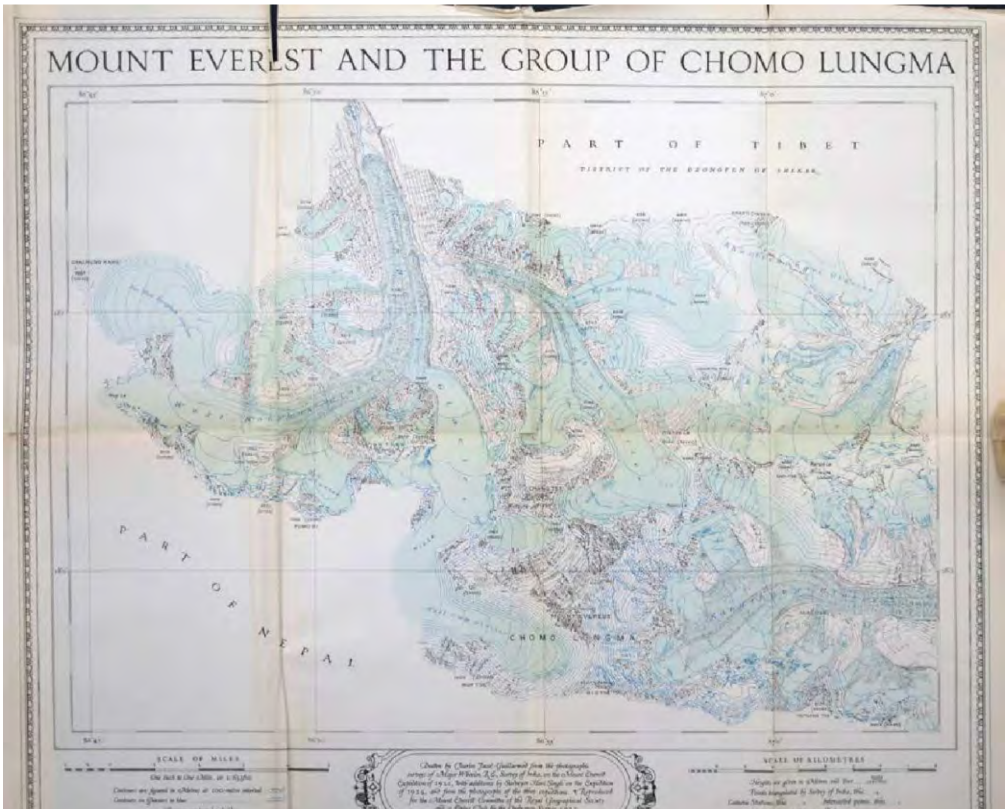

Figure 8: Map of Mount Everest and the Group of Chomo Lungma, 1925, scale of 1:63360, drawn by Charles Jacot-Guillemard, Royal Geographical Society, Ordnance Survey.

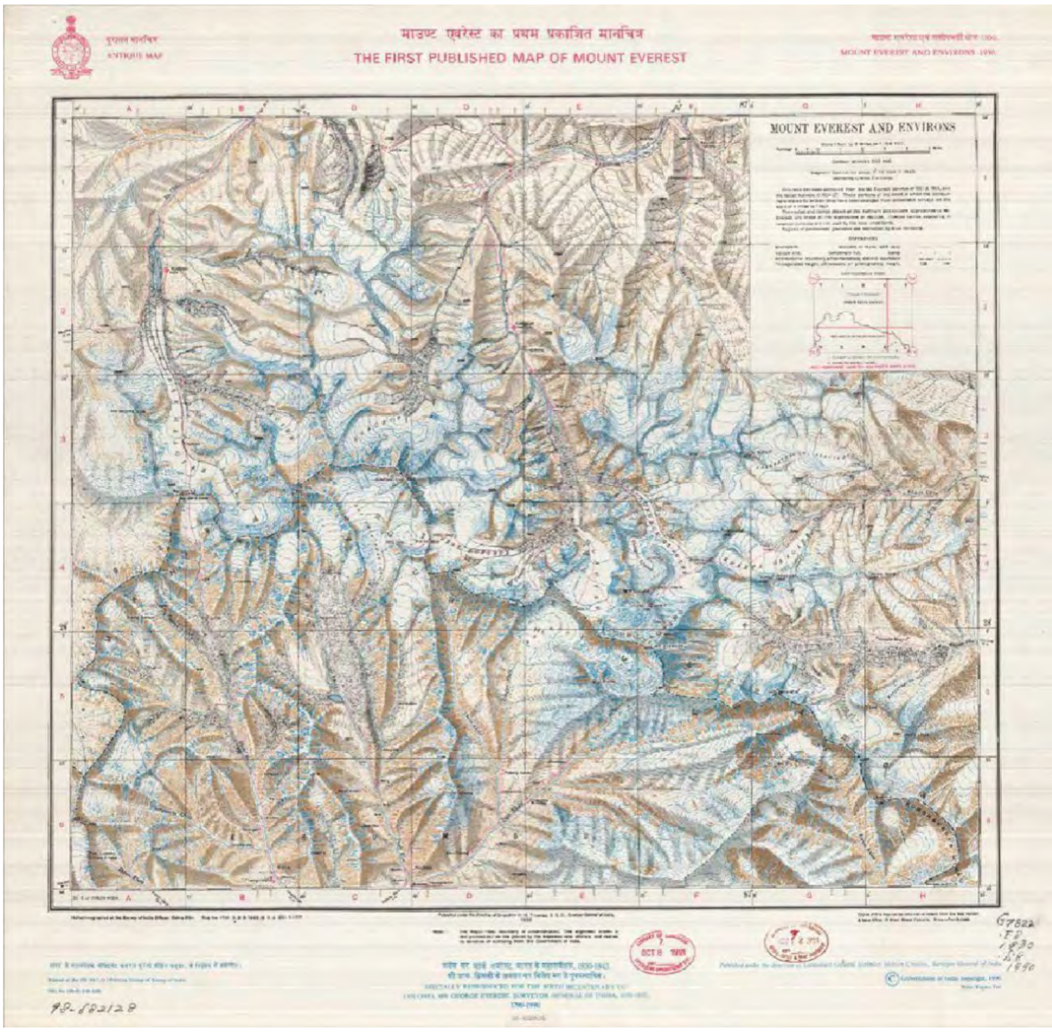

Figure 9: Mount Everest and Environs, 1930 (2002 reprint), scale of 1:126,720, by Survey of India.

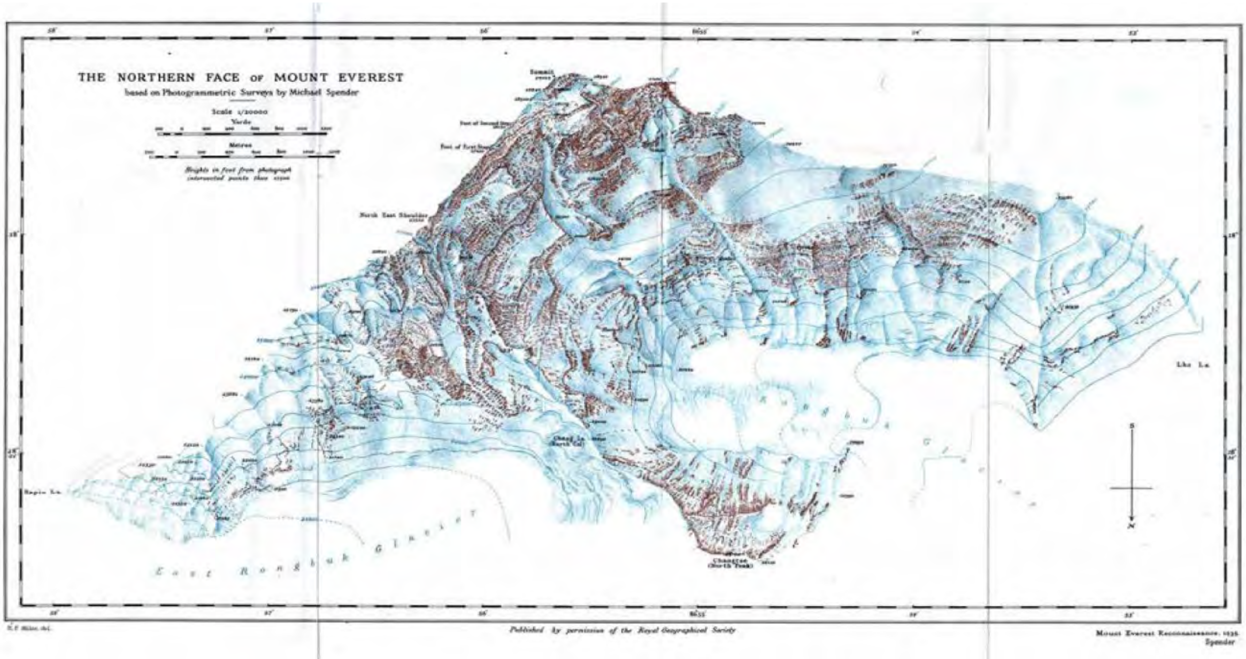

Figure 10: The Northern Face of Mount Everest, 1936, 1:20000, Spender (1935 survey work) and Milne, Royal Geographical Society (note that north is at top in this map).

exceptional work by surveyor Michael Spender that Royal Geographical Society cartographer Henry F. Milne would produce a more detailed map, at a scale of 1 to 25000, for the north reaches of Everest, see Figure 10.

Additional work by Henry Milne at the Royal Geographical Society filled in more details from aerial photographs and other materials gathered during the British expeditions in the 1930s see Figure 11. This map from the RGS archives, reproduced by Ward and Clark 1992, shows the state of knowledge of the geography and topography of Mount Everest up to the post-WWII era when climbing expeditions resumed attempting to summit the world's highest peak.

In 1949, Nepal opened its frontiers to foreigners for the first time and in 1950, Tibet closed its frontiers. Attempts to summit the mountain began in earnest from the south through the Dudh Kosi River valley and the Khumbu Glacier system. In 1952, Swiss teams attempted to summit Mount Everest via the Khumbu Glacier in both the Spring and Fall climbing seasons. They reached a high point of 28,220 ft. along the Southeast Ridge but it was not until the following Spring climbing season in 1953 that Edmund Hillary and Tenzing Norgay reached the highest point on Earth. They were the first to see all aspects of the mountain falling away from them from a perch on the summit. They could see what topographic cartographers had been constructing in their maps for almost four decades

The Swiss launched an additional climbing expedition in 1956 and completed a successful summit push. They gathered geographic information and produced a large-scale topographic map of a small portion of the mountain, see Figure 12 (Swiss Foundation for Alpine Research 1952- 1956?). It was not extensive, but it was important because it provide newly detailed topographic mapping of the Khumbu Glacier Icefall, the Western Cwm and the other portions of what is now the standard climbing route from the south.

The Austrian Erwin Schneider was key in the creation of a seminal topographic map of Mount Everest in 1957, see Figure 13 (the 1957 version of the map is included in Hagen et. al. 1963). He based the map on field

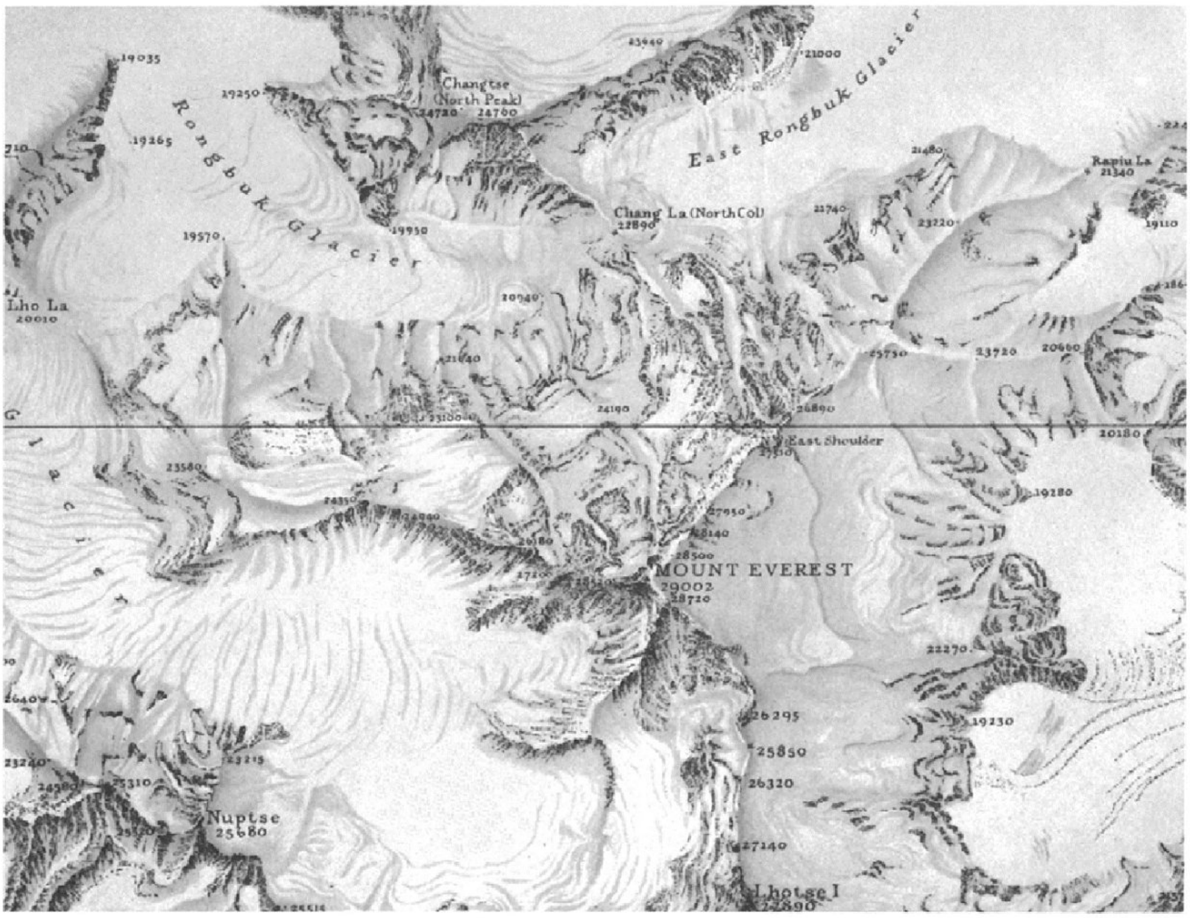

Fig. 1. An extract from the Milne-Hinks map, 1933–45

Figure 11: Mount Everest, 1:50000, compiled 1933-1950, Royal Geographical Society by H.F. Milne (Ward and Clark 1992).

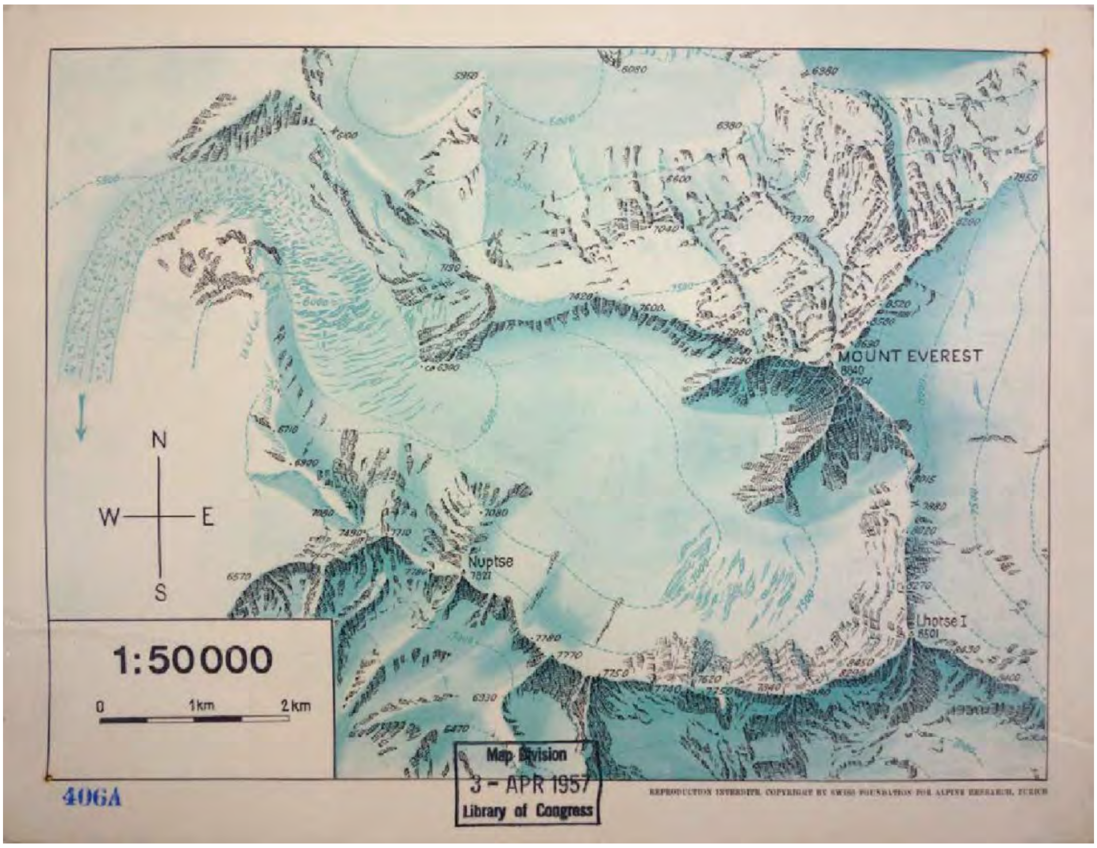

Figure 12: Mount Everest, 1952-1956?, scale of 1:50000, Swiss Foundation for Alpine Research.

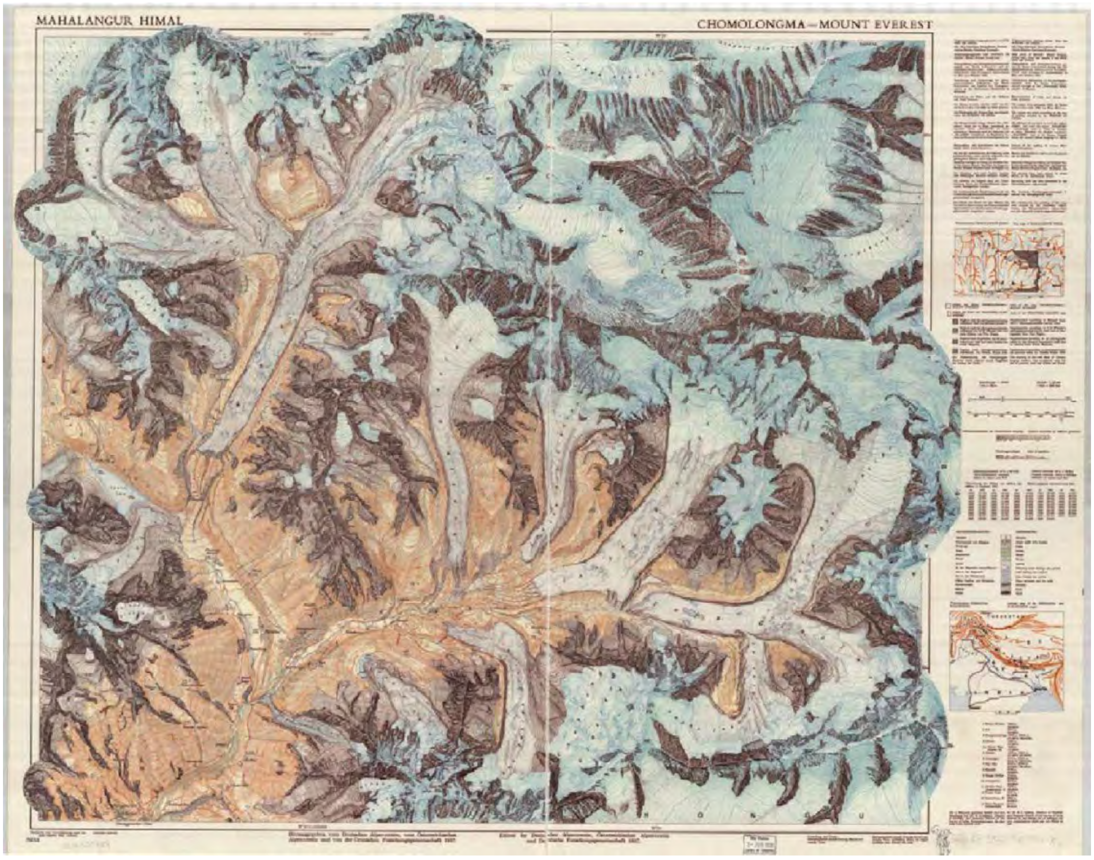

Figure 13: Chomolongma-Mount Everest, 1957, scale of 1:25000, Erwin Schneider (1955-56 survey), Fritz Ebster (cartographer).

Figure 14: Esquisse Topographic: Région de l'Everest et du Makalu, 1958, scale of 1:50000, by P. Bordet (cartographer), Fédération Française de la Montagne, Club Alpin Français, Institut Geographique National.

surveys he made during a 1955 expedition to the Khumbu region lead by American Norman Dyhrenfurth.

Schneider's work and the map he produced with cartographer Fritz Ebster were the basis for additional maps that have been published and updated from 1957 until the present day, at a scale of 1:25000 and in a second, expanded version at 1:50000 based on additional photos and surveys. The 1957 map presents an extensive and detailed mapping of the entire southern reaches of the Mount Everest-Lhotse-Nuptse massif.

Many of the alpine nations of Europe participated in the nationalist rush to send expeditions to explore and climb in the Everest region (and to many other major 8000m peaks in the great ranges of Asia). Surveying and mapping efforts accompanied many of the climbing expeditions.

The French explored the southern side of Mount Everest and parts of the greater Khumbu region in 1954 and 1955 (see Kielkowski 2000 for a full chronology of expeditions). In 1958, the Fédération Française de la Montagne with the Club Alpin Français and cartographer P. Bordet (cartographer), produced a detailed topographic map of Mount Everest and Makalu at 1:50000, printed by the Institut Geographique National (Figure 14).

British surveyors and cartographers had been the leaders in early topographic mapping of Mount Everest but after the 1930s did not publicly publish a compendium of their topographic information about Mount Everest until 1961 (Royal Geographical Society 1961).

Figure 15: Mount Everest Region, 1961, scale of 1:100000, G.S. Holland (cartographer), Royal Geographical Society.

Their map from that date, at a scale of 1:100000 (Figure 15) was the first to combine extensive and detailed topography about both the northern and southern reaches of the Mount Everest massif.

The 1961 map included extensive area around Mount Everest that lacked topographic detail, it appears to have been added from the Survey of India map that was published in 1930 and was slowly being updated with new information. By 1975, cartographers at the Royal Geographical Survey produced a revised map with the entire area filled with detailed topographic information, see Figure 16 (Royal Geographical Society 1975).

During the 1960s and 1970s, when access for foreigners to the northern side of Mount Everest from Tibet was restricted by the Chinese government, Chinese surveyors and cartographers completed a detailed topographic map of Mount Everest (Qomolangma Feng), first published in Chinese in circa 1969 at a scale of 1:50000, see Figure 17 (Langzhou University c.1969).

Additional versions of the map were published, including one in English at a scale of 1:100000 in circa 1990.

From the 1930s, air photos had been used for surveying and mapping Mount Everest and geographic data derived from them incorporated into maps. It was not until the efforts of Bradford Washburn, sponsored by the National Geographic Society, that a large scale topographic map was produced from a set of high-resolution air photos that were combined with infrared stereo imaging from a sensor on the U.S. Space Shuttle—the mapping procedure is described in Washburn 1988.

Figure 16: Mount Everest Region, 1975, scale of 1:100000, G.S. Holland (cartographer), Royal Geographical Society.

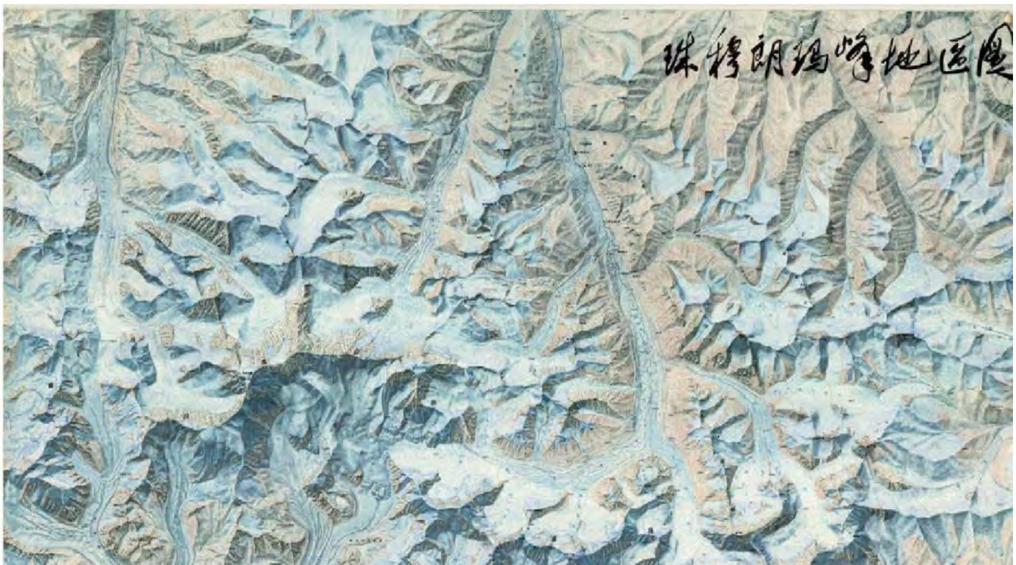

Figure 17: Qomolangma Feng, c.1969, scale of 1:50000, Langzhou University.

Figure 18: Mount Everest, 1988, scale of 1:50000, Bradford Washburn, National Geographic Society; with Swiss Airphoto, ETH Zurich, and Federal Office of Topography, Berne.

The map of Mount Everest shown in Figure 18 was published in National Geographic magazine in 1988 (Washburn 1988), and it set a new standard for topographic mapping of the mountain. It received extensive praise for its accuracy and beauty and it continues to get accolades as an exemplar of topographic map design (Field and Demaj 2012).

5 Three-dimensional Visualization

The efforts at topographic mapping were critical to a better understanding of the accurate measurements of the physical geography of Mount Everest and to its exploration and eventual to successful attempts to climb to the summit. A secondary mapping effort occurred at the same time: a visual representation of the third dimension, elevation, and its importance for understanding the mountain and in particular to telling the human story of habitation, exploration, climbing, and scientific research in the high mountain environment.

Figure 19: "Gaurisánkar, or Mount Everest", 1855, Hermann de Schlagintweit.

Figure 20: 1925 Panorama of the Route to Mount Everest, D. Macpherson, Royal Geographical Society, in *The Fight for Everest*.

The earliest 3D depictions of Mount Everest were paintings and illustrations in which an artist interpreted the topographic information about Mount Everest and rendered an image based on the visually constructed terrain. One remarkable painted image, in 1855 by German explorer Hermann de Schlagintweit (Figure 19), intending to portray Mount Everest, actually depicted a Makulu and used the name Guarisankar, a name applied by locals to a peak well to the west.

Schlangtweit managed to paint the wrong mountain and affix the wrong name (painting reproduced as a frontispiece in Ward 2003).

By the time that the Royal Geographical Society was presenting images of the amazing high mountains of

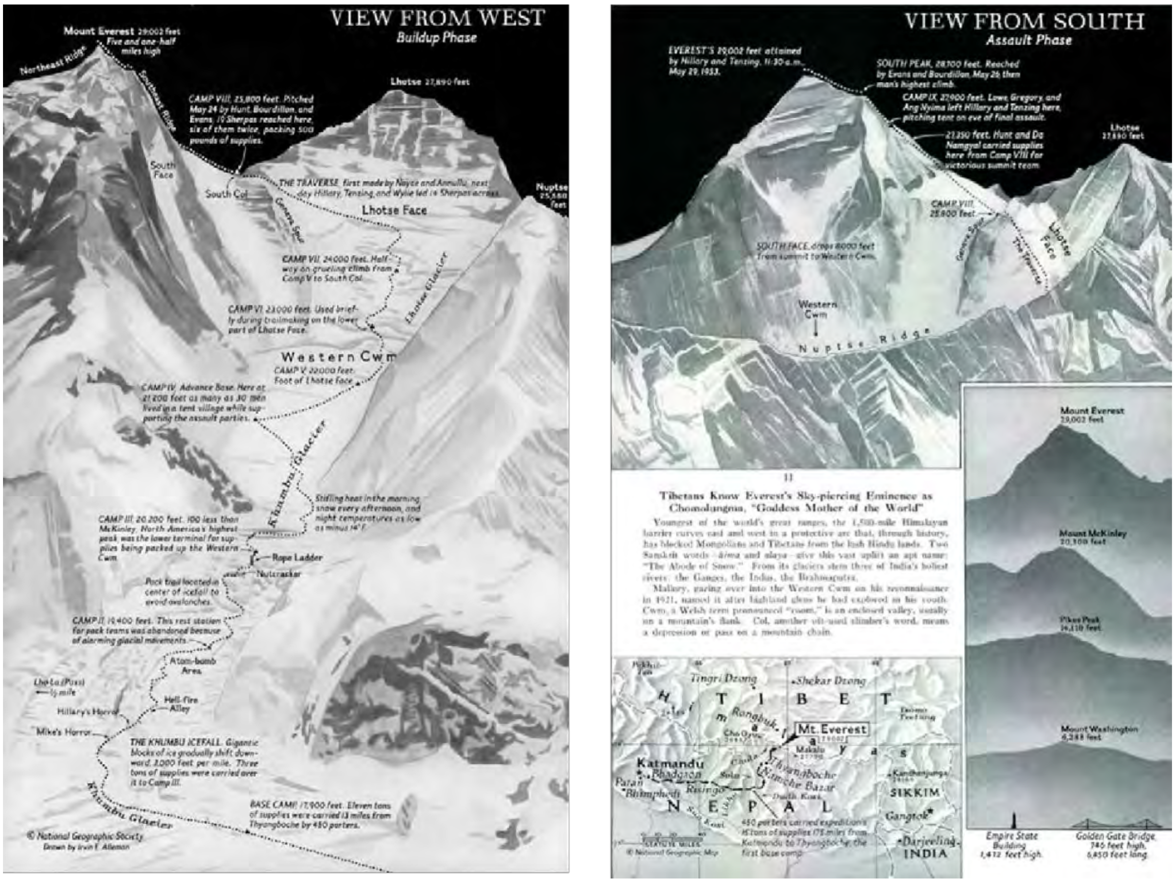

Figure 21: View from West and View from South, Irvin Alleman, National Geographic magazine, 1954.

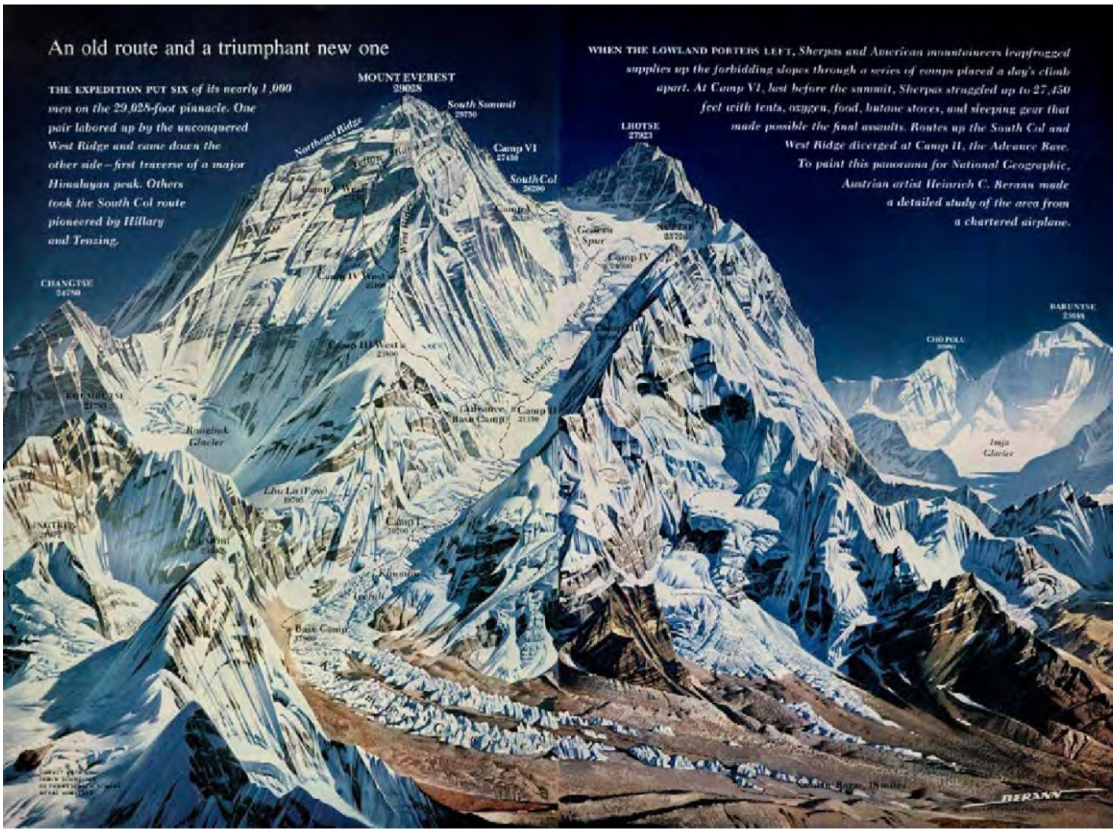

Figure 22: Everest: An Old Route and a Triumphant New One, H. Berann, National Geographic magazine, 1963.

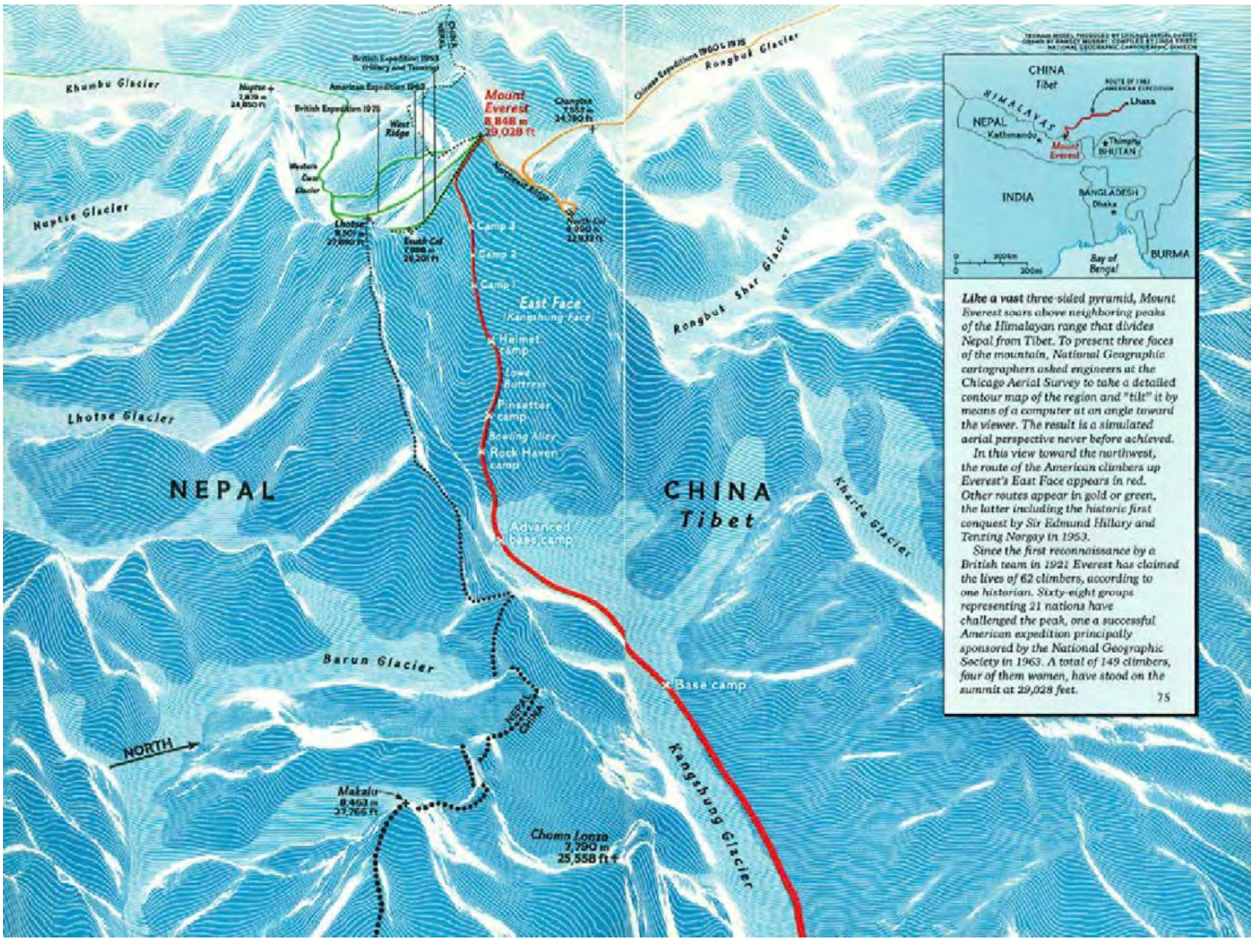

Figure 23: The Forgotten Face of Everest, computer modeled view, National Geographic magazine, 1984.

the Himalaya to an eager audience in Britain in the 1920s, there was far more known about the position and visual character of Mount Everest and its surrounding peaks. This view by Macpherson shown in Figure 20 was published in the book The Fight for Everest about the 1924 expedition (Norton 1925). The artist paints a compelling view of the approach route to Mount Everest and pictures the peak towering over the region, clearly the highest mountain, and the painting displays impressive accuracy for the valleys, ridges, and peaks given that this was based on geographic data collection from ground-based surveys.

An illustration shown in Figure 21 by Irvin Alleman was published in 1954 in the National Geographic magazine (Band et. al. 1954) to show Edmund Hillary and Tenzing Norgay's first ascent of the peak in 1953. While giving some impression of three-dimensionality, it lacked real depth and was little removed from a ground-based photograph. The info-graphic of the height comparisons to other mountains and human structures is perhaps more interesting!

National Geographic took a huge step forward in quality of landscape rendering when it contracted Austrian Heinrich Berann to illustrate a view of Mount Everest (Figure 22) from the southwest to illustrate the two routes completed by the NGS sponsored American Expedition to Mount Everest in 1963 (Bishop and Dyhrenfurth 1963).

Using techniques he had developed for his panoramic views of the Alps, such as vertical exaggeration, rotating of slop aspects and isolating and enhancing of specific features (Patterson 2000), Berann captured the enormity of the mountain and the icy character of the highly glaciated terrain. Note that the northwest and south-southwest faces of the mountain are both directly facing the camera. Also, there is a touch of an Alpine appearance to this Himalayan giant in the details of the rock and snow slopes.

The advent of the computer to assist cartographers in creating three-dimensional terrain landscape views dramatically changed visualizations of mountain landscapes. The production of a new view in 1984 that appeared in *National Geographic* magazine (Harvard

Figure 24: Mount Everest, computer views, 2002, Armin Gruen, ETH Zurich.

Figure 25: Mount Everest, computer generated view, National Geographic magazine, 2003.

1984) uses a digital elevation model created from topographic map lines and then represented the mountain using vertical profile lines following the forms of the terrain (Figure 23). The 3D map shows the remarkable new route put up the Kangshung Face of Everest. While innovative for the 1980s, it lacks the detail and drama of the Berann panorama.

The continued improvement in resolution and quality of topographic data and computing power provided for a new generation of digitally produced 3D maps of Mount Everest. Using photogrammetrically derived contours from the Washburn-NGS 1988 to create a detailed digital elevation model, Armin Gruen and colleagues at ETH Zurich created detailed views of Mount Everest (Gruen and Murai 2002). They used draped images from the original air-photos and the actual cartographic image itself in additional to newer photographic images (Figure 24). Their digital elevation model was at a scale of 10 m per pixel.

A view of Mount Everest view (Figure 25) published as a map supplement in National Geographic magazine in May 2003, made use of data collected by Brad Washburn. The map by National Geographic staff and Swissphoto AG illustrated an article about the 50th anniversary of the first successful summit bid by Hillary and Norgay in 1953.

Subsequent to the work by Armin Gruen, National Geographic Society, and Swissphoto AG there has been a proliferation of 3D data, aerial and satellite imagery, and views of Mount Everest. New cartographers and visual artists use digital tools to create stunning visualizations but also to enable navigation of the 3D virtual world.

Prominent examples include Google Earth (originally Keyhole's Earth platform) shown in Figure 26 (Google 2018), Everest3D from Reality Maps in Figure 27 (Reality Maps 2018), and the ArcGIS Globe Viewer (from Esri). An additional interesting example of creating a virtual reality view, though photographic and not cartographic (hard to tell the difference these days!), is the work shown using giga-pixel images by GlacierWorks and Microsoft in Figure 28 (GlacierWorks 2012).

6 Future Mapping of Mount Everest: What is left to Map?

When we consider the question of what is left to map we may feel that with the detailed topographic mapping of the 1920s through 1980s and the three-dimensional mapping and geographic data collection from about 2002 to the present, we have little left uncharted. I do think that there are three areas that could benefit from additional mapping. They are linked together into a need to assess the current status of the mountain environment and be able to map its dynamic future due to changes in climate, changes from tectonic activity, and changes to the human and natural communities that inhabit the high Himalaya.

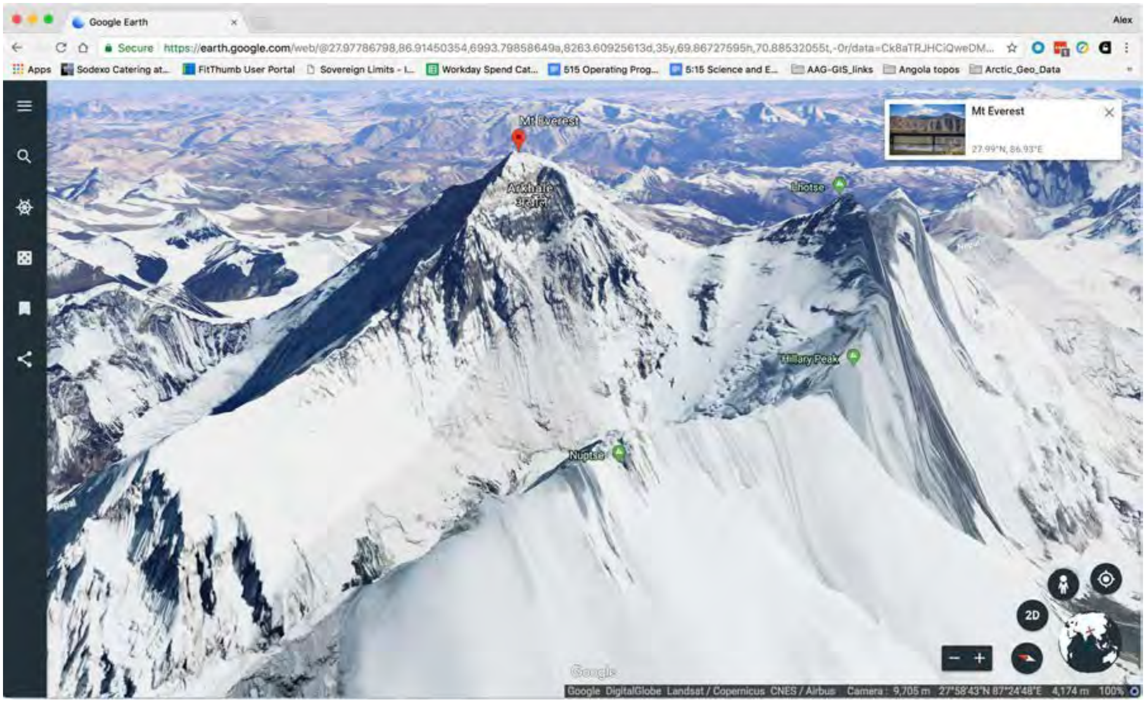

Figure 26: Mount Everest, Keyhole - Google Earth, 2001-2018.

Figure 27: Mount Everest, computer view, Everest3D (RealityMaps), 2011-2018.

First, there is still a need to improve the topographic mapping and, in particular, the digital elevation data for modeling Mount Everest. Data currently have been refined to about 2-3 meters per pixel based on photogrammetry but a new LIDAR based survey could yield a point cloud and elevation data at sub-meter resolution.

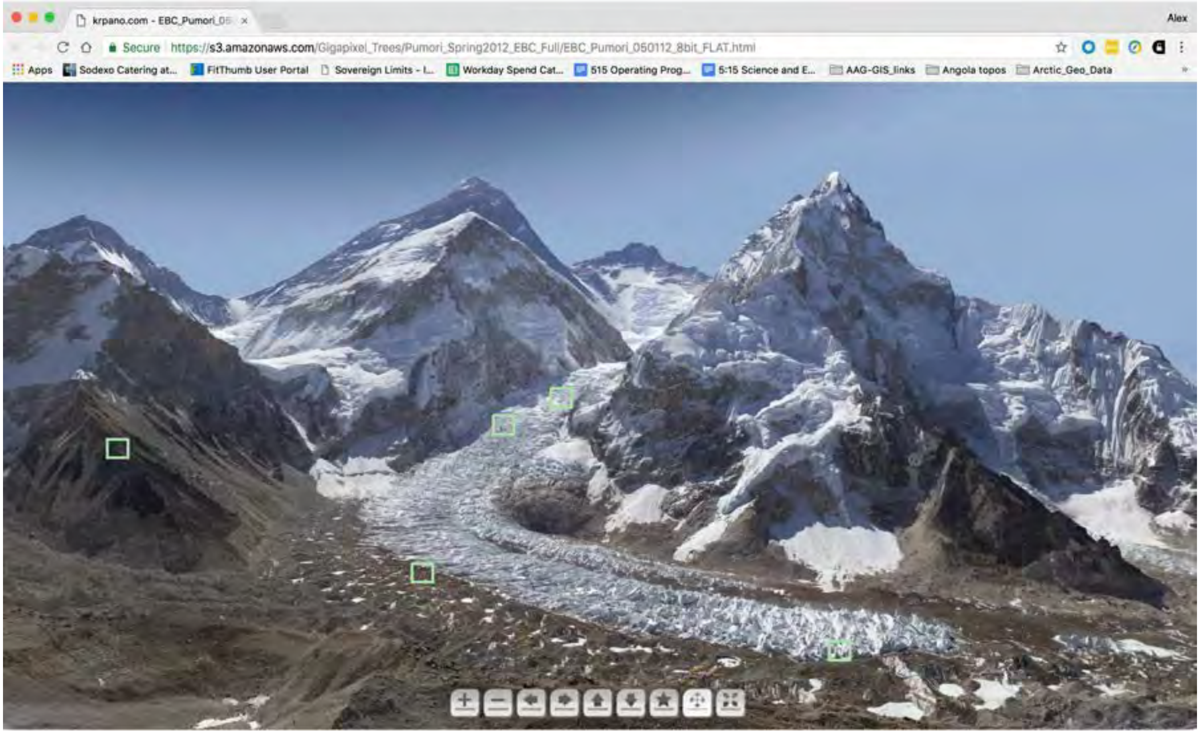

Figure 28: Gigapixel photos of Khumbu Glacier, Mount Everest, GlacierWorks – MicroSoft, 2012.

Figure 29: Map (c.2000) with 1 to 5000 contours derived from Washburn airphotos from the 1980s. This image is a portion of a display map from about 1999-2001 (source National Geographic Library).

An improved depiction of the morphology of Mount Everest using this data would facilitate better understanding of the geological and glaciological structure of the mountain as well as provide a detailed baseline for measuring future changes.

The National Geographic Society sponsored improvements in the 1988 Mount Everest topographic map data in additional work by Bradford Washburn and others in the 1990s, some results shown in Figure 29 (Washburn c.2000). There is continued interested at the Society to improve the base topographic mapping data and generate a new and updated printed topographic map based on the 1988 published sheet.

Additional mapping efforts can also refine geodetic measurements for the mountain and build on work by GPS/GNSS work by Washburn (National Geographic Society 2000), Poretti et. al. (2006) as shown in Figure 30, and Chen et. al. (2006). The Survey of Nepal is also conducting detail work in their current project to remeasure the height of Mount Everest (Sharma and Schultz 2018). The more precise geodetic locations can anchor all future mapping efforts with accurate control points and additional data input and provide important information about the geophysics of plate tectonics in the Himalaya.

A second important area for additional mapping is to enhance and illustrate scientific understanding of the high mountain environment. From work on mapping tectonic events as shown in Figure 31 (Bilham et. al. 2017) to recent efforts to use satellite imagery to map changes in ice volume in the Khumbu Region as shown in Figure 32 (King, et. al., 2017), maps and digital geographic information can play a vital role is assessing and understanding Mount Everest and the mountains of the Himalaya.

As you can see from the scientific work on both plate tectonics and glaciology, assessing change in the landscape through time is critical to understanding these Earth systems. Mapping the dimension of time is perhaps the most important aspect of future mapping efforts. In particular in relation to a changing climate, geographic data collection will provide a consistent and high- resolution baseline of the current status of the area of Mount Everest. New data collected at points in the future will provide a basis for measuring and mapping change. See figure 33 for a recent view of Mount Everest snow cover in 2017.

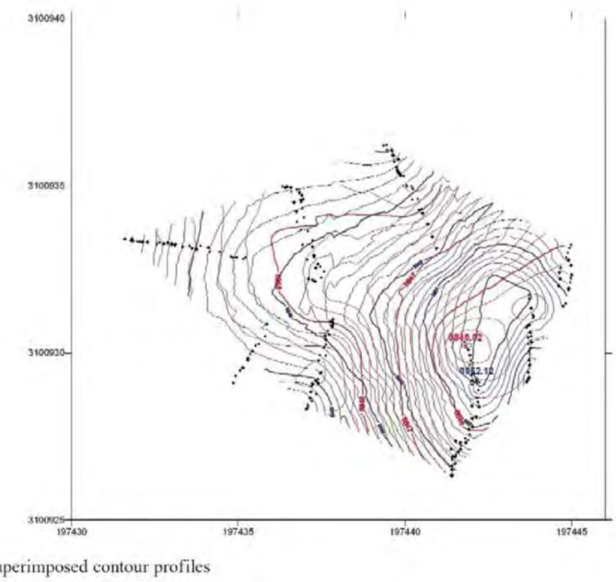

Figure 30: Map contours indicating the morphology of the snow surface at the summit (blue-black lines) and the rock surface (red lines) at determined by ground penetrating radar survey (Poretti et. al. 2006).

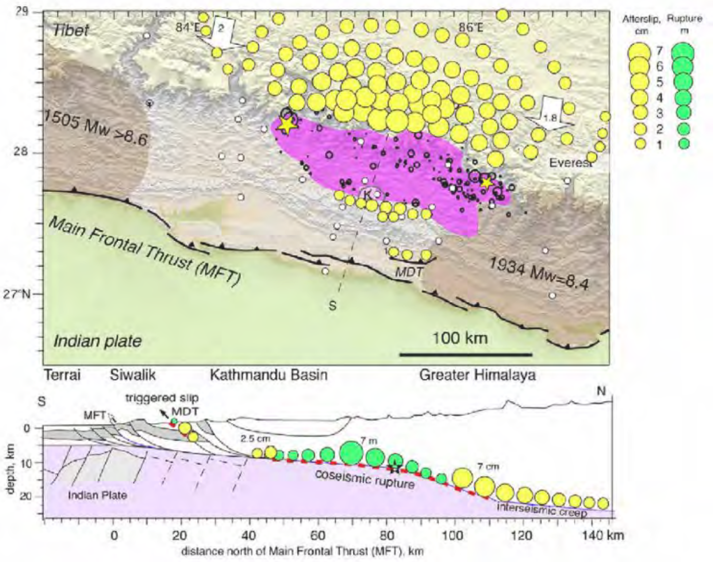

Figure 31: The Gorkha rupture (violet) showing inferred afterslip (yellow circles scaled in cm) six months after the main shock of the 2015 earthquake (Bilham et al, 2017).

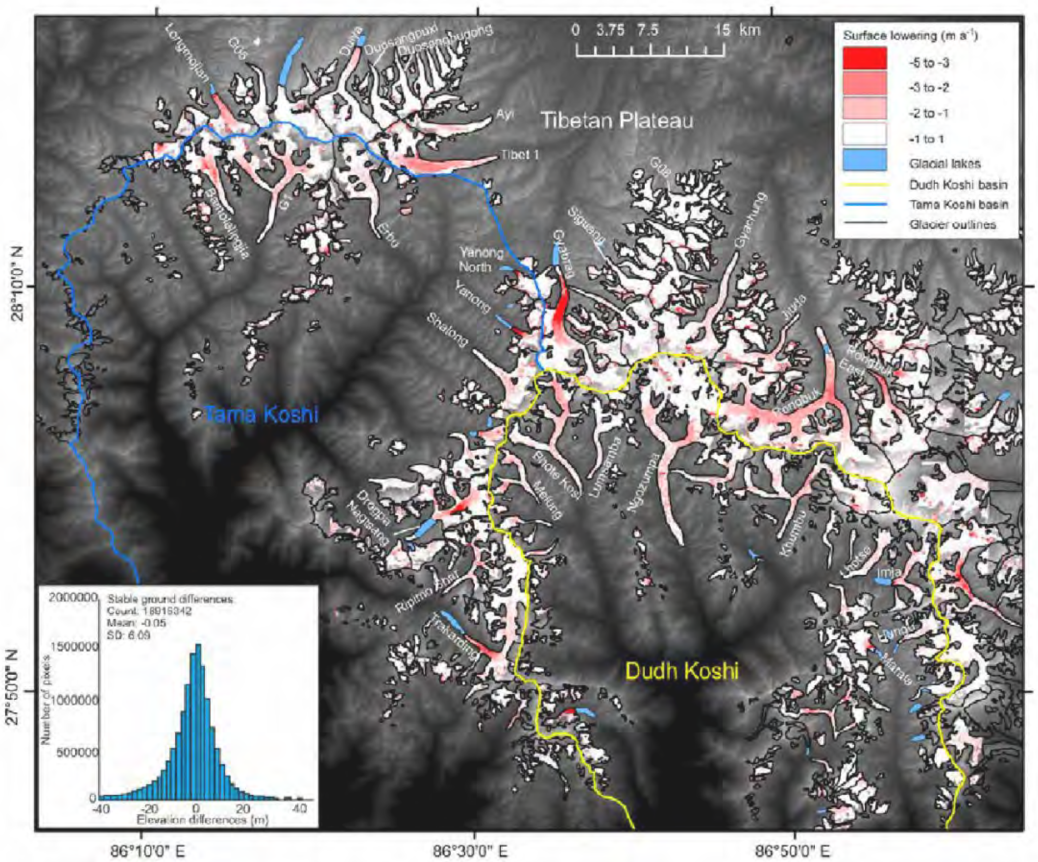

Figure 32: Owen King et al, 2017, Spatial variability in mass loss of glaciers in the Everest region, central Himalayas, between 2000 and 2015. For period 2000–2015: the mean mass balance of all 32 glaciers in our sample was –0.52 +/- 0.22m water equivalent (w.e.) a–1.

Figure 33: Mount Everest in December of 2017 displaying low amount of snow on its upper slopes (photo: Alex Tait).

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E-Logs of Hiking Tours

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Abstract. Hiking tours are made of mountaineering destinations that are connected to some meaningful whole, and the mountaineering association which is responsible for the tour, rewards visitors who fulfills the certain condition of the tour. To the visitor who proves his visit according to the given conditions, the organizer assigns a badge or written acknowledgment. Every hiking tour should have a suitable log for keeping the records about visiting checkpoints which represent exactly the specific hiking tour destinations where visitors by stamp or photo record their arrival. A visit to the checkpoint can be determined by the photo, but much more frequent practice is to confirm the visit by a stamp in the printed analog tour log. Today, digital cameras and smartphones are integral parts of hiking equipment, so proving visits by means of photographs is not only simpler, but increasingly favored by hikers. There are several advantages in confirming a visit to a checkpoint by a photograph, the most important of which are simplicity and reliability. Unlike the classic registration of checkpoint visits by stamps in conventional printed logs, digital registration requires a different type of a log – a digital log or e-Log – where stamps are replaced with digital photos which include a recognizable part of the checkpoint. At the Faculty of Geodesy in Zagreb, three e-Logs of Croatian hiking tours were developed. These Logs represents a significant step forward in tracking and managing statistics of checkpoints visits and they are completely end-user friendly.

Keywords: *hiking tours, e-logs, HPO, HPK, GPO*

1 Introduction

Croatian mountaineering is characterized by a wide variety of activities beyond the usual mountaineering, alpinism, and sport climbing, including speleology, mountain skiing, and excursion (URL 1). Croatia also has a long history of mountaineering—in fact, the first book ever written about mountaineering was by a Croat named Petar Zoranić in 1569. He titled his book with the straightforward name: Mountains. Also, Croatia was the ninth country in the world to organize a mountaineering society in 1875. Croatian hikers have promoted tourism in their country by building more than a hundred mountain huts and marking the trails, which have enabled access to numerous inaccessible areas. These new trails, huts and other mountain facilities and structures have created a foundation for the development of numerous hiking tours.

2 Hiking Tours

Hiking tours are mountain destinations connected to a meaningful whole where the mountaineering association responsible for that tour rewards visitors for fulfilling certain conditions. There are several types of hiking tours. They can be a mountain path, a series of different paths, interconnected points in the mountains, or a hiking competition without specific points but with some other conditions defining the visit (URL 2). In the past, hiking tours where called transversals. Nowadays we can find other names in use, such as connected path, mountain route, and similar terms.

Hiking tours can be defined by their length or time for completion; a visit to all checkpoints can take from one half a day to one year depending on the difficulty of the tour. The purpose of hiking tours is to acquaint hikers with most interesting destinations in a region or on a mountain and allowing them to navigate through the area by the easiest possible way.

Every hiking tour should have checkpoints (CP) that represent the exact mountain destination that hikers needs to visit. Checkpoints may be mandatory, conditional, alternate and optional. On some tours, checkpoints are replaced with conditions that a visitor needs to satisfy to obtain the acknowledgement. At checkpoints, visitors record their arrival by stamp in a log of the hiking tour, or by taking a photograph next to it (Ibid.).

Since 1957, more than a hundred hiking tours have opened in Croatia, although half of them have since been forgotten and abandoned. A list of all hiking tours in Croatia can be found on the Croatian Mountaineering Association website (URL 3) along with a detailed description of each tour.

3 Analog and Digital Logs of Hiking Tour

Every hiking tour should have a suitable log for keeping the records about visiting checkpoints. The checkpoint visit can be determined by taking a photograph, but the much more frequent and traditional way is by stamping an analog log of the tour. Today, digital cameras and smart phones have become an integral hiking equipment, so proving a visit with a photograph is not only simpler but increasingly favored by hikers. The most important advantages of confirming a visit to a checkpoint with photography are simplicity and reliability.

Unlike the traditional way of keeping records of checkpoint visits by a stamp in printed logs of the tour, a digital registration requires a different type of log—a digital log or e-Log, where stamps are replaced by photographs. Photographs in digital logs must include the visitor who confirms his or her visit by also including a recognizable part of the checkpoint (URL 4).

In the list of numerous hiking tours opened in Croatia in last sixty years, it is important to highlight the two most visited and famous national hiking tours: Croatian hiking tour (HPO) and Croatian mountain huts (HPK). The first e-Log hiking tour available on the Croatian thematic web was developed in 2006 and called HPO Calculator (URL 5). HPO Calculator was accepted by the HPS Mountaineering Commission and also

Figure 1: Front page of e-Log of GPO (URL 7).

made available to the public. However, it was little used. Poor software design was one of the reasons for this; preparing photographs was complicated and submitting them independently difficult. Inadequate promotion was another factor. In addition, the technologies we commonly use today, such as digital cameras, smartphones and high-speed internet, were extremely expensive at the time (Tomac, Špoljarić, 2016).

4 E-Logs of HPO, HPK and GPO Hiking Tour

Despite the failure and poor user response to the HPO Calculator, a new digital log of the Croatian hiking tour— e-Log of HPO (URL 4)—was developed at the Faculty of Geodesy in Zagreb. This new digital log is much simpler and easier to use. The biggest advantage over its predecessor is the simplified photo upload that is more accessible to the end user. The structure (model) of this e-Log can easily be applied to any other national, regional or local hiking tour. Shortly after launching e-Log of HPO, a second digital log was developed at the Faculty of Geodesy for the Croatian mountain huts hiking tour and named e-Log of HPK (URL 6).

Encouraged by the success of e-Logs of HPO and HPK, and the fact that many Croatian mountain peaks used as checkpoints have geodetic pillars and pyramid structures marking them, a new hiking tour – Geodetic hiking tour (GPO) and associated digital log – e–Log of GPO (URL 7) have been proposed, see Figure 1.

This hiking tour and e–Log are currently under consideration at the HPS Mountaineering Commission. As the same model (structure) is used for each of these three digital logs, each of them is based on the same technologies and provides same options for end users.

4.1 Technology Used

Several open source information technologies that do not depend on end-user device platforms have been used in the development of the three digital logs. Python programming language was used for the back-end of the hiking log with its web framework Django, while

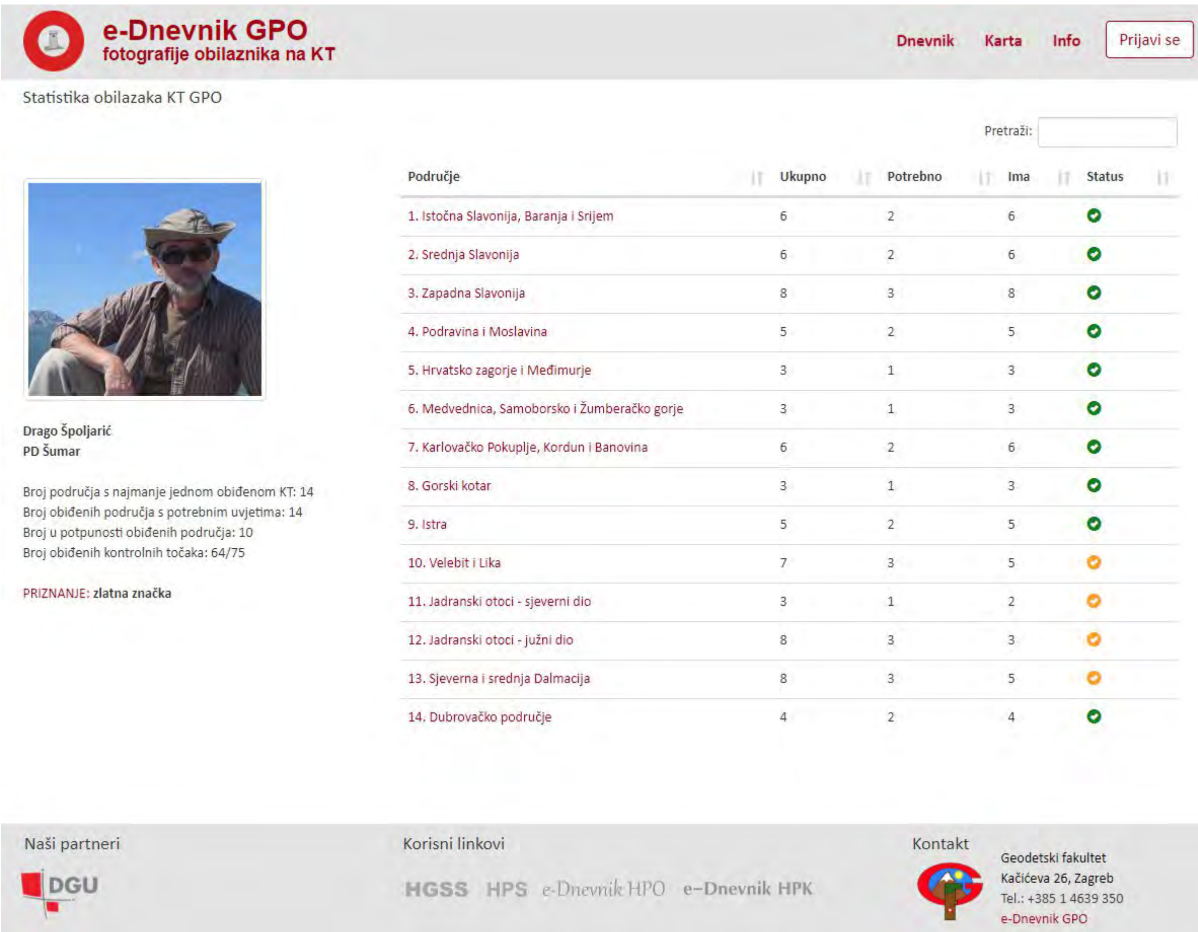

Figure 2: View of the registered user statistics on the e-Log of GPO (URL 7).

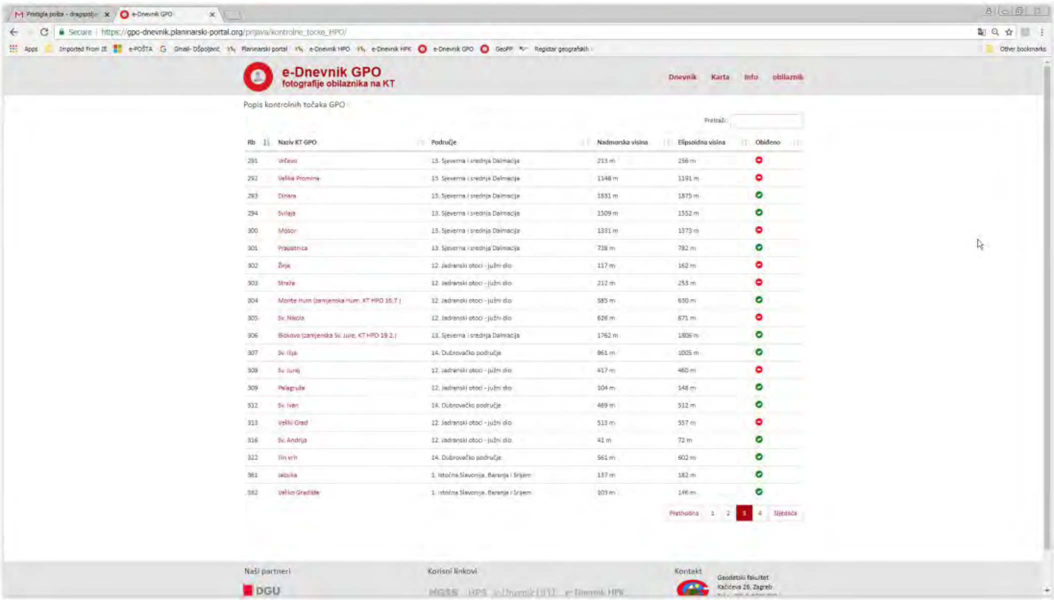

Figure 3: List of checkpoints for registered user with additional information and graphic marks on the e-Log of HPO (URL 7)

JavaScript and Cascading Style Sheets (CSS) were used for the front-end of hiking logs in conjunction with Leaflet and Bootstrap libraries. Leaflet is a JavaScript library for interactive maps, and the Bootstrap library adjusts the content of the e-log to the resolution of the end user's device. For data storage, we used PostgreSQL database with its PostGIS spatial database extender (Tomac, Špoljarić 2016).

4.2 Characteristic of E-Logs

Each of these developed e-Logs have the same characteristics in two different levels of view: unregistered users and registered users, with registered having additional features beyond those available to unregistered users.

One of the main reasons for the failure of the HPO Calculator was the complicated transfer of user photos. The biggest advantage of these new e-Logs is a simple and direct (authorized) transfer of photos. The end user no longer has to worry about the names or sizes of photos, because program routine within hiking log does this. With each photo certain attribute data, such as the information about visitor, name of the checkpoint, name of the area and date of visits, are stored. Photos uploaded into e-Log become visible after review and approval by the administrator (typically up to 24 hours). When uploading photos, the user must be aware that they are exclusively in JPEG format and limited to a maximum file size of 10 MB.

Based on photographs approved by the administrator, the system automatically generates visit statistics for each checkpoint and each user independently. The statistics of registered users, among others, include: total number of checkpoints visited, minimum number of checkpoint visited in each area, number of areas for which the minimum condition has been fulfilled, and number of areas where all checkpoints have been visited. Also, there are statistics of visitors, according to the areas where control points are located. The user sees a graphic indication of whether the minimum condition was fulfilled (an orange check mark) or if all control points were visited in that area (a green check mark). Clicking on the name of an area opens a photo gallery of that area. In the visitor's photo gallery, next to the view of uploaded photos, the user will see which checkpoints are left to visit. In the info window, the minimum requirements for each class of acknowledgment is also indicated. In the default tabular view, basic information about the user (name, surname and mountaineering society) is given (Tomac, Špoljarić 2016).

The checkpoint statistics indicate how many visitors have visited each checkpoint. In addition to statistics and photos, basic information about control points is also given (name, area, altitude, mountain / hill), as well as their presentation on the interactive map. A link to the Mountaineering portal or Geodetic mountain portal (URL 8, URL 9) provides detailed information for each point (Tomac, Špoljarić 2016).

It is also possible to search recent records on the e-Log, to learn about the current hiking tour, get information

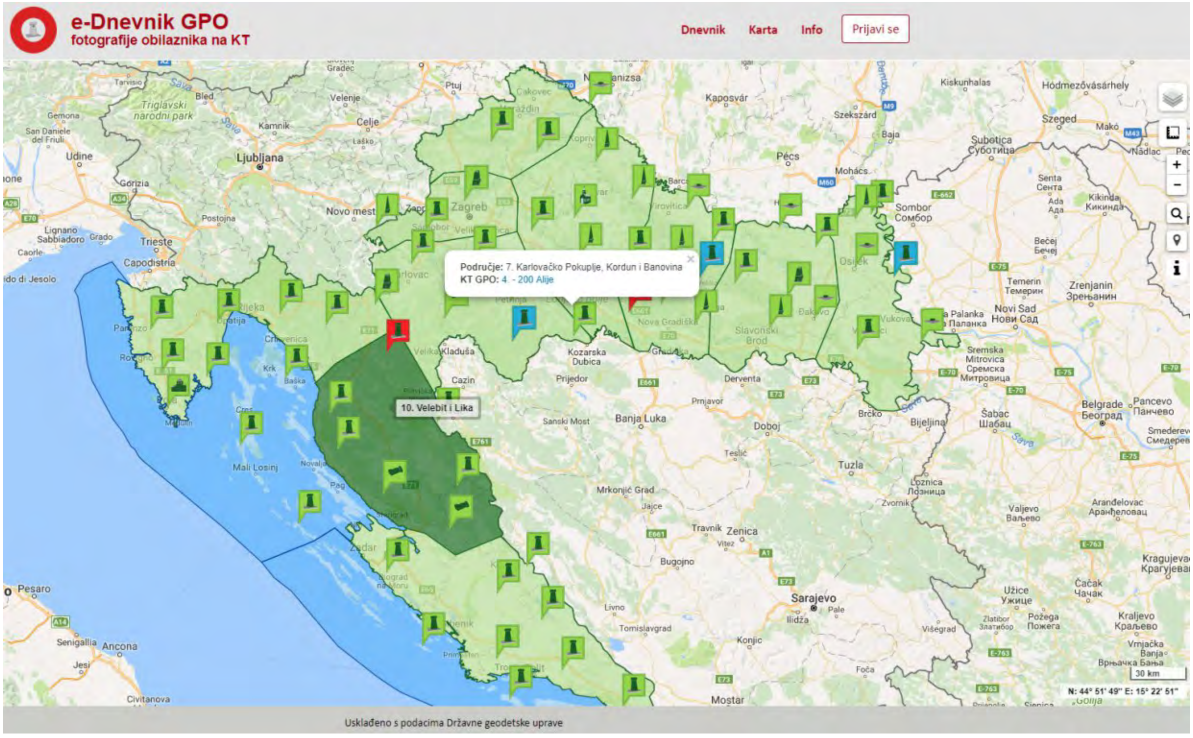

Figure 4: Interactive map with areas, icons and menu on the e-Log of GPO (URL 7).

about other hiking tours, and, in all publicly available spreadsheets of the e-Log, a filtering option is available. For example, registered users can be filtered or sorted by name, photos of each user can be filtered by the area, checkpoints can be sorted by name, mountain, etc.

Registered users have additional options. With the update option for personal profile data, they can also upload new photos and crop them. It is also possible to adjust, delete, and download photos which have already been entered. A registered user can also view all their past transfers—in checkpoint statistic view, a special graphical mark indicates the visit status for each checkpoint as shown in Figure 3.

In addition, it is possible to contact other registered users. Since most hikers keep the Log in an analog form, registered users are provided with the option to record a visit to a point, even though they do not have a photograph recorded.

4.3 Interactive Map

There is also an interactive map of checkpoints on each e-Log that enables checkpoints to be viewed and searched. On the map, the user has the option of choosing between five different background maps (Google Roads, OpenStreetMap, OpenTopoMap, DOF5 and TK25). Google Roads is installed as the default map.

The first thing a user will notice when the map opens are the specially designed icons that give information about checkpoints (e.g. checkpoint type) and its appearance. Clicking on the icon, an additional info window opens where the name and the area of the checkpoint are listed and there is also a link to Mountaineering portal or Geodetic mountain portal that offers additional information for each point. In the map menu on the right side, checkpoints can be removed from the map view.

The checkpoints on each hiking tour are grouped by area. These areas can be displayed on the map by selecting the area option on the right side of the map. Moving the mouse across an area reveals its name floating window. Clicking the area opens the info window with additional information.

In order to increase interactivity between users and the map, filtering options are available. Filtering enables the end user to access requested information quickly and easily. Data can be filtered by the name of a checkpoint, by the area in which it belongs, by the name of a hill or mountain, and by altitude. With the filtering option, the user can determine their current position on a map using the geolocation tool. This tool is primarily intended for use with smartphones. Although the geolocation tool is only accurate within a range of ten meters, it nevertheless can help disoriented users. On the map, it is also possible to use distance and area measurement

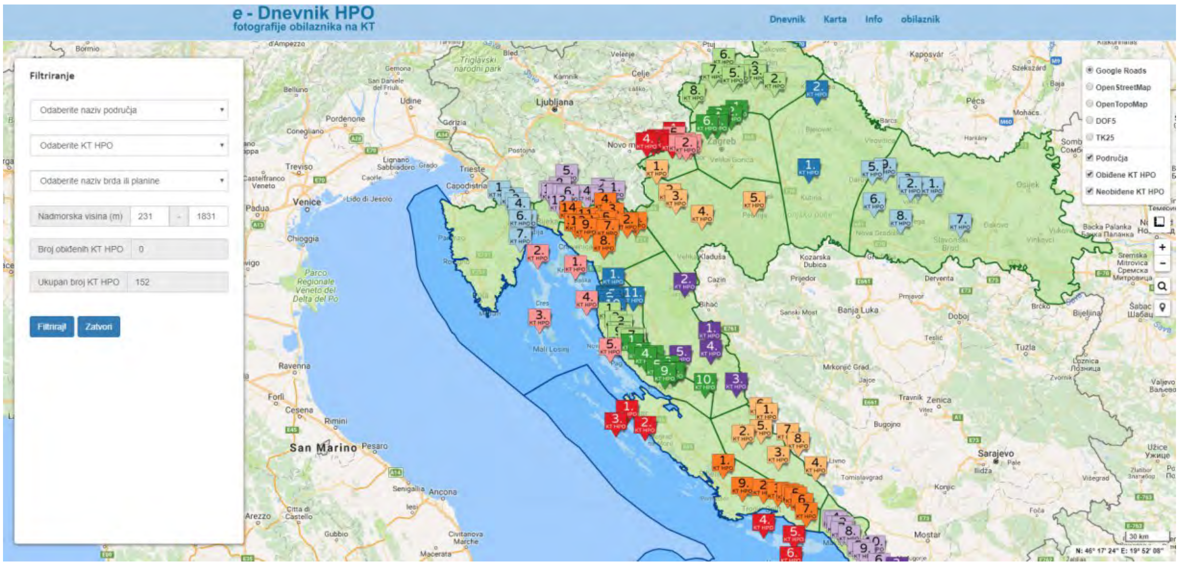

Figure 5: The filtering option for register users on interactive map of e-Log of HPO (URL 4).

tools. The interactive map is shown in Figure 4.

Registered users of the interactive map have additional display and data filtering options. Clicking on the checkpoint icon brings up an additional row in the info window that shows whether the selected checkpoint was visited or not. Also, registered users can choose whether to see only visited, unvisited, or all control points on the map. Plus, when opening the filtering option, the total and number of visited checkpoints appears (see Figure 5).

5 Conclusion

Because we live in a time when high-speed Internet and digital technologies, such as smart phones and digital cameras, exist in all spheres of human activity, keeping digital records is no longer a novelty. One example this ubiquity are digital Logs (e-Logs) of hiking tours, which represent a significant step forward in tracking and managing statistics for checkpoint visits as well as the statistics of visits of registered users. These electronic Logs are simple to use, completely end-user friendly, and are more reliable than traditional analog Logs. Moreover, they provide a wealth of information through various links on the platform. They contribute to the promotion of hiking tourism by familiarizing visitors with important mountain destinations and by facilitating accessible and easy navigation through a region. Three e-Logs have been developed at the Faculty of Geodesy in Zagreb for the two most famous and most visited national hiking tours—the Croatian hiking tour (HPO) and the Croatian mountain huts (HPK)—and for the newly developed Geodetic hiking tour (GPO), which is currently under consideration at the HPS Mountaineering Commission. Numerous hikers have accepted them as a solution for tracking checkpoint visits, and they have registered and entered their photos in e-Logs.

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URL 7: e-Log of Geodetic hiking tour, https://gpo-dnevnik.planinarski-portal.org/, (19.6.2018.)

URL 8: Mountaineering portal, https://planinarski-portal.org/, (15.6.2018.)

URL 9: Geodetic mountain portal, https://geopp.planinarski-portal.org/, (20.6.2018.)

Extended Abstracts

Mapping for Outdoor Activities in Mountains

Proceedings of the 11th ICA Mountain Cartography Workshop
May 21 – 25, 2018, Hvar, Croatia


Ծաղկաձոր
Հրազդան
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Joint Course of Mapping in a Mountainous Area

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Keywords: *joint course, field trip, mountainous area, topography style, open source data*

This paper reports on a joint course based on an Agreement of Academic Cooperation between the University of Ljubljana, Faculty of Civil and Geodetic Engineering (UL), and the University of Vienna, Department of Geography and Regional Research (UW).

Two elective subjects from master study programs in Geodesy and Geoinformation at UL and Geography at UW were organised as a joint course. Joint course was in English language to attract international exchange students.

Participants were 4 lecturers: From Slovenia, dr. Dušan Petrovič, assist. prof., and dr. Klemen Kozmus Trajkovski, assist. From Austria, dr. Karel Kriz, assist. prof., and Michael Heuberger, assist. There were 13 students from UL, including Erasmus student from Poland, and 6 from UW, including international student from Serbia.

The student's workload included 45 hours of organised activities and 45 hours of individual work worth 3 ECST. The organised hours consisted of introductory lectures at both universities and field work—a four-day field excursion. The individual work at first involved only communications between students from the different universities within the same group, followed by preparation and, after the field excursion, every group wrote impressions about their experience.

Lecture goals were to produce high quality topographic maps from open source data with the addition of data acquired from surveying in selected areas. Also, one of the main goals was fostering international collaboration and communication between students having different knowledge and approaches, but ultimately with the same goal—experiencing cartography in a mountainous environment. The selected area for the field excursion was in Slovenian Alps at Velika planina. The course results—documentation of students work and group presentations—were posted online.

The joint course was roughly organised into three parts. It started with introductory instructions for all 19 registered students and the creation of six groups featuring a mix of nationalities. Each group collected available open source data and did topographic mapping symbology analysis for a selected style. Based on the new information and data that was collected, each of the groups prepared a topographic map using open source software. After topographic mapping symbology analysis was finished, some details of original topographic mapping were intentionally changed in order to improve the map style.

Next, was a joint field trip to a mountainous area in Slovenian Alps, in May 2017. It was for four days and took place at Velika planina, Domžalski dom, at altitude 1534 meters. The hike to the hut Domžalski dom took 30 minutes and luggage was taken to the hut by jeep. Because the weather in Velika planina is very unpredictable, participants had to be well equipped. Necessary equipment included mountain gear and good physical condition, notebooks, GPS receivers, smartphones, maps, etc.

The first day of the field excursion was devoted to group coordination, a hike to the highest point of Velika planina and an evening icebreaking event.

On the second day, every group created a plan and did the necessary field work. The students collected additional data missing from the free data sources using GNSS receivers and visual interpretation. In the field, students defined boundary lines, walked over area, marked significant points, and collected missing data, for example: depressions, roads, and signposts. This new information

Figure 1: Hike to the highest point of Velika planina

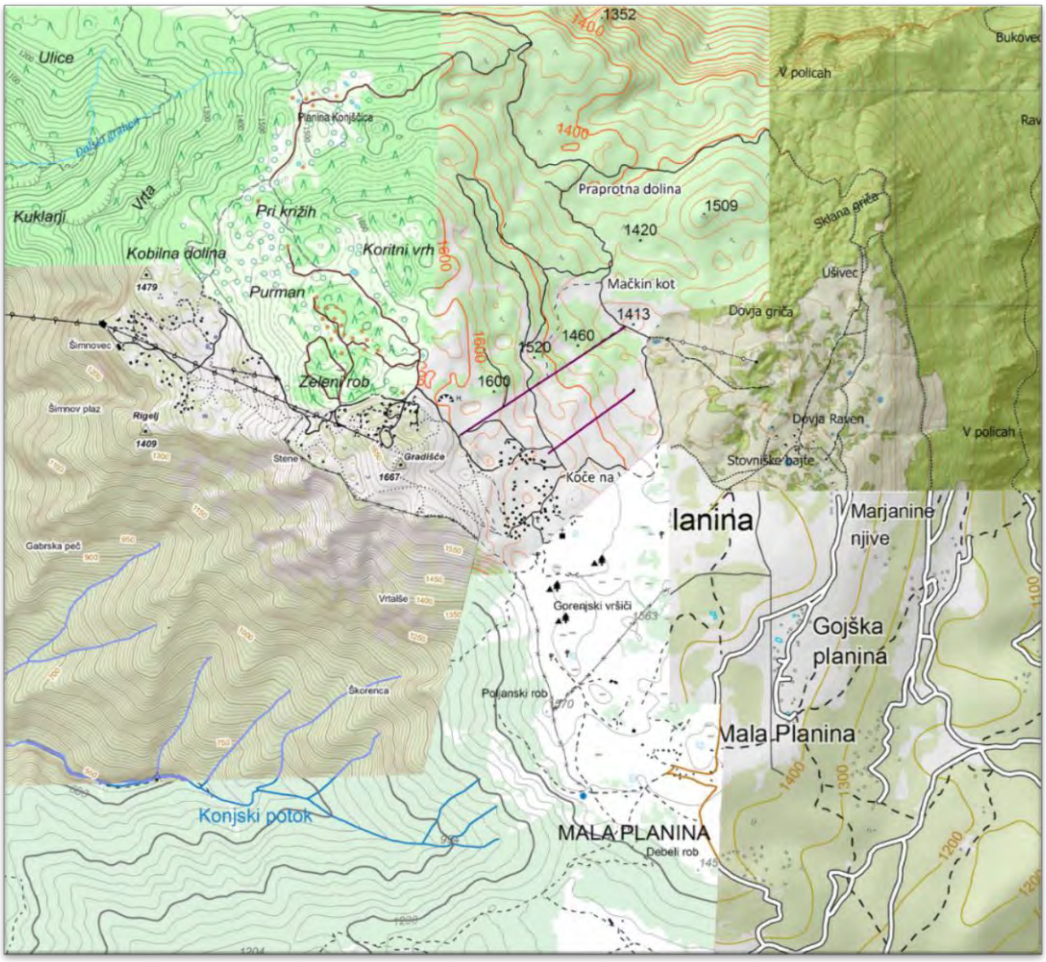

Figure 2: Compilation of the six different map styles - top left clockwise: Polish map style, Austrian Alpine Club, Austrian Map, Ordnance Survey, Canadian Map, Slovenian Map

was then added to a pre-prepared topographic map using established principles of cartographic generalization and map design. Office work mainly involved generalization of roads, buildings, contour lines, and adding data to the map that is important for hikers. Some groups had problems with using different the topographic styles, which did not include all necessary symbols.

On the third day, students did additional field work, fine tuning of the map, and final presentations. In the evening, every group had their final presentation (as an exam) about their work experience, problems, dilemmas, solutions, and results. The last day was a wrap up meeting and departure.

Based on theoretical lectures, experiences, field work, drone demonstration, and orienteerinq, the students created a better topographic map. The final product was topographic map of the whole selected area made by merging all six maps from every group into one unified topographic map.

Collecting the missing data in the field at Velika Planina was an experience that demonstrated the quality of the open data. All students were very happy with the joint course and learned a lot. The consensus was that universities from different countries should collaborate more often and encourage their students to participate in joint courses.

Volcanoes and Mountains in the Deep Ocean

The Challenge of Scientific Visualisation of Bathymetric Data

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Keywords: *bathymetry, deep sea mapping, marine research, public outreach, marine geosciences*

Introduction

For cartographers and scientists that work in subaerial regions, multiple datasets are nowadays available to create a meaningful map of high informational value and good graphical quality. High-resolution elevation data, satellite images, vector data and much more is often publically available in online repositories and can be downloaded within minutes. Also, high-resolution satellite, drone and aerial images with a good coverage of the target area can be acquired at relatively low costs. The mappers have plenty of data to work with and can, accordingly to their personal skills in mapping and map design, often focus their creativity on the map, the target group, and the product itself.

As maps from land are common in our daily use, the public that uses these maps (as print, in exhibitions, or online) mostly has a good sense for the features they see on a map as long as it shows things they are generally familiar with. For example, on land or at the coastlines people will recognise landscapes, vegetation colours, country and district borders, rivers, large and small cities, and get a good feel about the distances and dimensions of the depicted landforms and geographic features.

Quite the opposite is valid for maps and cartographers that work with deep-sea bathymetric data. The deep sea, far off the coasts and other oceanic areas with no direct economic use are not the focus of politics. Neither are the geomorphological structures and submarine landforms considered as spectacular as, for example, photographs from the Moon, Mars, and other planets; therefore submarine maps do not receive as much public attention. However, submarine maps are of great scientific value considering that the ocean covers about 70% of Earth's surface. Both studies on geological processes as well as any deep-sea research strongly depends of the quality and information provided by hydroacoustic mapping.

Bathymetry in general suffers from low-resolution data (in most case cell-sizes of several kilometres), bad data quality (e.g. due to weather conditions, ship configurations, system failures, etc.), and bad coverage (more than 80% of the ocean floor is unmapped with modern, high-resolution techniques; GEBCO Seabed 2030 Roadmap). Also, the amount of data bathymetrists can work with is often limited to bathymetric data and the information of the acoustic backscatter signal that provides basic insights into seafloor characteristics.

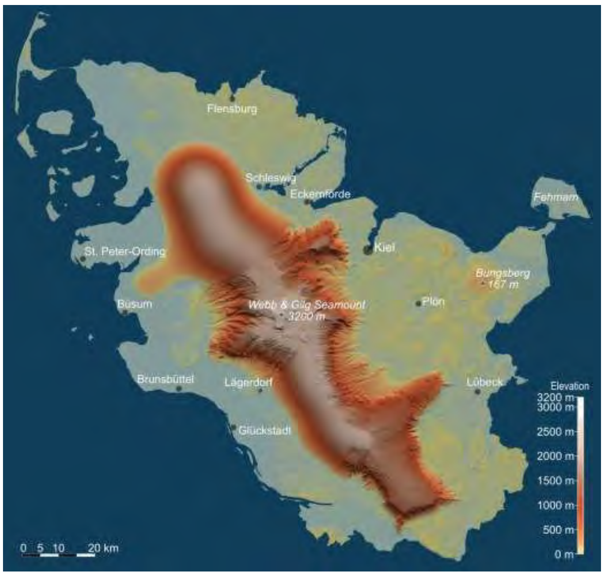

Figure 1: Visualization of a large submarine volcano (Webb & Gilg Seamount, Central Eastern Atlantic) that was mapped during a research cruise R/V Maria S. Merian, MSM70. This map was used for public outreach and the aim was to give the reader a sense of the dimensions of this structure as well as showing the huge gain in resolution by the ship-based seafloor mapping by comparing the low-resolution data lacking detail with the highly-detailed mapped parts of the structure. For comparative purposes, the seamount data are overlain on the shape of the German federal state of Schleswig-Holstein. The map was created by using Global Mapper, Photoshop (Geographic Imager Plugin), Affinity Designer.

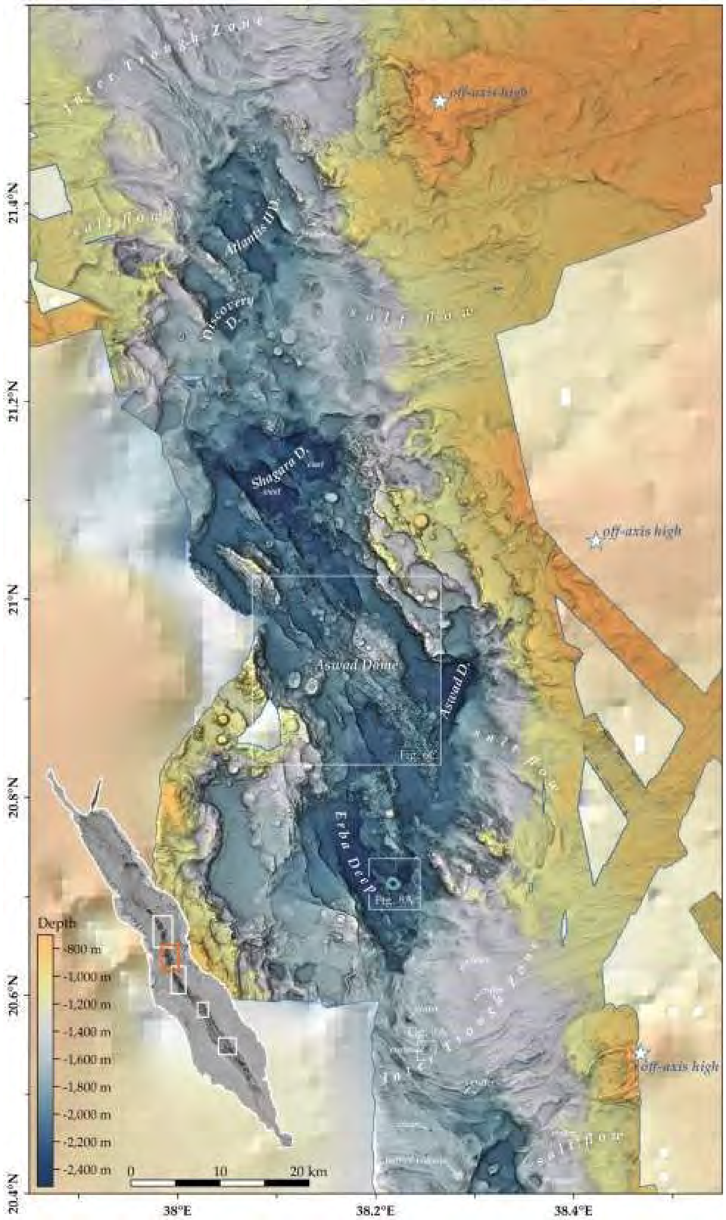

Figure 2: Scientific bathymetric map of volcanic terrain and submarine salt glaciers in the Red Sea Rift (Augustin et al., 2016). Data from research expeditions with R/V Poseidon and R/V Pelagia in 2011 and 2012, respectively. Map created with TTS-Shader, Global Mapper, Photoshop (Geographic Imager Plugin), Surfer and Corel Draw.

Additional data e.g., from seafloor sampling, seafloor observations with camera systems, sub-bottom profiles, or even seismic data that are essential for the interpretation of bathymetric data are mostly missing or at least very sparse. Thus, scientists and seafloor-mappers are faced with the challenge of extracting the most out of the available data. As a result, bathymetric data far too often have been reduced to a simply gridded elevation model, published in a rainbow color-scheme, leading to simple, tiny, non-understandable pictures that show the limits of a working area and/or to plot some sample locations, rather than that the maps are scientifically used.

Research and Results

Due to the difficulties of data acquisition, post-processing, and bathymetric map-making, the marine scientific community sees an increasing need to make marine-sciences more visible to the public. The applications of marine maps are numerous as every marine research discipline needs maps as a solid base for their science. Oceanographers need the ocean floor relief to model currents; biologists, petrologists, and chemists need the data to find their samples, e.g. to define migration barriers or simply find the hard substrate many species need to settle; geologists need the data to understand how Earth works, for marine hazard and mineral resource assessments, and much more. All of these disciplines are in need of reliable data and informative maps of the seafloor. The challenge of the modern bathymetrist is to provide these high-quality maps and prepare them in such a way that they can be used by non-specialist researchers and be understood by the general public. Recently researchers have started to see the need for meaningful, high-quality bathymetric maps that not only serve a scientific task but also that the general public will feel comfortable looking at for exploring undersea features. The maps should also become more useful for public outreach, have beautiful designs to attract people, and give them a sense for the dimensions of Earth´s undersea features — for instance, by making comparisons to known land features (Figure 1). Many of the tools and techniques used by terrestrial cartographers can also be used by submarine mappers to a certain degree, but should be adapted to deal with limited data quality and availability (Figure 2). Several possibilities and ways to present bathymetric maps to scientists, politicians, and the public in a meaningful and attractive manner, as well as the effective scientific use of these maps, will be discussed during the presentation.

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An Alpenvereinskarte for Canada

The Backcountry Ski Guide's Map for the Burnie Glacier Chalet, British Columbia

Morgan HITE
Hesperus Arts

Keywords: *mountain mapping, backcountry skiing, Burnie Glacier Chalet, British Columbia, Canada, QGIS, Inkscape, Blender*

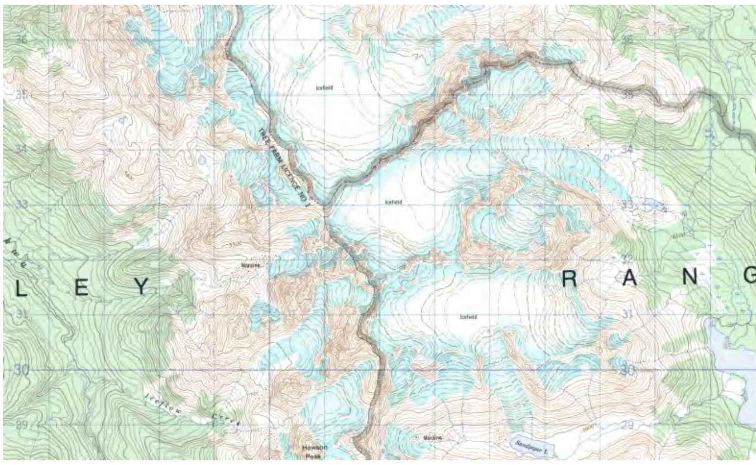
The federal (1:50,000) and provincial (1:20,000) topographic map series available in Canada's mountainous province of British Columbia often do not provide local names for peaks and other features, and are sometimes too inaccurate with respect to elevations and glacier extents to be ideal for demanding uses such as backcountry ski guiding. In this project, the author discusses a 1:25,000-scale topographic map produced in 2016 for use at the Burnie Glacier Chalet, a helicopter-accessed, ski-mountaineering destination in the Howson Range of British Columbia. The map contains typical elements such as contour lines, vegetation, trails and main ski routes, but also shaded relief, indications of scree, locations of crevasses and icefalls, as well as differentiating between rock and ice surfaces. Much of the underlying data had to be created from air photographs and the knowledge of a local ski guide. Elements of the map styling were deliberately chosen to imitate the classic 1:25,000 Alpenvereinskarte produced in Germany and Austria. A hybrid style, combining air photo and vector elements, was used in an inset map to give detail in one area that is both especially complex and frequently travelled. Produced using the free software packages QGIS, ScreePainter, Inkscape and Blender, the map also includes some new peak names, and place names given by the local indigenous people, the Wet'suwet'en.

The Location

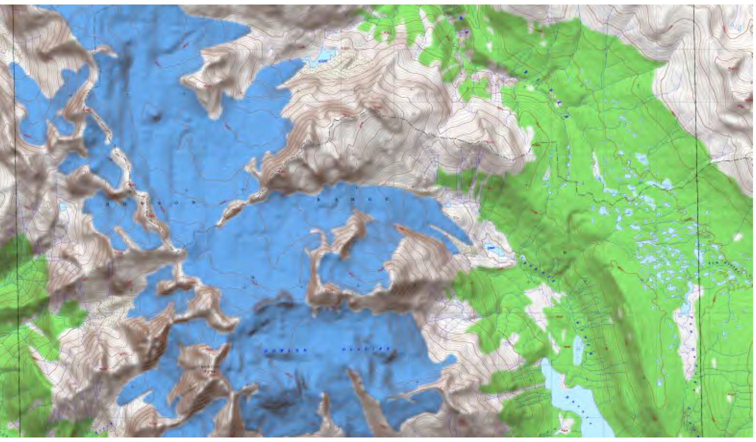
British Columbia is Canada's westernmost province and is distinguished by its mountains, which pile up along the western coast because of tectonic activity. The area mapped in particular is the Howson Range of the Coast Mountains, specifically the area around the Burnie Glacier Chalet.

Prior Mapping

The standard topographic map produced by Natural Resources Canada, a branch of the Canadian government, is at 1:50,000 scale. For this area, the most recent paper version is dated 1974. It has few of the feature names in current use, and in fact the label "Howson Peak" is on the wrong peak.

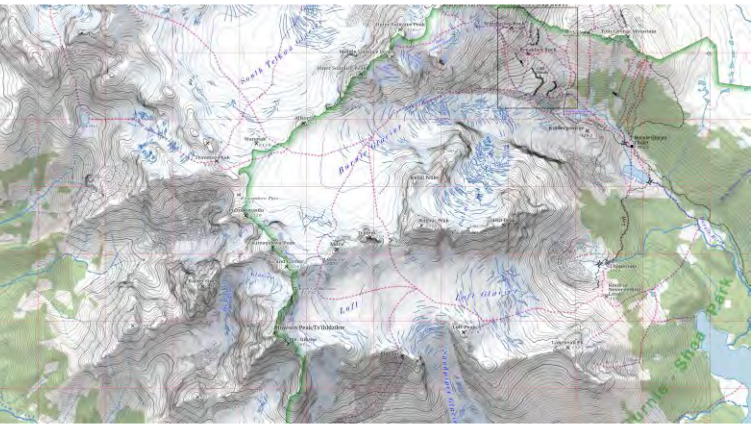


Another series of maps, this one produced by the province of British Columbia itself, is called TRIM mapping. It is at 1:20,000 scale and is updated more frequently. This one was produced in the 1990s. The Howson Peak label is in the right place now, and it features shaded relief, which is good. But in other ways it does not agree with present experience of this place. Ski mountaineers have named many features in this area, but these names are not officially recognized by the government, so they don't appear on this map. What is identified here as the Howson Glacier, for example, is actually known as the Loft Glacier. As well, glaciers have receded considerably since this map was produced. This southern lobe of the Loft Glacier is entirely gone.



The New Map

The new map is at 1:25,000 scale to make it useful for ski guiding. Other key elements which make this useful for winter backcountry touring are the large selection of named features, the ski routes and crevasse fields, plus shaded relief. Also, as an innovation, these peaks fall within the traditional territory of the Witsuwit'ren people, so we've added some names in the Witsuwit'en language.



Sponsorship

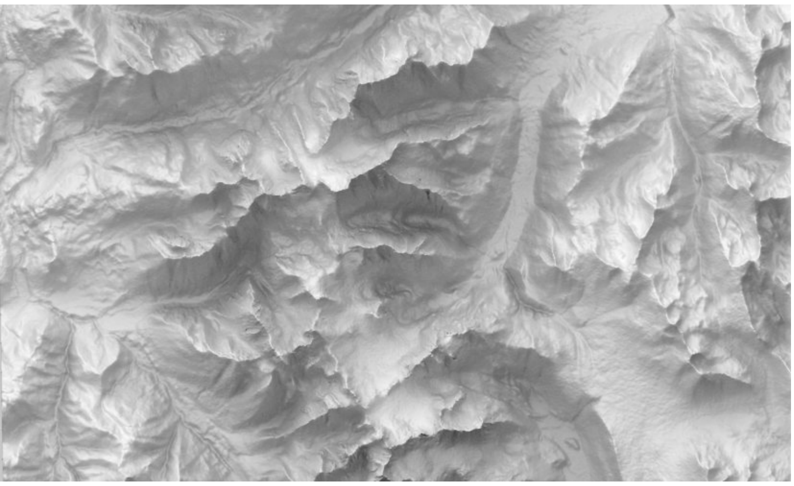
The map was commissioned and paid for by a ski guide in nearby Smithers, BC, Christoph Dietzfelbinger. He originally hails from a small village in Bavaria, but while completing his masters degree in medieval German literature in Munich he became a UIAGM mountain guide. In 1986 he emigrated to Canada, and provides snow avalanche risk management services to industry and government as well as heli-skiing.

In 2001, he built the Burnie Glacier Chalet in the Burnie -Shay Provincial Park. It is fly-in only, and he guides out of here as well as teaching professional avalanche courses for the Canadian Avalanche Association. More information on his guiding can be had online at http://bearmountaineering.ca.

Shaded Relief

I decided to use SRTM data processed through Blender to produce the shaded relief. The original DEM data here was 1" resolution. At this latitude the cells are roughly 17 x 30m. I resampled and reprojected to square

15m cells. I then ran it through Blender. If you were at Daniel Huffman's talk at the 2014 Banff workshop you may remember the details of how that works.

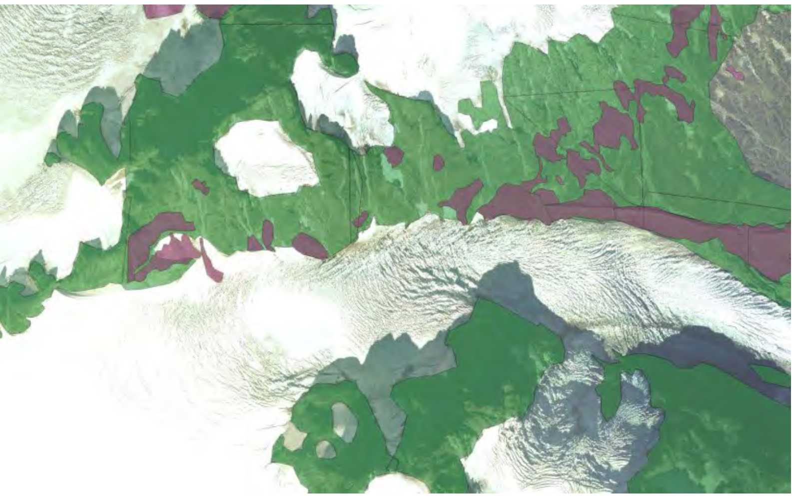


Mapping of Current Glaciers, Rock and Scree

I worked from two high resolution air photos that were dated 2013. These are 50cm pixel air photos that are produced by the Province of BC. I used these for a number of features.

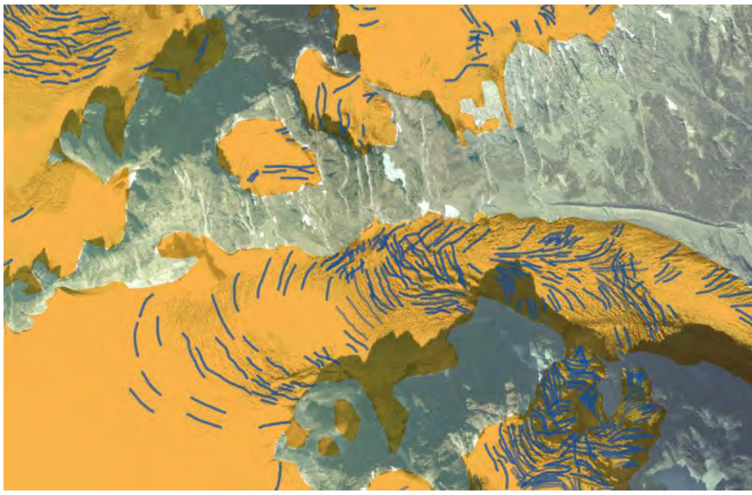
In some cases it was necessary to brighten them up to see what was going on in the deep shadows.

First, I digitized rock and scree. I used overlapping polygons and then dissolved them later.



Second, I digitized scree, including scree lying over ice. This would be fed later into Benhard Jenny's program Screepainter.

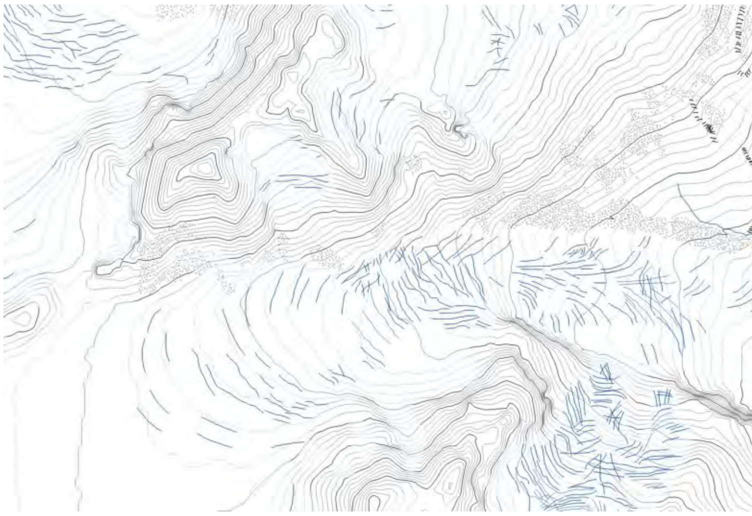
Third, I digitized what I called sloppy glaciers – glaciers that were just roughly drawn and were bigger than the actual glaciers – and clipped them against rock-scree to get the actual glaciers.



Fourth, I digitized crevasses as lines.

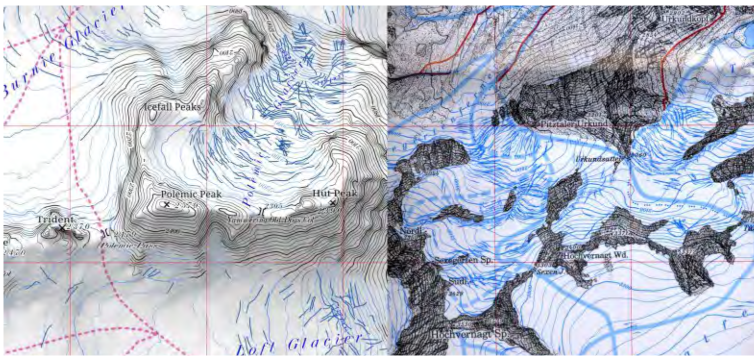
Fifth, I clipped the contour lines against the rock to get black contour lines, and against the glaciers to get blue contour lines.

This is the final result with the scree added in from ScreePainter.



Styling Inspired by Alpenvereinskarte

There are many different editions of Alpenvereinskarte, but the one we had on hand was a sheet called Ötzaler Alpe, in Austria.



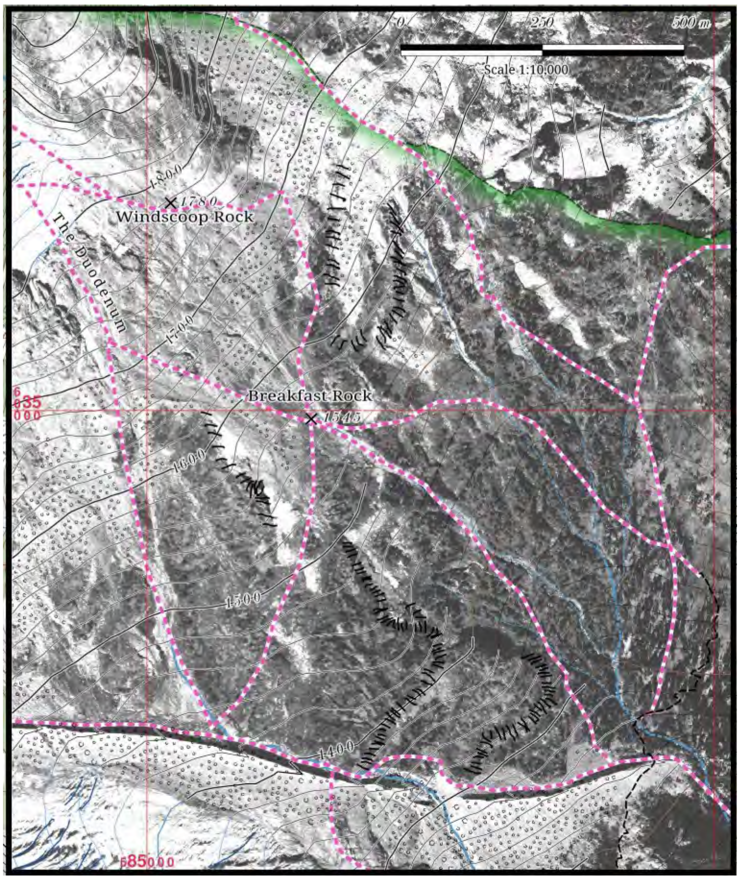
From this Alpenvereinskarte I copied the scale, the red grid lines, blue crevasses, blue contours on ice, and the scree representation. I did not copy the blue ski routes, but changed these to magenta for greater contrast. Unfortunately, I could not copy the rock hachuring.

Type is a key element of any map's design, so I went to some trouble to copy the fonts being used in the Alpenvereinskarte. Simply by placing various fonts over the original map and adjusting both leading and size, I was able to determine that the free fonts Dubiel and Droid Serif are quite good imitators.

Inset

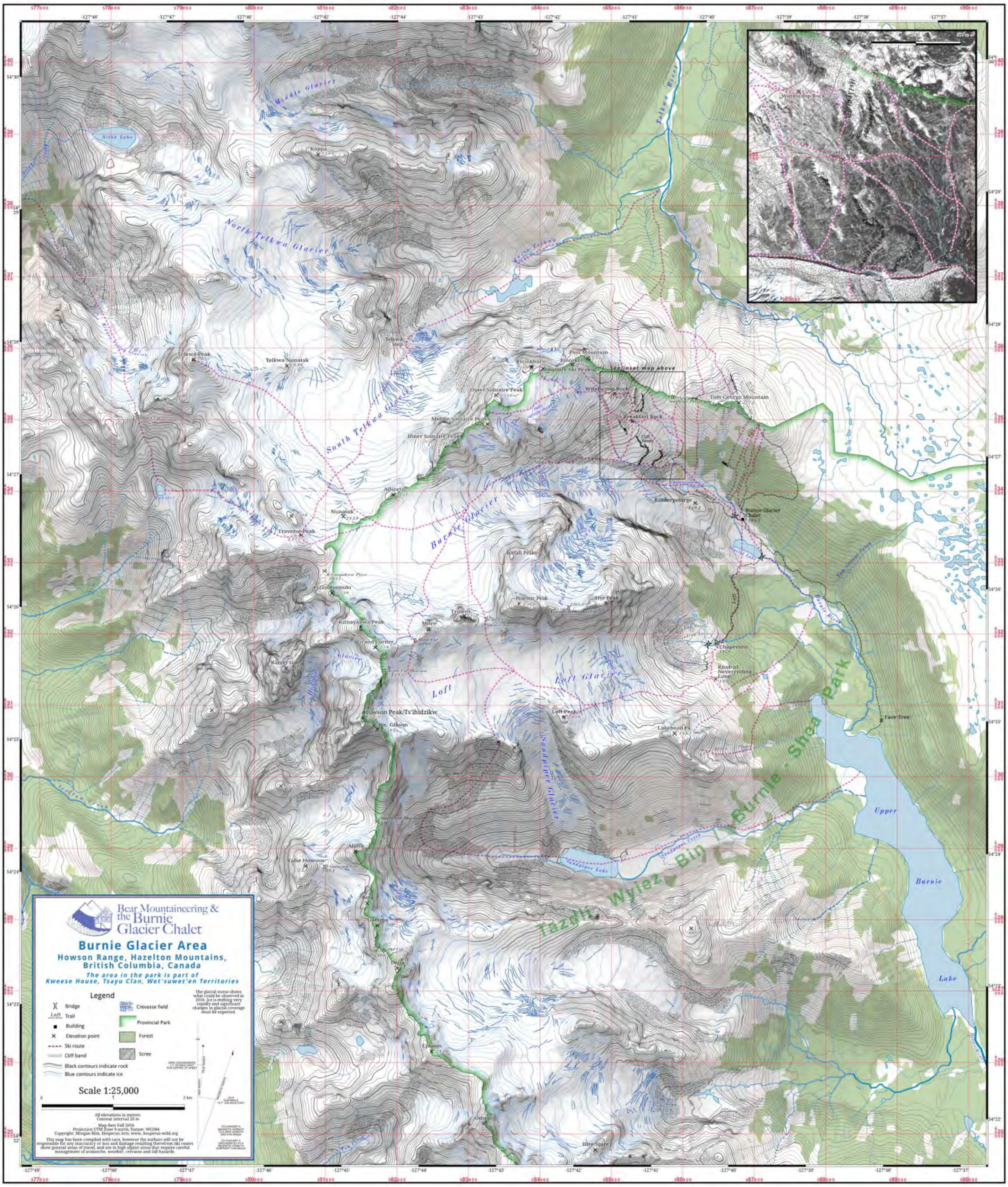
There was a need for an inset map at 1:10,000 showing a special area that required precise navigation. Parties leaving the chalet need to go up just past Breakfast rock and then up to Windscoop rock, and there are specific cliff bands to be avoided.

Behind the contours and some rough black hachuring for the cliff bands, I placed just the red band from the air photo, displayed as greyscale. I bumped up the brightness and contrast.



The full map

The final map is printed on waterproof paper, and measures 60 x 70 cm. Its folding scheme is designed to display the most commonly used terrain when you first open the map.


Bear Mountaineering &
the Burnie
Glacier Chalet
Burnie Glacier Area
Howson Range, Hazelton Mountains,
British Columbia, Canada
The area in the park is part of
Kweese House, Tsayu Clan, Wet'suwet'en Territories
Legend
Bridge
Trail
Building
Elevation point
Ski route
Cliff band
Black contours indicate rock
Blue contours indicate ice
Crevasse field
Provincial Park
Forest
Scree
The glacial status shows what could be observed in 2016. Ice is melting very rapidly and significant changes in glacial coverage must be expected.
Scale 1:25,000
0
1
2 km
All elevations in metres.
Contour interval 20 m
Map date Fall 2016
Projection UTM Zone 9 north; Datum: WGS84
Copyright: Morgan Hite, Hesperus Arts, www. hesperus-wild.org
This map has been compiled with care, however the authors will not be responsible for any inaccuracy or loss and damage resulting therefrom.Ski routes show general areas of travel, and are in high alpine areas that require careful management of avalanche, weather, crevasse and fall hazards.
North Telkwa Glacier
South Telkwa Glacier
Burnie Glacier
Loft Glacier
Sandpiper Glacier
Middle Glacier
Telkwa Peak
Telkwa Nunatak
Kappa
Nunatak
Traverse Peak
Howson Peak/Ts'ihldzikw
Pass Mountain
Tom George Mountain
Windscoop Rock
Breakfast Rock
Kindergabe
Burnie Glacier Chalet
Icefall Peak
Polemic Peak
Hot Peak
Chaperone
Lakehead Pk
Face Tree
Upper
Burnie
Lake
Alpha
Epsilon
Dire Spire
False Howson
Tazdli Wyiez Bin / Burnie - Shea Park

Delineation of Croatian Mountains for the Purpose of Name Placement on Maps

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Keywords: *mountains, delineation, map, name placement, Croatia*

Introduction

Sources of spatial data on Croatian mountains that are usable in GIS and mapping applications are sparse and their quality varies. The only national open spatial data source is the Gazetteer of Geographical Names published and maintained by the State Geodetic Administration (SGA) of the Republic of Croatia. Among geographical names of many feature types, it also contains names of mountains, hills, peaks, parts of mountains and hills, etc., which are structured as points with attribute data. Useful additional global open data sources include GeoNames and OpenStreetMap.

Using point data to represent areal geographical features is common in geospatial applications because it can lead to more efficient data processing and maintenance. But, for some purposes it also has drawbacks due to loss of geometrical details and information, such as when placing names (labels) of areal features on maps. Various algorithms for automated name placement of areal features are implemented in current GIS and mapping software. The input data for such algorithms are polygons with attached attribute data including names. This means that for both automated and manual placement of mountain names, polygons that represent their extents are required.

The definition and delineation of mountains depends on the application purpose, including agricultural subsidizing, statistical data collection and analysis (Price et al., 2004), hydrology (Viviroli and Weingartner, 2004), biogeography (Körner et al., 2017), etc. The problem of modelling and delineating areal physiographic features for the purpose of their naming on maps was also investigated. Buckley and Frye (2006) concluded that polygon geometry provides a multi-purpose and multi-scale model in GIS databases for labelling most physiographic features, with the exception of points that represent solitary peaks. They also discussed two methods of capturing geometry: the first, which they preferred, was manual digitizing from maps, and the second was automated feature extraction based on a DEM.

This research aims to propose a new methodology for delineating mountains using DEM analysis. The main objective is to create a dataset for placing names on the maps, but it could also serve in other applications where named entities require precise bounding limits. After landforms are automatically delineated from the surrounding land, the next required input is point data representing mountain peaks. Automated selection of peaks above a certain height is also possible and can be used to test consistency. Peaks are then used to filter mountain landforms. Lists of Croatian mountains are available from these sources: the SGA's Gazetteer of Geographical Names (45 features) (URL 1), the Statistical Yearbook of the Republic of Croatia 2017 (46 features) (URL 2) and on web-pages of Croatian Mountaineering Association (descriptive data and geographic coordinates) (URL 3). There are significant differences in these datasets.

Materials and Methods

In the first step, the methodology uses a DEM to identify areas of inverted terrain that represent natural breaks between mountains. Specifically, after identification of inverted terrain, flooding analysis is performed starting from the bottom, raising the "water" level up to the threshold where it flows downwards outside of the terrain area. On a typical DEM, this analysis results in naturally closed valleys. On an inverted DEM, the same analysis results in naturally closed mountains. This is a straightforward analysis that does not depend on any input parameter except for the DEM. The only concern is that the DEM must be expansive enough to ensure that it completely covers the area of interest. We accomplished this first step using GRASS GIS module r.terraflow. The resulting vector polygons for Croatia are shown in Fig 1. Most of the polygons represent multiple mountains, but there are some that only represent one prominent mountain (Fig 2.).

Figure 1: Polygons representing landforms isolated from surrounding lowlands.

The next step is the selection of vector polygons obtained from the DEM data that represent Croatian mountains. This step does not have a unique solution because the results depend on how one defines "Croatian mountains". Possible defining criteria include peak elevation, slope, mountain area, climate, administrative criteria, or common knowledge. Whatever criterion is used (in our case we used mountains listed in the 2017 Statistical Yearbook of the Republic of Croatia), for each included mountain the highest peak can be selected as a representative point. By overlaying these points and polygons from the previous step we obtained a set of polygons for selecting mountains (Fig 2, green polygons).

In order to get a single polygon for each mountain, we had to delineate polygons that contained two or more listed mountain peaks. For this final step, we again applied DEM analysis. First, the highest paths connecting peaks (with maximum height of the lowest point on the path) were determined using GRASS GIS (command r.walk and r.drain). The lowest point on that path was selected (it was usually a saddle) and then, from that point downward, flow paths were calculated. These paths were used as delineation boundaries (Fig. 3). The final result depends on selected peaks because this delineation is done only between pairs of selected peaks within the same elevated landform.

Figure 2: Different landform polygons: At Sljeme, one polygon represents one mountain. At Sveta Gera, Plešivica, and Japetić, one polygon represents many landforms. At Vodenica, one polygon represents the surrounding hills (in the southwest).

Figure 3: Delineation of landforms using only mountain peaks listed in the Statistical Yearbook of the Republic of Croatia 2017.

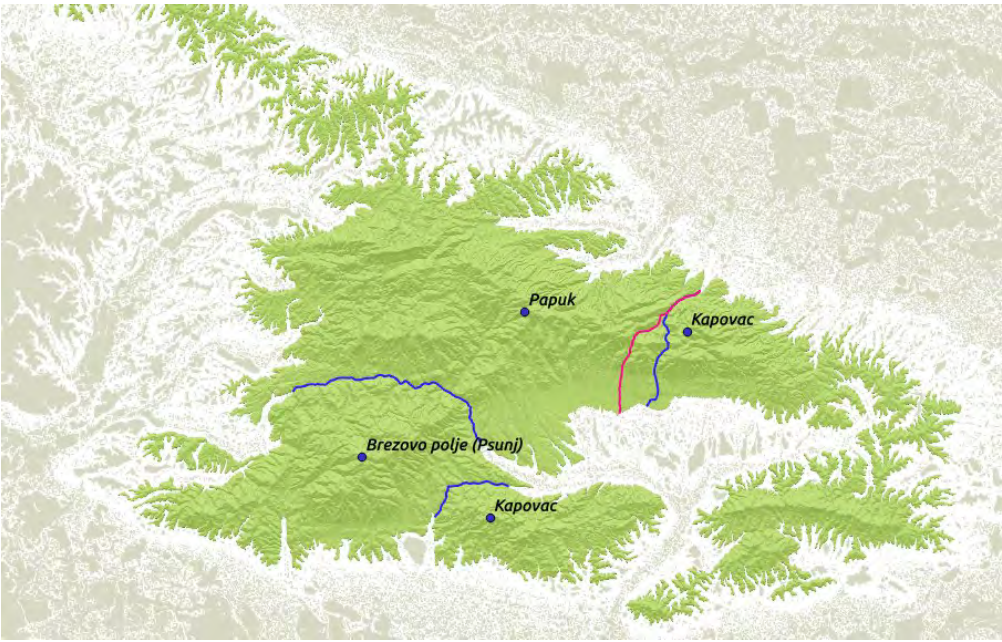

Figure 4: Example where further delineation is required, e.g. Papuk area includes surrounding hills in the west and north that should be excluded. Delineation between Papuk and Kapovac in the east is vague; the blue line was obtained analytically and the purple one from a descriptive boundary.

Results and Discussion

The dataset obtained by the proposed method just described is not enough for the automated placement of mountain landform names. Additional processing is needed (Fig 4.). Some landforms include surrounding hills and other elevated terrain that are unnamed. There are different methods on how to proceed with delineating named mountains, such as including peaks of unnamed hills (the result will depend on which peaks are selected). Using other terrain parameters, such as slope, height, topographic indexes, or even manual methods are additional solutions. The same procedure can be performed on a non-inverted DEM to get similar dataset for closed valleys (e.g. karst topography).

Conclusion

The delineation of mountains is a problem that does not have a unique solution. In the case of Croatia where mountain delineation does not yet exist, boundaries obtained analytically using only terrain geomorphology can provide an initial dataset. The results of our described method can be further modified by other criteria that can lead to delineations for purposes not considered in this paper. Publishing the results via spatial web services is an option that will ensure greater availability and encourage more people to enhance spatial datasets of Croatian mountains.

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Price, M. F., Lysenko, I., Gloersen, E. (2004). Delineating Europe's mountains. Revue de géographie alpine, 92 (2), 75–86.

Viviroli, D., Weingartner, R. (2004). The hydrological significance of mountains: from regional to global scale. Hydrology and Earth System Sciences Discussions, 8 (6), 1017–1030.

URL 1: Gazetteer of Geographical Names, Web site: https://data.gov.hr/dataset/registar-geografskih-imena (accessed February 5, 2018).

URL 2: Statistical Yearbook of the Republic of Croatia 2017, Web site: https://www.dzs.hr/Hrv_Eng/ljetopis/2017/sljh2017.pdf (accessed February 5, 2018).

URL 3: Croatian Mountaineering Association, Web site: http://www.hps.hr/info/hrvatski-vrhovi/ (accessed February 5, 2018).

Augmented Reality Display of a Mountainous Region

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Keywords: *augmented reality, terrain, mountains, 3D print, target image, target object*

Augmented reality (AR) is a direct or indirect live view of a physical, real-world environment whose elements are "augmented" by computer-generated information. AR is used to enhance the natural environments or situations. With the help of AR, the information about the surrounding real world of the user becomes interactive and digitally manipulable. Information about the environment and its objects is overlaid on the real world. This information can be virtual or real.

The main topic of the research is development of AR for a mountainous area. AR can be image or object based. The target image can be any raster image with enough distinctive points. A topographic map, a satellite image or an orthophoto image are well suited for such task.

Object based AR relies on a physical object, which can be a 3D print of a mountainous area. Two examples are shown in Fig. 1. A 3D print of a terrain is based on a Digital Elevation Model (DEM). The size of a single print is limited to the capabilities of the printer. However, several pieces can be joined together to form a larger model (Fig. 1, right). A 3D print has to be scanned using a special application in order to use it as a target.

The AR model was built within a development platform Unity with the Vuforia module. Unity was used to align the 3D model to the target image or the target object using scale, rotation and translation. The 3D model is based on the DEM. Fig. 2 depicts aligned 3D model to the image (left) and to the scan of the 3D print (right). After the alignment, an application for mobile

Figure 1: 3D print of mountainous areas

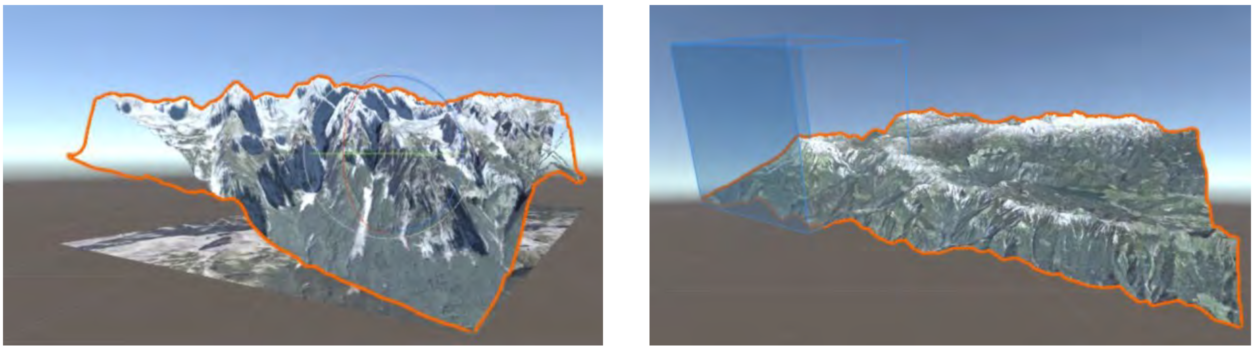

Figure 2: Aligning the models to the targets

devices is generated (APK for android). A tablet or a smartphone is then used to point at the target, to which the mobile application displays the 3D model with a draped image. Various data, such as orthophoto/satellite image, POI, contour lines, land use, topographic map, ridgelines, shading, etc., can be used as an overlay to the 3D model.

Fig. 3 and 4 show some examples of the image based AR and of the object based AR. An orthophoto is used in all cases as an overlay to the AR model, but other data can also be displayed.

Figure 3: A screenshot of the application on a tablet

Figure 4: Examples of the image based AR (left) and of the object based AR (right)

Seafloor Map of the Northeast Canyons and Seamounts Marine National Monument

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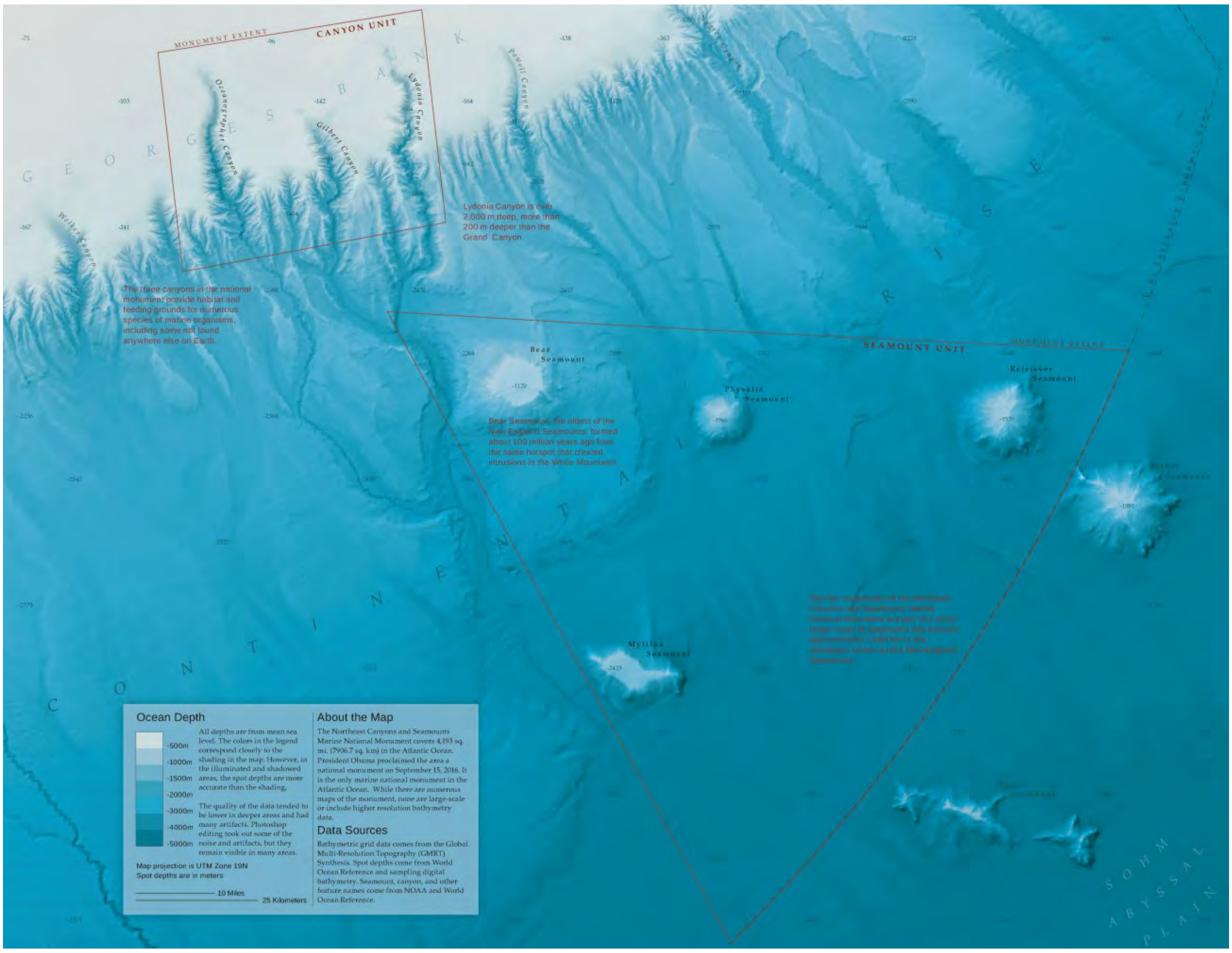
Keywords: *seamounts, canyons, seafloor, relief mapping*

The Northeast Canyons and Seamounts Marine National Monument lies approximately 140 miles east of Cape Cod and is the only U.S. National Monument in the Atlantic Ocean. It is made up of two separate units, a Canyons unit, which includes Oceanographer, Gilbert, and Lydonia canyons, and a Seamounts unit, which includes the four seamounts of the New England Seamount Chain that fall within the United States Exclusive Economic Zone: Bear, Physalia, Retriever, and Mytilus. Together, these two units cover 4,913 square miles (7,906.7 square kilometers) extending from the edge of the continental shelf to the abyssal plain. The wide range of depths of the area within the monument boundaries and the sharp relief of the canyons and seamounts themselves support highly productive and diverse ecosystems.

President Obama designated the area a national monument on September 15, 2016, closing it off to resource extraction and providing protections for the wide array of species that live there, many of which are rare or endangered. While the designation was largely hailed by environmental groups as an important step for



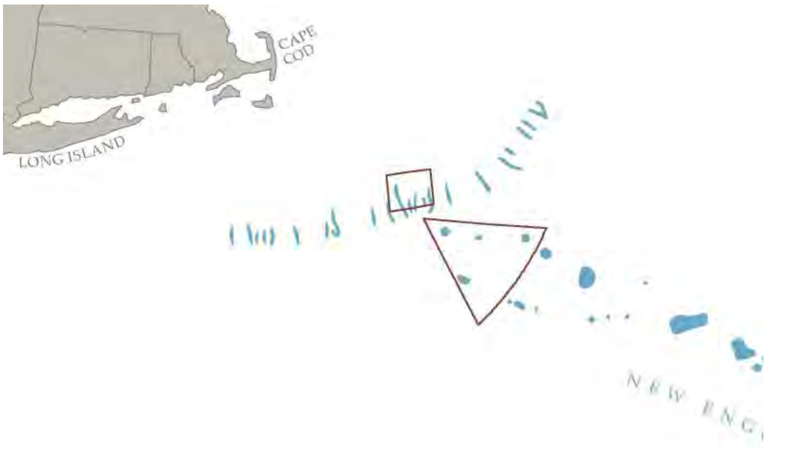
marine conservation, it was opposed by many East Coast fishermen's associations, most notably the Massachusetts Lobstermen's Association, the Atlantic Offshore Lobstermen's Association, the Long Island Commercial Fishing Association, the Rhode Island Fishermen's Alliance, and the Garden State Seafood Association, which together filed a lawsuit challenging the monument's creation. That case was dismissed in April 2018, but the monument remains controversial.

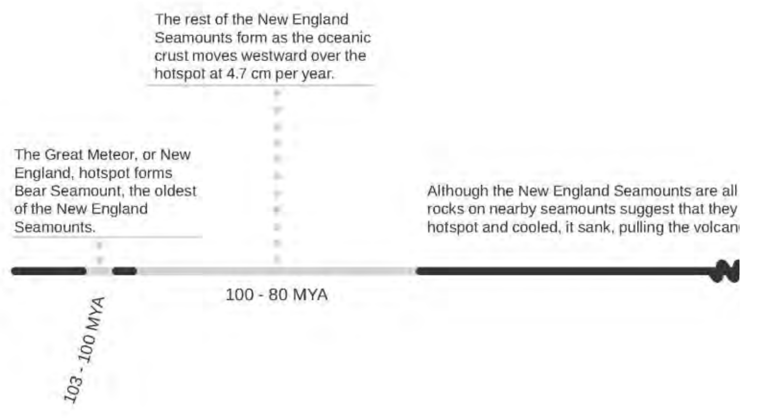
Unlike many national monuments on land, the Northeast Canyons and Seamounts Marine National Monument is not a place that can easily be visited or shown in photographs. Because the monument's most important and most interesting features lie deep below the ocean surface, the most accessible depictions of it are maps and diagrams. However, existing maps of the monument are fairly limited. Most maps of the area merely show the boundaries of the two monument units over an expanse of flat blue ocean. The few that do include seafloor relief, like the official map from the National Oceanic and Atmospheric Administration, are mostly small-scale maps, with coarse resolution, fuzzy relief, or little depth information. A more detailed and clearer to read map would be useful and of interest to the general public, who otherwise have no means of interacting with the monument.

The aim of this poster, which is made up of a large seafloor relief map, a small locator map, and a brief timeline showing key points in the geologic and social history of the area included in the monument, is to fill that void and to serve as an informational guide to area. The inspiration for the project came from a cartography course taught by Professor Jeff Howarth at Middlebury College in the spring of 2018 and from Tom Patterson's "Seafloor Map of Hawai'i". One of the challenges of this specific map was to apply terrain depiction techniques used for mountainous regions on land to this high relief area of seafloor. Specific problems that I encountered were related to data quality and availability and to coloring the terrain in a way that would make it intuitive to read.

Bathymetric grid data for the seafloor map came from the Global Multi-Resolution Topography (GMRT) Synthesis. Spot depths came from World ocean reference and from sampling the digital bathymetry from GMRT. The seamount, canyon, and other feature names came from NOAA and World Ocean Reference. Additional data sources for the map, used to cross check names, depths, and general structures were the Marine Geoscience Data System, hosted by the Lamont-Doherty Earth Observatory of Columbia University, and the General Bathymetric Chart of the Oceans.

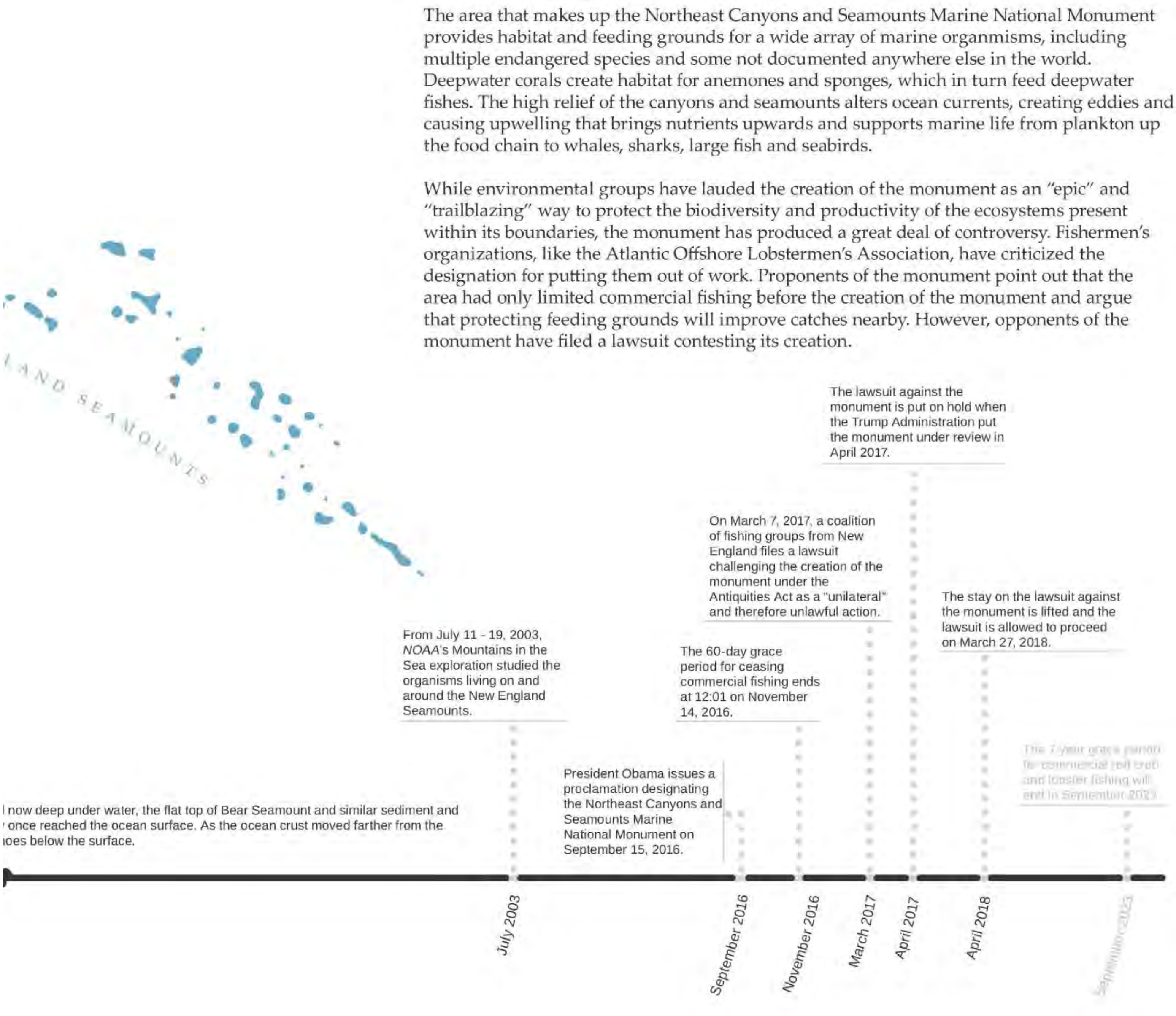
In order to create the relief for the seafloor map, I resampled and reprojected the bathymetric grids from GMRT and created a hillshade in ArcMap. I also used Leland Brown's Texture Shading 1.3 to create an enhanced version of a hillshade from the reprojected, resampled bathymetry. I combined these two images with a colorized version of the bathymetry in Adobe Photoshop and edited the result to get rid of artifacts and to smooth out some areas where there was more noise in the data. Once I finished editing the terrain, I added labels and linework in Adobe Illustrator. I obtained spot depths by extracting points from the bathymetry grid layer





in ArcMap and then overlaying them on the map in Illustrator. The depths are shown as negative values in keeping with Patterson's map, although that means they are not truly depth measurements, but rather elevations.

As noted above, one of the goals of this project was to apply terrain mapping techniques to seafloor maps. I ran into a number of challenges in trying to take a fairly simple workflow for creating shaded relief and adapting it for bathymetric data. Most notably bathymetry data was harder to find, had holes and many artifacts from collection, and was of varying resolution. Because the map is intended for informational purposes, not for navigation, some parts are generalized. However, the shapes of the seafloor structures are unaltered and all depths shown are as accurate as possible.



Web GIS of Mountain Lodges and Homes in Croatia with Control Points of Croatian Mountaineering Tour

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Keywords: *mountaineering portal, control points of Croatian Mountaineering Tour, mountain facilities, web GIS*

Cartography has always had a significant role in many human activities, including hiking. For centuries, analog maps and travel books were the most important sources of numerous positional and descriptive spatial information. Despite the rapid development of technology and information systems, most of the spatial data related to hiking facilities is only available in analogue format (as publications and thematic maps). For example, attribute (descriptive) information about hiking tours and access trails were found in hiking books, guides and diaries while the visualizations of those tracks were published on classic (printed) maps.

With the development of the information technology and Global navigation satellite systems (GNSS), especially laptops, smartphones, handheld (mobile) GNSS devices and the ubiquitous Internet, it became easier to collect, store, visualize and share such spatial data in the form of GNSS traces of hiking trails and position of mountaineering facilities. Today, most of the hikers and hiking clubs have detailed information and digital records of hiking tracks in GPX format. However, for hikers it's usually not enough just to have access to a specific GNSS trace of a hiking tour. The needs of hikers planning excursions often go beyond just needing access to information about a particular GNSS trace of a hiking trail. Besides a GNSS trace, it's quite useful to also have spatial and attribute information about mountain facilities (lodges / homes / shelters), while for the hikers of the Croatian Mountaineering Tour (CMT) it is useful to have information about the biggest and most beautiful tours with all control points. With development of a web GIS application, it is possible to merge all those data within a single system that can provide an easy way to view, search and exchange such data through the interactive web interface.

The idea was to develop a complete web GIS portal that would include all important information about hiking facilities in Croatia, mountain access trails and control points of CMT (checkpoints of the Croatian Mountaineering Tour). Visitors to such a portal would be able to view, visualize and analyse the data, while registered users would also have additional interaction controls such as adding comments about a specific facility or checkpoint, providing ratings and reviews of interactive map content, but also uploading and sharing their own GNSS traces. In that way, registered users would contribute to the portal with their inputs about the condition of various hiking facilities, checkpoints, trails, path markers, etc. Actually, they would be directly involved in creating the content of the application—crowdsource data.

Crowdsourcing is the new paradigm for collecting data using devices (sensors) that are nowadays available for most people. In most cases, those devices are mobile phones that could also be used to determine the location of the device and its user; we can define this approach as Volunteered Geographic Information (VGI). All of this leads to a new locational based service that supplements traditional cartographic methods.

With that in mind, the Faculty of Geodesy (University of Zagreb) has developed a web GIS application Hiking portal (URL 1) (Figure 1) with interactive map visualization and with the additional controls for various spatial queries over hiking facilities and control points (Pašić 2014).

Multiple technologies have been used for the development of the application. The server side of the application (backend) was mostly written using the Python programming language and Django as a Python's web framework, and the data is stored using a PostgreSQL database with the spatial extension PostGIS. The client side of the application (frontend) was developed using HTML5, CSS3 and JavaScript (JS) with several additional JS libraries, such as LeafletJS. LeafletJS is an open-source

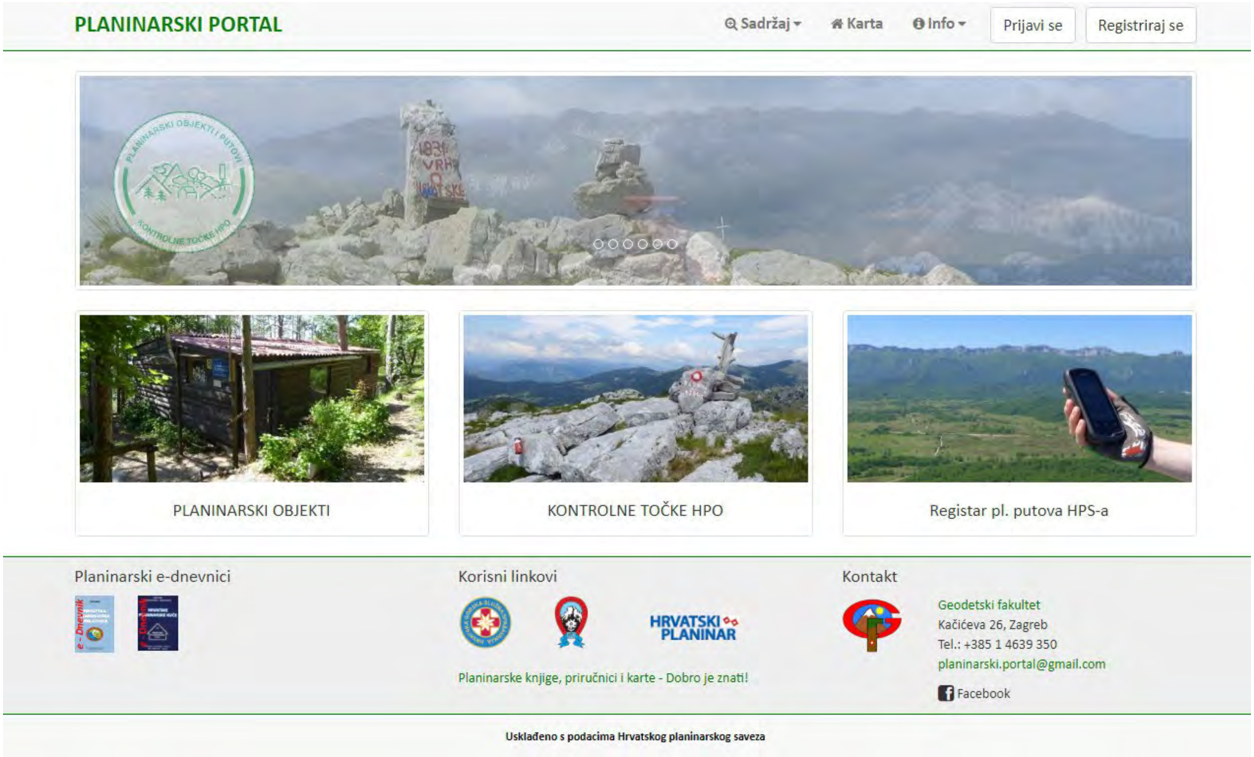

Figure 1: FrontPage of Hiking portal (URL 1)

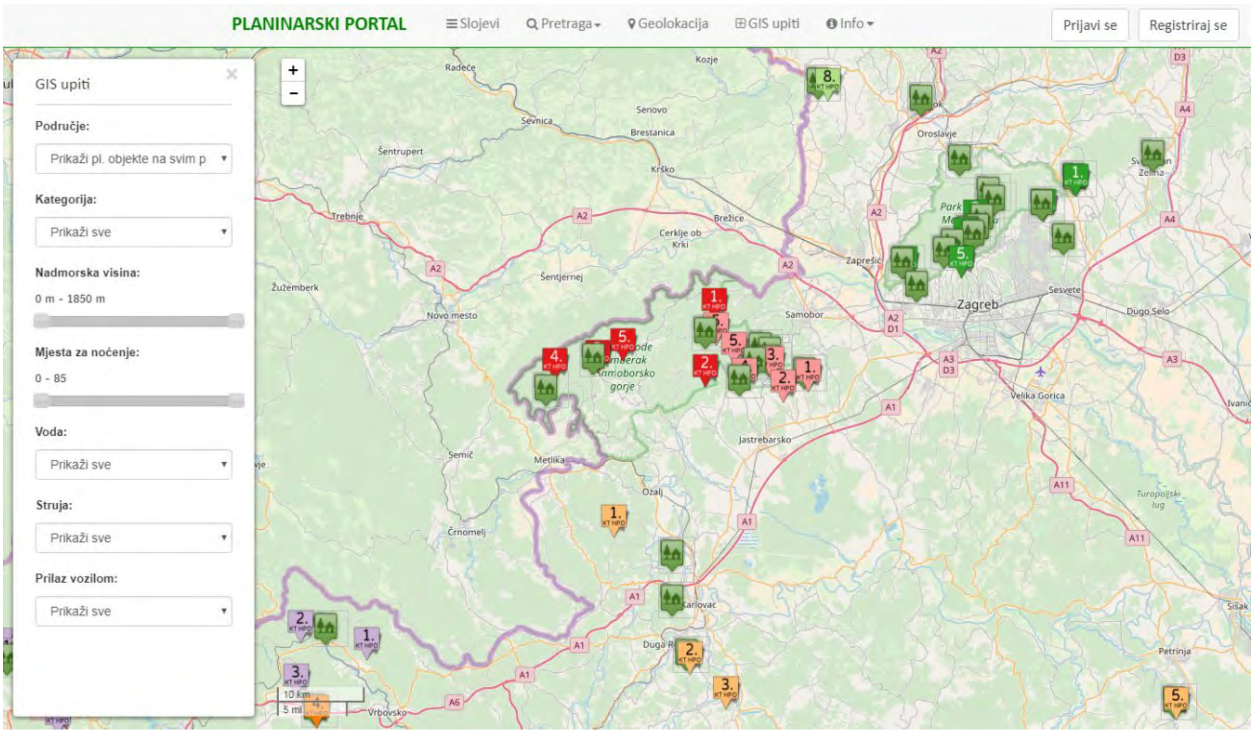

Figure 2: GIS functionalities of Hiking portal

JavaScript library used to build interactive web maps. The application was deployed to the Virtual Private Server (VPS) that has Ubuntu 14.04 as an operating system. The application is served using application server (Gunicorn) on a defined port and web server (Nginx), which in this case is mostly used for serving static files.

There are multiple GIS functionalities within the portal. The user can simply execute various spatial and attribute queries to easily get and filter information

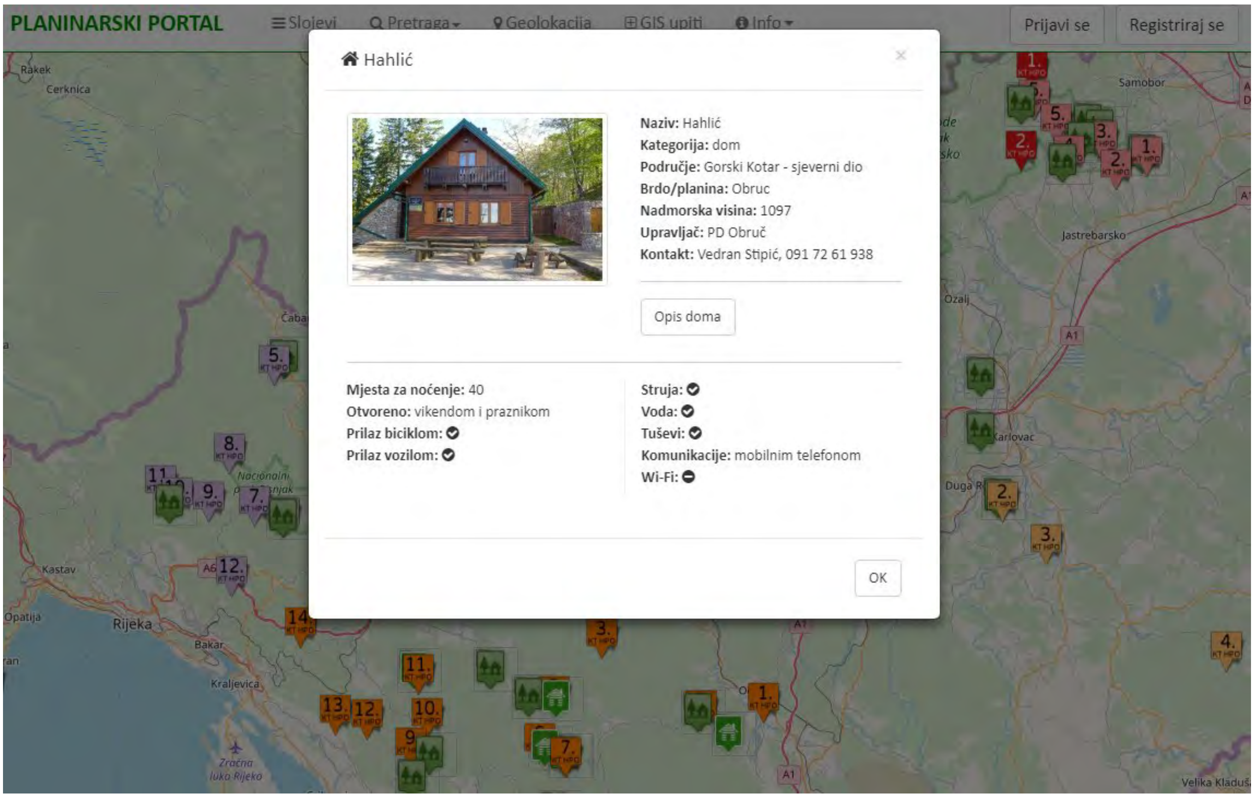

Figure 3: Basic information about hiking object

about hiking facilities in the area of the interest (Figure 2). One layer has data about hiking facilities while another one is used to display control points of CMT.

When hovering the mouse over the icon (marker) of each hiking object, the user can see basic information about that object, while clicking on icon and choosing Opis doma (description of the object) gives the user a more detailed description, contact information, information about the infrastructure, the number of sleeping rooms and beds, etc. (Figure 3). Below this information is also a photo gallery with illustrations of the interior and exterior of the facility.

The same approach is used for another layer where by hovering or clicking on the icon of the control point, the user can see information about the point as well as detailed description with photo galleries. Besides that, the application also provides a set of other tools, including those for measuring distances and areas on the map as well as for determining the user's location (geolocation) using the GPS sensor of the mobile device or triangulation based on mobile network signals. For better terrain representation, there are also multiple base maps that user can select. Besides standard web maps such as OpenStreetMap, GoogleMaps, etc., the user can select additional maps from the State Geodetic Administration (DOF, TK25) and also thematic maps, including HikeBikeMap, OpenTopoMap, etc. It is important to note that an interactive web interface has responsive design so it can easily be used also on smaller devices such as smartphones, tablets, etc.

An additional value of the portal are the numerous and reliable up-to-date entries about hiking facilities, control points and GNSS traces. To give an example, presently on the portal the user can find basic information about 160 hiking facilities with more than 1000 photos and around 100 GNSS traces in gpx format. The database of the web application is constantly updating with new entries and it is one of the most complete thematic databases on the Croatian mountaineering web.

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Automated Generation of Additional Contours to Enhance Contoured Relief Representation

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Keywords: *contours, algorithms, relief representation*

Relief representation by contours follows the height levels selected manually or using the automated classification of elevation data. However, it is impossible to capture all terrain features by a fixed number of height levels. Many surface forms are hidden between contours. There are geomorphological zones that are subject to high probability of such cases. The situation is typical for the foot of the mountains, where the steep slopes are adjacent to the flat planes. Topographic maps use arithmetic progression of height levels, which cannot represent both regions equally vividly without clutter or emptiness. Another common example is the representation of a flood plain, which is characterized by numerous subtle features between the main contours. The solution to the problem is to use additional contours. Additional contours are usually depicted by dashed lines and are drawn in areas with large distances between standard contours at the intermediate height. Additional contours are an essential element of terrain depiction and they are used by national mapping agencies on map series at all scales. Despite the relevance and expressive power of this graphical technique, no algorithms for the automated creation of additional contours have been developed to date, which was the motivation for launching this study.

We have developed automated approach for the generation of additional contours to enhance the representation of relief where the distances between main contours are excessively large.

The entire algorithm can be divided into several stages. At the first stage, the main contours are constructed with a given (constant or variable) height progression. Then an auxiliary raster surface is constructed, in each cell of which the approximate distance between the main contours is estimated. This is the trickiest part of the workflow, since the width of a zone between lines could be estimated in numerous ways. We have implemented and tested the following options for solving this task:

1. Using Euclidean distance from pixel to the nearest contour;
2. Using the sum of Euclidean distances from pixel to the nearest two contours;
3. Using the Delaunay triangulation of contours (triangle altitude is used as an approximation of zone width, all pixels inside triangle have the same width value then);
4. Using the slope angle at the pixel;
5. Using the maximum between 2 and 3.

Experimental work shows that the best and the most stable way to estimate the local width of a zone is the second case, in which the sum of the distances to the nearest two contour lines is calculated.

After the width surface is constructed, a series of intermediate contours are derived between the main contours (height progression is shifted by the half of the height step). Each node of the additional contour is enriched with a local zone width value interpolated from the width surface. By setting the threshold width, one then can then filter the nodes of additional contours, leaving only those that are located in areas of significant width (exceeding a specified threshold value). Initially this was the last stage of the processing workflow, since it is possible to reconstruct the additional contours from the remaining points after filtering.

However, natural variation in the width of the zone often leads to generation of short gaps between segments of a single additional contour, or generation of excessively short segments. In order to eliminate such artefacts, the processing workflow includes additional tolerances for the minimum allowable gap between segments of a single additional contour line and the minimum allowable length of the segment itself. Therefore, after filtering the nodes, short spaces are first

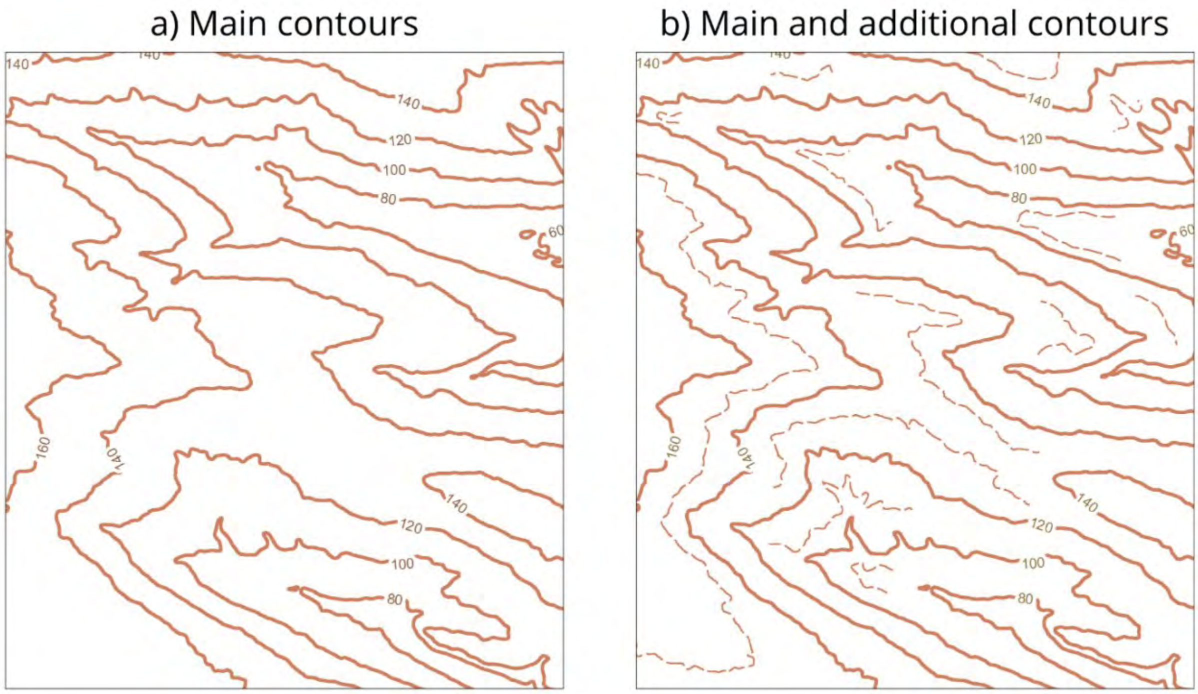

Figure 1: Enhancing contour relief representation by additional contours

filled (their points are returned to additional contours), which leads to an increase in the length of the additional contour segments. After that, the segments which are still shorter than the defined tolerance, are excluded from the resulting set of additional contours.

An example image obtained using the developed approach is shown in Figure 1. Main contours are represented on the left side of the figure (a), while the right side shows the same image with empty areas filled by additional contours. The image becomes more informative and reveals many additional terrain features without overcrowding the representation.

The developed processing approach is simple and allows for the automated generation of additional contours. However, obtaining the high-quality results requires experimenting with the algorithm parameters (the minimum width of the zone, the length of the segment and the length of the gap), taking into account the morphological features of the relief and the selected height progression of the main contours. The result of this experimentation on various terrains can be used to derive the optimal automatic parameterization of the algorithm, which is the subject of ongoing research.

Mapping New Zealand's Alpine Fault

Roger SMITH
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Keywords: *geomorphology, tectonics, mapping, faulting*

Christchurch earthquake – February 2011

Anyone who lives in New Zealand is familiar with earthquakes. We average around 20,000/year though only around 250 of these are big enough to be felt.

Recently though we experienced two events that made us sit up and take more notice.

First there was Christchurch, our second largest city. In September 2010 it was hit by a 7.1 magnitude earthquake. The earthquake was not directly on the Alpine Fault but on a small, previously unmapped fault line. There was considerable damage to Christchurch but no loss of life, probably because it happened in the early hours of the morning when the streets were empty.

Nearly six months later in February 2011, Christchurch was hit by a second, smaller 6.3 magnitude earthquake that struck in the middle of the day.

The second earthquake was centred on yet another unmapped fault line, close to the city centre and very shallow at only 5km deep. The rupture was underground, never reaching the surface. There are extensive alluvial gravels on the Canterbury Plains where Christchurch is located and they are thick, up to 500m deep in places.

Nonetheless, the results were catastrophic with widespread liquefaction, severe damage to property and infrastructure, 185 people dead and several thousand injured. Peak Ground Acceleration (PGA) was extreme in both the vertical and horizontal planes – over 1000 commercial buildings in the CBD and more than 10,000 homes were either destroyed or subsequently demolished. The total cost of this earthquake (and we are still counting) was somewhere between 40 and 50 billion dollars.

The second major event centred on Kaikoura, 120km north of Christchurch.

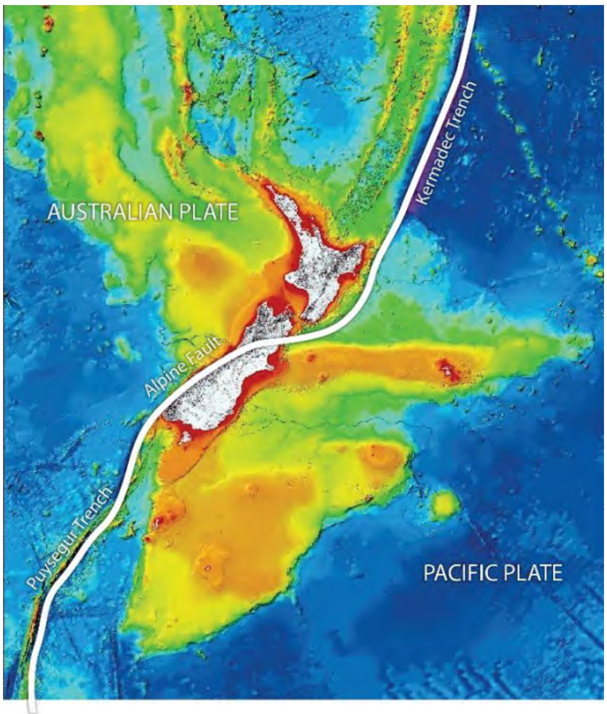
A 7.8 magnitude earthquake struck in November 2016, causing widespread damage along the sparsely populated Kaikoura coastline and adjacent inland rural areas.

The initial rupture triggered a 2 minute long sequence, with 21 different faultlines rupturing along a 180 km line trending east of north up toward Wellington. Many of these faultlines had not been previously mapped. Ground displacement was up to 12 metres in places, there was extensive coastal uplift and the distance across Cook Strait was supposedly shortened by 2 metres. The economic damage was extensive. Road and rail access up the east coast was cut and remains restricted today, despite ongoing remedial work costing up to $65 million/month. The damage extended to Wellington, the capital city. Several tower blocks were damaged beyond repair, land in parts of the port area subsided by up to half a metre and the container cranes jumped their rails, necessitating closure of the container port for 10 months.

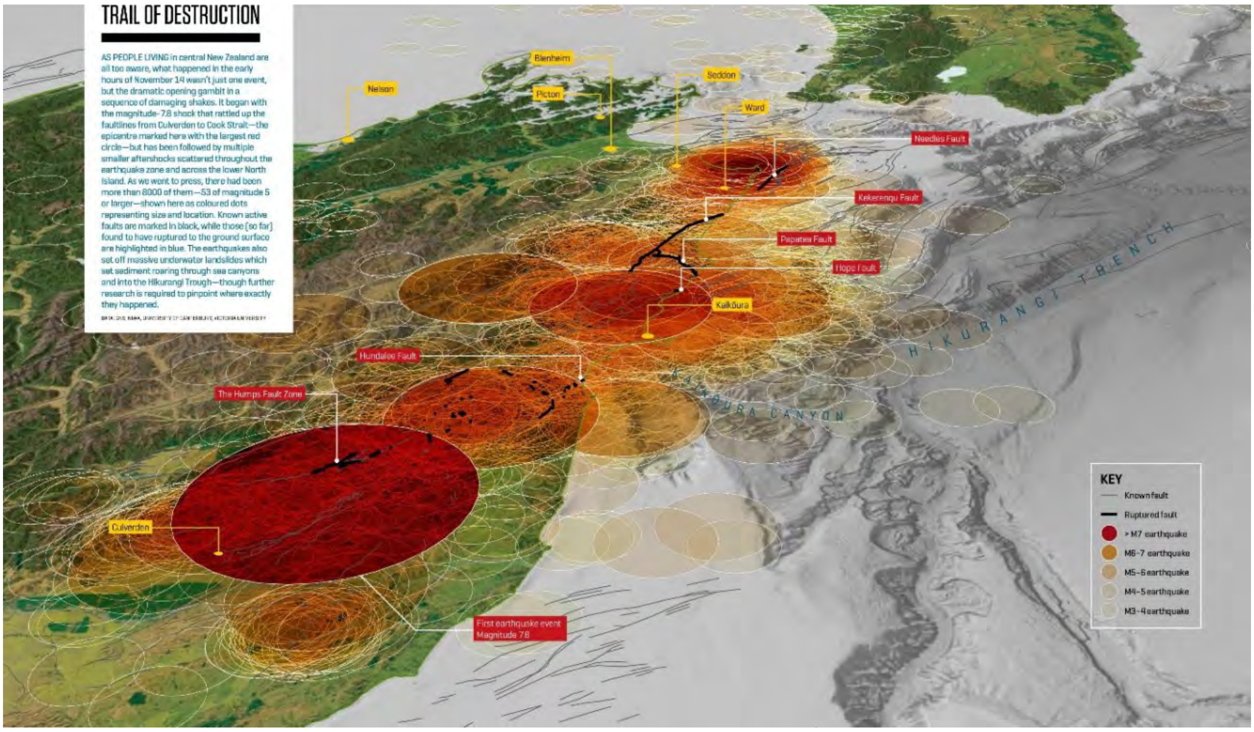
The two events described above were centred on secondary faultlines. However they served to focus thinking on the risk posed by New Zealand's major tectonic feature, the Alpine Fault.

One of many fault scarps – Kaikoura 2016

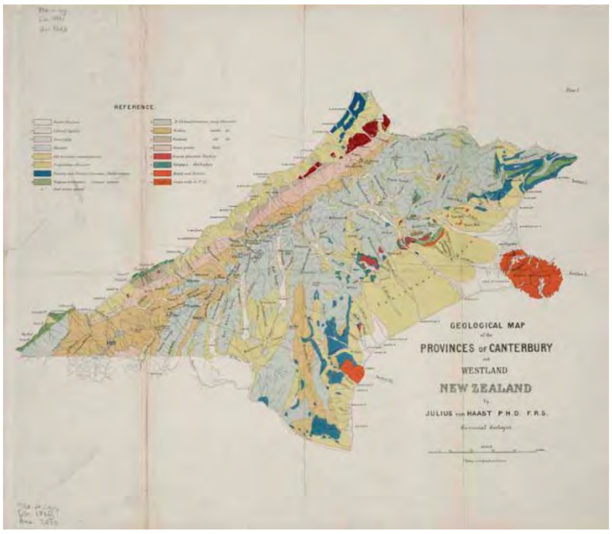
Kaikoura Earthquake 2016



Until quite recently we knew little about the Faultline.



Geographx map showing the 8000 aftershocks experienced in the fortnight immediately following the Kaikoura 2016 earthquake.



This geological map of part of the South Island was drawn by Julius von Haast in or around 1866. The Alpine fault runs parallel to the west coast, centre left to centre top of the graphic. As was customary at the time, the boundaries between different lithologies or rock types are mapped but fault lines don't appear –there was no understanding of plate tectonics at that time.

It is similar here with this more detailed topographic map by explorer Charlie Douglas, based on fieldwork he carried out in the 1880s and 1890s. The Alpine fault runs horizontally along the top of the blue band, its position obvious to us now but not recognised by Douglas himself.

If the Christchurch and Kaikoura earthquakes can cause so much trouble, what is going to happen when the "big one" hits.

The Alpine fault is supposedly just one of three places on Earth where a tectonic plate boundary is exposed and accessible at the earth's surface. It runs uninterrupted for 600km on a southwest-northeast axis along the western edge of New Zealand's Southern Alps. Recent oceanographic work has shown that the fault actually continues on for several hundred kilometres south of New Zealand. It marks the boundary between the Australian plate to the west and the much larger Pacific plate to the east.

Even when the NZ Geological Survey started systematic geological mapping in 1905, the Alpine Fault was not initially recognised. Part of the problem was that mapping focused on clearly defined areas called subdivisions, and geologists were discouraged from looking further afield. While part of the fault was mapped in 1908 (the Mikonui subdivision near Hokitika) there was no recognition that it might be part of a much larger feature.

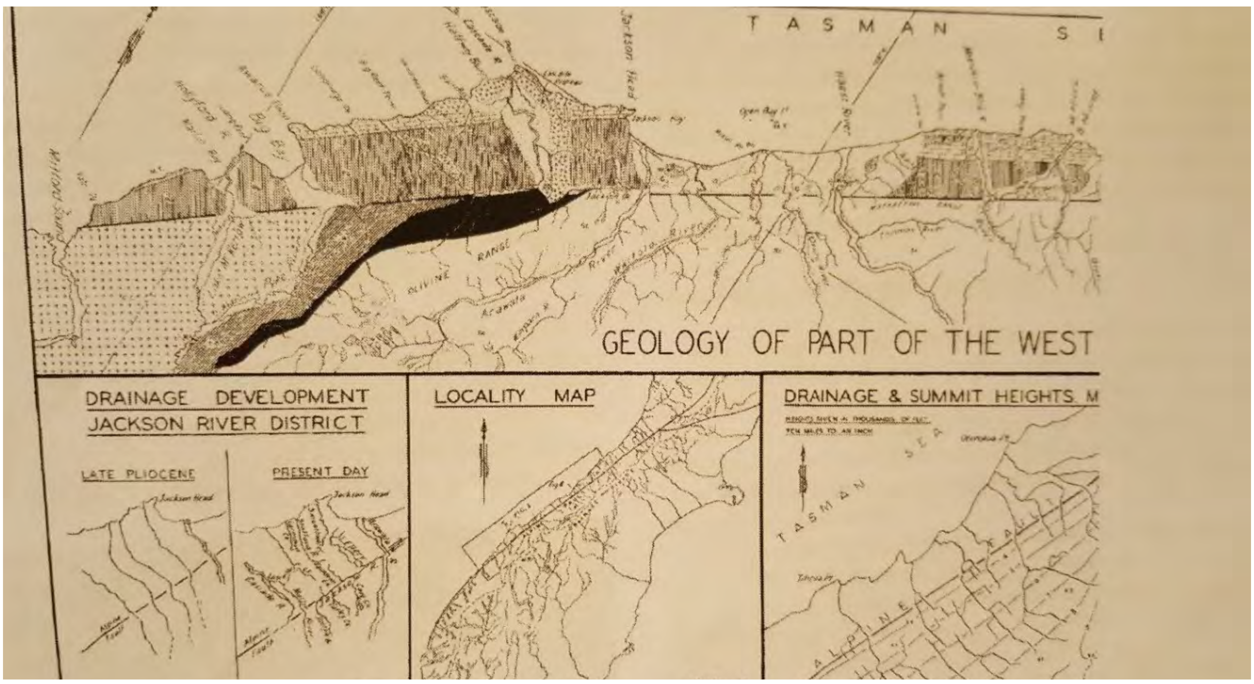
The Alpine Fault wasn't acknowledged or described as such until 1941 when a relatively inexperienced geologist called Harold Wellman was tasked with travelling down to South Westland to check out possible mica deposits. Mica was then in short supply for building radios as part of the war effort. As part of his brief Wellman was instructed to keep his eyes open and report on the structural geology of the area as he saw it.

Wellman did have an acknowledged ability to read geology from the landscape, having trained under Charles Cotton at Victoria University in Wellington. Cotton was a pioneer in recognising that most landscapes reflect tectonic and climatic influences and was well known for drawing distinctive sketchmaps to communicate his understanding. One could say that Cotton was to Geomorphology what Imhof was to Cartography.

As Wellman travelled down the West Coast, he recognised he was following a single linear fault line separating the granite to the northwest from the greywackes and schistose rocks of the Southern Alps. Once the road ran out, he and his companion Dick Willett (later Director of the NZGS) continued on foot, tracing the fault (which they were now calling the Alpine Fault) all the way down to Lake McKerrow, just short of where it cuts the coast and continues southwards into the Southern Ocean.

Wellman wrote his report and the first paper describing the Alpine Fault was submitted for publication just five weeks after his return to civilisation. This has been described as one of the classics of NZ geology, it was accompanied by a hand drawn geological map at a scale of ten miles to the inch.

Wellman proposed a major geological reinterpretation and his conclusions were immediately accepted



with one exception. Wellman noted that many rivers crossing the Alpine Fault showed consistent offsetting of about a mile, and he cited this as evidence of lateral offsetting. This idea was rejected because current thinking of the time did not recognise horizontal strike-slip movement along fault lines.

Wellman was not yet finished. Next he noticed that ultramafic rocks in the Nelson area on the west side of the fault had an uncanny resemblance to rocks 480 km further south on the east side of the fault.

Forward to 1949 and the Pacific Science Congress, a major event with geologists attending from around the Pacific. Amongst them were Gutenberg and Richter, two highly regarded seismologists from the United States. The profession at that time was still skeptical about horizontal strike-slip movement along fault lines, so there was some commotion when Wellman presented and dramatically put forward his evidence for a 480 km offset on the Alpine Fault. The idea was hotly debated for a decade, and it wasn't until the 1960s that the 480km offset became widely accepted.

Wellman next began investigating the rate at which the Alpine Fault had moved. Conventional thinking assumed that any movement must have occurred over hundreds of million years. However the analysis of offset river terraces soon proved otherwise. By studying sites where the fault line cut across rivers, it was apparent that the older terraces showed bigger offsets than the newer terraces. Wellman calculated that the entire 480km horizontal displacement had occurred within the past 20 million years, giving an average lateral movement of up to 25mm/year.

In the late 1960s the theory of plate tectonics took hold. It was recognised that the Alpine Fault formed a boundary between the Australian and Pacific Plates, and that tectonic activity along this boundary was responsible for the uplift that had formed the Southern Alps. For the first time geologists started to think seriously about structural geology at depth and how the stress between colliding plates could be relieved. Not only could a collision cause the subduction of one plate and the uplifting of another, stress could also be relieved by the plates sliding along each other, and to a much greater degree than previously thought.

Researchers next began to study old landslide debris, looking for organic material that could be accurately dated. They also took core samples from older living trees to determine whether and when there had been significant breaks in the growth ring pattern – breaks that might signify significant historic earthquake events on the Alpine Fault. At least 24 such events have been identified over the past 8000 years. It is now believed that the Alpine fault is prone to rupturing at regular intervals, and that when it does it ruptures in a big way. The average return period is 291 years, The last major rupture event has been dated to 1717 so we are already overdue for the next "big one".

The latest evidence suggests that the lateral offset may be even greater than previously realised. That the Alpine Fault slid laterally for 220k in the opposite direction before starting its current movement where the Australian plate moves north. This means that the offset generated over the past 20 odd million years is not 480km but 700km, with an average annual slide of 3cm per annum.

The Deep Fault Drilling Programme (DFDP)

Since 2011, there has been a concerted scientific effort to better understand the geometry and processes beneath the Alpine Fault.

The Deep Fault Drilling Program (DFDP) drilled its first pilot hole that year and reached a depth of around 700m before disaster struck (concrete poured to stabilise the casing instead found its way into the actual drillhole). The final depth was reduced to more like 350m and very little seismic imaging was possible. However a second phase, DFDP2 is now underway which aims to drill to a depth of 1300m. This is supported by international partners from Canada, the USA, France, Germany, Japan and the UK.

An emergency management initiative, Project AF8, is also now planning ahead for the 'big one'.

This assumes a magnitude 8.2 earthquake centred near Haast, a remote village in South Westland. It anticipates rupturing of the Alpine Fault with 10m displacement over a 400km length, with a modified Mecali Intensity scale of MM9.9 to MM10. The total energy released is expected to be up to 700x that of the 2011 Christchurch event. Luckily most of this will be spread across isolated areas with low population density. One notable exception is the small tourism town on Franz Josef, where the Alpine Fault runs through the middle of town.

The Magic of LiDAR and Satellite Images to Show Alpine Glacier Retreat

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Keywords: *geomorphology, tectonics, mapping, faulting*

Alpine glaciers in Canada and around the world have retreated (area) and downwasted (elevation) at an increasing rate over the last 30 years. It is impractical for national mapping agencies to monitor and update glacier extents and topography, so these often remain out of date by some decades. The glaciers are mostly in remote locations, so knowledge of their current condition is restricted to selected visitors, such as mountaineers and cryospheric scientists. However, there is an increasing volume of satellite imagery and digital elevation data which can enable more regular mapping of changes in glacier extents and elevations.

Individual glaciers can be manually digitised from satellite imagery, ideally using a Mid-IR/Near-IR/Red colour composite, but extensive glacier areas more often utilise 'semi-automatic' identification by thresholding a red/Mid-IR ratio channel which enhances the contrast between high reflection in the visible wavelengths versus low mid-IR reflectance for glacier and snow surfaces (e.g. Bolch et al. 2010). This is illustrated for the Carstenz Pyramid / Puncak Jaya area in western Papua / Indonesia where remnant glaciers have lost 87% of their area (and volume) in the last 25 years decreasing from 3.4 to 0.4 km2, and are likely to disappear completely in the next few years. The equatorial location with high sun angle involves minimal interpretation issues with shadow and debris covered ice (figure 1).

In this study, the glaciers selected were those geographically closest (~100km to the northwest) to our city of Prince George (British Columbia, Canada), but they are difficult to access, located next to Monkman Provincial Park, and the Tumbler Ridge Global Geopark, the only one in western North America. Data sources include imagery from Landsat 5 / 8, along with global elevation data and more recent LiDAR data.

The glaciers and park are on the western edge of the Canadian Rocky Mountains (figure 2). In the foreground, the Parsnip River flows from the Parsnip Glacier into the MacGregor River, a tributary of the Fraser River. The Red/Mid-IR ratio applied to Landsat images from 1989 and 2014 revealed an area change of 50.89 to 40.76 km2, a loss of 20% or an average rate of 0.8% per year. The updated glacier extents can be used for local mapping and visualisation.

Glacier loss can be measured by area retreat as evident on satellite image sequences and also by vertical downwasting using multiple digital elevation models, which may be available as local or global datasets. The latter include the ASTER GDEM, SRTM DEM and ALOS DEM. The ALOS (Advanced Land Observing Satellite) is the most recent, first made available in 2015 and generated from RADAR data 2006-11. In addition, we acquired a high resolution LiDAR dataset from summer

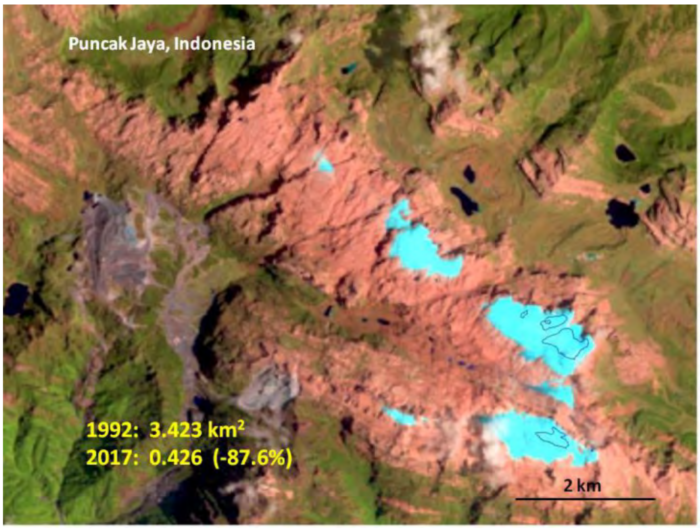


Figure 1: Landsat image 1992, Puncak Jaya, Indonesia, with glacier extents 2017 overlain in blue vectors

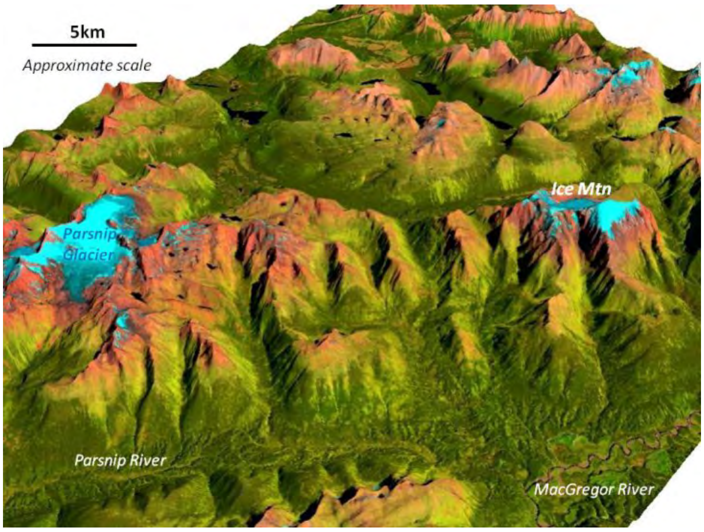


Figure 2: Perspective view from southwest of Monkman Park glaciers; Landsat 2014 image.

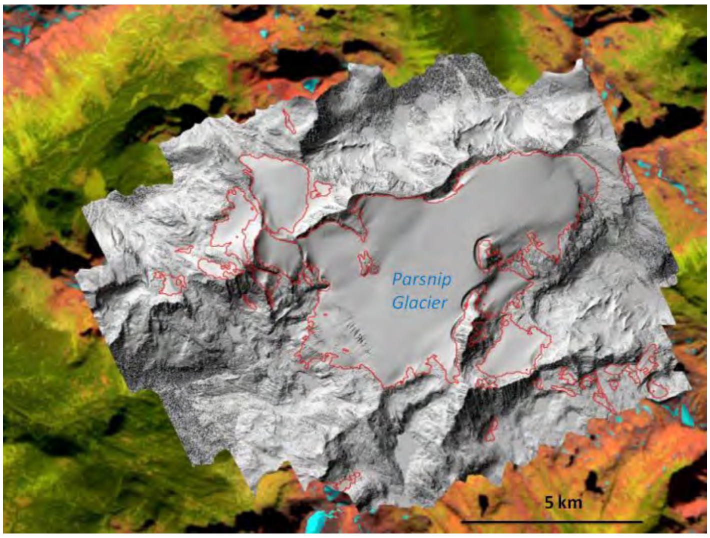
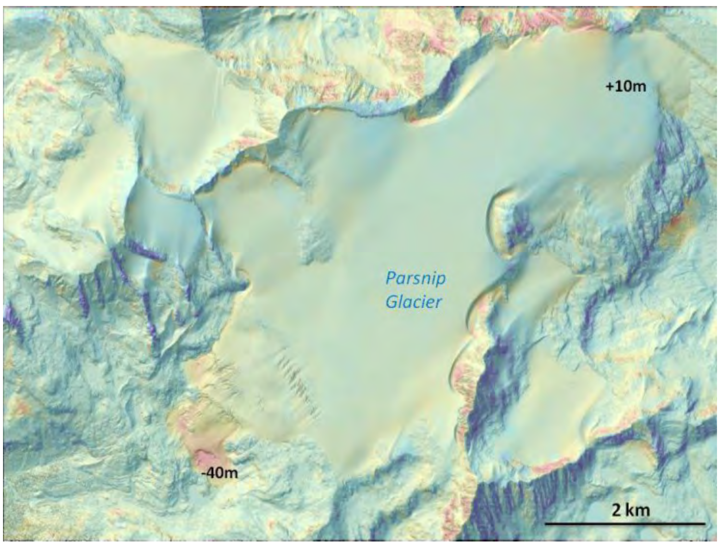


Figure 3: LiDAR shaded relief for Parsnip Glacier overlain on Landsat 2014 image.



2017, processed to generate an elevation model with 1 metre resolution pixels, and subsequent shaded relief model (figure 3). This DEM can also be used to generate more current contour lines for the glacier surface, which can be depicted in blue to contrast with standard brown contour lines on non-ice surfaces.

Subtracting these two layers (LiDAR – ALOS) creates a layer of elevation change for the time interval, which is interpreted to vary from 6-12 years based on the ALOS temporal range. Thus the highest values of 40 metre loss at the snout represent an average of 3-6 m per year (figure 4). The slight apparent increases or accumulation of snow/ice in the upper glacier elevations may be discounted because RADAR involves some energy penetration of snow surfaces, yielding reduced elevations in the earlier DEM and thus a degree of bias in the results. Apparent elevation change for non-ice locations suggest errors which can be reduced or removed through the co-registration process developed by Nuth and Kääb (2011).

This work is ongoing requiring further investigation of additional elevation layers including the National Topographic System (NTS) data from the 1980s and SRTM data (2000). We will examine methods to display both the changing area extents and ice elevations in a series of maps, perspective views and animations, to be shared with the Geopark community.

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Figure 4: Parsnip Glacier: LiDAR (2017) minus ALOS (~2010) DEM; maximum ice elevation loss = 40 metres

Abstracts

Mapping for Outdoor Activities in Mountains

Proceedings of the 11th ICA Mountain Cartography Workshop
May 21 – 25, 2018, Hvar, Croatia


Areal Mapping of the Ice Thickness of the World's Biggest Ice Cave

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Abstract. The Eisriesenwelt Cave in the Tennen Mountain Massif, above the village of Werfen, ca. 55 km south of the city of Salzburg, is the biggest ice cave on earth and one of the top-ten touristic sights of Austria. After a series of biannual laser-scanning surveys of its ice-covered part carried out by the Institute for Cartography of Dresden University of Technology, the owners of the cave asked the prime author if an areal survey of the rockbed below the ice would be possible. Hence, from 20th to 23rd April 2017 a field campaign using a ground penetrating radar (GPR) instrument was carried out. By means of this non-invasive method a series of 143 profiles over the whole ice-covered part of the cave have been completed. They cover the entire more than one kilometer long ice part of the Eisriesenwelt.

For the raw GPR data multiple signal pre-processing steps were conducted to enhance the ice-rock boundary, including dewow filtering, time-zero correction, gain functioning, and trace editing. Dewow filtering eliminates the so-called "wow" effect which causes signal biases in the low-frequency domain. This first step of signal pre-processing improves raw data accuracy. Then the "time-zero" of the temporal domain of the dewow-filtered reflected radar signals needed to be corrected: the corrected time-zero was set to 18 nanoseconds to eliminate the reflection echo from ice surface and radar shell. To further enhance the resolving power of subject amplitude-differences, gain functions were used. During the hand-dragging of the GPR antenna over the ice surface occasionally incidental stops occurred, resulting in the collection of redundant traces. Hence, in a last step, trace editing, was performed in order to get rid of these data redundancies by deleting repeating traces.

Like in all directions, also vertically, radar signals propagate in the temporal domain. To convert the propagation time into the depth domain and for the spatial correction of the reflection signal, GPR data migration based on velocity modelling was applied. Using the information of electron-magnetic propagation velocities in the cave-ice, determined during previous investigations to amount to 0.167 m/ns, a velocity model can be built for data migration. This resulted in a recorded maximum ice-thickness of 20.2 m in the so-called Odin's Hall. At two separate spots the measured GPR values could be validated by earlier drill-hole depths.

Along the profiles, sets of feature points containing ice-depth information were extracted with a quasi-equidistance method for further interpolation. Empirical Kriging was chosen to interpolate the final ice-thickness distribution. By interpolating the results using the Empirical Kriging method, a contour-line map of the ice thickness with 2 m and locally one and even 0.5 m intervals was generated. In addition, five detailed-scale maps sheets were prepared and the actual ice volume calculated. The latter will be described in an upcoming journal paper.

In contrast to overground glacier-thickness displays, the ice thickness was not only measured perpendicular to the ice surface (rather than in vertical direction) but also cartographically depicted this way, thus – so-to-speak – displaying the local thickness of the "ice coating". – By bringing both the surface laserscan-data and the rock-bed data into the same geometric reference system, the ice volume of the Eisriesenwelt can be calculated, thus delivering a valuable proxy for future palaeoclimate archives. Globally, the whole undertaking was the first-ever areal ice-thickness mapping in a cave.

Keywords: *ice cave, ground-penetrating radar, ice-thickness mapping, Eisriesenwelt*

The Map of the Upper Mara Valley

A Storytelling Map

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Abstract. Storytelling maps are increasingly popular among educators and marketers as they offer incentives of otherwise intangible places or services. That is why, a tangible object – the printed map is mediating the process of storytelling. This particular map is designed to enhance tourists' experience during outdoor activities in a mountain area with relatively accessible infrastructure and scenic physical features: Mara Valley and Creasta Cocosului (Maramures, Romania). The main research questions revolve around the experience design. The research is based on designing and testing a specific storytelling map in experiential mountain tourism. Therefore, the main stages of development are the experience design and the map. Focusing on a complex geographic locale featuring volcanic relief and rich heroic narratives, it tells the story of the mountain by tracing a parallel between the geological features and a national legend. Multimedia files were incorporated in order to facilitate the process. The map scale is 1:10000 printing on a 50x70cm sheet. There is also an online version.

Keywords: *storytelling map, experiential, Maramures*

Panta Rhei: Movement Change of Tschadinhorn Rock Glacier (Hohe Tauern Range, Austria) for the Time Period 1954-2017

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Abstract. In this paper we present the reconstruction of the kinematics of the Tschadinhorn rock glacier using multi-temporal conventional (metric) aerial photographs (1954-2015) and additional non-metric aerial photographs (2016, 2017) taken with in-house unmanned aerial vehicles (UAVs). A rotary-wing aircraft (hexacopter twinHEX v.3.0) was used in 2016 and a fixed-wing aircraft (QuestUAV) in 2017. The historical image data was acquired from the Austrian Federal Office of Metrology and Surveying (BEV). Both a digital orthophoto (DOP) and a digital terrain model (DTM) were computed for each given epoch. Precise georeferencing of the image data was carried out in the Austrian Gauss-Krüger M31 coordinate system using available aerotriangulations (ATs) of BEV and additional ground control points (GCPs) measured geodetically during both UAV campaigns. Change detection analysis provided multi-temporal 2D flow velocity fields. Subsequently, these data were aggregated to come up with a simpler velocity graph showing clearly the temporal evolution of the flow velocity of Tschadinhorn rock glacier: A maximum mean annual flow velocity of 3.28 m/year was obtained for 2014-2015, whereas the lowest annual flow velocity of 0.16 m/year was observed for 1969-1974. The velocity graph obtained also reveals that the time span 1954-2009 is characterized by generally moderate activity (0.16 - 0.79 m/year) and that much higher flow velocities prevail from 2009. The present value for 2016-2017 is 1.92 m/year.

Keywords: *permafrost, rock glacier, flow velocity, photogrammetry, UAV, environmental change, Tschadinhorn*

Using Normal Offsets to Smooth Terrain Models

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Abstract. Digital elevation models allow for efficient display and analysis of 2.5-dimensional terrain surfaces. They can be smoothed with procedures that typically vary the z-values of grid cells in the elevation model. This presentation proposes an alternative method for generalizing DEMs that varies elevation values in the surface normal direction. These normal offsets can be applied above or below the original surface, and results can be combined for desired effects. Offsets above and below the surface tend to expand major features in the x,y direction that have concave downward (e.g. hills and ridges) and upward (e.g. valleys and drainages) curvature, respectively. Additionally, minor features such as bumps or pits tend to get smoothed over on the new surfaces. The resulting DEM can be used to create various generalized cartographic products, such as smoothed contour lines or shaded relief maps with widened valleys that provides additional map area for displaying other cartographic features.

Keywords: *terrain, smoothing, generalization, digital elevation models, DEMs*

Possibilities of Mapping and Spatial Analysis of Hilly and Mountainous Areas of the Island of Hvar through Elective High School Teaching

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Abstract. The co-operation of educational and development institutions and community stakeholders can serve as a basic foundation for the sustainable development by educating students to solve key spatial problems. By introducing the elective course "Geoinformatics in Geography", co-financed by the European Social Fund, Hvar High School has focused on 21st century educational practices, giving emphasis to information and communication technologies as important teaching aids. The course curriculum defined the educational outcomes, including course content that covers geological and island relief characteristics and using GIS technology. Considering that Hvar island is predominantly mountainous, apart from the Stari Grad Plain, students are compelled to learn more about the relief features of their home island, to identify the fundamental processes and the forces that have shaped and still shape it, and to consider how topography influences various spatial phenomena. The students are also introduced to other relief-related concepts, including the spatial analysis of basic geostratigraphic units, hypsometry features, inclination, and exposure of mountainous island zones. In addition to digital analysis of karst topography, field training is conducted to collect spatial data for the purpose of developing hiking trails on Hvar island, with the aim of promoting preservation of natural island resources and supporting rural tourism.

Keywords: *island of Hvar, GIS, elective teaching, digital analysis of reliefs, mapping*

Monitoring Glacier Retreat and Forefield Sedimentation in the Swiss Alps Using UAV Photogrammetry and IoT

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Abstract. Glaciers are made up of fallen snow that, over many years, compresses into large, thickened ice masses. Glaciers form when snow remains in one location long enough to transform into ice. What makes glaciers unique is their ability to move. Due to sheer mass, glaciers flow like very slow rivers. Some glaciers are as small as football fields, while others grow to be dozens or even hundreds of kilometers long (URL1). The changes of the most important or dangerous glaciers in the Swiss Alps are monitored regularly. As the technology rapidly advances, the possibilities for mapping such areas have increased and new methods could be applied. One of these methods consists in the use of drones or UAV's (unmanned aerial vehicles) combined with close range photogrammetry to map the volumetric changes and movements. The use of drones for these mapping tasks is very efficient in terms of time and cost compared to classical terrestrial surveying methods as total stations or precision GNSS measurements. Images that are taken during the drone flights are then processed using photogrammetry methods which produce dense point clouds of surveyed areas. Those point clouds are then used to create high-quality Orthophotos and Digital elevation models (DEM) of the surveyed terrain. Such data is very helpful for further visualization, analysis and calculations and can give much more information about measured terrain and topography than the output data from classical terrestrial surveys. Having this in mind, it's not surprising that in the past few years UAVs have become an inevitable tool for site monitoring.

In-Terra ltd (URL 2) is a Swiss based company that pioneered drone mapping since 2005 and among many other projects, we are monitoring glacier dynamics (using UAV photogrammetry) for several glaciers in the Swiss Alps. One is the Fiescher Glacier, which is located on the south side of the Bernese Alps in the canton of Valais (Switzerland). With length of 16 km it is the second longest glacier in the Alps. Due to climate changes, this glacier is constantly melting and retreating so the shape of it is rapidly changing. The glacier meltdown leads to a quickly increasing, poorly consolidated sediment accumulation in the glacier foreland and the buildup of small glacial lakes. Sudden lake outburst floods and mudflows constitute a risk for the villages, infrastructure and people living downstream of the glacier. This makes tight risk-monitoring necessary.

To make it easier to document, visualize and analyse those changes, in-Terra is periodically flying the UAV above the glacier and making photogrammetry models which can then be compared and analysed to see the change between different stages.

Each model is precisely geo-referenced using the previously measured fixed ground control points (GCPs) that are visible on multiple images taken from the UAV. Ground control points are always marked and measured before the flight using the highly-precise GNSS devices and they are equally distributed along the terrain to avoid distortion in the models. Besides the GCP distribution, the quality of the output data depends on many other factors such as surveying precision, UAV camera sensor, flying altitude, etc. However, with a fairly cheap drone, good quality camera sensor and with high-precision GNSS device for GCP measurement, it's possible to generate precision, high-quality and high-resolution data. For example, the resolution of the Fiescher Glacier's orthophoto created by in-Terra is 3cm which makes it extremely useful for further analysis. Furthermore, resolution of the created elevation models for this glacier is only 10cm. However, creating such geodata is only one part of the process when monitoring glacier's dynamics. Another part of the workflow is then to make good and meaningful analysis based on this data.

With the high-quality elevation models from different glacier stages, it is possible to perform different sets of analysis. One of the most common and most useful is volume calculation. For example, by comparing two overlapping elevation models between two different time stages we can calculate volume difference between those two

and see how much volume of ice has been removed (melted) or accumulated between two surveys. Volume calculation can be performed on specific areas of interest defined by the vector outline, but it's also possible to calculate elevation difference between two stages across the complete surveyed area. In that way, it's possible to see how the glacier changes in specific areas or where the biggest change is happening. To make it easier to visualize such an output, one can then perform simple hillshading algorithms and create heat maps using custom color ramps.

To make it easier for scientists to perform such operations, in-Terra has developed a custom web GIS solution, Terra3D, where all the data (orthophoto, DEM, point clouds, etc.) can easily be uploaded and used for further analysis within the simple web interface. Besides the 2D/3D map visualization of such data, there is also a set of developed tools to perform different kinds of operations. So, for example, besides volume and mass-balance calculations, within the Terra3D there are also tools for creating cross sections across uploaded models, heat map generation tools, measuring tools, PDF report tools, etc.. For easier visualisation of the glacier's movement it is possible to compare multiple orthophotos at the same time with the help of transparency sliders for better visibility control. To make following of glacier movements even easier, in-Terra is also researching and developing IoT solutions (Internet of Things) where the main idea is to install sets of different low-powered sensors directly on the glacier locations and sense all the movements (blocks, landslides). Such data could then be transmitted over wide area networks (e.g. LoRaWAN) and displayed in real-time within the Terra3D ecosystem. That would bring many additional benefits and make tracking of glacier movements easier, richer, more reliable and more responsive in time-critical situations.

Sources

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Comparison of the Triglav Model at Bohinj Lake with the Actual Mountain Shape

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Abstract. In the Ribčev Laz near Lake Bohinj there is a topographic model of Triglav, the highest mountain of Slovenia. The model, built from stone, is the work of the painter Valentin Hodnik from Bohinj. Although it is a work of art, we were interested in evaluating the correctness of its shape. To this end, we captured the model with a photo camera and a laser scanner to create point cloud models. By transforming the point cloud into its actual size, we compared it with the shape of the actual Triglav mountain range, obtained from National Laser Scanning Data (LSS). As expected, the shape of the topographic model varies considerably from the actual shape of the mountain and also the scale of the individual slopes and ridges are not the same. For the qualitative evaluation of the model, we calculated the distances between the transformed model and the actual surface. The results are represented by a picture of absolute distances. In addition, we also produced a smaller 3D plot of the Triglav model and the actual shape of the mountain.

Keywords: *Mount Triglav, V. Hodnik's model, 3D model, point cloud*

NSDI Datasets Supporting the Development of Mountain Areas

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Abstract. Mountain areas are particularly sensitive environments in every community that are exposed to depopulation, economic downturn and the threats caused by climatic conditions. The measures taken by the state and local authorities are largely based on spatial data, and the quality of these measurements depend on their availability, sharing possibilities and quality. In this context, the spatial data infrastructure (SDI) plays a special role in creating the prerequisites for the development and conservation of mountainous areas. The establishment of the National Spatial Data Infrastructure (NSDI) in the Republic of Croatia is defined by the Law on NSDI. It represents the implementation of the Directive 2007/2/EC of the European Parliament and of the Council of 14. March 2007 about establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) in the legislation of the Republic of Croatia. The INSPIRE directive applies to spatial data held by or on behalf of public authorities and the uses of spatial data by public authorities in the performance of their tasks. Geoportal NSDI makes it possible to access the services related to searching, viewing, downloading, transformation, retrieving and other data services, and it presents an initial point of access to spatial data sources as enacted in the Law on NSDI. As of March 2018, a total of 39 NSDI stakeholders have made their data available via Geoportal NSDI. The information about these data has been published in 288 metadata and 76 network services. This paper provides an overview of spatial datasets needed to support development of hilly and mountainous areas in the Republic of Croatia, as well as the data requirements for the sources mentioned.

Keywords: *NSDI, mountain areas, mountain cartography*

Traveler's Map of Krka National Park

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Abstract. Krka National Park recently published a Traveler's Map of that park. The map dimensions are 100×70 cm, it is two-sided, and it is printed on high-quality paper. Side A is a topographic map at the scale of 1:50000. Side B contains textual tourist information and three A3 size maps of special areas of interest, including Skradinski buk, Roški slap, and Burnum-Puljane. The special interest maps are depicted using a digital model of the terrain and are attractively designed to meet the expectations of map end-users (tourists). In this paper, all aspects of the map preparations are discussed, from data sources and their quality, through GIS data processing and cartography, to final design touches using graphic applications, and with consideration given to printing issues.

Keywords: *Krka national park, tourist map, GIS, digital terrain model*

Interactive Storytelling on Physical 3D Models

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Abstract. In this presentation, we discuss the creation of large physical landscape models using digital elevation data and CNC machines to carve out the landscape, which is an efficient method for creating large models. The next component of the project was developing software for projecting maps onto the 3D models, taking into account the graphical deformation created by the 3D landscape. The end result: user stories can come to life through graphics and animation on an adjacent screen to show additional video or images. This system allows the audience to interact with the content.

Keywords: *physical landscape models, augmented reality, storytelling*

Finding Potentially Suitable Orienteering Terrains in Croatia and Slovenia

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Abstract. In this paper we describe a method for automated detection of suitable terrains for foot orienteering based on geomorphology and land cover. Existing orienteering maps in Croatia and Slovenia were used as reference data to define criteria for geomorphology and land cover used for GIS analysis. Geomorphology parameters, slope and aspect, were derived from EUDEM digital elevation model. These two parameters define components of direction of surface normal. Land cover criteria were applied using CORINE land cover data set. Analyzed area includes Slovenia, Croatia, Bosnia and Herzegovina and parts of neighboring countries.

Keywords: *orienteering terrains, slope, aspect, land cover, multi-criteria analysis*

National Park Service Lands, Santa Cruz Island, California

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Abstract. This is a prototype of a map layout I have designed for a portion of the Channel Islands National Park in California. The large-scale map portrays the National Park Service lands on Santa Cruz Island in a naturalistic manner with shaded relief, trails, roads, and placenames. The purpose of the map is to help visitors navigate the island while also educating them on the human-induced environmental legacies that can be discerned in the natural- and wild appearing landscape.

Keywords: *shaded relief, toponymy, recreation*

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