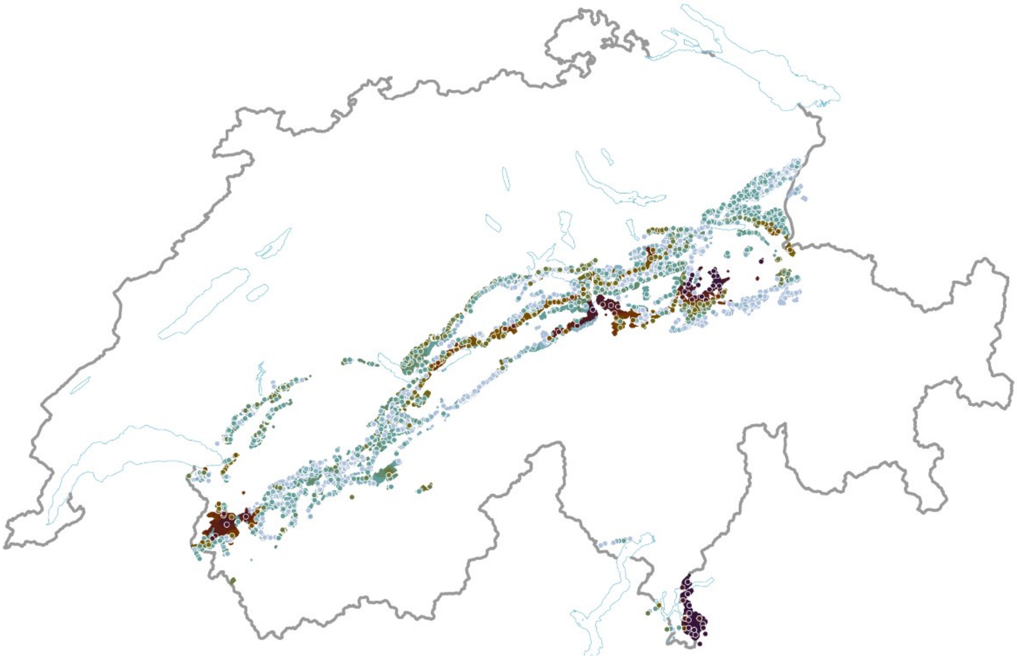
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Defence, Civil Protection
and Sport DDPS

Federal Office of Topography swisstopo

Hard rock aggregates: Thickness and quality of geological occurrences



Technical description of the dataset and modelling method

Status: 18.12.2024

Editor
Federal Office of Topography (swisstopo)

Authors
Lukas Nibourel [1]*, Thomas Galfetti [2], Anja Amrein [1], Lorena Juchler [1], Joël Morgenthaler [1], Leila Mizrahi [3] & Stefan Heuberger [1]

* Main author

[1] Georesources Switzerland Group (FGS), ETH Zurich, Sonneggstrasse 5, 8092 Zürich, Switzerland
[2] Federal Office of Topography swisstopo, Seftigenstrasse 264, 3084 Wabern, Switzerland
[3] Swiss Seismological Service at ETH Zurich, Zürich, Switzerland

Keywords
Mineral resources, Hard rock aggregates, Technical documentation, Federal geoportal

Recommended citation
Nibourel, L., Galfetti, T., Amrein, A., Juchler, L., Morgenthaler, J., Mizrahi, L. & Heuberger, S. (2024): Hard rock aggregates: Thickness and quality of geological occurrences. Technical description of the dataset and modelling method. – Federal Office of Topography swisstopo, Wabern.

Front cover
Map showing the spatial distribution and thickness of the investigated hard-rock-bearing geological units (points and areas). The thickness of the units ranges from 0 metres (light blue) to more than 2000 m (dark red).
Sources: swisstopo, Georesources Switzerland Group, ETH Zurich.

pdf file available at www.swisstopo.ch

Abstract

This document describes in detail the modelling method applied to produce the geospatial dataset "Hard rock aggregates: Thickness and quality of geological occurrences" published on the federal geoportal of the Swiss Confederation.

Table of Contents

Introduction

Hard rock aggregates play a central role particularly for the construction and maintenance of the Swiss railway network (railway ballast) as well as of high-performance roads (road surfacing). With the current and projected growth in rail and road traffic in Switzerland, the load on the transportation infrastructure and the demand for high-performance hard rock aggregates is expected to increase over the coming decades. Many factors, in particular land-use conflicts, environmental restrictions and difficult logistical access, make most of the geological occurrences of hard rock challenging or impossible to exploit, especially if an open-pit mining operation is considered.[1]

The geospatial dataset “Hard rock: occurrences”[2] (raster cell size: 50 x 50 m) shows an estimation of the spatial distribution, the thickness and the quality of 12 hard-rock-bearing geological units situated at a ground elevation lower than 1300 m a.s.l. and with a usable thickness exceeding 30 m. The results must be regarded as estimates, which are based on geological profiles, stratigraphic descriptions and an automated MATLAB- and Python-based method. The motivation for producing the dataset was to support the cantonal and federal authorities and the industrial sector in the spatial planning process, by enabling these users to locate the most promising occurrences.

To evaluate the geometry and to characterise the quality of each geological unit, the following three parameters were used: (i) the true stratigraphic *thickness* of a geological unit (red arrow in Figure 1), (ii) the *usability ratio* describing the proportion of usable lithologies within a geological unit and (iii) the usable thickness (blue arrows, Figure 1). The *usable thickness*, reflecting both the geometry (thickness) and quality (usability ratio) of a given geological unit, is used as the main parameter in the evaluation procedure.[3]

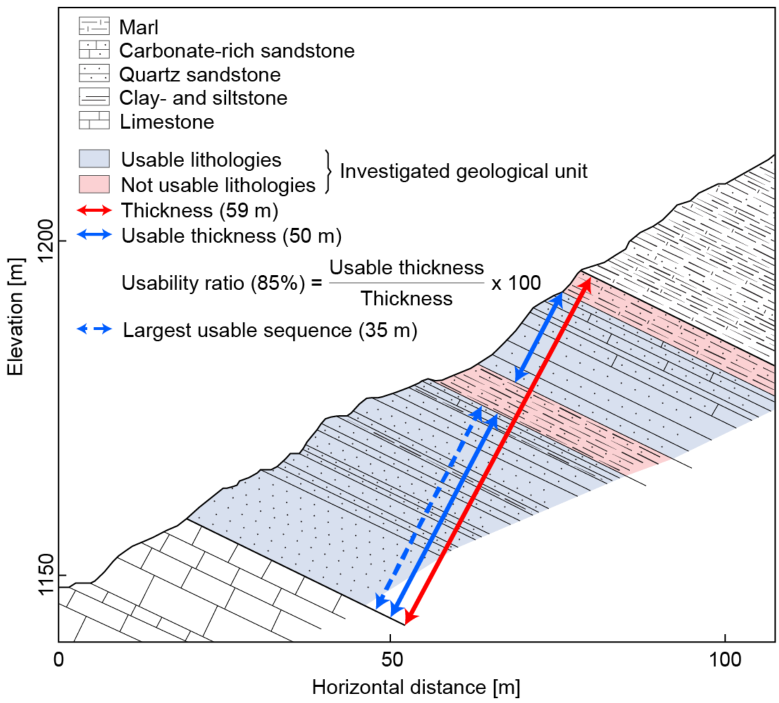


Figure 1: Schematic example of a cross-section / stratigraphic profile (modified from NIBOUREL et al. 2024) highlighting the key parameters compiled in this investigation. Example values are given in brackets.

[1] For further information and access to up-to-date data, the reader is invited to consult the website www.mat-min.ch.
[2] Geospatial dataset Hard rock aggregates: Thickness and quality of geological occurrences on federal geoportal www.map.geo.admin.ch.
[3] Further information regarding the evaluation of the quality of geological units are found in the Catalog of the hard rock-bearing geological units in Switzerland (Nibourel et al. 2024).

The input data and the processing steps that were used to develop the dataset are described in Chapters 1 to 4.

The quality and the uncertainties related to the input and output datasets are discussed in Chapter 5. The data structure, application guidelines and legal matters are documented in Chapters 6, 7 and 8.

Processing workflow

A simplified description of the processing workflow is given in the flow chart diagram in Figure 2.

The modelling method includes only a few manual work steps (red boxes in Figure 2). All other steps (i.e. preparation, extraction and calculation) are executed by means of custom MATLAB- and Python-based scripts. Steps 1–3 are extensively described in NIBOUREL et al. (2023) as well as in JUCHLER (2022). Many of the scripts are available at GitHub and can be run at once from a Driver Shell script.

A manual quality check and output validation (step 3) was performed with the literature-based and automatically processed thickness data as well as the usability ratio data. The validated data were finally used as input to interpolate and prepare the final dataset (step 4).

In Chapters 1 to 4, the input datasets and work steps are briefly described, according to the workflow shown in Figure 2. A complete list of (i) the input and output datasets and (ii) the scripts used to produce the geospatial dataset is included in Appendix A1 and A2.

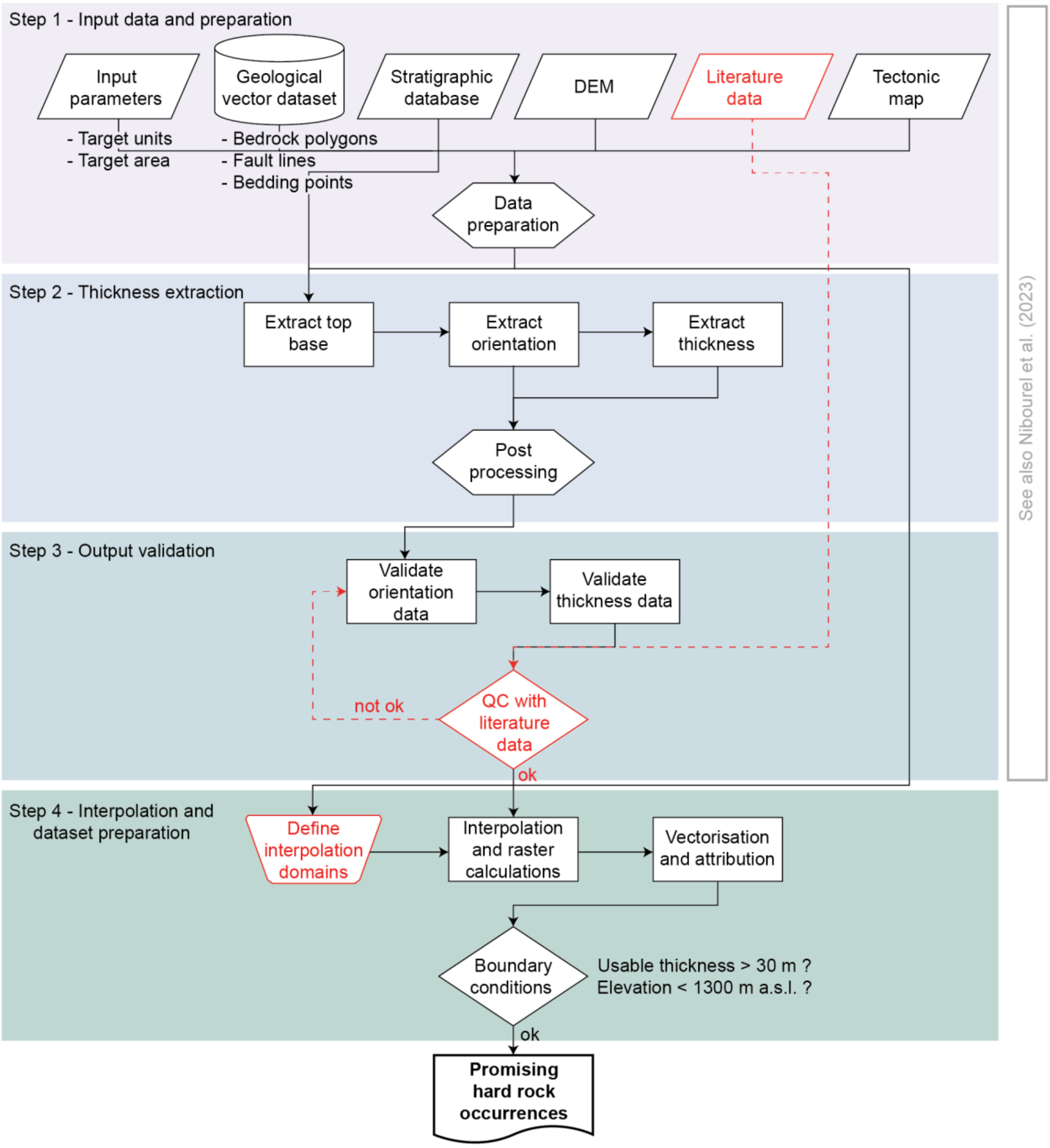


Figure 2: Simplified flow chart diagram showing the processing workflow to create the geospatial dataset. Manual work and decision-making steps are highlighted in red.

1 Input data and preparation

The input data used for producing the dataset are listed in Table 1 (see also Figure 2 and the dataset overview in Appendix A2):

Table 1: List and description of the used input datasets.

Input dataset	Feature (data type)	Data source (version used)
Geological vector datasets (GeoCover)	Bedrock (polygons) Faults (lines) Orientation measurements (points)	https://www.swisstopo.admin.ch/en/geological-model-2d-geocover (20.06.2022)
Coverage (target area)	Data table	Data table listing the GeoCover / GA25 map sheets considered in the investigation, including map sheet edge coordinates
Stratigraphic database	Data table	https://backend.swisstopo.admin.ch/fileservice/sdweb-docs-prod-swisstopoch-files/files/2024/05/17/13a76f94-302b-4fff-9245-699fd54066fc.xlsx, see also lithostratigraphic lexicon of Switzerland strati.ch For the project, a “work in progress file” (14.06.2022) was provided by swisstopo
Target units	Data table	Extract of the stratigraphic database, created for this project
Digital elevation model (swissALTI3D)	(raster)	https://www.swisstopo.admin.ch/en/height-model-swissalti3d#swissALTI3D---Download (November 2020)
Literature data Geological profiles (GA25, and other sources) Geological maps (GA25 Explanatory notes, and other sources)	Thickness (points) Usability ratio (points)	https://data.geo.admin.ch/browser/index.html#/collections/ch.swisstopo.geologie-geologischer_atlas_profile?language=en https://www.swisstopo.admin.ch/en/geological-atlas-of-switzerland-1-25000-pixel See Hard rock catalog (NIBOUREL et al. 2024) for the full list of references (18.10.2024)
Tectonics (TectonicMap of Switzerland 1:500’000)	Tectonic domains (polygons, lines)	https://www.swisstopo.admin.ch/en/geomaps-500-vector (pre-print version of 21.06.2023)

1.1 Considered hard rock-bearing geological units (target units)

Twelve potentially hard rock-bearing geological units, in the following referred to as target units, were investigated. The selection of these units, based on the stratigraphic database (see Chapter 1.4), is the result of extensive literature research and field investigations. These units are listed in Table 2 and ordered by tectonic position and chronostratigraphic age (from old to young).

Table 2: List of the investigated hard-rock-bearing geological units (target units).

Target unit	Tectonic position	Chronostratigraphy
Spitzmeilen Formation	Helvetic domain	Sinemurian–Pliensbachian (Early Jurassic)
Sexmor Formation	Helvetic domain	Pliensbachian (Early Jurassic)
Torrenthorn Formation	Helvetic domain	Sinemurian–Toarcian (Early Jurassic)
Mont-Joly Formation	Helvetic domain	Sinemurian–Pliensbachian (Early Jurassic)
Helvetic Kieselkalk	Helvetic domain	Valanginian–Hauterivian (Early Cretaceous)
Garschella Formation	Helvetic domain	Aptian Cenomanian (Early Cretaceous)
Niederhorn Formation	Helvetic domain	Bartonian Priabonian (Middle Late Eocene)
North-Helvetic Flysch Group	Helvetic domain	Eocene Oligocene
Obflue Formation	Middle Penninic Klippen	Pliensbachian (Early Jurassic)
Petit-Liençon Formation	Middle Penninic Klippen	Pliensbachian (Early Jurassic)
Rossinière Formation	Middle Penninic Klippen	Toarcian Aalenian (Early–Middle Jurassic)
Moltrasio Formation	Southalpine domain	Hettangian Pliensbachian (Early Jurassic)

The selected units contain potentially suitable hard rock lithologies such as siliceous limestone, carbonate-rich sandstone and/or flysch-sandstone/greywacke. They have a usable thickness greater than 30 metres and are likely promising in terms of thickness and quality, at least in some areas. Details regarding the quality requirements of potential hard rock lithologies, the evaluation and selection of the target units and the associated references can be found in Chapter 5 of the Hard rock catalog (Nibourel et al. 2024).

1.2 Coverage (target area)

The geospatial dataset covers all GeoCover / GA25 map sheets containing at least one target unit (Figure 3). The boundary coordinates and map sheet names, used to extract the necessary information for every GeoCover map sheet, are stored in the data table *Map sheet information.* Table 3 shows an example for the GA25 map sheet “Muotathal” (located as red rectangle in Figure 3).

Table 3: Example of the input data stored for each investigated GeoCover / GA25 map sheet.

Map name	Xmin	Xmax	Ymin	Ymax	Remarks	Target units
Muotathal	2690 000	2707 500	1194 000	1206 000		Sexmor Formation, Spitzmeilen Formation, Helvetic Kieselkalk, Garschella Formation, North-Helvetic Flysch Group

Before starting the processing, a few manual adjustments were made to the GeoCover bedrock polygons (only the attribution was modified, not the geometry). These are noted in the "Remarks" field shown in Table 3. The table also specifies the target units occurring on the corresponding map sheet.

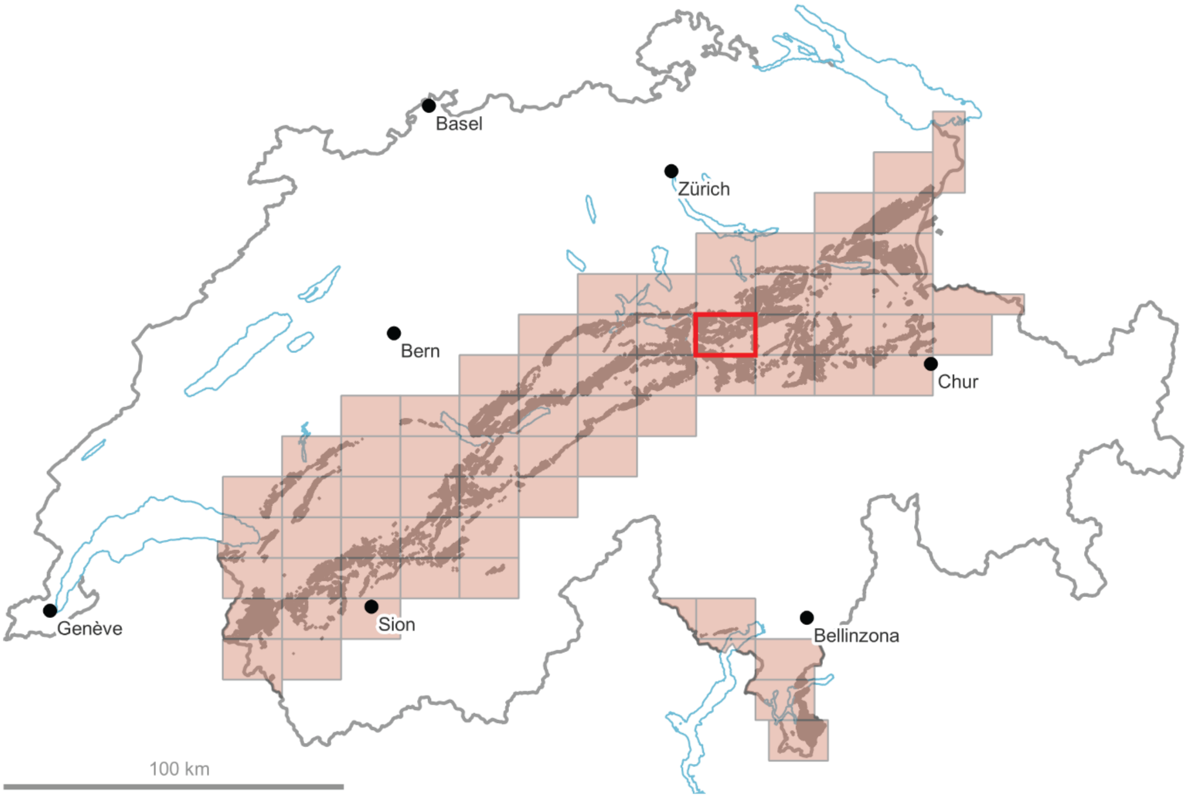


Figure 3: Exposures of hard-rock-bearing geological units (dark polygons) defining the coverage of the dataset. The red-filled and grey-outlined rectangles represent the investigated map sheets. The example map sheet “Muotathal” is highlighted as a red rectangle.

1.3 Geological vector dataset (GeoCover / GA25)

GeoCover, a Switzerland-wide geological vector dataset with harmonised lithostratigraphy, represents the main input dataset (Figure 4). GeoCover is primarily based on the available sheets of the Geological Atlas of Switzerland at the scale of 1:25 000 (GA25). Where no GA25 map sheet data are available, GeoCover is based on an unvalidated compilation of special maps and map originals of varying scales and quality (more information regarding the geological vector dataset can be found in the swisstopo "FAQ – Geological vector datasets". Bedrock polygons, fault lines and bedding orientation measurements are processed by an automated thickness extraction and thickness map generation routine (see Chapters 1.3.1–1.3.3 below). In the used GeoCover version, many bedrock and fault geometries are not mapped consistently across map sheet boundaries (pale red rectangles in Figure 3). To avoid map sheet boundary effects, a script was used to prepare the input data for each map sheet (see for example Figure 5), using the map sheet information specified in Chapter 1.2.

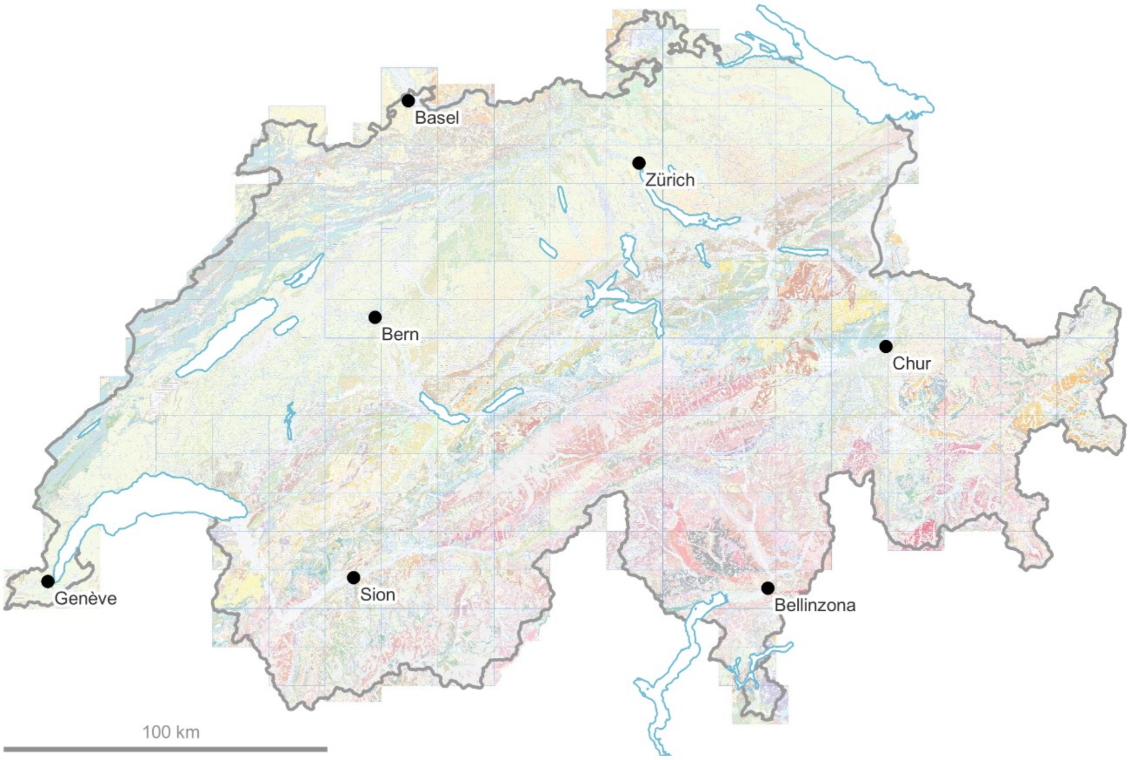


Figure 4: GeoCover input dataset including bedrock polygons, fault lines and field orientation measurements used in this project.

1.3.1 Bedrock polygons

The purpose of the geospatial dataset is to identify promising geological occurrences close to the surface (assuming an open pit operation). Some hard rock occurrences may be covered by unconsolidated deposits such as glacial till, gravel, sand or silt/clay. Unconsolidated deposits are also mapped in the GeoCover dataset (areas with no bedrock exposure, Figure 5), but their thickness is often poorly known. Therefore, only the occurrences with an exposed bedrock target unit (and not covered by unconsolidated rocks) are shown in the dataset. Slope instabilities, even if bedrock is involved, are also treated as unconsolidated deposits and were therefore omitted from the final dataset. A script was used to prepare the bedrock polygons for each map sheet (see the blue polygons in the example in Figure 5).

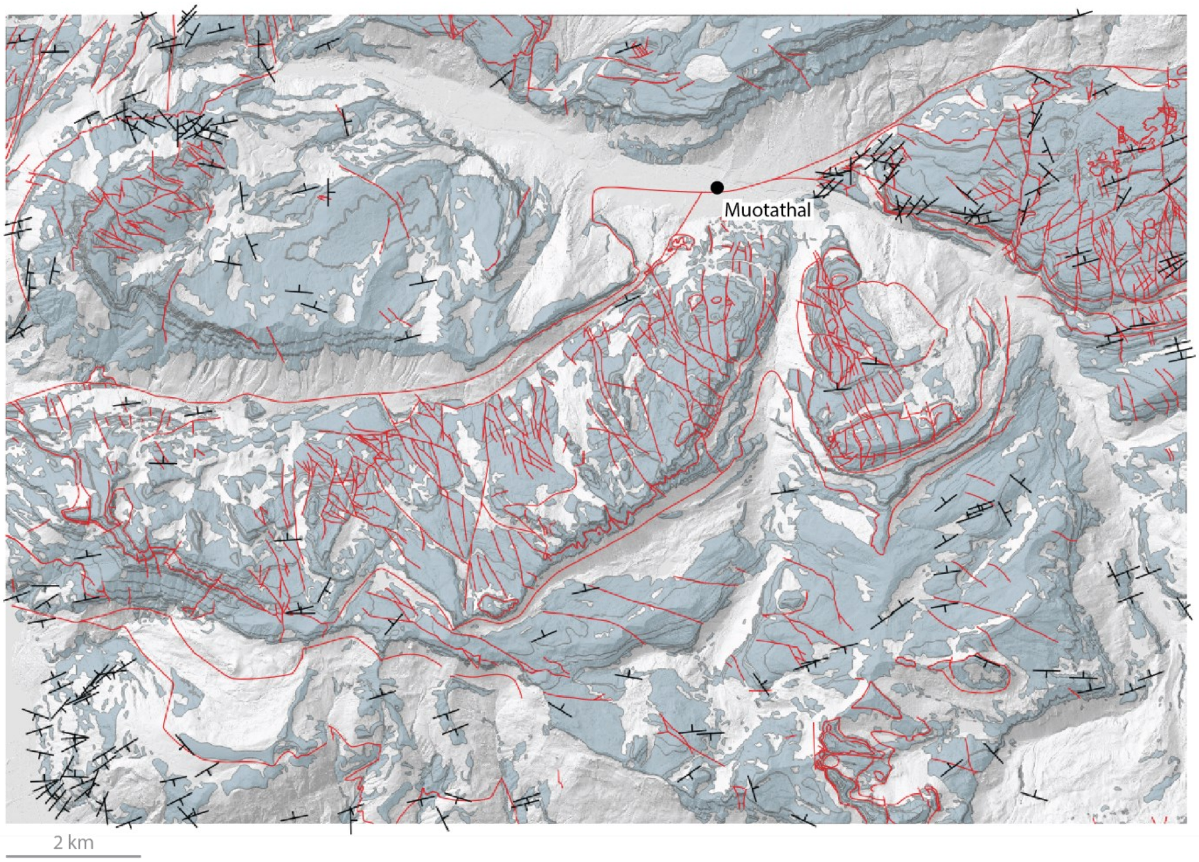


Figure 5: Example of the GeoCover-related input data for the map sheet Muotathal including bedrock polygons (pale blue), fault lines (red) and bedding orientation measurements (black dip symbols). Areas with unconsolidated deposits or slope instabilities (grey areas) are not considered in the processing workflow. The map sheet extent is shown in Figure 3.

In the processing workflow, the bedrock polygons are used to locate the target units and their base and top contacts as well as to extract the orientation and thickness information stored along these contacts / exposures (Nibourel et al. 2023).

1.3.2 Fault lines

Knowing the position and extent of faults is a requirement for the automated extraction of reliable orientation and thickness data from GeoCover. Extracted orientation and thickness information is only considered if:

(i) Both the top and the base contacts, used for calculating a thickness value, are stratigraphic. Tectonic contacts are not considered for the calculations.

(ii) Fault effects are absent, because the presence of a fault can lead to an over- or underestimation of the thickness. Thickness data related to a geological unit affected by faults were discarded.

A script prepares the fault lines individually for each map sheet (Figure 5).

1.3.3 Bedding orientation measurements

Bedding orientation measurements (measured by a field geologist) yield important information regarding the local orientation (dip direction, dip) of the exposed bedrock units (see the example in Figure 5). The bedding orientation measurements, extracted from GeoCover, served as input for the automated calculation of thickness data (see also Chapter 2.3.2. in

JUCHLER 2022). Additionally, the bedding orientation measurements were used to validate the automatically extracted orientation information (see Chapter 2.2. in NIBOUREL et al. 2023).

More than 18 000 measurements (red points, Figure 6) were processed and used to calculate the thickness of nearby target units. As seen on Figure 6, the spatial distribution of these orientation measurements is heterogeneous and not all relevant areas are covered.

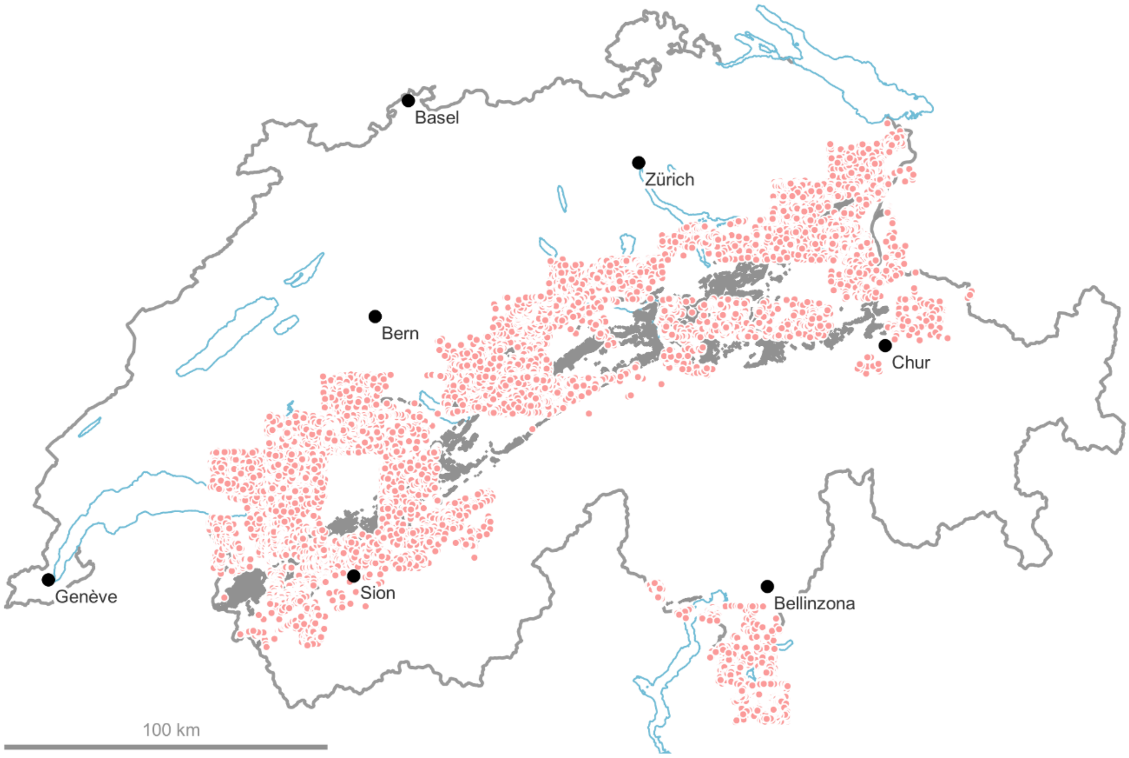


Figure 6: Bedding orientation measurements (in red), which served as an input dataset for the automated calculation of the thickness of the hard rock target units (grey polygons).

1.4 Stratigraphic database

Table 4 shows an extract of the stratigraphic database. It defines which geological units (i.e. group, formation or member) were considered as target units (green, Table 4). The table also defines which geological unit is situated at the top (younger, above target unit in the table) or at the base (older, below the target unit) of the target unit. The table corresponds to the current state of the Lithostratigraphic Lexicon of Switzerland (strati.ch) and was developed by the swisstopo's team of scientific editors. In the processing workflow, the numeric field GeolCode in GeoCover (Table 4) is used to identify the target unit bedrock polygons and to automatically extract the stratigraphic top and base contacts of each target unit.

Table 4: Extract of the stratigraphic database used to create the geospatial dataset. One of the target units and several mapped sub-units are highlighted in pale green.

GeolCode	Group	Formation	Member
15202075	Kreide des Helvetikums	Tierwis-Formation	x
15202077	Kreide des Helvetikums	Tierwis-Formation	Drusberg-Member
15202078	Kreide des Helvetikums	Tierwis-Formation	Altmann-Member
15202079	Kreide des Helvetikums	Helvetischer Kieselkalk	x
15202080	Kreide des Helvetikums	Helvetischer Kieselkalk	«Kieselkalk-Echinodermenbrekzie»
15202081	Kreide des Helvetikums	Helvetischer Kieselkalk	Lidernen-Member
15202515	Kreide des Helvetikums	Helvetischer Kieselkalk	Helvetischer Kieselkalk, Basisschiefer

GeolCode	Group	Formation	Member
15202537	Kreide des Helvetikums	Helvetischer Kieselkalk	Ringgenberg-Schichten
15202083	Kreide des Helvetikums	Helvetischer Kieselkalk	Rahberg-Bank
15202382	Kreide des Helvetikums	Helvetischer Kieselkalk	Palis-Bank
15202082	Kreide des Helvetikums	Helvetischer Kieselkalk	Gemsmättli-Bank
15202084	Kreide des Helvetikums	Betlis-Formation	x
15202085	Kreide des Helvetikums	Betlis-Formation	Pygurus-Member
15202398	Kreide des Helvetikums	Betlis-Formation	«Oberer Betliskalk»
15202399	Kreide des Helvetikums	Betlis-Formation	«Unterer Betliskalk»

1.5 Digital elevation model (DEM)

Digital elevation data from the swissALTI3D dataset were used to extract the elevation along target unit contacts mapped in GeoCover and to highlight all hard rock occurrences situated at a ground elevation lower than 1300 m a.s.l. A script was used to resample the elevation data at a 2-meter raster cell size and to prepare the DEM data for every GeoCover map sheet shown in Figure 3 (see for example hillshade background in Figure 5).

1.6 Literature data (LitD)

The geometry and the quality of a target unit at a given locality are assessed based on thickness and usability ratio data (Figure 1). Thickness and usability estimates were compiled from more than 350 published articles, theses, technical reports and the explanatory notes and profiles covering 47 GA25 map sheets. All references and the method used to compile the literature data are given in the Hard rock catalog (Nibourel et al. 2024). An extract from the data table, including the literature-based thickness and usability estimates, is shown in Table 5. In the following, the literature-based thickness and usability data are referred to as "LitD".

Table 5: Extract from the data table, including the literature-based thickness and usability ratio data (LitD). The columns "Thickness" and "Usability ratio" are used as input for the production of the geospatial dataset.

Spatial reference			Formation	GeolCode	Thickness	Usable thickness	Usability ratio	Largest usable sequence	Reference
X (m)	Y (m)	Z (m)			(m)	(m)	(%)	(m)	
2622 180	1161 140	1440	Helvetischer Kieselkalk	15202079	184	167	91	179	Mojon (1984)
2624 770	1159 750	2155	Helvetischer Kieselkalk	15202079	250	219	88	219	Mojon (1984)
2624 380	1175 295	1615	Helvetischer Kieselkalk	15202079	110				Mojon (1984)
2699 418	1198 762	2225	Helvetischer Kieselkalk	15202079	179				Hantke et al. (2013)
2696 650	1201 248	1780	Helvetischer Kieselkalk	15202079	433	303	70	303	Hantke et al. (2013)
2694 725	1197 753	1190	Helvetischer Kieselkalk	15202079	130				Hantke et al. (2013)

Spatial reference			Formation	GeolCode	Thick-ness	Usable thick-ness	Usabil-ity ratio	Largest usable se-quence	Reference
X	Y	Z							
(m)	(m)	(m)			(m)	(m)	(%)	(m)	
2746 780	1236 710	1605	Helvetischer Kieselkalk	15202079	48				Funk (1971)
2747 230	1236 070	1375	Helvetischer Kieselkalk	15202079	56				Funk (1971)
2748 600	1238 650	1555	Helvetischer Kieselkalk	15202079	49	42	86	22	Funk (1971)
2749 275	1238 475	1355	Helvetischer Kieselkalk	15202079	59	42	71	22	Funk (1971)

1.6.1 Thickness

The thickness literature data are collected from geological cross-sections and stratigraphic profiles/descriptions as described in Figure 1. Figure 7 shows the spatial distribution of the literature-based thickness data. The scale of the geological cross-section and the orientation of the cross-section with respect to the trend of the large-scale structures in the area were reported for each entry in Table 5. The literature-based thickness data served as input for the geospatial data set and were used to validate the automatically extracted thickness data. For further details, see Chapters 2.3 and 3 in Nibourel et al. (2024).

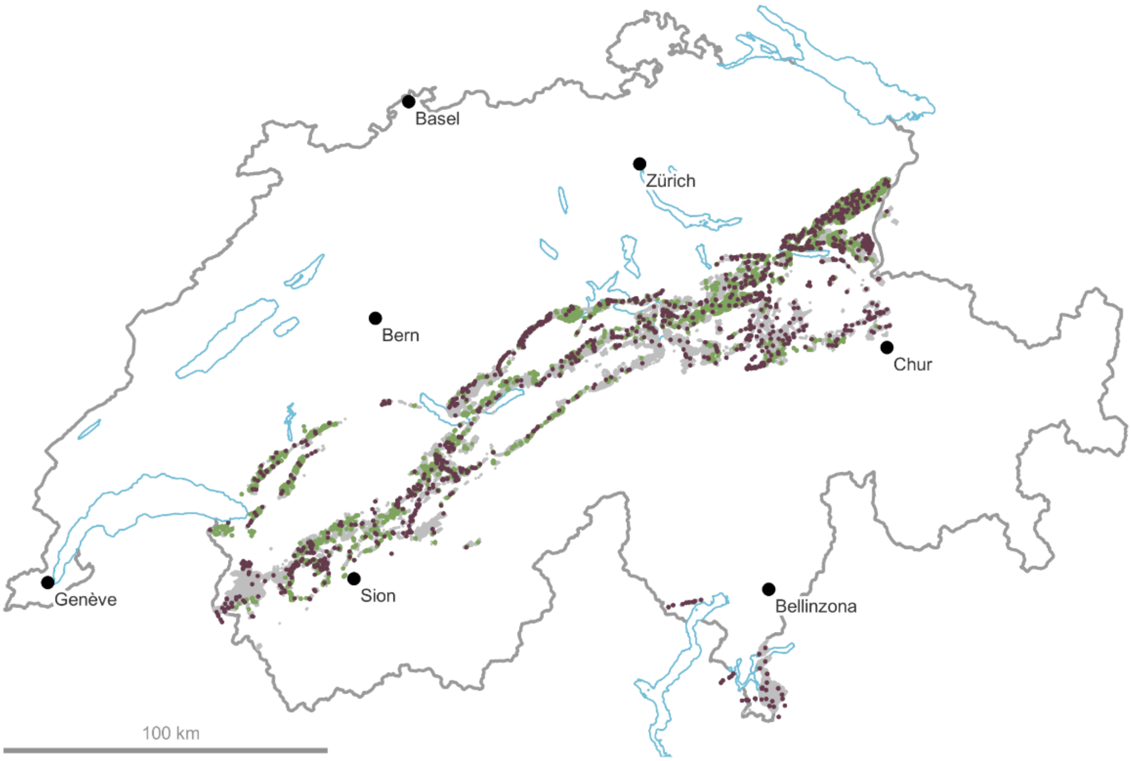


Figure 7: Spatial distribution of the 1325 literature-based (dark red) and the 11 079 automatically extracted (green) thickness data used to produce the geospatial dataset. The references to the literature-based thickness data are given in the Hard rock catalog (Nibourel et al., 2024).

1.6.2 Usability ratio

The usability ratio is a calculated parameter used to express the proportion of hard rock quality material of a target unit (Figure 1). Details regarding the assessment of the quality of the hard-rock-bearing geological units can be found in Chapter 5 of the Hard rock catalog (NIBOUREL et al. 2024). Figure 8 highlights the spatial distribution of the compiled usability ratios. In the final dataset, the usability ratio is used to predict the usable thickness of a given target unit at a given location.

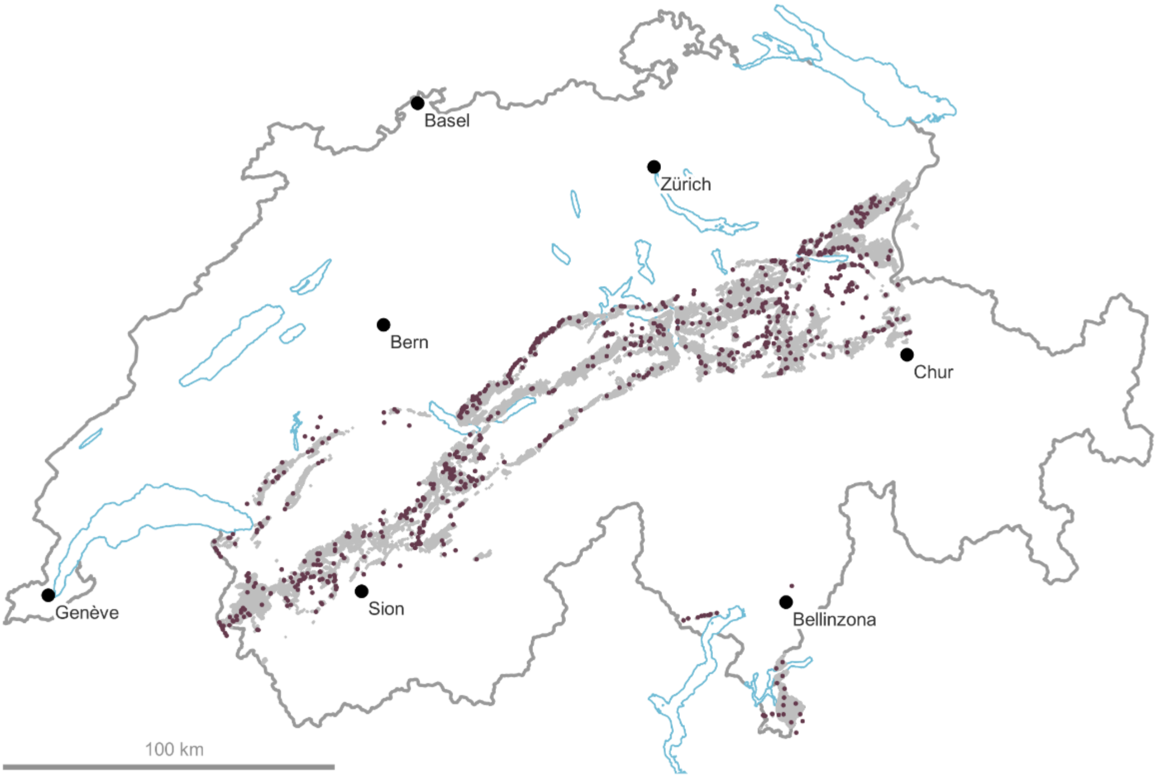


Figure 8: Spatial distribution of the 924 literature-based (dark red) usability ratios used to evaluate the quality of the geological occurrences shown in the geospatial dataset. The references used to estimate the usability ratio data can be found in the Hard rock catalog (NIBOUREL et al. 2024).

1.7 Tectonic map

Both the thickness and the usability ratio of the target units often change significantly across major tectonic nappe boundaries (grey lines, Figure 9). Therefore, the thickness and usability data shown in Figure 7 and Figure 8 were not interpolated across major tectonic boundaries (Chapter 4).

Ten interpolation domains were defined based on the Tectonic Map of Switzerland (swisstopo 2024). These interpolation domains and the target units occurring within these domains are listed in Table 6. The spatial extent of these domains is shown in Figure 9.

Table 6: List of the tectonic domains used to interpolate the thickness data.

Technical name (Abbreviation, Fig. 9)	Tectonic		Target unit
	Domain/Subdomain	Unit	
Helvetic domain			
Lower Helvetic *(LH)*	Lower Helvetic	undifferenciated	Torrenthorn Formation, Mont-Joly Formation, Helvetic Kieselkalk, Garschella Formation, Niederhorn Formation, North-Helvetic Flysch
Axen Nappe *(Ax)*	Upper Helvetic	Axen Nappe	Spitzmeilen Formation, Sexmor Formation, Helvetic Kieselkalk, Garschella Formation
Glarus Nappe Complex *(Gl)*	Upper Helvetic	Glarus Nappe Complex and Tavetsch Nappe	Spitzmeilen Formation, Sexmor Formation, Helvetic Kieselkalk, Garschella Formation
Wildhorn Nappe Complex *(Wi)*	Upper Helvetic	Wildhorn Nappe Complex, Pillon and Bulle Mélange Zones	Mont-Joly Formation, Helvetic Kieselkalk, Garschella Formation, Niederhorn Formation, North-Helvetic Flysch
Drusberg Nappe *(Dr)*	Upper Helvetic	Drusberg Nappe, Habkern Mélange Zone, Iberg and Einsiedeln Slices	Helvetic Kieselkalk, Garschella Formation, Niederhorn Formation
Säntis Nappe *(Sä)*	Upper Helvetic	Säntis, Fläscherberg and Liebenstein Nappes, Wildhaus mélanges	Helvetic Kieselkalk, Garschella Formation
Penninic domain			
Penninic Klippen *(P, C)*	Lower to Middle Penninic Nappes, *P* = Prealps, *C* = Klippen of Central Switzerland	Préalpes Médianes Nappe, Breccia, Voirons, Gurnigel, schlieren, Wägital, Niesen, Gets, Simme, Dranses, Sarine, Ochsenweid, and Üntschen Nappes	Rossinière Formation *(P)*, Heiti Formation *(P)*, Obflue Formation *(C)*
Southalpine domain			
Southalpine West *(UO)*	Southalpine	Upper Orobic Nappe, Ivrea-Ceneri Complex	Moltrasio Formation
Southalpine East *(LO)*	Southalpine	Lower Orobic Nappe	Moltrasio Formation

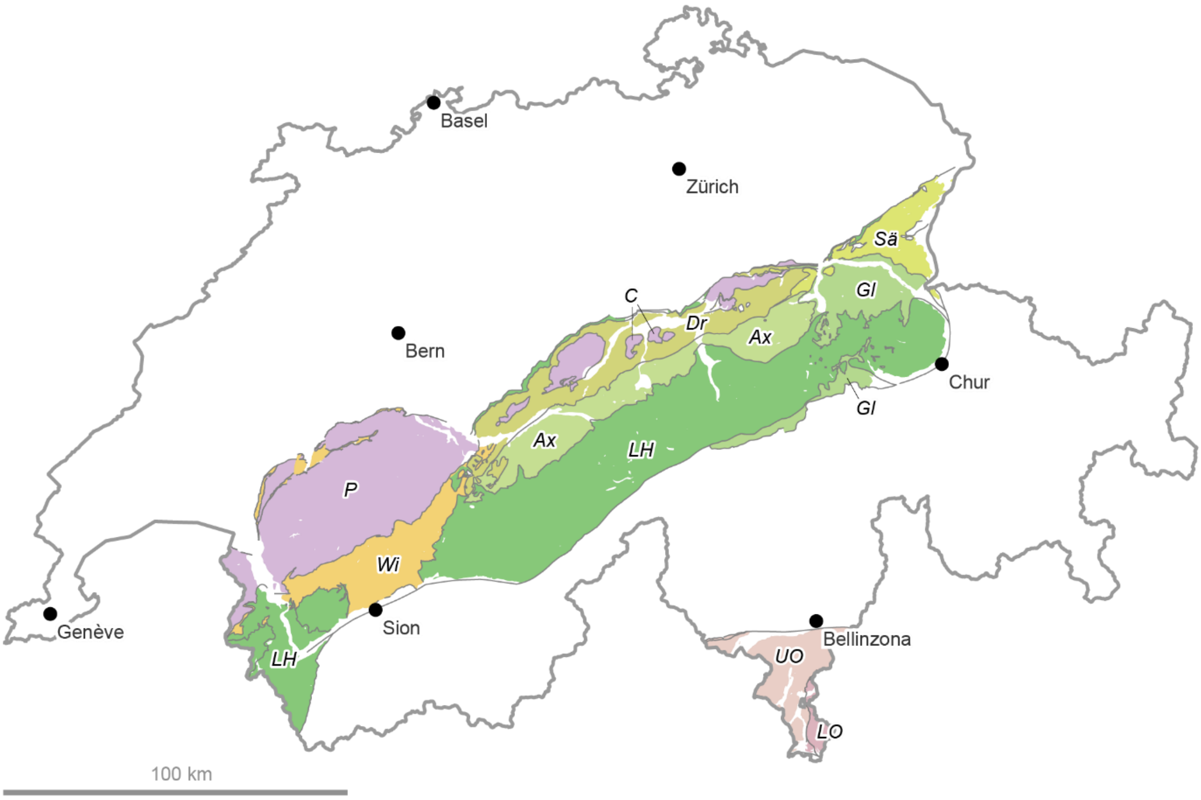


Figure 9: Tectonic domains used to interpolate the thickness and usability data (Chapter 4) modified from the Tectonic Map of Switzerland 1:500 000 (swisstopo 2024).
LH = Lower Helvetic, Ax = Axen Nappe, Gl = Glarus Nappe, Wi = Wildhorn Nappe, Dr = Drusberg Nappe, Sä = Säntis Nappe, P = Lower to Middle Penninic Nappes (Prealps), C = Lower to Middle Penninic Nappes (Klippen of Central Switzerland), UO = Southalpine, Upper Orobic Nappe, Ivrea and Canavese Zone, LO = Southalpine, Lower Orobic Nappe.

2 Automated orientation and thickness extraction

To improve the spatial density of the input data and to independently verify the literature-based thickness data (Chapter 1.6), we developed two new modelling methods to automatically extract the orientation (dip direction and dip) and thickness information from the GeoCover dataset (see Figure 10 for an overview).

A first method "bedrock contacts method (BED)" exploits the orientation information stored along the top and base contacts, since the geological map is projected onto a DEM (Figure 10a-d). This method, including the preparation of the input data, the extraction of the 3D information and the filtering of the model output based on numeric reliability indicators are documented in NIBOUREL et al. (2023).

All scripts related to NIBOUREL et al. (2023), as well as a test input data set are available at the following GitHub repository:

https://github.com/lukasflu/Orientation_Thickness_Extraction_Geol_Maps (Version 1.0).

A second method, in the following referred to as the "orientation measurement method (OM)", uses the orientation information stored in field orientation measurements of bedding to calculate the thickness of a target unit (Figure 10e-f). The method was developed as part of a MSc thesis (JUCHLER 2022).

The most important steps are described in the subchapters below. For further information, refer to NIBOUREL et al. (2023) and JUCHLER (2022).

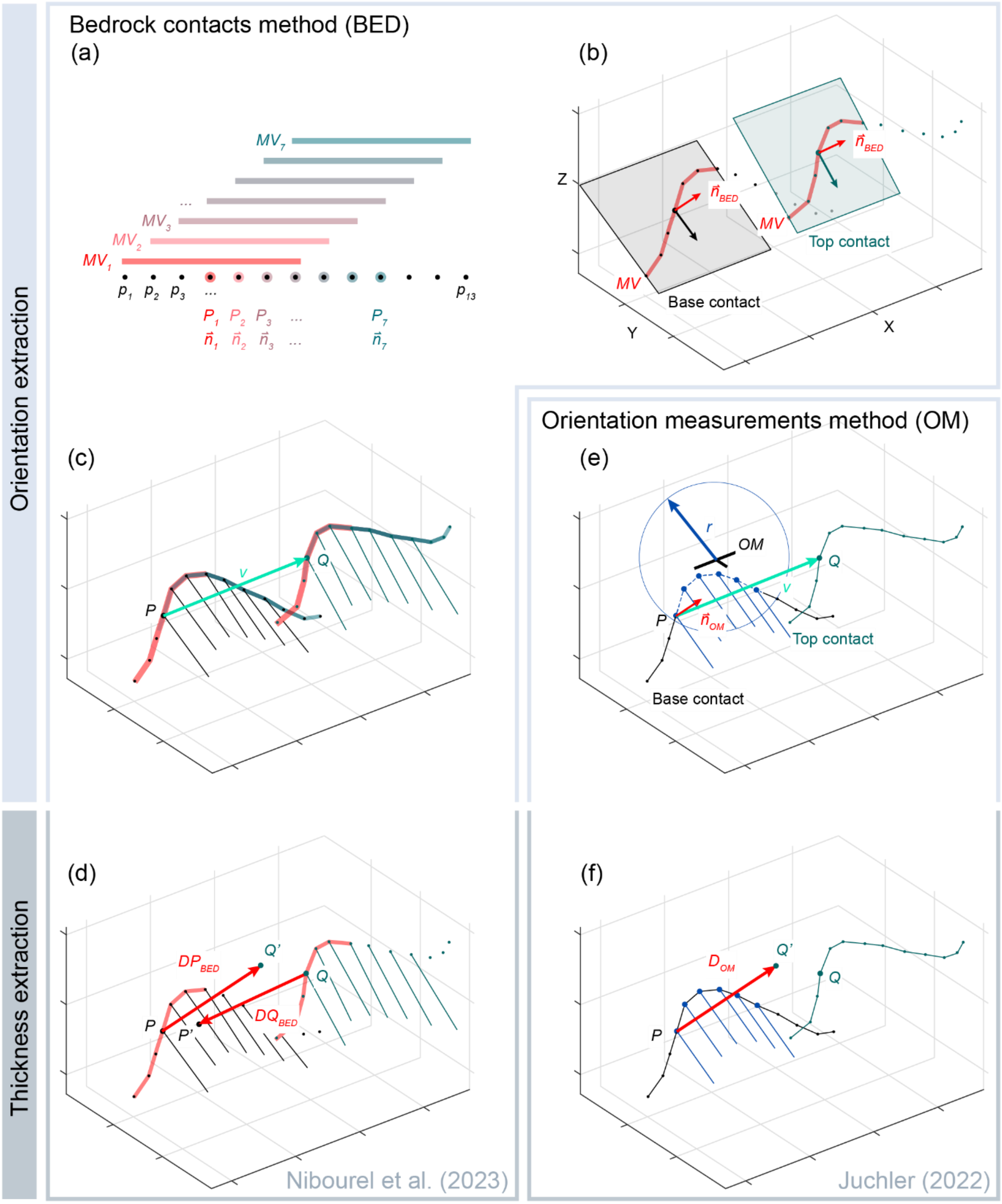


Figure 10: Simplified sketch of the orientation and thickness extraction methods. Subfigures a–d show the bedrock contacts method (BED, NIBOUREL et al. 2023), Subfigures e-f the orientation measurements method (OM, JUCHLER 2022). (a) Moving window MV_1–MV_7 used to extract the orientation information along the *XYZ* points p_1–p_{13}. The corresponding orientation information (see Subfigure b) is stored at the points P_1–P_7. (b) Base (black dots) and top (green dots) contact points *p*, including planar best fit planes (black and green planes for the base and top traces, respectively) through subsets of XYZ points *p*, as defined by the moving window *MV* shown in subfigure a. Black and green vectors highlight the dip direction and dip of the base and top traces, respectively. The normal vectors $\vec{n}_{BED}$ to these best fitting planes are highlighted in red. (c) Vector $\vec{v}$ connects the two nearest neighbours on the base (*P*) and top (*Q*) contacts. (d) DP_{BED} and DQ_{BED} are parallel to the normal vectors at the points *P* (DP_{BED}) and *Q* (DQ_{BED}). The lengths of the vectors *P-Q′* (DP_{BED}) and Q-P′ (DQ_{BED}) represent the true stratigraphic thickness. (e) Base or top contact points (thick blue points *p*) that are situated within the radius *r* of an orientation measurement (thick black dip symbol *OM*) are attributed with the corresponding orientation information (see blue lines and $\vec{n}_{OM}$). Vector $\vec{v}$ highlights the two nearest neighbours on the base (*P*) and top (*Q*) contacts. D_{OM} is parallel to the normal vector at the point *P* ($\vec{n}_{OM}$). The lengths of the vector P-Q′ (D_{OM}) represents the stratigraphic thickness.

2.1 Extract top and base

Calculating the thickness of a target unit requires stratigraphic top and base contacts. With help of the stratigraphic database (Chapter 1.4, Figure 11), the top and base contact lines were extracted. To achieve this automatically, the mapped geological units were subdivided into three groups:

(i) Younger geological units (grey units above target unit, Figure 11)

(ii) Target unit, including subunits (green units, Figure 11)

(iii) Older geological units (grey units below target unit, Figure 11)

The trace information extraction toolbox (TIE, RAUCH et al. 2019) was modified to store the geometric information of each top and base contact line of the GeoCover dataset. Tectonic contacts (i.e. top and base contacts coinciding with fault lines, see Chapter 1.3.2) were discarded, so that the final database *top and base contact lines* contains only stratigraphic contacts. Each top and base contact line is projected onto the DEM, and the corresponding 3D information is stored as a *XYZ* point cloud (see Chapter 2.2). Further details regarding the extraction of the top and base contacts can be found in NIBOUREL et al. (2023) as well as in RAUCH et al. (2019).

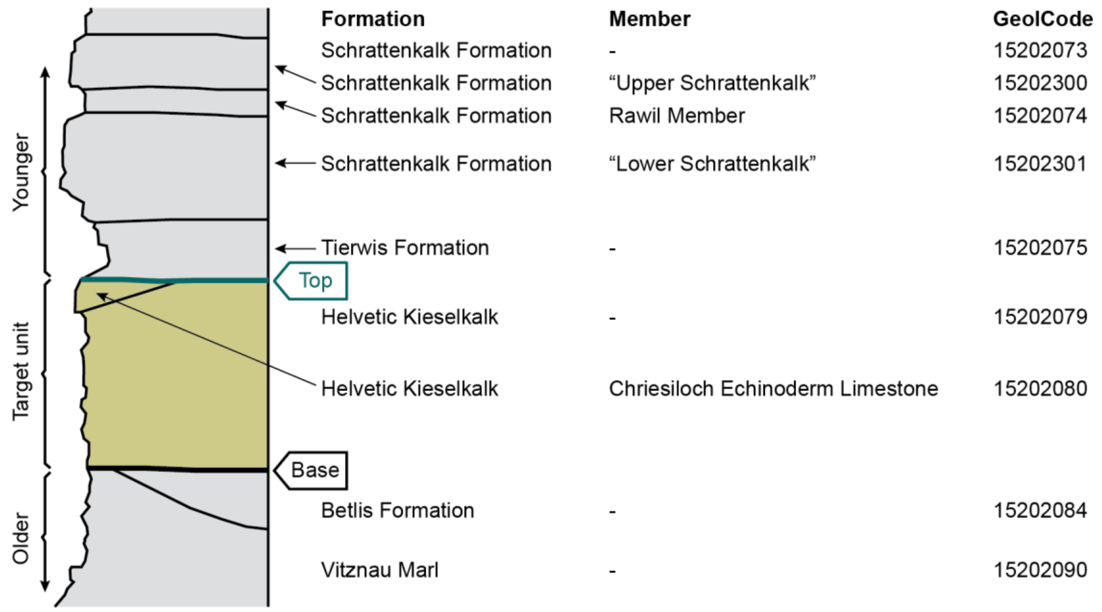


Figure 11: Stratigraphic profile modified from TRÜMPY (1980) and NIBOUREL et al. (2023) showing the relative age relationships used to automatically extract the top (contact between target unit and younger geological unit) and base (contact between target unit and older geological unit) contacts.

2.2 Extract orientation

2.2.1 Bedrock contacts method (BED)

The BED method uses the existing moment of inertia algorithm (FERNÁNDEZ 2005) to extract the orientation information (dip direction and dip) along the top and base contact *XYZ* point clouds (points *p*, Figure 10a). The method is based on the concept that the axis of maximum moment of inertia *I* represents the pole to the best-fitting plane through a set of points *p* (Figure 12a and b).

A moving window (see *MV* in Figure 10a) was used to incrementally extract the potentially changing orientation information along the top and base contacts. For each step, the orientation information, represented by the normal unit vector $\vec{n}_{BED}$ (Figure 10b, see also X, Y and Z components *(Dir_X*, *Dir_Y* and *Dir_Z*) of the orientation vector (*n*) in Table 7), was attributed to the central point of the corresponding points *p* (see points P_1 to P_N in Figure 10a, NIBOUREL et al. 2023). The green and black lines in Figure 13a show the automatically extracted orientation information for the base and top contacts, respectively.

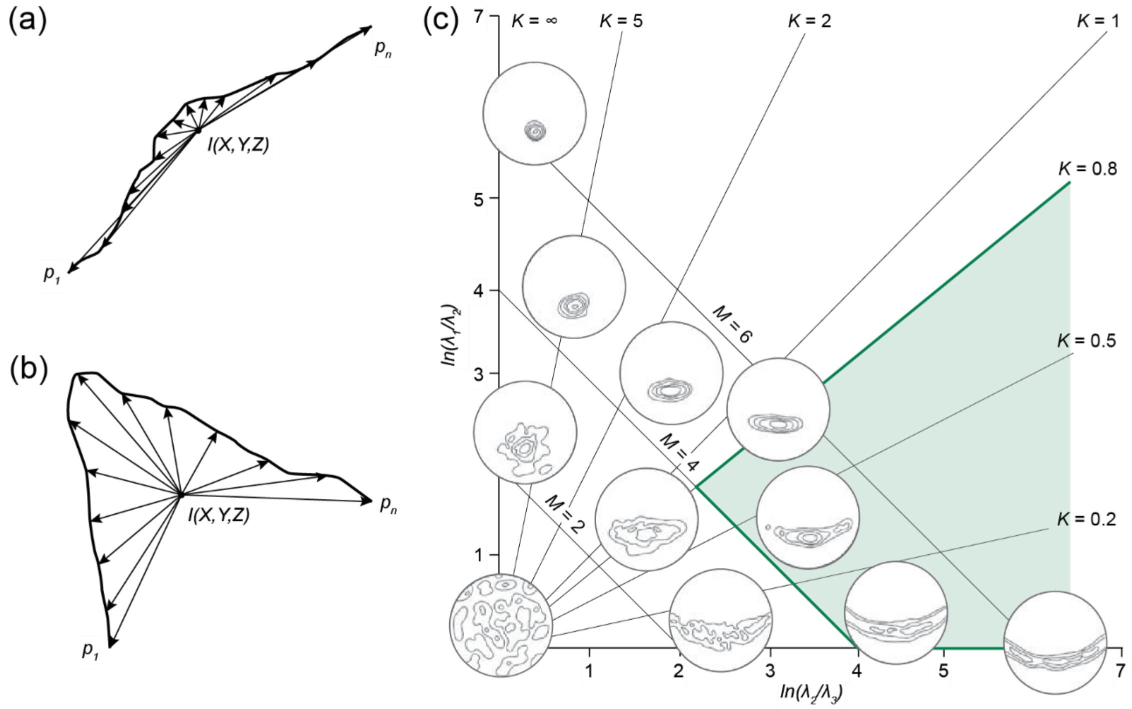


Figure 12: (a, b) Moment of inertia (*I*) approach used in the BED method to calculate a best planar fit for a group of *XYZ* points *p* (p_1 to p_n, modified from FERNÁNDEZ (2005), see also Figure 10a–d). (c) The values *M* and *K* are used to evaluate the planar fit depending on the distribution of p_1 to p_n (modified from FERNÁNDEZ 2005, WOODCOCK 1977). *M* values > 4 and *K* values < 0.8 (green) are considered to indicated good planar fits with reliable orientation. (a) Example of a high-quality planar fit. (b) Example in which the points *p* are aligned in a co-linear manner, so that no reliable orientation information can be obtained. See text and NIBOUREL et al. (2023) for further explanation.

Two parameters were used to validate the fit and the reliability of the orientation obtained using the BED method (FERNÁNDEZ 2005). The first parameter *M* reflects the degree of the planar fit, which is calculated for a given set of points *p* (Figure 12c). A high *M* value indicates a reliable planar fit. The second parameter *K* reflects the co-linearity of the points *p*. A high *K* value indicates that the points *p* are arranged in a co-linear manner, so that no reliable orientation can be extracted (Figure 12a). In contrast, a low *K* signifies a reliable orientation extraction, for example when the corresponding contact is mapped across a topographic ridge or valley (Figure 12b).

Table 7 shows an extract of the automatically extracted orientation output using the BED method. An example of the spatial distribution and the dip direction of the orientation information extracted using the BED method are shown on Figure 13a, for the map sheet Muotathal.

Table 7: Data structure of automatically extracted orientation output using the BED method.

Spatial reference			**Orientation (*n*)**			**Orientation**		**Reliability**	
***X* (m)**	***Y* (m)**	***Z* (m)**	***Dir_X***	***Dir_Y***	***Dir_Z***	**Dip direction (°)**	**Dip (°)**	***M***	***K***
2690 083	1199 701	572	0.370	–0.637	–0.677	330	47	7.27	1.74
2690 085	1199 701	574	–0.369	0.648	0.667	330	48	7.11	1.7
2690 087	1199 701	576	–0.369	0.650	0.664	330	48	7.24	1.42

Spatial reference			Orientation (*n*)			Orientation		Reliability	
X **(m)**	***Y*** **(m)**	***Z*** **(m)**	***Dir_X***	***Dir_Y***	***Dir_Z***	**Dip direction (°)**	**Dip (°)**	***M***	***K***
2690 089	1199 701	577	0.369	–0.652	–0.662	330	49	7.44	1.29
2690 319	1199 677	692	–0.318	0.584	0.747	331	42	8.09	1.41
2690 321	1199 675	699	–0.317	0.587	0.745	332	42	8.05	1.47
2690 323	1199 673	699	–0.315	0.589	0.744	332	42	8.03	1.53
2690 325	1199 673	696	–0.313	0.592	0.743	332	42	8	1.58
2690 327	1199 671	700	–0.310	0.596	0.741	333	42	7.98	1.64
2690 329	1199 671	696	–0.307	0.600	0.739	333	42	7.96	1.7

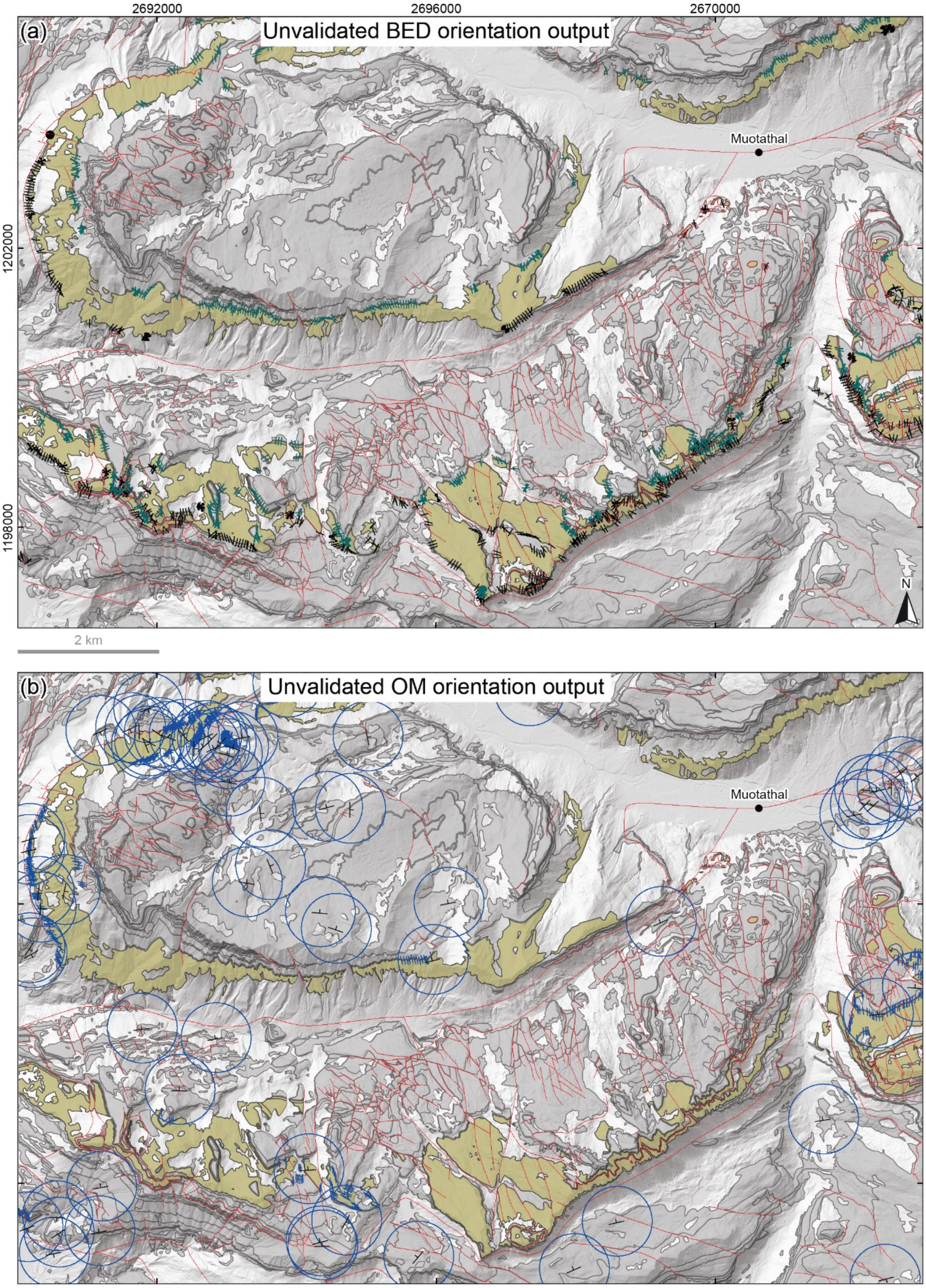


Figure 13: Example of the extracted orientation information using (a) the BED and (b) the OM methods. (a) The green and black lines represent the BED orientation outputs for the base and top horizons, respectively. The orientation of the line symbols indicates the extracted dip direction. (b) The blue lines indicate the orientation information attributed according to the bedding orientation measurements (black symbols) using a search radius r = 500 m (blue circles). Bedrock colours are those shown in Figure 11.

2.2.2 Orientation measurements method (OM)

In the OM method, the orientation information stored in bedding orientation measurements, measured by a field geologist and stored in the GeoCover dataset, is exploited (thick black symbol indicating the strike and dip, Figure 10e). The method uses a spherical search (blue circle with radius *r* = 500 m, Figure 10e) to select top and base contact points *P* (thick blue points, Figure 10e). The selected contact points are attributed with the dip direction and dip stored in the corresponding bedding orientation measurement (see normal unit vector $\vec{n}_{OM}$, Figure 10e), assuming constant orientation within the search radius *r*. This assumption, and the output validation procedure, are discussed in Chapter 3.2.2. An extract of the data table containing the extracted orientation information is shown in Table 8. The blue lines in Figure 13b show the dip direction of the automated orientation attribution, following the OM method for the map sheet Muotathal.

Table 8: Data structure of automatically extracted orientation output using the OM method

Spatial reference			**Orientation (n)**			**Orientation**	
X (m)	**Y (m)**	**Z (m)**	**Dir_X**	**Dir_Y**	**Dir_Z**	**Dip direction (°)**	**Dip (°)**
2690 083	1199 701	572	0.370	–0.637	–0.677	330	47
2690 085	1199 701	574	0.370	–0.637	–0.677	330	47
2690 087	1199 701	576	0.370	–0.637	–0.677	330	47
2690 089	1199 701	577	0.370	–0.637	–0.677	330	47
2690 319	1199 677	692	–0.318	0.584	0.747	331	42
2690 321	1199 675	699	–0.318	0.584	0.747	331	42
2690 323	1199 673	699	–0.318	0.584	0.747	331	42
2690 325	1199 673	696	–0.318	0.584	0.747	331	42
2690 327	1199 671	700	–0.318	0.584	0.747	331	42
2690 329	1199 671	696	–0.318	0.584	0.747	331	42

2.3 Extract thickness

Extracting the thickness requires the exact position of the top and base contacts, and the orientation of these contacts at a given locality as shown in Figure 13a and b. The two independent BED and OM methods used to calculate the thickness are described in the Chapters 2.3.1 and 2.3.2. In both methods, the model finds nearest neighbour pairs of points sitting on the top and base contacts, respectively (points *P* and *Q* on Figure 10c–e). For calculating the thickness of the target unit, the absolute value of the dot product between $\vec{v}$ representing the vector *P*-*Q* and the normal unit vector $\vec{n}$ at point *P* or *Q* is determined as shown in Figure 10c–f, see also NIBOUREL et al. 2023).

The data structure of the resulting thickness data, using the BED and OM methods, is shown in Table 9.

Table 9: Data structure of the automatically extracted thickness data using the BED and OM methods. The first five rows are based on the BED method, the last five rows in blue are based on the OM method. *dist_OM* = Distance between the bedding orientation measurement and point *P*, *α* = Orientation difference, *δ* = Thickness difference, δ_{MEAN} = Thickness mean difference, *T1* and *T2* = identifier of base and top contacts, *n(T1)* = length of contact *T1, GeolCode* = Numeric code identifying the geological unit. See text for further explanations.

Spatial reference				Reliability thickness				Feature info			
X (m)	Y (m)	Z (m)	Thick-ness (m)	*dist_ OM* (m)	*α* (°)	*δ*	δ_{MEAN}	*T1*	*n(T1)*	*T2*	*GeolCode*
2690 108	1199 416	707	375	–-	56	0.2	0.23	198	59	1	15202079
2690 109	1199 416	707	359	–	57	0.2	0.24	198	59	1	15202079
2690 110	1199 417	707	343	–	55	0.1	0.24	198	59	1	15202079
2690 111	1199 417	707	351	–	50	0.2	0.23	198	59	1	15202079
2690 112	1199 418	707	355	–	48	0.2	0.25	199	59	1	15202079
2707 281	1202 187	1636	130	139	–	–	0.09	333	47	193	15202079
2707 280	1202 187	1636	131	140	–	–	0.08	333	47	193	15202079
2707 279	1202 186	1636	132	141	–	–	0.07	333	47	193	15202079
2707 278	1202 186	1636	132	143	–	–	0.07	333	47	193	15202079
2707 277	1202 186	1636	133	145	–	–	0.06	333	47	193	15202079

2.3.1 Bedrock contacts method (BED)

The BED method calculates two thickness values for each *P*-Q pair. A first thickness was calculated with the estimated orientation at point *P* (DP_{BED}, Figure 10d):

$$DP_{BED} = \left|\vec{v} \cdot \overrightarrow{nP_{BED}}\right|$$

On Figure 10d, DP_{BED} is represented by the length of the vector *P*-*Q*'. A second thickness (DQ_{BED}, see vector Q-P' in Figure 10d) was calculated using the estimated orientation at point Q:

$$DQ_{BED} = \left|\vec{v} \cdot \overrightarrow{nQ_{BED}}\right|$$

Both thickness values were stored in a data table, from which an extract is shown in Table 9. Figure 14a shows an example of the raw and unvalidated thickness output using the BED method.

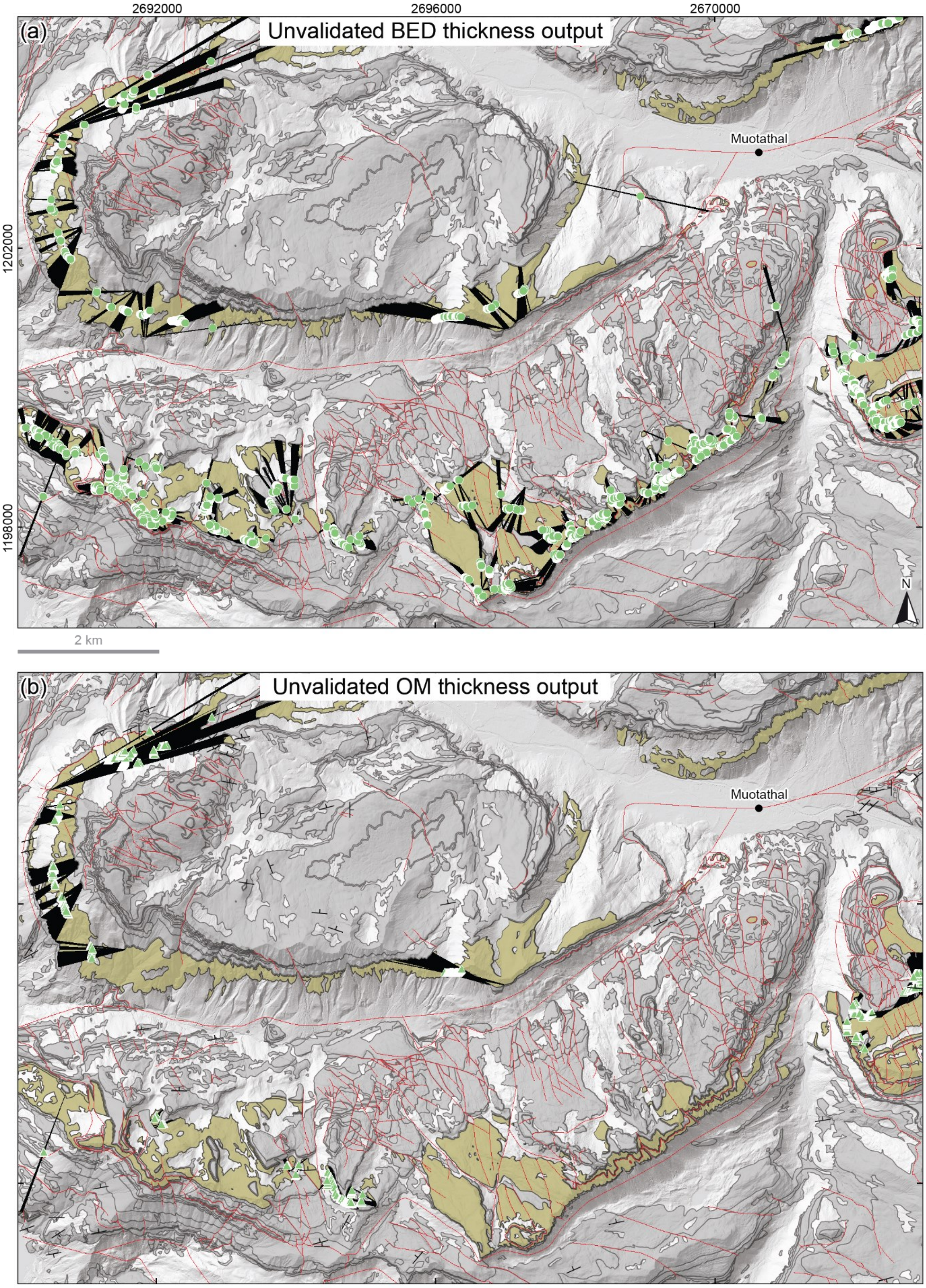


Figure 14: Unprocessed thickness output using (a) the BED and (b) the OM methods. The nearest neighbours *P* and *Q*, based on which the thickness values were estimated, are connected by thin black lines. (a) The green circles represent the BED thickness output, (b) the green triangles the OM thickness output. Bedrock colours are those shown in Figure 11.

2.3.2 Orientation measurements method (OM)

The same formula was applied by the OM method to calculate the thickness, but using the orientation information stored at a nearby bedding orientation measurement:

$$D_{OM} = |\vec{v} \cdot \overrightarrow{n_{OM}}|$$

In contrast to the BED approach, only one thickness value was calculated per nearest neighbour pair *P*-*Q*. Figure 14b shows an example of the raw and unvalidated thickness output of the BED method. The data structure can be viewed in Table 9 (lower half, highlighted in pale blue).

2.4 Post processing

During the post processing, the automatically generated thickness data had to pass two tests:

(i) All thickness data that were calculated across one or more faults were discarded (see red *P*-*Q* line and red circles / triangles, Figure 15a). Such thickness values do not represent the true stratigraphic thickness.

(ii) All thickness data, which fall outside a mapped target unit polygon were not considered for the subsequent work steps (red arrows in Figure 15a).

The remaining thickness data points (green circles and triangles and black *P*-*Q* lines, Figure 15b) were further validated as described in Chapter 3).

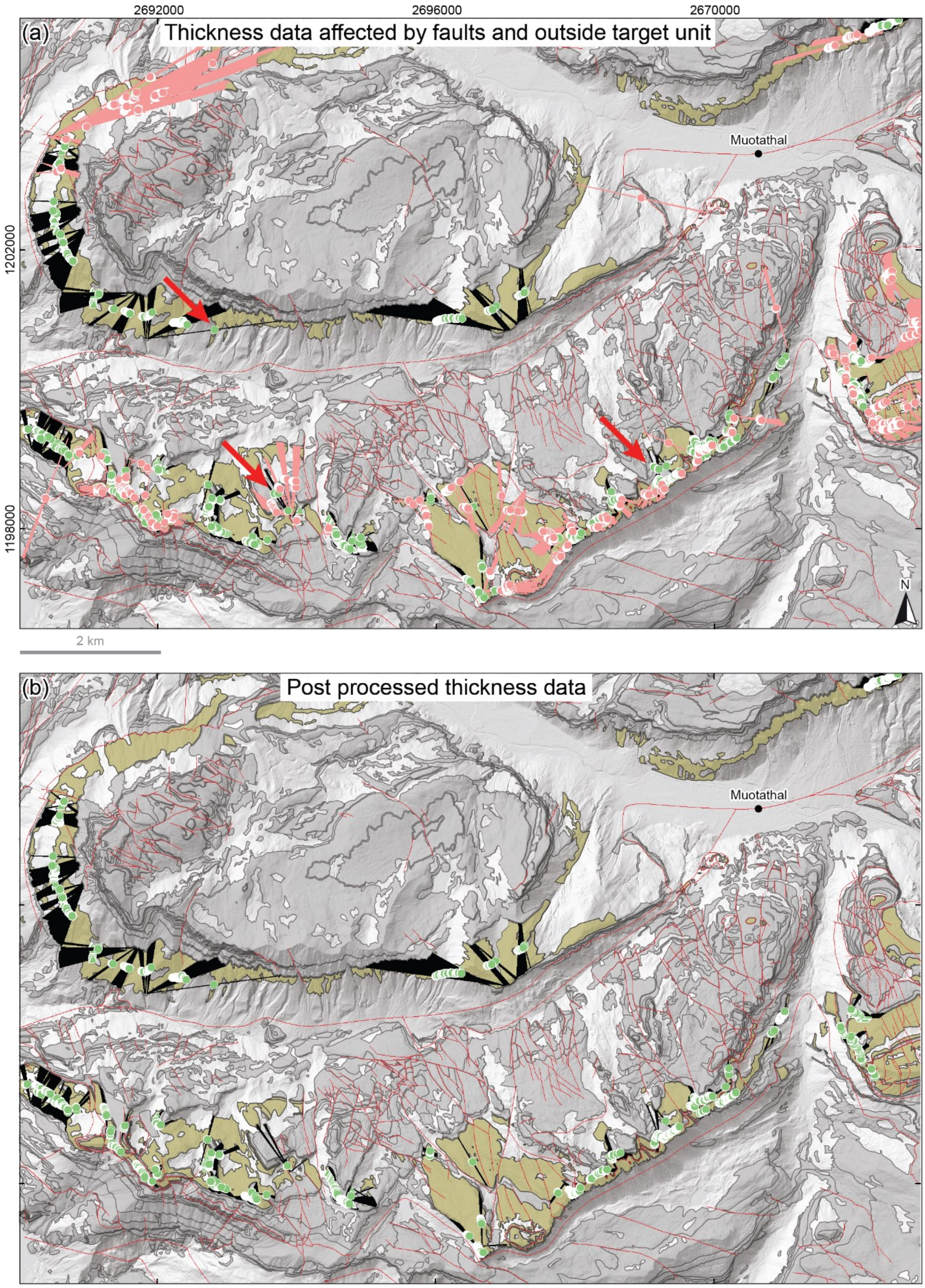


Figure 15: Visualisation of the thickness data post processing of both the BED (red and green circles) and the OM (red and green triangles) methods. (a) Thickness outputs (*P-Q* lines and point symbols) that are affected by faults are shown in red. Thickness outputs that do not fall into a target unit polygon (green polygons) are highlighted by red arrows. (b) Remaining thickness data after the post processing step (BED and OM). Bedrock colours are those shown in Figure 11.

3 Output validation

The automatically generated orientation and thickness outputs were validated using eight numeric reliability indicators, listed in Table 10. Other parameters were tested during the investigation, but did not improve the result significantly.

3.1 Validation of orientation information

3.1.1 Bedrock contacts approach (BED)

For contacts comprising less than 500 points *p*, a moving window *MV* of half the contact length was used (Figure 10a). A maximum moving window length MV_{max} of 250 points *p* was used for longer contact lines. At a DEM resolution of 2 m, the MV_{max} corresponds to a trace length of approximately 500 m (see also Table 10). Contact lines comprising less than 40 points (this corresponds to a moving window length of 20 points) were discarded, since these may not yield significant 3D information (see also the minimum contact length in Table 10). The minimum and maximum contact lengths chosen in this investigation reflect:

(i) the rate of change in the orientation of lithological contacts

(ii) the degree of mapping generalisation in the GeoCover dataset and

(iii) the resolution of the DEM

As shown in Chapter 2.2.1, the degree of fit and the reliability of the extracted orientation information using the BED method was quantified by the *M* and *K* values. FERNÁNDEZ (2005) suggests that *M* values > 4 and *K* values < 0.8 yield planar best-fits with good degrees of fit and reliability (Figure 12c, Table 10). Hence, only thickness data fulfilling these criteria are considered for the subsequent work steps. Further details can be found in FERNÁNDEZ (2005) and NIBOUREL et al. (2023).

3.1.2 Orientation measurements approach (OM)

The larger the distance between a bedding orientation measurement and the contacts attributed with the corresponding orientation information, the more likely is the assumption of constant orientation true. Therefore, this distance (see *dist_OM* in Table 8, Table 9 and Table 10) was used as an indirect reliability indicator. In this study, only thickness values with a *dist_OM* < 500 m were considered.

3.2 Validation of thickness data

The reliability indicators used to automatically validate the BED and OM thickness outputs are listed in the lower part of Table 10.

As seen in Figure 14, the BED and OM methods generate very densely spaced (ca. 2 m) thickness data. To reduce the size of the dataset and to calculate one more representative thickness value, a mean thickness D_{MEAN} was calculated. One D_{MEAN} summarises all post-processed and validated single thickness data points which:

(i) correspond to the same base / top contact segments (BED and OM)

(ii) are situated within the same target unit polygon (BED and OM)

(iii) are calculated based on the same bedding-orientation measurement (only OM method)

The normalised thickness mean difference δ_{MEAN} quantifies the difference between D_i, representing a single thickness value based on the BED or OM methods, and D_{MEAN}:

$$\delta_{MEAN} = |(D_i - D_{MEAN})/D_{MEAN}|$$

Thickness outputs with a δ_{MEAN} < 1 were considered for the interpolation of the thickness data (Table 10). Thickness outputs with a δ_{MEAN} > 1 were discarded for the subsequent work steps.

Table 10: List of reliability indicators, including the threshold values used to validate the thickness data and a short description.

Reliability indicators (unit)	Condition	Value	Description
Orientation data BED			
Contact length (# points)	>	40	Minimum length of a contact line to be considered for the orientation extraction (NIBOUREL et al. 2023)
MV_{max} (# points)	=	250	Maximum length of the moving window *MV* used for the orientation extraction (NIBOUREL et al. 2023)
M ()	>	4	Degree of planar fit of considered *XYZ* points (FERNÁNDEZ 2005)
K ()	<	0.8	Degree of co-linearity of considered *XYZ* points (FERNÁNDEZ 2005)
Orientation data OM			
Dist_OM (m)	<	500	Euclidean distance between bedding orientation measurement and points *P* or *Q* to be attributed with the orientation information (JUCHLER 2021)
Thickness data BED and OM			
δ_{MEAN} ()	<	1	Normalised difference between thickness D_{BED} or D_{OM} and the mean thickness D_{MEAN} calculated for all thickness values corresponding to the same top / base contact segments and target unit polygon
Thickness data BED			
Relative thickness ratio δ ()	<	0.75	Normalised ratio between DP_{BED} and DQ_{BED} (NIBOUREL et al. 2023)
Orientation difference α (°)	<	30	Degree of parallelism between DP_{BED} and DQ_{BED} (NIBOUREL et al. 2023)

3.2.1 Bedrock contacts method (BED)

Two parameters were used to validate the reliability of the BED thickness output. The orientation difference α quantifies the degree of parallelism between the two thickness vectors DP_{BED} and DQ_{BED} (Figure 16a):

$$\alpha = atan \frac{norm(\overrightarrow{nP_{BED}} \times \overrightarrow{nQ_{BED}})}{\overrightarrow{nP_{BED}} \bullet \overrightarrow{nQ_{BED}}}$$

A low angle α indicates that the top and base contacts yield consistent orientation information and are subparallel. In this investigation, thickness values with an α < 30° were regarded as consistent and, thus, potentially reliable (see Table 10).

The relative thickness ratio δ quantifies the difference between the thickness values DP_{BED} and DQ_{BED} of a nearest neighbour pair P and Q (Figure 16b):

$$\delta = \frac{|DP_{BED} - DQ_{BED}|}{max(DP_{BED}, DQ_{BED})}$$

As sketched in Figure 16b, a high δ value can for example highlight thickness data which were extracted in a dip-slope setting. In such a setting, small orientation differences can lead to very contrasting thickness values (Figure 16b). Thickness data with a $\delta > 0.75$ were considered for the subsequent work steps (Table 10).

Approximately 90% of the BED thickness output is discarded when the M, K, α and δ filters are applied to the BED thickness output, as illustrated in Figure 17a and b.

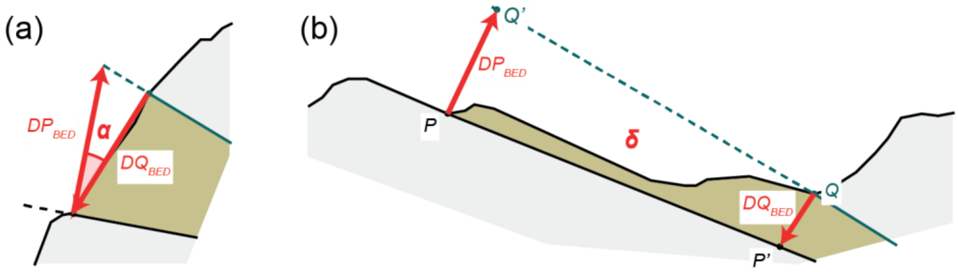


Figure 16: Schematic sketch of the reliability indicators α and δ (modified from NIBOUREL et al. 2023). (a) The angle α represents the degree of parallelism between the top and base contacts. (b) The relative thickness ratio δ reflects the ratio of thickness values DP_{BED} and DQ_{BED}, calculated with the orientation information of the two nearest neighbours P and Q and normalised to the larger of the two obtained values.

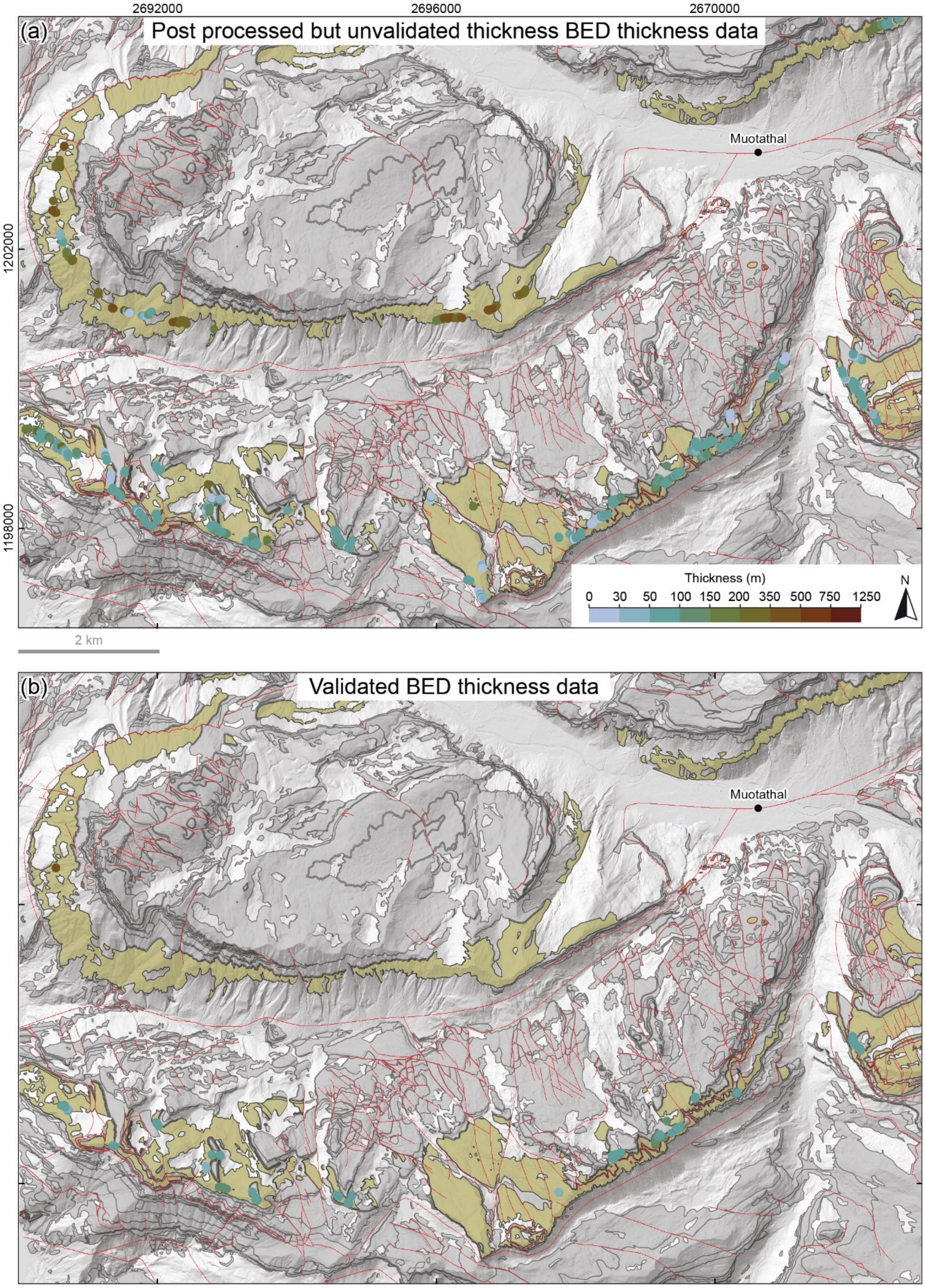


Figure 17: Visualisation of the validation of the thickness data extracted using the BED method. (a) Post processed but unvalidated thickness data (circles) using the BED method. (b) Validated BED thickness data (circles) using the reliability indicators listed in Table 10.

3.2.2 Orientation measurements approach (OM)

No specific reliability parameters were applied to the OM thickness outputs.

3.3 Manual quality check with literature data

To improve the quality, the literature-based thickness and usability data (LitD) as well as the thickness data extracted using the BED and OM methods were checked manually, using the criteria listed in Table 11.

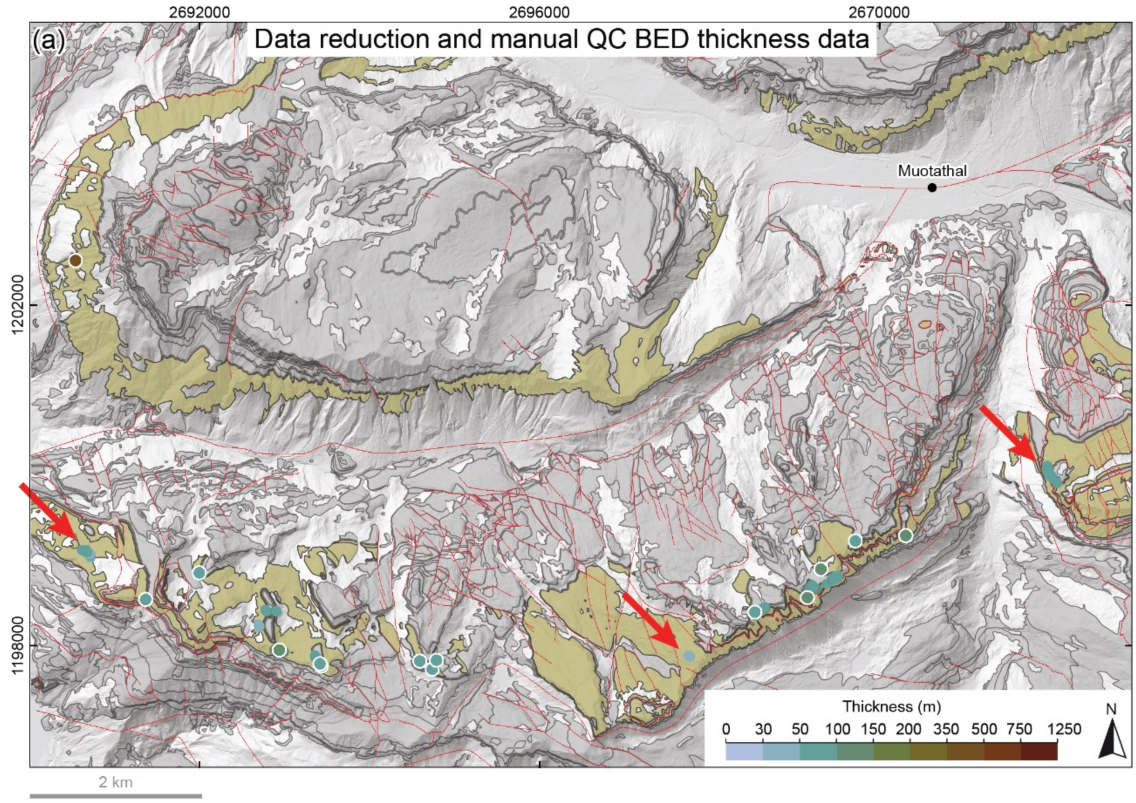
Table 11: Criteria used to manually quality check the literature-based thickness data and usability ratios (summarised as LitD) and the thickness data extracted using the BED and OM methods.

Criteria for quality check	Concerned datasets	Description
Affected by fault	LitD (thickness and usability), BED, OM	Thickness estimate appears to be affected by faults (most cases are automatically detected during the post processing).
Incomplete exposure	LitD (thickness and usability), BED, OM	Thickness estimate from area with poor or no exposure of the base and / or top contacts.
Fold hinge	LitD (only thickness), BED, OM	Rapid thickness and orientation changes are often observed close to fold hinges. Therefore, thickness data from hinge areas are discarded.
Unsuitable nearest neighbours	BED, OM	The nearest neighbours P-Q points appear unsuitable for the calculation of a thickness (for example very far away from each other).
Wrong orientation information	BED, OM	Thickness estimate is based on orientation information that does not reflect the true orientation of the strata in the area (often the case in very steep areas).
Underground data	LitD (thickness and usability)	Underground tunnel or borehole data that do not represent the conditions close to the surface (depth > 500 m) are discarded.
Poor quality	LitD (thickness and usability)	Generally poor documentation in the cross-section or stratigraphic description, so that the information has to be regarded unreliable.
Unsuitable cross-section orientation	LitD (only thickness)	Analysed cross-section that is not oriented normal (+/– 25°) to the overall trend of the main structures in the investigated area. Hence, the data do not reflect the true stratigraphic thickness.
Location unsure	LitD (only thickness)	Cross-section or stratigraphic description does not include a clear spatial reference.

If one or more of the criteria listed in Table 11 are not met, the corresponding data point is flagged and discarded for the subsequent preparation of the final dataset. The red arrows in Figure 18a point to examples of thickness data that were calculated based on ”wrong orientation information” extracted using the BED method. Figure 18b shows the quality-checked thickness data, including the LitD, BED and OM data.

3.4 Data reduction of BED and OM thickness data

To avoid an overrepresentation of the densely (2 m) spaced BED- and OM-derived thickness data with respect to the less abundant literature-based data, the number of BED and OM thickness data points was ”reduced”. The individual BED- and OM-derived data points are represented by D_{MEAN} values, as illustrated in Figure 18a (dots with white outline, see Chapter 3.2 for the calculation of D_{MEAN}).



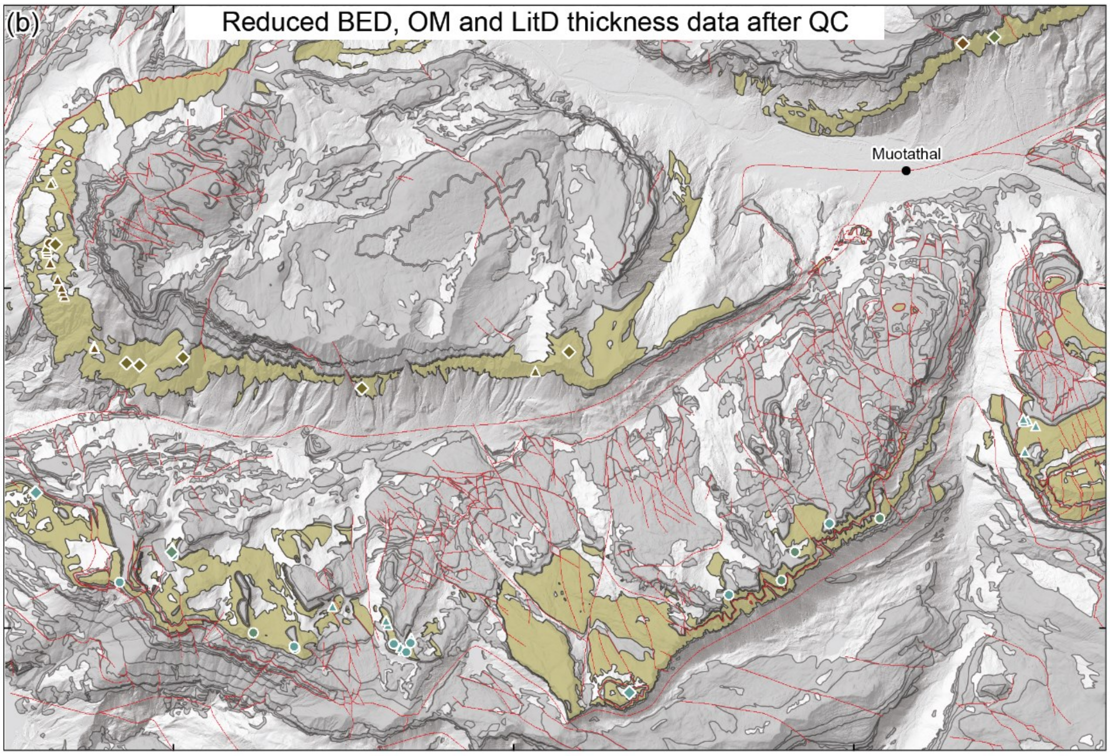


Figure 18: (a) Visualisation of the data reduction of the thickness data extracted using the BED method. Many of the validated thickness data points, shown as circles without white stroke, are represented by mean thickness values D_{MEAN} and highlighted as larger circles with white stroke. Thickness outputs that were classified unreliable during the manual quality control (QC) work step are highlighted by red arrows. See text for further explanation. (b) Validated, manually quality-checked and reduced BED (circles), OM (triangles) and literature (diamonds) thickness data. Bedrock colours are those shown in Figure 11.

4 Interpolation and dataset preparation

Figure 19 illustrates the step-wise procedure to prepare the final dataset for highlighting the promising hard rock occurrences (see step 4 in Figure 2).

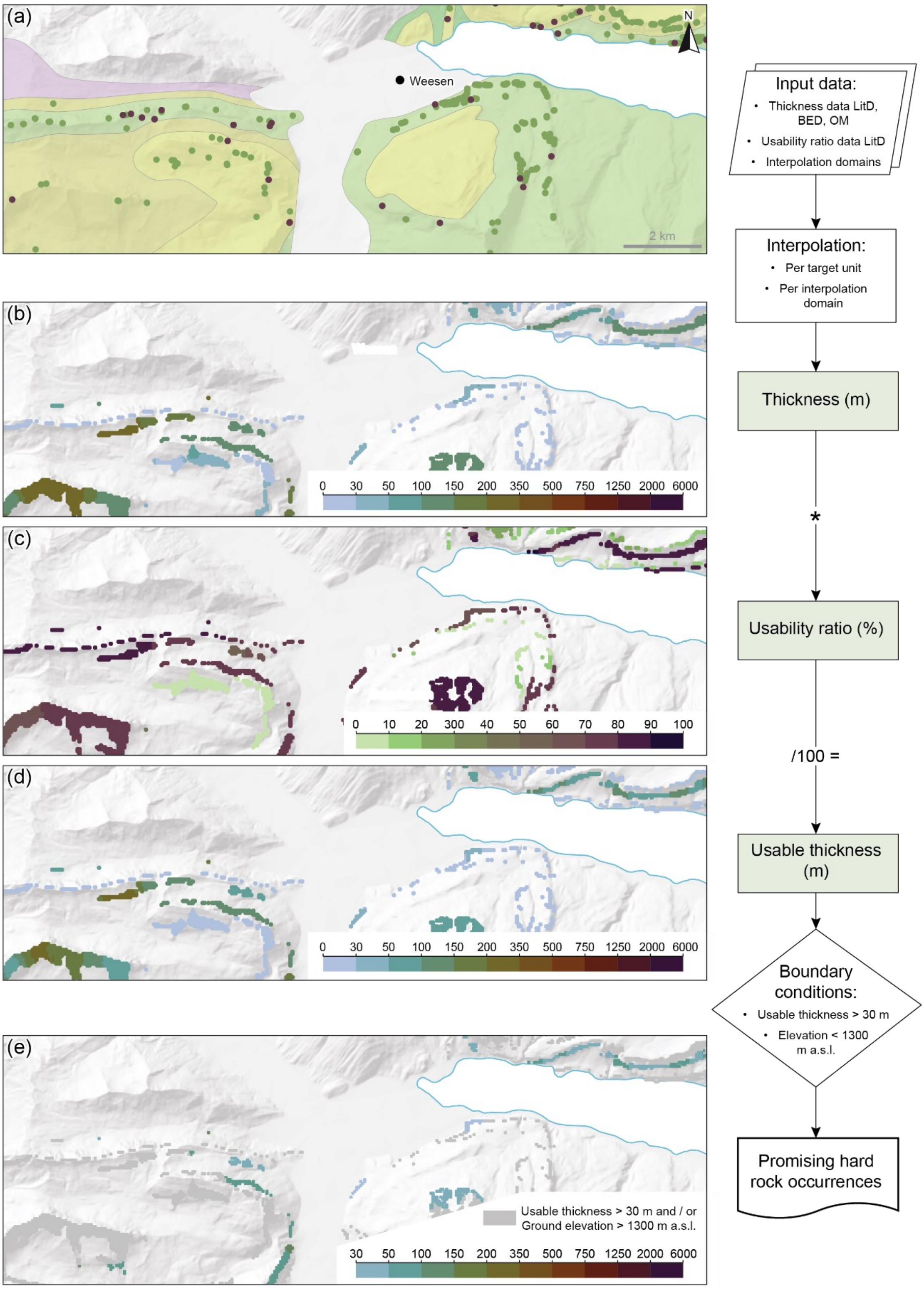


Figure 19: Map views (left) and flow chart diagram (right) illustrating the interpolation and dataset preparation work steps. (a) Literature-based (LitD) and automatically extracted thickness estimates (BED, OM) are shown as green dots, literature-based usability ratio input data (LitD) as red dots. The tectonic domains used for the interpolation of these data are shown as coloured polygons (see Figure 9). (b) Interpolated thickness data. (c) Interpolated usability ratio data. (d) Estimated usable thickness calculated by multiplying rasters (b) and (c). (e) Final map view highlighting the hard rock occurrences with a usable thickness > 30 m and situated at a ground elevation lower than 1300 m a.s.l.

4.1 Input data and interpolation domains

The following data-sets are used as input data for the interpolation and dataset preparation work step: (i) The validated and manually quality-checked thickness data extracted using the BED and OM methods (D_{MEAN} values) and compiled from the literature (LitD) are used to assess whether a target unit at a given location is sufficiently thick (green dots, Figure 19a). (ii) The compiled usability ratios (LitD) are used to assess the proportion of potential hard-rock-quality material within a given unit at a given location (red dots, Figure 19a). (iii) The coloured polygons in Figure 19a highlight the interpolation domains used for the subsequent interpolation work step. The interpolation domains were defined based on the Tectonic Map of Switzerland (see Chapter 1.7, Table 1 and Figure 9).

4.2 Interpolation and raster calculations

As seen in Figures Figure 7, Figure 8 and Figure 19a, the density of thickness input data is much higher than the density of the usability ratio input data. In order to achieve the best possible prediction of the usable thickness, the thickness data (Figure 19b) and the usability ratio data (Figure 19c) were first interpolated individually. One interpolation was performed per target unit and per interpolation domain (see coloured polygons in Figure 19a). The resulting interpolated thickness and usability ratio rasters were then simply multiplied as shown in Figure 19d.

The inverse distance weighting (IDW) formula used for interpolating a value V_i at raster cell i is given below:

$$V_i = \frac{\sum_{j=1}^{n} \frac{v_j}{\left(\sqrt{d_{ij}^2 + s^2}\right)^p}}{\sum_{j=1}^{n} \frac{1}{\left(\sqrt{d_{ij}^2 + s^2}\right)^p}}$$

where d_{ij} is the distance between the raster cell i and the data point j in meters, v_j is the known value at point j, p is the power parameter and s is the smoothing parameter. The cell size as well as the parameters p and s used for interpolating the thickness and usability ratio data are listed in Table 12.

Table 12: Inverse distance weighting (IDW) interpolation parameters.

Raster cell size (m)	50
Power value *p*	2.25
Smoothing parameter *s*	1000

Quantitative and qualitative tests were performed to select the best-suited power and smoothing parameters for the dataset.

After a first interpolation, suspicious input data (visible as extreme depressions or summits in the interpolation surface) were removed if necessary, and the interpolation process was repeated with the remaining values. This procedure was repeated until a high-quality interpolation was reached.

Finally, the usable thickness *UD* was calculated by multiplying the thickness *D* and usability ratio *U* rasters as follows:

$$UD = D \bullet \frac{U}{100}$$

The resulting usable thickness raster is shown in Figure 19d.

4.3 Vectorisation and attribution

To add text information (strings) to the final dataset, the interpolated raster was first vectorised, and all numeric values were stored into a GeoPackage file. The string information of the corresponding target units stored in the file (HSt_unit_info.xlsx) was then appended to the vector dataset using the GeolCode field as a join key. All attributes included in the dataset are shown in Table 13.

4.4 Boundary conditions

The final dataset shows all hard rock geological occurrences situated at a ground elevation lower than 1300 m a.s.l. and with a usable thickness exceeding 30 m (see also Figure 19d, e). These boundary conditions were chosen in consultation with the hard rock industry. For more details, the reader is referred to Chapter 5.4 of the Hard rock catalog (NIBOUREL et al. 2024). The elevation information was retrieved from the digital elevation model swissALTI3D.

5 Quality assessment and uncertainties

The quality and the uncertainty of the predicted thickness values stored in the dataset mainly depend on (i) the variability of the input values, (ii) the quality of the input data and (iii) the density of the input data used to estimate the usable thickness. An absolute determination of the quality is not possible. However, attempts to quantify the variability of input values (Chapter 5.4) and the density of input data (Chapter 5.3) are given below and are communicated to the user in the form of input data density maps and error estimates. The most important uncertainties include the following:

(i) Uncertainties in the LitD, BED or OM input data: clearly incorrect thickness or usability ratio values are usually detected during the manual quality check, e.g. pronounced depressions or highs in the interpolated raster output. If necessary, these can be adjusted. Smaller inconsistencies are practically impossible to detect. There are many reasons for errors or inaccuracies, e.g. poor exposure of the target units and the corresponding top and base contacts, complex structures including folds and faults.

(ii) Subjective interpretations: during the production of geological maps, cross-sections or stratigraphic descriptions, the author always generates an interpretative structural geological model. This can introduce a subjective bias to the literature-based input data.

(iii) Age and style of geological mapping: the mapping style and the accuracy of geological maps have evolved from the first GA25 geological map sheets published between ca. 1930 to today. Older geological maps include fewer unconsolidated deposits and thus more mapped bedrock (RAUCH et al. 2019). Therefore, hard rock occurrences may appear larger on older map sheets. In recent years, 3D data and new tools are increasingly being used in the map production process. Additionally, older geological maps were produced using poorer-quality topographic base maps. Therefore, these maps are likely to yield less accurate 3D information than more recent ones, especially from areas of very steep terrain. Especially along very steep slopes (> 45°), small imprecisions in the mapping of contacts have a large impact on the extracted orientation and thickness information. Therefore, orientation and thickness data extracted from very steep areas are associated with higher uncertainties.

5.1 Uncertainty of orientation data

Figure 20 shows a comparison of the automatically extracted orientation data using the BED method with nearby (i.e. within a radius of 500 m) bedding orientation measurements (OM method). The validated orientation data extracted using the BED method have a median misfit with respect to the closest bedding orientation measurement of about 10°, thus indicating relatively good agreement between the two independent datasets. However, more than 50% of the extracted orientation data differs by more than 30°, even when *M* and *K* are used to validate the quality and degree of fit (see dark grey histogram, Figure 20). This observation shows that the orientation data extracted using the BED method data are generally associated with high uncertainty, which leads to more uncertainty in the corresponding BED thickness data (see Figure 21). Generally, the main sources of uncertainty associated with the orientation data are the following:

(i) Assuming constant orientation within 500 m in OM method: assuming constant orientation over 500 m is in many cases an oversimplification, especially in strongly folded areas.

(ii) Representativeness of field orientation measurements: the uncertainty is generally ±10° and may be more if the measurements do not represent the large-scale orientation of the structures in the area. In some cases, they could have been taken on a parasitic fold or close to a fault.

(iii) Relocated bedding orientation measurements: bedding orientation measurements of the GeoCover / GA25 dataset are sometimes relocated to enhance the legibility of the geological map. Consequently, the spatial reference of the bedding orientation measurements is associated with some uncertainty.

(iv) Systematic false-fits in the BED output: systematic false-fits represent a major source of bias. For example, when a fold structure intersects a flat topographic surface, the BED method will fit a planar surface through the contact, and the reliability indicators *M* and *K* are not able to recognise the wrong orientation data (see NIBOUREL et al. 2023 for further details regarding such false fits).

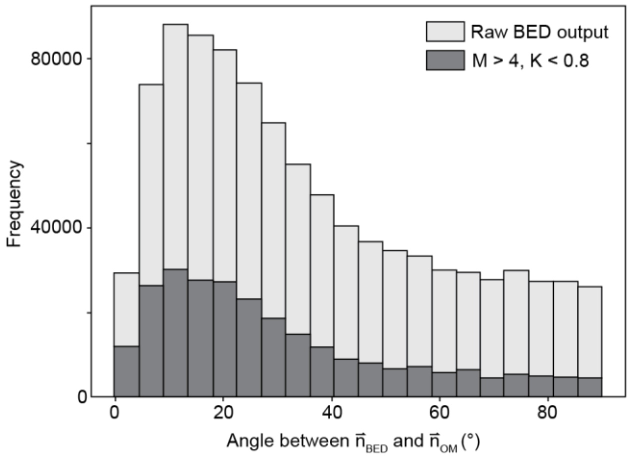


Figure 20: Comparison of the orientation information extracted using the BED method with the bedding orientation measurements (OM method) within a radius of 500 m. The unvalidated orientation output is shown in light grey, the validated orientation output using the reliability indicators *M* and *K* are highlighted in dark grey. Only the data for the Garschella-Formation are shown in this figure. See text and Chapter 2.2 for further explanations.

5.2 Uncertainty of thickness data

Comparing the independent thickness datasets (i.e. BED, OM, LitD) makes it possible to roughly estimate the uncertainties associated with the thickness input data. Thickness data points from areas within a radius of 500 metres were compared.

Figure 21 presents the normalised difference *ΔThickness*(*BED, LitD*) between the validated and quality-checked thickness input data, extracted using the BED method, and the nearby literature data (LitD). It was calculated using the following equation:

$$\Delta Thickness(BED, LitD) = \left(\frac{D_{\text{BED}} - D_{\text{LitD}}}{D_{\text{LitD}}}\right) \bullet 100$$

where D_{BED} represents the thickness value extracted using the BED method and D_{LitD} is the corresponding nearby literature-based thickness value. The difference between the two thickness values is normalised by D_{LitD} and expressed in percent. Positive *ΔThickness*(*BED, LitD*) values indicate that D_{BED} is higher than the corresponding literature value. Negative *ΔThickness*(*BED, LitD*) values indicate that D_{BED} is lower than the corresponding literature value. The BED method tends to underestimate the thickness by about 25% with respect to the literature data (see median difference, Figure 21). The BED method commonly underestimates the thickness by up to 50% with respect to the literature-based estimates.

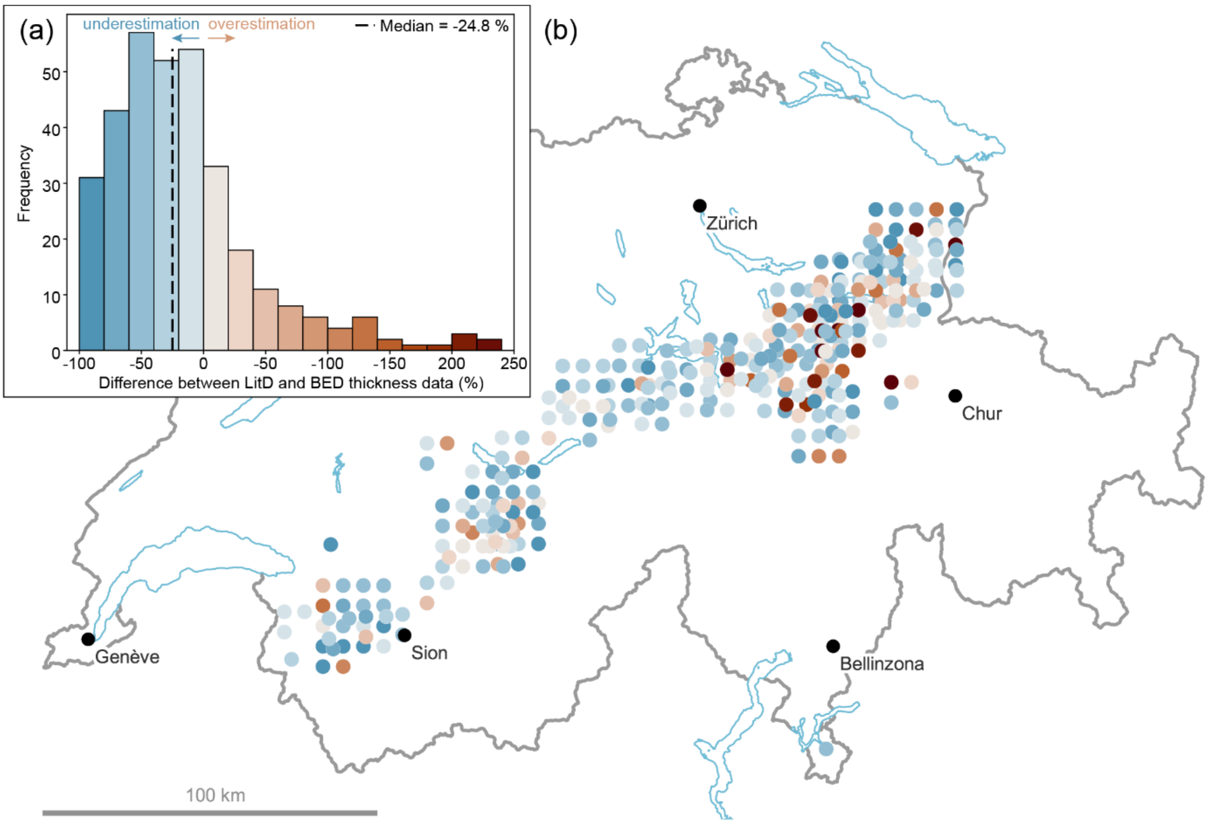


Figure 21: (a) Map and (b) histogram plot showing the normalised difference *ΔThickness*(*BED, LitD*) between the validated and quality-checked thickness input data, extracted using the BED method, and the literature-based (LitD) data within a radius of 500 m. The thickness difference is normalised to the LitD value, which is treated as ground truth. See text for further explanations.

Figure 22 shows the normalised difference *ΔThickness*(*OM, LitD*) between the validated and quality-checked thickness input data, extracted using the OM method, and the nearby literature data (LitD). The *ΔThickness* was calculated using the following equation:

$$\Delta\text{Thickness}(\text{OM, LitD}) = \left(\frac{D_{\text{OM}} - D_{\text{LitD}}}{D_{\text{LitD}}}\right) \bullet 100$$

where D_{OM} represents the mean thickness value extracted using the OM method and D_{LitD} is the corresponding literature-based thickness value. The difference between the two thickness values is normalised by D_{LitD} and expressed in percent. Positive *ΔThickness*(*OM, LitD*) values indicate that D_{OM} is higher than the corresponding literature value. Nagative *ΔThickness*(*OM, LitD*) values indicate that D_{OM} is lower than the corresponding literature value. The OM method tends to underestimate the thickness by about 5% with respect to the literature-based data (see median difference, Figure 22).

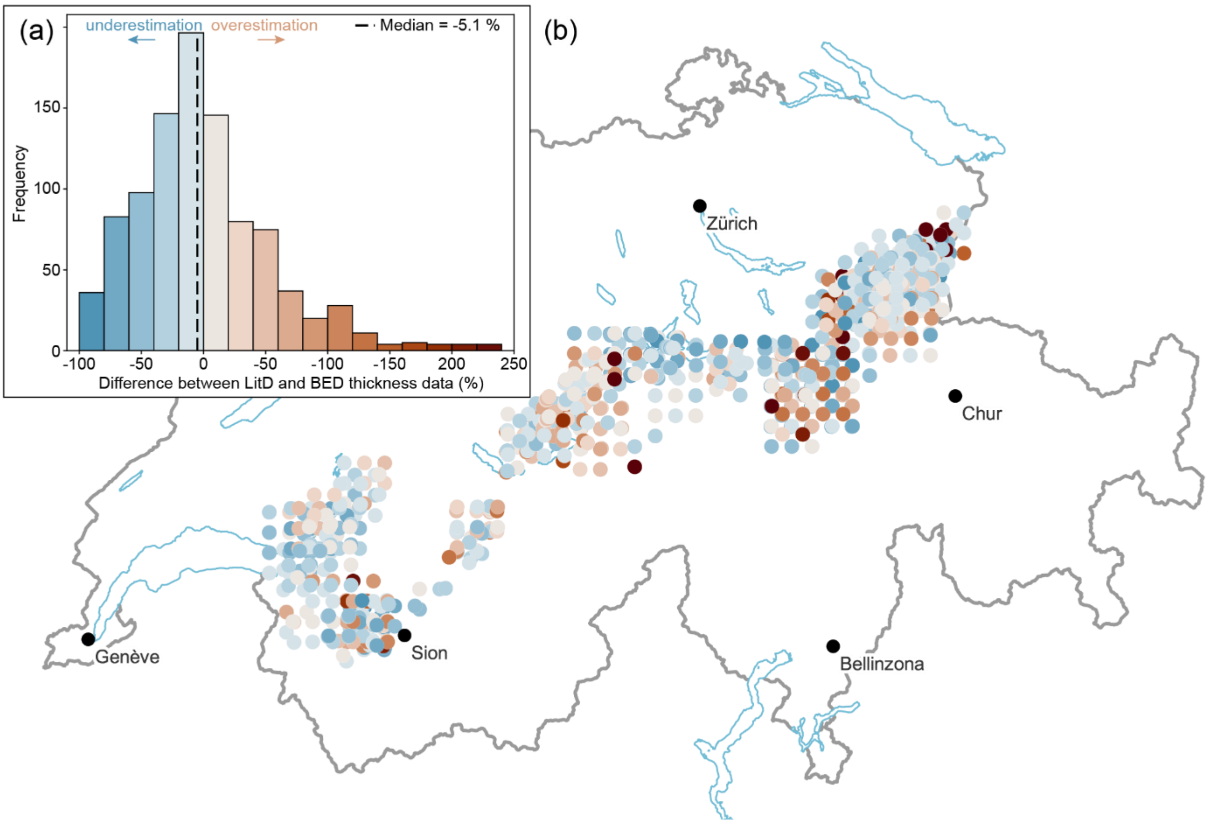


Figure 22: (a) Map and (b) histogram plot showing the normalised difference $\Delta Thickness(OM, LitD)$ between the validated and quality-checked thickness input data, extracted using the OM method, and the literature-based (LitD) data within a radius of 500 m. The thickness difference is normalised to the LitD value which is treated as ground truth. See text for further explanations.

The following are the main sources of uncertainty related to the thickness data:

(i) Underestimation of the thickness using the BED and OM methods: the nearest neighbour search used to calculate the thickness may generally lead to an underestimation of the thickness by the BED and OM approaches.

(ii) Dip slope: when the slope of the terrain is subparallel to the dip of the exposed bedrock units, the two nearest neighbours *P* and *Q* may be located at a large distance relative to the thickness of the unit. In such a setting, a slight difference in orientation will lead to a major change in the resulting thickness value, calculated by the BED or the OM method. In such areas, the thickness data are subject to a particularly high degree of uncertainty.

(iii) Steep terrain and map quality: the limited performance of the BED orientation extraction in very steep (> 45°) terrain likely leads to an overestimation of the dip and, in many cases, to an underestimation of the resulting thickness. This effect may be even more pronounced in older geological maps, which were made based on a poorer-quality old topographic information.

(iv) Systematic false fits: systematically false planar fits using the BED orientation extraction method can occur, for example near fold hinges (see also Chapter 5.1).

(v) Literature data: although regarded as ground truth for the uncertainty analysis, these data are also associated with significant uncertainties.

Some inconsistencies among the independent LitD, BED and OM thickness input data-sets remain also after validation and manual quality checks, as shown in Figure 21 and Figure 22. The systematic underestimation of the thickness by the BED method must be noted. However, the analyses also highlight that the normalised differences are, overall, mostly less than 50%.

5.3 Input data density

The density maps show the density of the thickness (Figure 23) and the usability ratio (Figure 24) input data. For each raster cell, the data density is represented by the number of points within a radius of 10 km. Figures Figure 23 and Figure 24 highlight major differences in the density of input data for both the thickness and the usability ratio data.

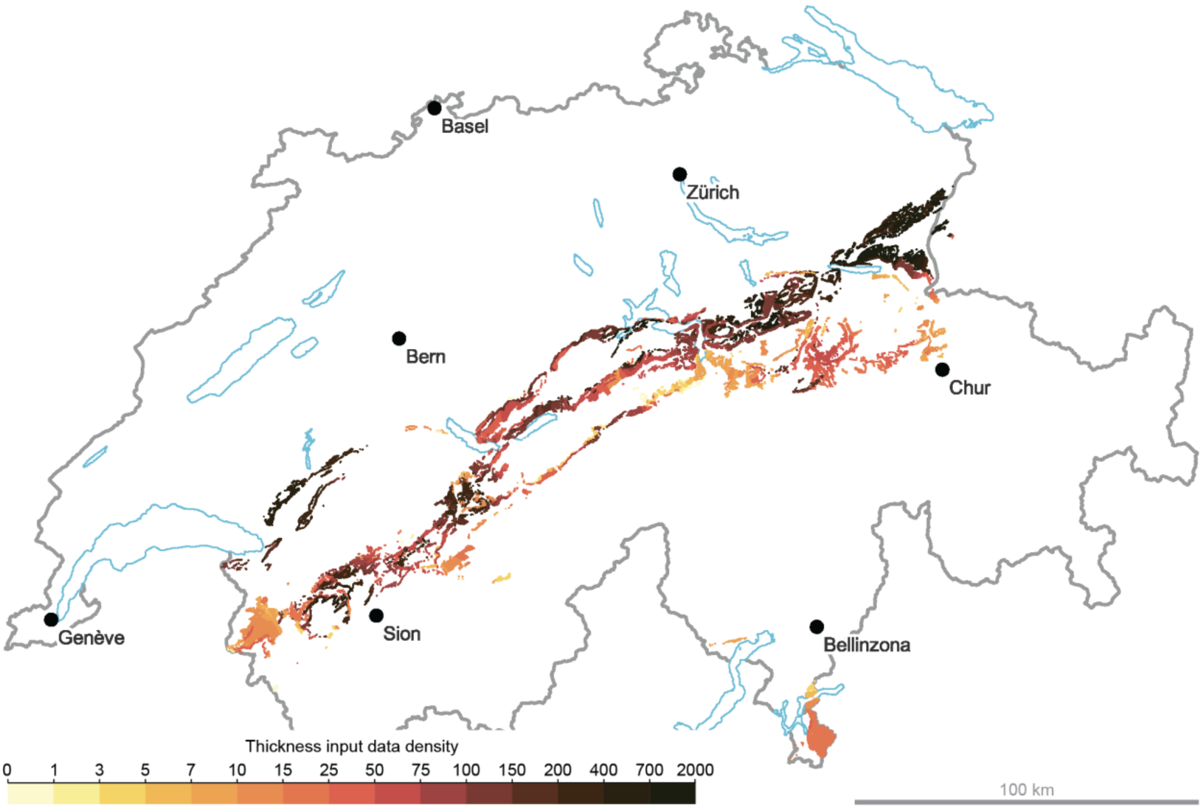


Figure 23: Data density (number of points within a 10 km radius) of the thickness input data (see attribute "Data_density_thickness" in the geospatial dataset, Table 13). To visualise the higher density of the thickness data, the same colour scheme as that in Figure 24 was chosen.

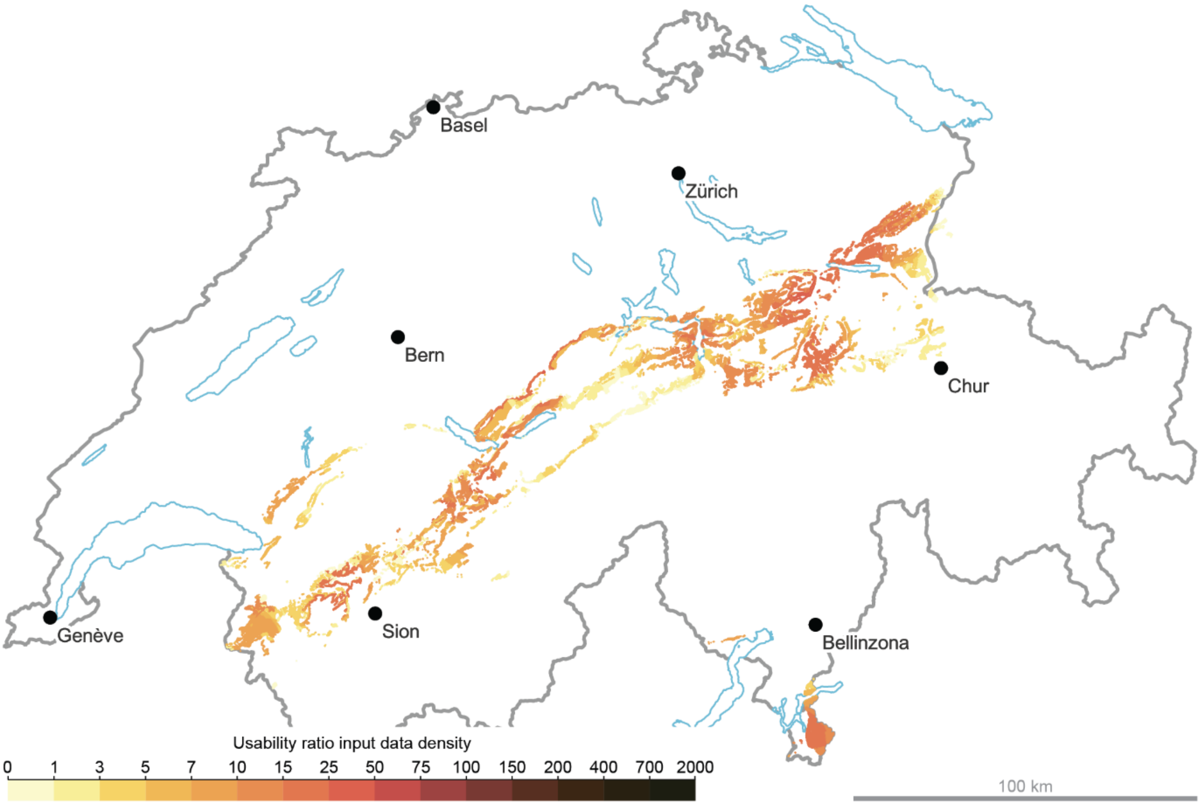


Figure 24: Data density (number of points within a 10 km radius) of the usability ratio input data (see attribute "Data_density_usability" in the geospatial dataset, Table 13). To visualise the lower density of the usability ratio data, the same colour scheme as that in Figure 23 was chosen.

5.4 Variability of input values and quantification of uncertainties

To quantify and to roughly estimate the uncertainty of the model predictions, a *distance-weighted mean standard deviation* σ_i was calculated. The parameter σ_i reflects how much the nearby input values deviate from the weighted mean input value at the *i*-th raster cell. As a first step, the distance-weighted mean thickness value V_i is calculated for each raster cell *i* using the IDW formula given in Chapter 4.2. Once this value is known, σ_i can be calculated for each raster cell using the following formula:

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n} \frac{(v_j - V_i)^2}{(d_{ij}^2 + s^2)^p}}{\sum_{j=1}^{n} \frac{1}{(d_{ij}^2 + s^2)^p}}}$$

where d_{ij} is the distance between the raster cell *i* and the data point *j*, *p* is the power parameter, and *s* is the smoothing parameter. To be consistent with the weighting applied during the interpolation step (Chapter 4.2), the standard deviations were calculated using the power and smoothing parameters listed in Table 12.

To visualise the variability of our input values, σ_i is normalised by the corresponding thickness or usability ratio V_i:

$$\sigma_i^{\text{percent}} = \left(\frac{\sigma_i}{V_i}\right) \bullet 100$$

Close to some planned, existing or abandoned mining sites, the estimated input data variability / uncertainty (i.e. the attributes "Uncertainty_thickness", "Uncertainty_usability", "Uncertainty_usable_thickness" of the geospatial dataset, see also Table 13) was manually adjusted to better reflect the high level of *geological knowledge and confidence* in these areas (see red areas in Figure 25). Note that only the uncertainty values were corrected to smaller values. The modelled thickness, usability and usable thickness were not manually adjusted.

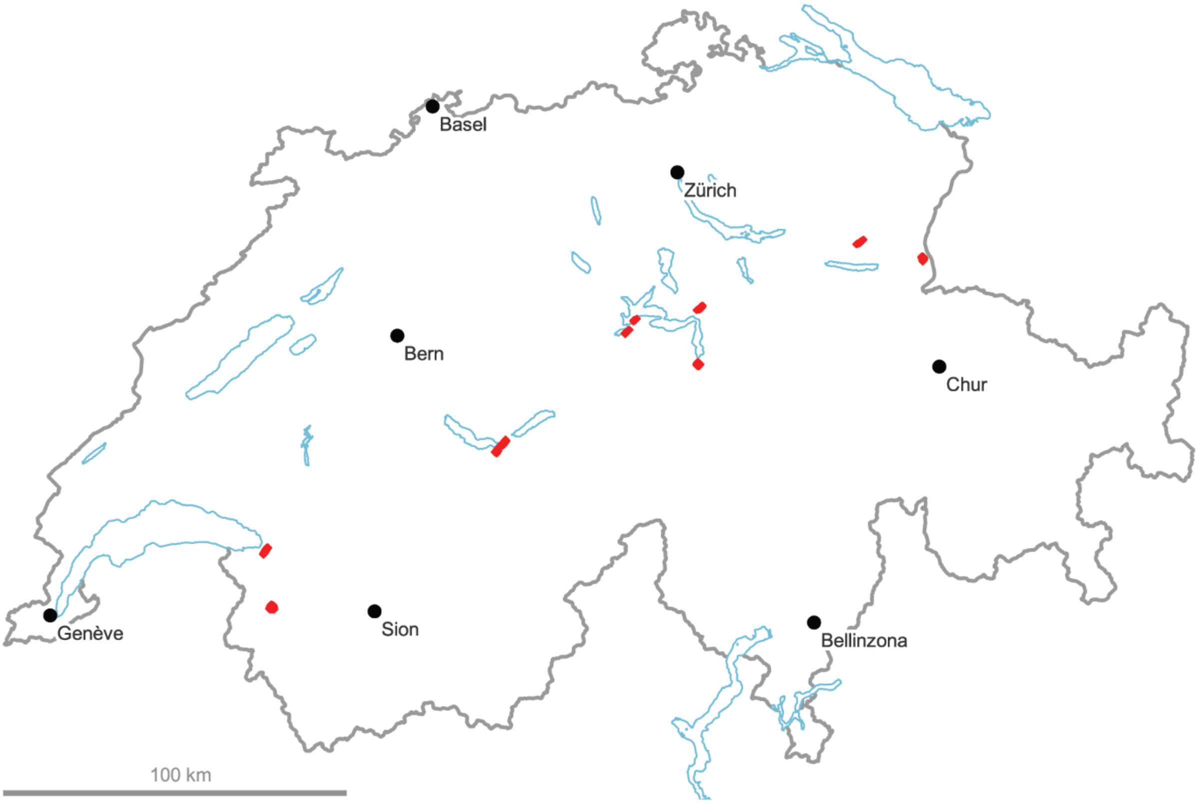


Figure 25: Red polygons highlight areas in which the estimated variability / uncertainty was manually adjusted to reflect the high level of geological knowledge and confidence in the vicinity of some of the planned, existing or abandoned mining sites.

Figure 26 shows the variability / uncertainty of the *thickness* input values (expressed as the distance-weighted normalised mean standard deviation, $\sigma_i^{\text{percent}}$). The values are typically between 20 and 60%. Given the commonly smaller misfit values (Figure 21 and Figure 22, Chapter 5.2), this uncertainty estimation has to be regarded as rather pessimistic / conservative.

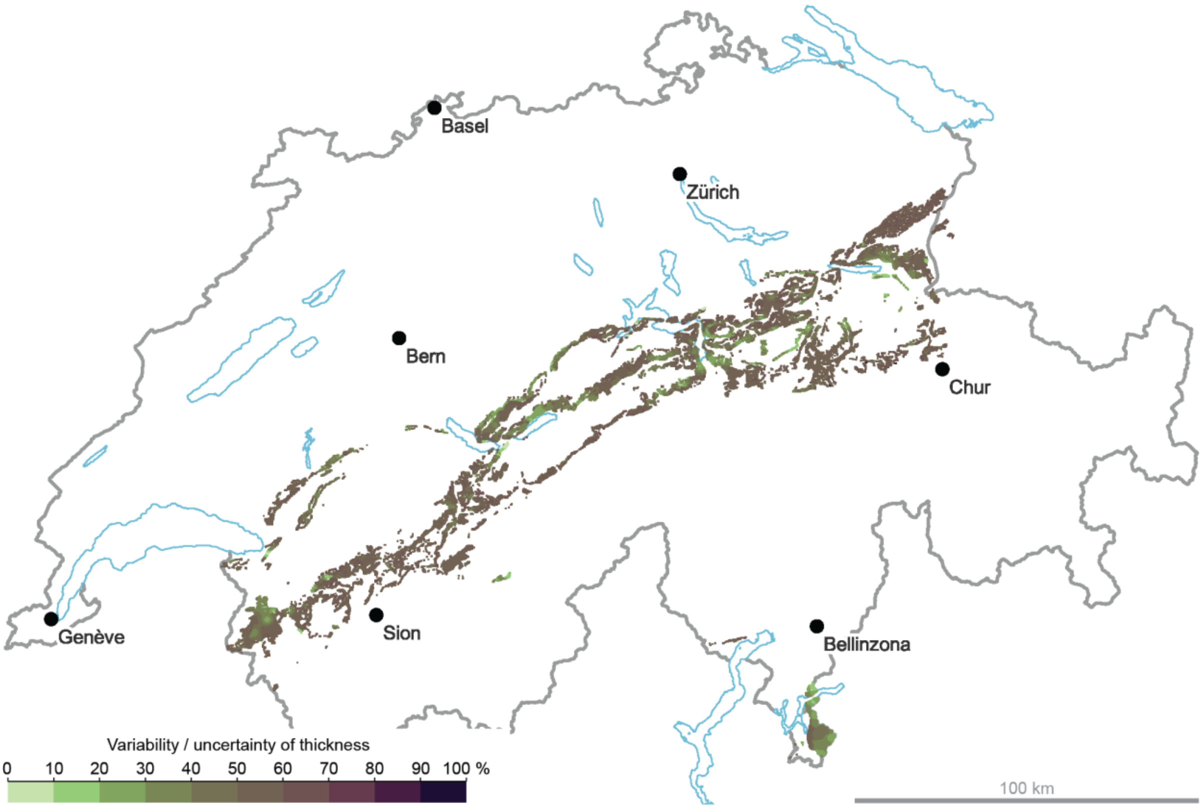


Figure 26: Map showing the normalised distance-weighted mean standard deviation $\sigma_i^{\text{percent}}$ of the thickness input values, which are used to estimate the uncertainty of the interpolated thickness in the final dataset (see attribute "Uncertainty_thickness" in Table 13).

Figure 27 shows the variability / uncertainty of the usability ratio input values (expressed as the normalised weighted mean standard deviation, $\sigma_i^{\text{percent}}$). The values are typically between 0 and 40% and thus lower than the uncertainties estimated for the thickness. The lower uncertainty estimated for the interpolated usability ratio data may partly reflect the lower data density, which is uniquely based on stratigraphic descriptions from the literature.

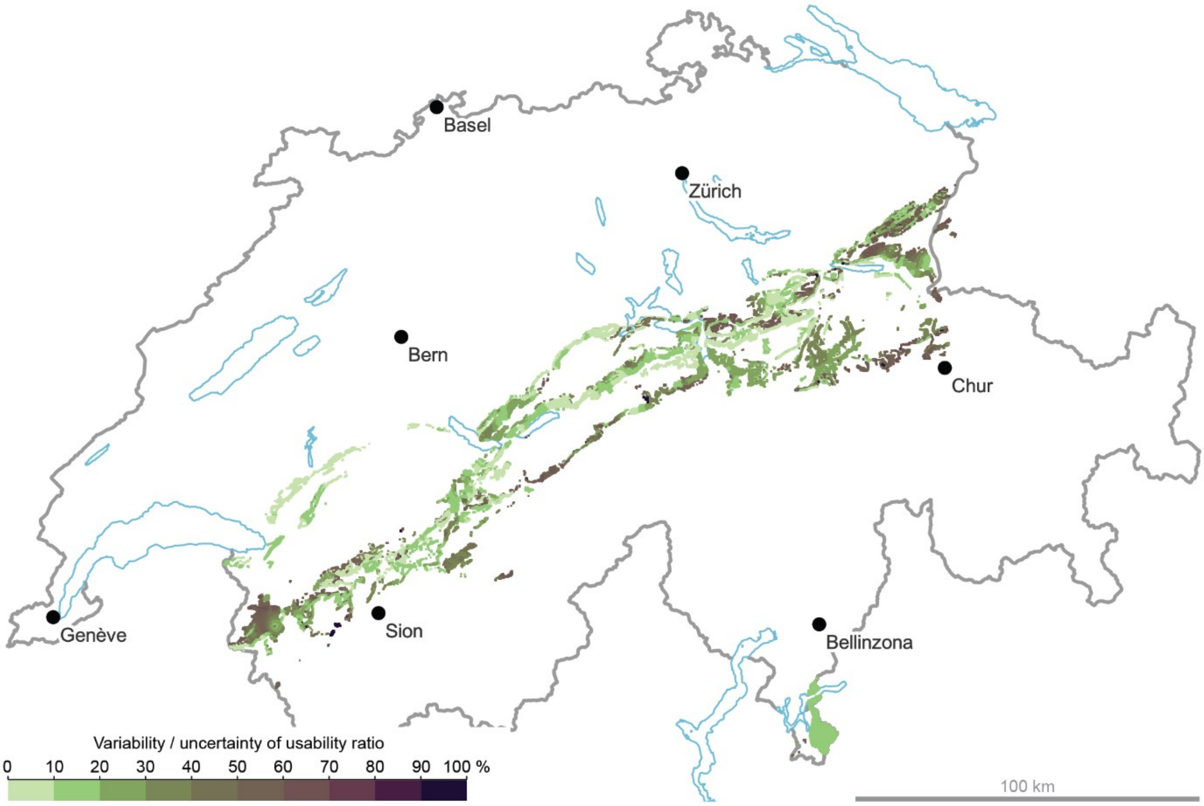


Figure 27: Map showing the normalised distance-weighted mean standard deviation $\sigma_i^{\text{percent}}$ of the usability ratio input values used to estimate the uncertainty of the interpolated usability ratio in the final dataset (see attribute "Uncertainty_usability" in Table 13).

The variability / uncertainty of the estimated usable thickness σ_{DU} is calculated based on the normalised mean weighted standard deviation of the thickness σ_D and the usability ratio (σ_U) using the following formula:

$$\sigma_{DU} = D_U \times \sqrt{\left(\frac{\sigma_D}{D}\right)^2 + \left(\frac{\sigma_U}{U}\right)^2}$$

Where D is the interpolated thickness, U the interpolated usability ratio and D_U the calculated usable thickness at a given raster cell. The value σ_{DU} is stored in the attribute "Uncertainty_usable_thickness" in the final dataset (Table 13). The standard deviations shown in Figure 28 are normalised to the corresponding D_U:

$$\sigma_{DU}^{\text{percent}} = \left(\frac{\sigma_{DU}}{D_U}\right) \bullet 100$$

The values are typically between 40 and 60%.

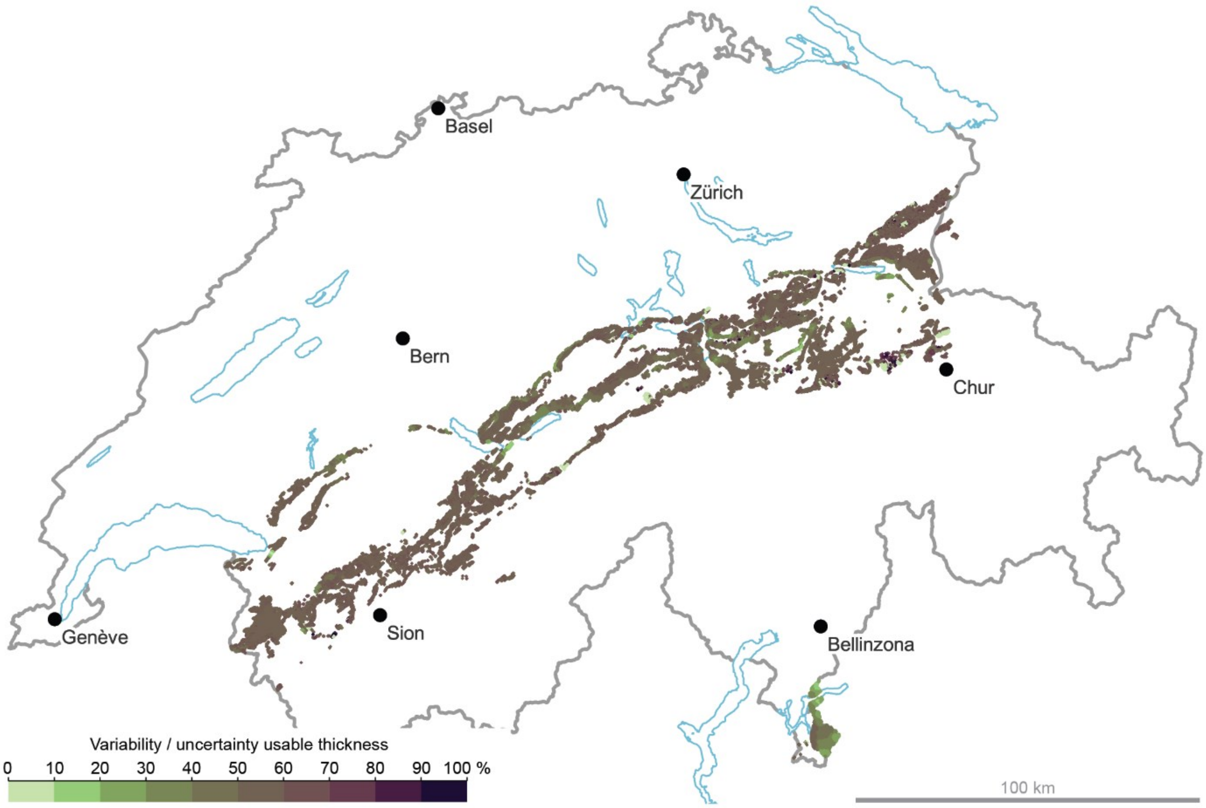


Figure 28: Map showing the normalised standard deviation $\sigma_{DU}^{\text{percent}}$ of the usable thickness, which is used to estimate the uncertainty of the usable thickness in the final dataset (see attribute "Uncertainty_usable_thickness" in Table 13).

5.5 Limitations

The following are the most important limitations of the dataset "Hard rock occurrences":

(i) In GeoCover, the geological units are typically mapped at the formation level. Therefore, the geological units were evaluated at the formation level whenever possible. Geological units of interest not mapped at the formation level were omitted from the geospatial dataset.

(ii) The raster cell size of 50x50 m limits the visualisation of thin occurrences in very steep (> 45°) terrain in map view. However, the raster cell size reflects the approximate character of the geospatial dataset and avoids potential land-use speculation.

(iii) Areas mapped as unconsolidated deposits are generally not included in the dataset, regardless of the thickness of the unconsolidated deposits. Promising occurrences may be covered by relatively thin unconsolidated deposits but are not included in the dataset.

6 Data structure

6.1 Attributes and data format

The dataset Hard rock aggregates: Thickness and quality of geological occurrences can be downloaded as a GeoPackage (.gpkg) file or accessed via a Web Map Service (WMS) from the federal geoportal. Each 50 m x 50 m vectorized raster cell contains the numeric and string information, summarised in Table 13. The used grid is based on the Swiss coordi-nate reference system CH1903+ / LV95 (EPSG:2056).

Table 13: Attributes included in the dataset. Attribute names marked with an asterisk (*) are reproduced in German, French, Italian and English.

Attribute name	Type	Explanation
GeolCode	Real	Numeric code for lithostratigraphic unit (see also lithostratigraphic database)
Thickness	Integer	Inter- / extrapolated thickness of the unit (m), as defined in Figure 1
Usability_ratio	Integer	Inter- / extrapolated usability ratio (0–100 %) of the unit (m), as defined in Figure 1
Usable_thickness	Integer	Estimated usable thickness, as defined in Figure 1 and calculated as shown in Figure 17
Symbol_code	Real	Modified usable thickness used for the symbology, according to the boundary conditions given in Figure 1 (i.e. when ground elevation ≥ 1300 m a.s.l., the corresponding raster cell value is set to dummy value = 9999)
Uncertainty_thickness	Integer	Estimated uncertainty related for the interpolated thickness as defined in Chapter 5.4
Uncertainty_usability	Integer	Estimated uncertainty related for the interpolated usability ratio, as defined in Chapter 5.4
Uncertainty_usable_thickness	Integer	Estimated uncertainty related to the predicted usable thickness as defined in Chapter 5.4
Elevation	Real	Ground elevation at centre point of the corresponding raster cell
Data_density_thickness	Real	Number of thickness input data points within a 10 km radius
Data_density_usability	Real	Number of usability ratio input data points within a 10 km radius
Please_note_*	String	Important note regarding the reliability of the estimated thickness and usability values
Unit_*	String	Name of the lithostratigraphic unit, according to the lithostratigraphic lexicon strati.ch
Usable_lithologies_*	String	List of usable lithologies (i.e. competent lithologies with promising hard rock quality) occurring in the geological unit, sorted by abundance
Not_usable_lithologies_*	String	List of not usable lithologies (i.e. incompetent lithologies) occurring in the geological unit, sorted by abundance
Level_of_confidence_*	String	Description of the geological knowledge and the level of confidence regarding the estimation of the usability ratio, the usable

Attribute name	Type	Explanation
		thickness and the lateral continuity and quality of potential hard rock lithologies within the unit
Strati_ch_link	String	Link to the Lithostratigraphic Lexicon of Switzerland (www.strati.ch)
Mat_min_link	String	Link to the website www.mat-min.ch containing up-to-date information regarding the status of raw material supply
HSt_catalog_link	String	Link to the Hard rock catalog, describing the characteristics of hard rock-bearing geological units considered
Tech_doc_link	String	Link to this document
Auto_thickness_paper_link	String	Link to NIBOUREL et al. (2023) describing the BED method used to automatically extract the orientation and thickness extraction

6.2 Additional documents

6.2.1 Hard rock catalog

The Hard rock catalog (NIBOUREL et al. 2024) contains the explanatory notes to the geospatial dataset Hard rock aggregates: Thickness and quality of geological occurrences. The references to all input data included in this document are listed in the catalog together with important information regarding the evaluation and selection of the investigated hard rock-bearing geological units.

6.2.2 Related publications

The BED method used to automatically extract orientation and thickness input data is extensively described in NIBOUREL et al. (2023). All related scripts and a test data set are available at GitHub.

6.3 Model updates

Should further geological and analytical investigations lead to new discoveries or should the technical criteria for the characterization of hard rock change, these documents may be updated in the future to consider these findings.

7 Application guidelines

Models and data sets must be regarded as predictions or basic information. The quality of these predictions and the associated uncertainties vary within the processing perimeter. In areas with a high input data density, the models and datasets are more reliable than in areas with a lower input data density. An absolute determination of the quality is not possible. The uncertainty depends on the following factors:

(i) Input data (type, quality, density, age, resolution etc.)
(ii) Modelling method and technical criteria
(iii) Geological complexity
(iv) Geological knowledge and confidence regarding geological interpretations and models

The best result can be obtained when this model is used together with the associated input data. Each use of this dataset requires a plausibility check.

The resolution (e.g. cell size) does not reflect the model accuracy or the data density. The resolution is related to the targeted degree of generalisation (target scale).

Therefore, users are strongly invited to consult the above-mentioned paragraphs on the quality assessment, uncertainties and prediction accuracy (Chapter 5).

8 Legal matters

Source / reference to the source	Model name / name of the dataset ` EN: Hard rock aggregates: Thickness and quality of geological occurrences DE: Hartstein: Mächtigkeit und Qualität der geologischen Vorkommen FR: Roches dures: Épaisseur et qualité des gisements géologiques IT: Roccia dura: Potenza e qualità dei giacimenti geologici © Federal Office of Topography swisstopo
Terms of use	Open and free geodata DE: https://www.swisstopo.admin.ch/ogd-konditionen FR: https://www.swisstopo.admin.ch/conditions-ogd IT: https://www.swisstopo.admin.ch/condizioni-ogd EN: https://www.swisstopo.admin.ch/ogd-conditions
Access authorisation (SR 510.620 GeoIV)	Access level A: open and free geodata
Reproduction	The dataset / the model can be used with a highly visible reference to the source.
Privacy policy	The dataset / the model does not contain any personal data that is subject to data protection.
Technical support	infogeol@swisstopo.ch

9 Disclaimer

The authors have taken every reasonable effort to ensure that the information contained in these documents is as accurate as possible. There is no guarantee that the data related to a definite point in the subsurface are completely accurate. Should further geological and analytical investigations lead to new discoveries or should the technical criteria for the characterization of hard rock change, these documents may be updated in the future to consider these findings.

The user acknowledges that detailed on-site geological investigations (including industrial-scale material testing) are required to determine whether one or more of the geological occurrences shown in the geospatial dataset have a real geological potential to produce norm-conformal hard rock aggregates at any given location.

Under no circumstances will the publisher be liable for any loss or damage of a material or immaterial nature arising from access to, use or non-use of published information, or from misuse or technical breakdown. The regulations of the Swiss Confederation apply.

The available datasets / geological models represent simplifications of the real geology. They are based on the interpretation of various data (geological maps, cross-sections, stratigraphic descriptions, boreholes, etc.) of different age, quality and level of detail. Models and datasets may be based on many input datasets that were not originally harmonised and therefore required further simplification. The knowledge of the authors and the local geological context can influence the development of the model or dataset. The quality of the observations and interpretations is subject to change as new data is collected, integrated into the datasets and models or the interpretation methods and modelling software are improved.

10 References

FERNÁNDEZ, O. (2005): Obtaining a best fitting plane through 3D georeferenced data. – J. struct. Geol. *27*/5, 855–858, https://doi.org/10.1016/j.jsg.2004.12.004.

JUCHLER, L. (2022): Automated extraction of layer thickness information from geological maps for the rapid evaluation of mineral occurrences. – MSc Thesis, eidg. tech. Hochsch. [ETH] Zürich.

NIBOUREL, L., GALFETTI, T., AMREIN, A., CORAY, M., GRAZIOLI, S., JUCHLER, L., MAYER, I., MORGENTHALER, J., SCHUMACHER, I., SCHLÄFLI, S., EPINEY, C., & HEUBERGER, S. (2024): Catalog of the hard rock-bearing geological units in Switzerland. Explanatory notes to the geospatial dataset “Hard rock aggregates: Thickness and quality of geological occurrences”. – Rep. swiss geol. Surv. *23* (only as pdf).

NIBOUREL, L., MORGENTHALER, J., GRAZIOLI, S., SCHUMACHER, I., SCHLÄFLI, S., GALFETTI, T. & HEUBERGER, S. (2023): Automated extraction of orientation and stratigraphic thickness from geological maps. – J. struct. Geol. *172*, 104865, https://doi.org/10.1016/j.jsg.2023.104865.

RAUCH, A., SARTORI, M., ROSSI, E., BALAND, P., & CASTELLTORT, S. (2019): Trace Information Extraction (TIE): A new approach to extract structural information from traces in geological maps. – J. struct. Geol. *126*, 286–300, https://doi.org/10.1016/j.jsg.2019.06.007.

swisstopo (2021): Hartstein – Bedarf und Versorgungssituation in der Schweiz. – Ber. Landesgeol. *18* (nur als pdf).

swisstopo (2024): Tectonic Map of Switzerland 1:500 000. – Fed. Off. Topogr. swisstopo, Wabern.

TRÜMPY, R. (1980): Geology of Switzerland: A Guide-Book. Part B: Geological excursions. Excursion No. IV. – Wepf & Co.

WOODCOCK, N.H. (1977): Specification of fabric shapes using an eigenvalue method. – Bull. geol. Soc. Amer. *88*/9, 1231–1236.

11 Appendix

Appendix A1: List of scripts in the order in which they are to be executed during the workflow (the file is available on request from swisstopo or the Georesources Switzerland Group).

Appendix A2: Dataset overview (the file is available on request from swisstopo or the Georesources Switzerland Group).

Appendix A1

Scripts and workflow of the dataset “Hard rock aggregates: Thickness and quality of geological occurrences”

Rootpath = YourPath\Hst_thickness_map_generation

	Scripts names (in the order they should be run)	Path to script	Input	Output	Short description	Remarks
GLOBAL	**Superordinate scripts**					
	230308_bash_Hst_*.sh	Rootpath\			Bash scripts for automatic run of scripts in a row (multiple mapsheets and / or target units)	
	Prep_folder_tree_manager.py	Rootpath\01_data_preparation\	-	adjusted folder structure	Create, rename, delete folders among specific pattern	Test on separate environment before overwriting / deleting folders
	Data preparation					
	Prep_BED_OM_TEC_global.py	Rootpath\01_data_preparation\	GeoCover GC_BEDROCK_Joint.shp (GeoCover modified after Pauline Baland) from geocover_tooltips_20220620.gdb: - POLYGON_AUX_2 - LINE_AUX - POINT_STRUCT	Bedrock polygons: inputBED_idBED.gpkg Bedding points: inputOM_idOM.gpkg Fault lines: inputTEC.gpkg	Prepares GeoCover based bedrock polygons (BED), faults (TEC) and orienation measurements of bedding (OM) for auto thickness extraction, generates UUIDs to be used in the later processing	Do not rerun! Prep_BED_OM_TEC_global.py, otherwise the links to the id_BED (UUID) will be lost <- used in 230308_bash_Hst_PrePro.sh
	Prep_BED_Polys_erase_arcpy.py	Rootpath\01_data_preparation\	Extracted from GC_BEDROCK_Joint.gdb - GC_UNCON.shp - GC_AUX2_LAKES_DOLINES.shp {target_unit}_Polys.shp	updated {target_unit}_Polys.shp	Automatical deletion of unconsolidated deposits and lakes/ rivers in target unit polygons	
	Prep_TU_perMapsheet.py	Rootpath\01_data_preparation\	inputBED_idBED.gpkg HSt_relevant_units_20220617.xlsx Mapsheetnames_boundaries.xlsx	updated Mapsheetnames_boundaries.csv	Automatic extract of TU present in a mapsheet (or inside a given bbox)	Attention for GeoCover boundary effects (only lines outcropping because polygon touching boundary)
	Prep_LitD_global.py	Rootpath\01_data_preparation\	HSt_Maechtigkeit_Literatur_20221209.xlsx inputBED_idBED.gpkg	HSt_thickness_LitD.gpkg HSt_rel_thickness_LitD.gpkg	Cleaning, controlling, affiliation of UUID to thickness literature data	
	Prep_LitD_Polys_perTU.py	Rootpath\01_data_preparation\	TU_all_Polys_final.shp (inputBED_idBED.gpkg modified in QGIS) HSt_relevant_units_20220617.xlsx HSt_thickness_LitD_20231007.gpkg	(target_unit + '_HSt_thickness_LitD.gpkg') (target_unit + '_HSt_usability_LitD.gpkg') (target_unit + '_Polys.shp')	Saves the output of Prep_*LitD_global.py* to individual files for each target unit	Not necessary, Only used for visualisation, quality control
	Prep_BED_OM_TEC_mapsheet.py	Rootpath\01_data_preparation\	inputBED_idBED.gpkg inputOM_idOM.gpkg inputTEC.gpkg Mapsheetnames_boundaries.csv HSt_relevant_units_20220617.xlsx	(mapsheet + '_BED.shp') -> BED per mapsheet (mapsheet + '_TEC.shp') -> TEC per mapsheet (mapsheet + '_OM.shp') -> OM per mapsheet (mapsheet + '_' + target_unit + '.gpkg') -> BED polygons per TU + mapsheet (mapsheet + '_' + target_unit + '_extent.txt') -> extent	Takes the output from *Prep_BED_OM_TEC_global.py* and generates all input files for BED, OM, TEC, BED per TU data and mapsheet extent information needed for auto thickness extraction	
	Prep_DEM-Hillshade.py	Rootpath\01_data_preparation\	(mapsheet + '_swissALTI3D_LV03.tif') (mapsheet + '_swissALTI3D_epsg2056.tif') (mapsheet + '_swissALTI3D_hs_epsg2056.tif')	updated (mapsheet + '_swissALTI3D_epsg2056.tif') updated (mapsheet + '_swissALTI3D_hs_epsg2056.tif')	Prepares, reprojects and resamples the DEM to a 2 m resolution so it matches the rest of the data	
	Prep_domains.py	Rootpath\01_data_preparation\	TK500_V_230621.gdb (Version of Yves Gouffon) HSt_tectonic_domains.xlsx	Hst_tectonic_domains_prep.xlsx	First automatic extraction of polygons of Tec500 which intersects TU polygons --> more semi-manual corrections in GIS needed	Auxiliary script to get idea where TU polygons are overlapping tectonic domain polygons
MAPSHEET	**Thickness extraction**					
	X_loop_Euler_ABC.m	Rootpath\02_auto_thickness_generation\matlab\	Mapsheetnames_boundaries.xlsx A_INPUT_TIE.m B_THICKNESS_EXTRACTION.m C_FILTERING_PLOTTING.m	error_log.txt	Runs MATLAB scripts in a row automatically	Bash script for MATLAB scripts A, B and C
	A_INPUT_TIE.m	Rootpath\02_auto_thickness_generation\matlab\	StratiCH_LiSt_20220614.xlsx HSt_relevant_units_20220617.xlsx Mapsheetnames_boundaries ParameterSpace.xlsx Outputs from - *Prep_BED_OM_TEC_mapsheet.py* - *Prep_DEM-Hillshade.py*	MATLAB workspaces: (mapsheet, '_', target_unit,'_workspace_input_BED) (mapsheet, '_', target_unit,'_workspace_input_OM')	Loads and rasterises geol. input data, extraction of base and top traces of the target unit	
	B_THICKNESS_EXTRACTION.m	Rootpath\02_auto_thickness_generation\matlab\	MATLAB workspaces from *A_INPUT_TIE.m*	(mapsheet, '_', target_unit, '_ModOrient_BED_Raw.txt') (mapsheet, '_', target_unit, '_ModOrient_OM_Raw.txt') (mapsheet, '_', target_unit,'_ModThickn_BED_Raw.txt') (mapsheet, '_', target_unit,'_ModThickn_OM_Raw.txt') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_BED') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_OM')	Automated extraction of orientation and thickness data	
	C_FILTERING_PLOTTING.m	Rootpath\02_auto_thickness_generation\matlab\	MATLAB workspaces from *B_THICKNESS_EXTRACTION.m*	(mapsheet, '_', target_unit,'_ModThickn_BED_Filtered.txt') (mapsheet, '_', target_unit,'_ModThickn_OM_Filtered.txt') (mapsheet, '_', target_unit,'_ModThickn_Packages_BED.txt') (mapsheet, '_', target_unit,'_ModThickn_Packages_OM.txt') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_filtered_BED') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_filtered_OM') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_packages_BED') (mapsheet, '_', target_unit,'_workspace_thickness_extraction_packages_OM') (mapsheet, '_', target_unit, 'Top_traces_','.txt) (mapsheet, '_', target_unit, 'Base_traces_','.txt) (mapsheet, '_', target_unit, '1_Tect_traces_','.txt) (2_PQ_lines_filt_K=',K_val,'_e=',e_val,'_',mapsheet,'.txt')	Reliability assessment, filtering and generation of outputfiles	Only first four are used, others commented out, the final filtering work step is carried out in the script 'Domains_Interpol_ThicknessData.py' (see below)
	FIG01..10*.m	Rootpath\02_auto_thickness_generation\matlab\	MATLAB workspaces from *C_FILTERING_PLOTTING.m*	Fig1..10*.png	Visualization of differenct processing steps	Not necessary, Only used for visualisation, quality control
	Post processing of thickness data					
	PostPro_thickness.py	Rootpath\03_parameter_optimisation\	Mapsheetnames_boundaries.xlsx HSt_relevant_units_20220617.xlsx (mapsheet, '_', target_unit,'_ModThickn_BED_Raw.txt') (mapsheet, '_', target_unit,'_ModThickn_OM_Raw.txt') (mapsheet + '_' + target_unit + '.gpkg') (mapsheet + '_TEC.shp') (mapsheet + '_swissALTI3D_epsg2056.tif)	(mapsheet + '_' + target_unit + '_' + type +'_PQ_Fault.gpkg') (mapsheet + '_' + target_unit + '_' + type +'_PQ_NoFault.gpkg') (mapsheet + '_' + target_unit + '_ModThickn_' + type + '_Raw_NoFault.gpkg') (mapsheet + '_' + target_unit + '_ModThickn_' + type + '_Raw_Fault.gpkg') (mapsheet + '_' + target_unit + '_ModThickn_' + type + '_Raw_NoFault_TU.gpkg')	Adds a UUID (id_thicknBED) to each data point, filters thickness data that are situated outside target unit exposures, generates geometries of the PQ nearest neighbor lines and removes thickness data which are affected by faults	
TARGET UNIT	**Output validation**					
	231204_PrepQC_collect_PQ-lines.ipynb	Rootpath\04_interpolation\	(mapsheet + target_unit + '*' + '_PQ_NoFault.gpkg')	(target_unit + '_all_PQ' + '.gpkg')	Collects all PQ lines needed in the manual QC	
	231204_PrepQC_misfit_BED_OM_LitD.ipynb	Rootpath\04_interpolation\	HSt_relevant_units_20220617.xlsx	(target_unit + 'allDomains_' + setName + '_idw_clip_TU.tif')	Interpolates each data set separatly (preparation	
	Important note: the following scripts are different approaches used to find the most suitable parameters to validate the orientation and thickness data. They are run independantly of the rest of the scripts and are not required for the subsequent interpolation and map generation work steps.					
	all_misfits_global.py	Rootpath\03_parameter_optimisation\	geoprocessing.py HSt_relevant_units_20220617.xlsx HSt_thickness_LitD_20231007.gpkg (mapsheet + '_' + target_unit + '_ModThickn_' + type + '_Raw_NoFault_TU.gpkg')	(target_unit + '_output_misfits_BED_nn.csv) (target_unit + '_output_misfits_OM_nn.csv)	Iterates though a range of possible reliability indicators with the goal to find a filter parameter set best fitting the thickness literature data	older version: main_rmse.py, Not necessary, Only used for visualisation, quality control
	geoprocessing.py	Rootpath\03_parameter_optimisation\	-	-	Function for optimisation	Not necessary, Only used for visualisation, quality control
	plot_allTU_misfits.ipynb	Rootpath\03_parameter_optimisation\	Output from *all_misfits_global.py*	statistics_parameter.txt {param_BED_OM}_{target_unit}_{parameter}.png 20231023_countData_filter.xlsx	Visualisation of optimisation misfit data for determination of threshold filter values of parameters; counting of data per approach and TU (saved in statistics txt-file)	Not necessary, Only used for visualisation, quality control
	230920_3Dworkshop_interpolation_comparison.ipynb	Rootpath\04_interpolation\	TU_LitD/BED/OM_idw.tif	misfit_LitD_BED/OM.tif rel_misfit_LitD_BED/OM.tif	Calculates difference between separatly interpolated data sets BED/OM and literature data points	Not necessary, Only used for visualisation, quality control
	230922_3Dworkshop_normal_vector_LN.ipynb	Rootpath\04_interpolation\	GC_BEDROCK_Joint.shp (GeoCover modified after Pauline Baland) from geocover_tooltips_20220620.gdb: - POLYGON_AUX_2 - LINE_AUX - POINT_STRUCT (Mapsheet + '_' + target_unit + '_ModThickn_BED_Raw.txt')	All_OM.gpkg (target_unit + '_orientation_data_BED_raw.gpkg) angle_between_BED_OM.shp' orientation_info_BED/OM.gpkg date_hist_dip.png date_hist_azimut.png	Comparison of modelled orientation (dip and normal vector of orientation plane) with GeoCover measurements	Not necessary, Only used for visualisation, quality control
	Manual quality check with LitD, BED and OM					
	Manual, in QGIS	Rootpath\04_interpolation\	allBands_allDomains_allTU_filtered_240205.gpkg	allBands_allDomains_allTU_filtered_mod_240321.gpkg	Around existing extraction sites with high-quality data, the uncertainties were adjusted manually to reflect thei high degree of geological knowledge and confidence	
	Interpolation and dataset preparation					
	Domains_Interpol_ThicknessData.py	Rootpath\04_interpolation\	HSt_relevant_units_20220617.xlsx Hst_tectonic_domains.xlsx (target_unit + '_Polys.shp) (target_unit + '_HSt_thickness_LitD.gpkg) (target_unit + '_HSt_usability_LitD.gpkg) (Mapsheet_name + target_unit + '_ModThickn_' +'*' + '_Raw_NoFault_TU.gpkg') *or* (target_unit + '_ThicknessDataAll.shp') ('DHM25_2056_cellsize_' + str(cell_size) + '.tif')	target_unit_Domain_dom_name.shp target_unit_Domain_TU_dom_name.shp (target_unit + '_ModThickn_unfiltered' + '.gpkg') (target_unit + '_MatlabData_unfiltered.shp) (target_unit + '_ModThickn_Fi_*X* ' + '.gpkg'/'.shp') (target_unit + '_MatlabData_red.gpkg') (target_unit + '_LitD_thickness.shp') (target_unit + '_MatlabData_red_*BED/OM* .shp') (target_unit + '_ThicknessDataAll.shp') (target_unit + '_ThicknessData_' + dom_name + '.shp') (test_bigscale_' + cell_size + '.tif') target_unit_*Y* .tif target_unit_*Y* _clip.tif target_unit_*Y* _clip_TU.tif target_unit_*Y* _clip_TU_allDomains.tif for *Y* =['_thickness_idw', '_ratio_thickn_idw', '_extr_thickn_idw', '_extr_thickn_idw_masked', '_thickness_std', '_ratio_thickn_std', '_extr_thickn_std', '_thickn_density', '_LitD_density'] (target_unit + '_extr_thickn_idw_masked_clip_TU_allDomains.tif') (target_unit + '_GeolCode_clip_TU_allDomains.tif)	Filtering and packaging of MATLAB Data, filtering of literature data, interpolation per target unit	
	Combining_TU_rasters.ipynb	Rootpath\04_interpolation\	Output of *Domains_Interpol_ThicknessData.py*	raster_band_*X* _allTU.tif for X=['_GeolCode', '_thickness_idw', '_ratio_thickn_idw', '_extr_thickn_idw', '_extr_thickn_idw_masked', '_thickness_std', '_ratio_thickn_std', '_extr_thickn_std', '_thickn_density', '_LitD_density'] **allBands_allDomains_allTU.tif**	Inter- / Extrapolates thickness data within the interpolation domains defined in *Prep_ExDomains.py* , Creates raster outputs for the thickness, relative thickness and the estimated extractable thickness, reliability of the output is highlighted by different point density maps	
	Vectorise_rasters.ipynb	Rootpath\04_interpolation\	allBands_allDomains_allTU.tif	allBands_allDomains_allTU_filtered.gpkg	Vectorises the raster dataset and stores all attribute values in square-shaped polygons following the extent of the previously used raster cells	
GLOBAL	**Expert driven manual adjustments around extraction sites**					
	Manual, in QGIS	Rootpath\04_interpolation\	allBands_allDomains_allTU_filtered.gpkg	allBands_allDomains_allTU_filtered_mod.gpkg	Around existing extraction sites with high-quality data, the uncertainties were adjusted manually to reflect thei high degree of geological knowledge and confidence	
	Correct_Recalculate_Thickness_Data_Uncertainties.ipynb	Rootpath\04_interpolation\	allBands_allDomains_allTU_filtered_mod.gpkg	allBands_allDomains_allTU_filtered_mod_corr.gpkg	Removes uncertainties > 100% to avoid negative output values in the uncertainty range, recalculate uncertainties after the manual adjustments of previous step	
	Join_Concat_Final_Dataset.ipynb	Rootpath\04_interpolation\	allBands_allDomains_allTU_filtered_mod_corr.gpkg, HSt_unit_info.xlsx	hard_rock_occurrences_final.gpkg	Adds string attributes stored in 'HSt_unit_info.xlsx' to the vectorised interpolated data using the join key 'GeolCode'	
	Final_Corrections_only_string_data.ipynb	Rootpath\04_interpolation\	hard_rock_occurrences_final.gpkg, HSt_unit_info.xlsx	hard_rock_occurrences_final_updated.gpkg	Optional script to update the final dataset if only string data from the file 'HSt_unit_info.xlsx' have been modified	Optional
	230920_3Dworkshop_interpolation_comparison.ipynb	Rootpath\04_interpolation\	TU_LitD/BED/OM_idw.tif	misfit_LitD_BED/OM.tif rel_misfit_LitD_BED/OM.tif	Calculates difference between separatly interpolated data sets BED/OM and literature data points	Optional
	230922_3Dworkshop_normal_vector_LN.ipynb	Rootpath\04_interpolation\	GC_BEDROCK_Joint.shp (GeoCover modified after Pauline Baland) from geocover_tooltips_20220620.gdb: - POLYGON_AUX_2 - LINE_AUX - POINT_STRUCT (Mapsheet + '_' + target_unit + '_ModThickn_BED_Raw.txt')	All_OM.gpkg (target_unit + '_orientation_data_BED_raw.gpkg) angle_between_BED_OM.shp' orientation_info_BED/OM.gpkg date_hist_dip.png date_hist_azimut.png	Comparison of modelled orientation (dip and normal vector of orientation plane) with GeoCover measurements	Optional
	231020_InterpolTesting_Kriging_arcpy.py	Rootpath\04_interpolation\	(target_unit_ThicknessData_domain_name.shp)	(target_unit_domain_name_thickness_ok.tif) (target_unit_domain_name_thickness_ok_var.tif)	Creating Ordinary Kriging interpolation maps	Optional
	231020_InterpolTesting_Kriging_cell200.ipynb	Rootpath\04_interpolation\	Hst_tectonic_domains.xlsx (domain_name + '.shp) (target_unit + '_ThicknessDataAll.shp') (target_unit + '_Polys.shp)	params_kriging.txt kriging_result_UK/OK_cellSize.tif kriging interpolation per domain: (target_unit + '_thickness_ok/uk.tif) - (target_unit + '_thickness_ok/uk_clip.tif) - (target_unit + '_thickness_ok/uk_clip_TU.tif) - (target_unit + '_thickness_ok/uk_clip_TU_allDomains.tif)	Variogramm analysis, Kriging parameter calculation, Ordinary / Universal Kriging for cell size >200m, clipping and merging of domain based OK/UK interpolation raster performed by ArcGIS *231020_InterpolTesting_Kriging_arcpy.py*	Optional
	231115_InterpolTesting_IDW.ipynb	Rootpath\04_interpolation\	Hst_tectonic_domains.xlsx (domain_name + '.shp) (target_unit + '_ThicknessDataAll.shp') (target_unit + '_Polys.shp)	mse_results_X_target_unit_dom_name.csv test_grid_target_unit_dom_name_pow_{}_sm_{}.csv MSE_all_TUs_and_domains.csv target_unit_dom_name_thickness_idw_test_sm{s}.tif target_unit + '_' + dom_name + '_thickness_idw_test_rad10000.tif target_unit + '_' + dom_name + '_thickness_idw_test_shifted.tif	Testing of Root mean squarred relative error on different smoothing and power factors, visualisation tests of smoothing, radius parameters, tests with shifted raster grid to prevent interpolation error tendencies	Optional

Appendix A2

Overview of the structure of the dataset "Hard rock aggregates: Thickness and quality of geological occurrences"

Status: controlled | controlled | controlled | controlled | controlled | controlled | controlled | controlled

Input data

HSt_relevant_units_20220617 (Target units)		
..\0_input_global\0_data_raw\HSt_relevant_units_20220617		
Field	Type	Description
GeolCode	int	Numeric code for lithostratigraphic unit (see
Name_Code	string	Name of the <TargetUnit> called in the Matl
Supergruppe	string	Subgroup according to StratiCH_LiSt_202206
Gruppe	string	Subgroup according to StratiCH_LiSt_202206
Subgruppe	string	Subgroup according to StratiCH_LiSt_202206
Formation	string	Formation name according to StratiCH_LiSt_202206
Member	string	Subgroup according to StratiCH_LiSt_202206
Bank	string	Subgroup according to StratiCH_LiSt_202206
R	int	color code of StratiCH_LiSt_20220614.xlsx
G	int	color code of StratiCH_LiSt_20220614.xlsx
B	int	color code of StratiCH_LiSt_20220614.xlsx

Mapsheetnames_boundaries (Target area)		
..\0_input_global\0_data_raw\Mapsheetnames_boundaries.xlsx		
Field	Type	Description
Mapname_original	string	Original mapname from GA25
Publicatiotion_year	int	
Mapname_technical	string	Technical mapname used for processing
Map_number	int	Original mapnumber from GA25/GeoCover
Esting_min	int	West boundary; CH1093+/LV95
Easting_max	int	East boundary; CH1093+/LV95
Northing_min	int	South boundary; CH1093+/LV95
Northing_max	int	North boundary; CH1093+/LV95
Remark	string	
TU	boolean	Is the TU outcropping in this mapsheet? (1=

HSt_Maechtigkeit_Literatur_20221209 (Literature data)		
..\0_input_global\0_data_raw\HSt_Maechtigkeit_Literatur_20221209.xlsx		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
Subgroup	string	Subgroup according to StratiCH_LiSt_202206
Formation	int	Formation name according to StratiCH_LiSt_
Member	int	Subgroup according to StratiCH_LiSt_202206
Bank	int	Subgroup according to StratiCH_LiSt_202206
GeolCode	int	Numeric code for lithostratigraphic unit (see
Thickness	int	True stratigraphic thickness of target unit (m
Extr_thickness	int	Est. usable thickness of target unit (m)
Relative_thickness	float	Usability ratio = Extr_thickness/Thickness [0.
Thickness_largest_extr_doma	int	Largest extractable domain without interbur
Ref_style	valuelist	Specify source type of thickness information
Scale	string	Scale of cross-section
Angle_Profile2Structures	valuelist	Is the profile orientation suitable to image tr
Reference	string	Name of file (Author_Year_Journal_Geograp
Profile_Nr	string	Profile Number in Publication
Editor	valuelist	Person who compiled/modified the data
Comment	string	Important comment
Tasks	string	Note for the person doing the quality checkin
Illustrative_Examples	string	Note for the person doing the quality checkin
LastProcessed	date	Date of last modification/merge of entry
Fold_hinge	boolean	QC: Is the locality is situated near fold hinge?
Underground_data	boolean	QC: Underground data? (1=yes, 0=no)
Incomplete_exposure	boolean	QC: Incomplete exposure of top and/of base
Location_unsure	boolean	QC: Affected by fault (1=yes, 0=no)
Low_quality	boolean	QC: Low quality of publication? (1=poor, 0=o
Import_from_Baertschi	boolean	Data imported from Baertschi (2011) (1=yes,
Unsuitable_profile_orientatio	boolean	QC: (1=unsuitable, 0=suitable profile orienta
Scale_verified	boolean	QC: Scale of data verified? (0=yes, 1=no)
Comment_after_QC	boolean	QC: Important comments by quality controlle

GeoCover_2022 (Geological vector dataset)		
..\0_input_global\0_data_raw\geocover_tooltips_20220620.gdb		
Bedrock polygons (BED) are stored separate shapefile (extract by P. Baland containing Ge		
Field	Type	Description
DESCRIPT_D	string	Lithostratigraphic unit of mapped polygon
TECTO_D	string	Tectonic unit
LITSTRAT	int	GeolCode, numeric code for lithostratigraphi
geometry	geom(polygon)	Bedrock polygons
Faults (TEC) are stored in feature class: LINE_AUX		
Field	Type	Description
DESCRIPT_D	string	Abschiebung, Bruch, Überschiebung
geometry	geom(line)	Linear features
Orientation measurements (OM) are stored in feature class: POINT_STRUCT		
Field	Type	Description
DESCRIPT_D	string	Orientierung der Schichten
AZIMUTH	int	Dipazimuth of field measurement (°)
DIP	int	Dip of field measurement (°)
geometry	geom(point)	Point data
Slope instabilities are stored in feature class: POLYGON_AUX_2		
Field	Type	Description
DESCRIPT_D	string	Gebiet mit Hakenwurf, Rutschgebiet, Sackun
geometry	geom(polygon)	Auxiliary polygons

StratiCH_LiSt_20220614 (Stratigraphic database)		
..\0_input_global\0_data_raw\StratiCH_LiSt_20220614.xlsx		
Field	Type	Description
GeolCode	int	Unique numeric code for each lithostratigrap
Name_Code	string	Unique name code for each lithostratigraphi
Supergruppe	string	Lithostratigraphic hierarchy
Gruppe	string	Lithostratigraphic hierarchy
Subgruppe	string	Lithostratigraphic hierarchy
Formation	string	Lithostratigraphic hierarchy
Member	string	Lithostratigraphic hierarchy
Bank	string	Lithostratigraphic hierarchy

Tectonic Map 500 (Version 2023-06-21)		
..\0_input_global\0_data_raw\TK500_V_230621.gdb -> TK500 – Tecto_Basis_Flaechen		
Field	Type	Description
Ordnung_1	string	Helvetikum, Penninikum, ect.
Ordnung_2	string	Unterhelvetikum, Oberhelvetikum, etc
Ordnung_3	string	Axen-Decke, Wildhorn-Decke etc
Ordnung_4	string	*-Schuppe, etc.
geometry	geom(polygon)	Tectonic units polygons

DEM_original (swissALTI3D data downloaded per mapsheet from		
..\0_input_mapsheet\<mapsheet>\<mapsheet>\swissALTI3D_epsg2056.tif		
BAND	Type	Description
Band 1	Float	Elevation (m a.s.l) at each raster cell at a 2 m

Description of hard rock-bearing geological units (for geospatial dataset)		
..\0_input_global\0_data_raw\HSt_unit_info.xlsx		
Tab 1: HSt_units_info		
Field [* = DE, FR, IT or EN]	Type	Description
GeolCode	int	Unique numeric code for each lithostratigrap
Please_note_*	string	Standard disclaimer text
Unit_*	string	Lithostratigraphic name
None_usable_thickness_*	string	Note regarding the usable thickness
Usable_lithologies_*	string	List of usable lithologies (i.e. competent litho
Not_usable_lithologies_*	string	List of not usable lithologies (i.e. incompeten
Level_of_confidence_*	string	Description of the geological knowledge and
Legend_*	string	Link to legend file
Thickness_boxplot_filename	string	Link to thickness boxplot file
Thickness_boxplot_descr_*	string	Caption text with explanation to thickness b
Strati_ch_link	String	Link to the Lithostratigraphic Lexicon of Swit
Mat_min_link	String	Link to the website www.mat-min.ch contai
HSt_catalog_link	String	Link to the hard-rock catalog, describing the
Tech_doc_link	String	Link to this document
Tab 2: Missing		
Field	Type	Description
Name_Code	string	Unique name code for each lithostratigraphi
Level	string	Level in lithostratigraphic hierarchy
Tectonic_Domain	string	Tectonic unit
GeolCodes	int	Unique numeric code for each lithostratigrap
Missing_Mapsheet	string	Mapsheet name, on which the unit is missing
Missing_Mapped_parent_unit	string	Mapped parent unit on this mapsheet
Missing_GeolCode	int	GeolCode of the mapped parent unit
Tab 3: Mutations		
Field	Type	Description
Name_Code	string	Unique name code for each lithostratigraphi
Level	string	Level in lithostratigraphic hierarchy
Tectonic_Domain	string	Tectonic unit
GeolCodes	int	Unique numeric code for each lithostratigrap
Mutations_Mapsheet	string	Mapsheet name, on which the unit is missing
Mutations_Unit_Old	string	Name of lithostratigraphic unit to be replaced
Mutations_GeolCode_Old	int	GeolCode of the mapped parent unit
Mutations_Unit_New	string	Name of lithostratigraphic unit to be used in
Mutations_GeolCode_New	int	GeolCode of the mapped parent unit
Tab 4: Extraction_Sites_2022		
Field	Type	Description
Name_Code	string	Unique name code for each lithostratigraphi
Canton	string	Canton of extraction site
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
Status	string	status of extraction work (active, on hold, pl
Underground	boolean	is it an underground mining site? 1=yes, 0=n
Geological Unit	string	Name of the lithostratigraphic unit
Level	string	Level in lithostratigraphic hierarchy
GeolCode	int	Unique numeric code for lithostratigraphic unit
Comment	string	Important comment

HSt_tectonic_domains.xlsx		
..\0_input_global\0_data_raw\HSt_tectonic_domains.xlsx		
Tab 1: Global		
Field	Type	Description
Domain_Name	string	Name of domain
Domain_Number	int	Number of domain
Tab 2: Overview_TU		
Target_Unit	string	Name of target unit
Domains	boolean	1=outcropping in domain, 0=not outcropping
Tab 3-15: Tectonic domain per TU		
Ordnung_1	string	Tectonic order level 1 (Tectonic map 1:5000
Ordnung_2	string	Tectonic order level 2 (Tectonic map 1:5000
Ordnung_3	string	Tectonic order level 3 (Tectonic map 1:5000
Ordnung_4	string	Tectonic order level 4 (Tectonic map 1:5000
Domain_Name	string	Name of domain to which tectonic unit belo
comments	string	Remarks for special cases

Datasets after data preparation (pre-processing)

Associated scripts:

1. Prep_BED_OM_TEC_global.py
2. Prep_BED_Polys_erase_arcpy.py
3. Prep_TU_perMapsheet.py
4. Prep_LitD_global.py
5. Prep_LitD_Polys_perTU.py
6. Prep_BED_OM_TEC_mapsheet.py
7. Prep_DEM-Hillshade.py
8. Prep_domains.py

BED_polygons (.shp)		
Global: (..\0_input_global\1_data_preprocessed\inputBED_idBED.gpkg)		
Global targetunit: (..\0_input_global\1_data_preprocessed\0_per_targetunit\<TargetUnit>\<Targ		
Mapsheet: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_BED.gpkg)		
Field	Type	Description
DESCRIPT_D	string	Lithostratigraphic unit of mapped polygon
TECTO_D	string	Tectonic unit
LITSTRAT	int	GeolCode, numeric code for lithostratigraphi
ID_BED	string	UUID for each bedrock polygon
geometry	geom(polygon)	Bedrock polygons

TEC_lines (.shp)		
Global: (..\0_input_global\1_data_preprocessed\inputTEC.gpkg)		
Mapsheet: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_TEC.gpkg)		
Field	Type	Description
DESCRIPT_D	string	Abschiebung, Bruch, Überschiebung
FIELDTEC	int	Dummy '999' numeric field required by the
geometry	geom(line)	Fault lines

OM_points (.shp)		
Global: (..\0_input_global\1_data_preprocessed\inputOM_idOM.gpkg)		
Mapsheet: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_OM.gpkg)		
Field	Type	Description
DESCRIPT_D	string	Orientierung der Schichten
AZIMUTH	int	Dipazimuth of field measurement (°)
DIP	int	Dip of field measurement (°)
ID_OM	string	UUID for each orientation measurement, use
geometry	geom(point)	Orientation of bedding

LitD (.gpkg)		
Thickness data global: ..\0_input_global\1_data_preprocessed\HSt_thickness_LitD.		
Rel. thickness data global ..\0_input_global\1_data_preprocessed\HSt_rel_thicknes		
..\0_input_global\1_data_preprocessed\0_per_targetunit\<TargetUnit>\<TargetUn		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
Subgroup	string	Subgroup according to StratiCH_LiSt_202206
Formation	int	Formation name according to StratiCH_LiSt_
Member	int	Subgroup according to StratiCH_LiSt_202206
GeolCode	int	Numeric code for lithostratigraphic unit (see
Thickness	int	True stratigraphic thickness of target unit (m
Extr_thickness	int	Est. extractable thickness within target unit (
Relative_thickness	float	Ratio Extr_thickness/Thickness [0..1]
Ref_style	valuelist	Specify source type of thickness information
Reference	string	Name of file (Author_Year_Journal_Geograp
Profile_Nr	string	Profile Number in Publication
Fold_hinge	boolean	QC: Is the locality is situated near fold hinge?
Underground_data	boolean	QC: Underground data? (1=yes, 0=no)
Incomplete_exposure	boolean	QC: Incomplete exposure of top and/of base
Location_unsure	boolean	QC: Affected by fault (1=yes, 0=no)
Low_quality	boolean	QC: Low quality of publication? (1=poor, 0=o
id_LitD	string	QC: (1=unsuitable, 0=suitable profile orienta
Unsuitable_profile_or	boolean	UUID for each literature data point, used for
ID_BED	string	UUID for each bedrock polygon, used for sub
LITSTRAT	int	GeolCode, numeric code for lithostratigraph
geometry	geom(point)	Literature thickness data point

DEM (.geotiff, reprojected)		
Mapsheet: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_swissALTI3D_epsg205		
BAND	Type	Description
Band 1	Float	Elevation (m a.s.l) at each raster cell at a 2 m

Hillshade (.geotiff)		
Mapsheet: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_swissALTI3D_hs_epsg2		
BAND	Type	Description
Band 1	Float	Hillshade illumination (0..255)

Extent (.txt)		
Per mapsheet and target unit: (..\0_input_mapsheet\<mapsheet>\<mapsheet>_<Ta		
Field	Type	Description
Extent	int	xmin, ymin, xmax, ymax of target unit expos

Datasets after MATLAB routine

Associated scripts (in the order they should be run):

1. A_INPUT_TIE.m
2. B_THICKNESS_EXTRACTION.m
3. C_FILTERING_PLOTTING.m

* for Euler: automated runs with K_loop_Euler_ABC.m

MATLAB orientation data raw output (BED) (.txt)		
Model output auto generated thickness routine (BED, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_Mod		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
Dir_X	float	X component of orientation unit vector r
Dir_Y	float	Y component of orientation unit vector r
Dir_Z	float	Z component of orientation unit vector r
Dip-direction	float	Corresponding dip-direction (°)
Dip	float	Corresponding dip (°)
M	float	Indicates goodness of planar fit
K	float	Indicates degree of planarity of fit
n(T)	float	Length of contact segment T

MATLAB orientation data raw output (OM) (.txt)		
Model output auto generated thickness routine (OM, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_Mod		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
Dir_X	float	X component of orientation unit vector r
Dir_Y	float	Y component of orientation unit vector r
Dir_Z	float	Z component of orientation unit vector r
Dip-direction	float	Corresponding dip-direction (°)
Dip	float	Corresponding dip (°)
n(T)	float	Length of contact segment T

MATLAB thickness data raw output (BED) (.txt)		
Model output auto generated thickness routine (BED, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_Mod		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
thickness	float	Automatically estimated thickness
M	float	Indicates goodnes of planar fit
K	float	Indicates degree of planarity of fit
thicknessDiff	float	(delta) Difference between two thickness value
AngularDiffN	float	(alpha) Degree of paralleleity of top and base (°
distance_PQ	float	Eucledian distance between nearest neighbors
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
n(T1)	int	Length (number of points) of segment
T2	int	Number of neighboring segment
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
diffMeanThickn	int	Normalised difference to the mean value calcul

MATLAB thickness data raw output (OM) (.txt)		
Model output auto generated thickness routine (OM, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_Mod		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
thickness	float	Automatically estimated thickness
distance_PQ	float	Eucledian distance between nearest neighbors
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
T2	int	Number of neighboring segment
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
diffMeanThickn	int	Normalised difference to the mean value calcul

Datasets after MATLAB post processing

Associated scripts:

1. PostPro_thickness.py

MATLAB_thickness_postprocessed (BED, target unit, faults) (.gpkg)		
Model output auto generated thickness routine (BED, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_ModThi		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
thickness	float	Automatically estimated thickness
M	float	Indicates goodnes of fit
K	float	Indicates degree of planarity of fit
thicknessDiff	float	Difference between two thickness values calcul
AngularDiffN	float	Degree of paralleleity of top and base (°)
distance_PQ	float	Eucledian distance between nearest neighbors
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
n(T1)	int	Length (number of points) of segment
T2	int	Number of neighboring segment
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
diffMeanThickn	int	Normalised difference to the mean value calcul
id_thicknBED	string	UUID for each thickness data point
id_BED	string	UUID of underlying bedrock polygon
Fold_hinge	boolean	QC: Is the locality is situated near fold hinge? (1
Uncomplete_exposure	boolean	QC: Incomplete exposure of top and/of base? (1
Affected_by_fault	boolean	QC: Affected by fault (1=yes, 0=no)
Wrong_orientation_in	boolean	QC: based on wrong orientation info (1=yes, 0=
Unsuitable_nearest_n	boolean	QC: based on unsuitable nearest neighbors (1=y
geometry	geom(point)	Location of auto extracted thickness data

MATLAB_thickness_postprocessed (OM, target unit, faults) (.gpkg)		
Model output auto generated thickness routine (OM, .txt) [e.g. outputtable]		
Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_ModThi		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
thickness	float	Automatically estimated thickness
distance_PQ	float	Eucledian distance between nearest neighbors
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
n(T1)	int	Length (number of points) of segment
T2	int	Number of neighboring segment
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
diffMeanThickn	int	Normalised difference to the mean value calcul
id_thicknBED	string	UUID for each thickness data point
id_BED	string	UUID of underlying bedrock polygon
Fold_hinge	boolean	QC: Is the locality is situated near fold hinge? (1
Uncomplete_exposure	boolean	QC: Incomplete exposure of top and/of base? (1
Affected_by_fault	boolean	QC: Affected by fault (1=yes, 0=no)
Wrong_orientation_in	boolean	QC: based on wrong orientation info (1=yes, 0=
Unsuitable_nearest_n	boolean	QC: based on unsuitable nearest neighbors (1=y
geometry	geom(point)	Location of auto extracted thickness data

PQ_Lines (.gpkg)		
Visualisation of combined nearest neighbors		
BED, Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_BE		
OM, Mapsheet: (..\2_output_mapsheet\<mapsheet>\<mapsheet>_<TargetUnit>_OM		
Field	Type	Description
idx	intindex	in raw unfiltered Matlab output
id_thicknBED	string	UUID for each thickness data point
geometry	geom(line)	PQ lines for fault analysis and QC

Datasets associated with the validation process

Associated scripts (in the order they should be run):

Optional: the following scripts are used to find the most performant filter pa

1. all_misfits_global.py (incl. function: geoprocessing.py)
2. plot_allTU_misfits.py
3. 230920_3Dworkshop_interpolation_comparison.ipynb
4. 230922_3Dworkshop_normal_vector_LN.ipynb

output_rmse (.txt)		
Field	Type	Description
niter	int	Iteration step through geoprocessing
rmse	float	Calculated Root Mean Square Error (
Buff	int	used BufferDistance
tDPQr	float	used ratio thickness/DistancePQ
ThD	float	used Thickness Difference
AnD	float	used Angular Difference
M	float	used M value
K	float	used K value
len_y_true	int	number of thickness points out of lit
len_y_pred	int	number of thickness points from the

optimisation_%s.gpkg %niter		
Layer: Matlab_Data_Filter		
Same as <mapsheet>_<TargetUnit>_ModThickn_BED_Raw_TU_NoFault.gp		
(only if enabled in geoprocessing function)		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic u
thickness	float	Automatically estimated thickness
M	float	Indicates goodnes of fit
K	float	Indicates degree of planarity of fit
thicknessDiff	float	Difference between two thickness va
AngularDiffN	float	Degree of paralleleity of top and bas
distance_PQ	float	Eucledian distance between nearest
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
n(T1)	int	Length (number of points) of segmen
T2	int	Number of neighboring segment
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
id_thicknBED	string	UUID for each thickness data point
id_BED	string	UUID of underlying bedrock polygon
Fold_hinge	boolean	QC: Is the locality is situated near fol
Uncomplete_exposure	boolean	QC: Incomplete exposure of top and/
Affected_by_fault	boolean	QC: Affected by fault (1=yes, 0=no)
Wrong_orientation_in	boolean	QC: based on wrong orientation info
Unsuitable_nearest_n	boolean	QC: based on unsuitable nearest neig
geometry	geom(point)	Location of auto extracted thickness

optimisation_%s.gpkg %niter		
Layer: Buffer_overlay_BED		
Clipped [<mapsheet>BED.gpkg] to Buffer Literature Datapoints, reduced to		
(only if enabled in geoprocessing function)		
Field	Type	Description
DESCRIPT_D	string	Lithostratigraphic unit of mapped po
TECTO_D	string	Tectonic unit
LITSTRAT	int	GeolCode, numeric code for lithostra
ID_BED	string	UUID for each bedrock polygon
geometry	geom(polygon)	Buffered bedrock polygons

optimisation_%s.gpkg %niter		
Layer: Buffer_overlay_BED_STATISTICS		
Same as Buffer_overlay_BED including count & mean		
(only if enabled in geoprocessing function)		
Field	Type	Description
DESCRIPT_D	string	Lithostratigraphic unit of mapped po
TECTO_D	string	Tectonic unit
LITSTRAT	int	GeolCode, numeric code for lithostra
ID_BED	string	UUID for each bedrock polygon
geometry	geom(polygon)	Bufferd bedrock polygons
count	int	number of MATLAB thickness datapo
mean	float	mean thickness of MALTAB thickness

Datasets validated and after manual QC

Associated scripts (in the order they should be run):

1. 231204_PrepQC_collect_PQ-lines.ipynb
2. 231204_PrepQC_misfit_BED_OM_LitD.ipynb

MATLAB thickness data validated and filtered (BED + OM) (.gpkg)		
Global per target unit : (..\2_output_global\<TargetUnitt>\04a_Thickn_global\01_raw		
MATLAB thickness data quality checked BED (*QC.gpkg)		
Create global copy for QC: (..\2_output_global\<TargetUnitt>\04a_Thickn_global\02_		
Field	Type	Description
X	int	Easting, CH1093+/LV95
Y	int	Northing, CH1093+/LV95
Z	int	Elevation (m a.s.l)
GeolCode	int	Numeric code for lithostratigraphic unit (see als
thickness	float	Automatically estimated thickness
M	float	Indicates goodnes of fit
K	float	Indicates degree of planarity of fit
thicknessDiff	float	Difference between two thickness values calcula
AngularDiffN	float	Degree of paralleleity of top and base (°)
distance_PQ	float	Eucledian distance between nearest neighbors
thickn_distPQ_ratio	float	Ratio (thickness/distance_PQ)
T1	int	Segment number in Matlab Routine
n(T1)	int	Length (number of points) of segment
T2	int	Number of neighboring segment
ind_uuid_OM	int	Number of orientatin measurement used to calc
P_X	int	Easting, CH1093+/LV95 of point P
P_Y	int	Northing, CH1093+/LV95 of point P
P_Z	int	Elevation (m a.s.l) of point P
Slope_P	float	Elevation (m a.s.l) of point P
Aspect_P	float	Elevation (m a.s.l) of point P
Q_X	int	Easting, CH1093+/LV95 of point Q
Q_Y	int	Northing, CH1093+/LV95 of point Q
Q_Z	int	Elevation (m a.s.l) of point Q
Slope_Q	float	Elevation (m a.s.l) of point P
Aspect_Q	float	Elevation (m a.s.l) of point P
id_thickn	string	UUID for each thickness data point
id_BED	string	UUID of underlying bedrock polygon
r	int	Minimum radius between orientation measuren
N	int	Each Nth point along the top or base contact is
e	int	Number of nearest neighbors Q considered per
No_th	int	Number of thickness values calculated per orien
mean	float	Mean value calculated per top, base (+ orientat
diffMeanThickn	float	Difference between the mean and the single th
std	float	Standard deviation corresponding to the mean
normStd	float	Normalised standard deviation
median	float	Median calculated per top, base (+ orientation r
Fold_hinge	boolean	QC: Is the locality is situated near fold hinge? (1
Uncomplete_exposure	boolean	QC: Incomplete exposure of top and/of base? (1
Affected_by_fault	boolean	QC: Affected by fault (1=yes, 0=no)
Wrong_orientation_in	boolean	QC: based on wrong orientation info (1=yes, 0=
Unsuitable_nearest_n	boolean	QC: based on unsuitable nearest neighbors (1=y
geometry	geom(point)	Location of auto extracted thickness data

MATLAB thickness data quality checked OM (*QC.gpkg)		
Create global copy for QC: (..\2_output_global\<TargetUnitt>\04a_Thickn_global\02_		
Field	Type	Description
Same attribution as for BED above, but individual outputfile for OM data		

PQ lines (.gpkg)		
Global per target unit: (..\2_output_global\<TargetUnit>\04a_Thickn_global\01_raw\		
Field	Type	Description
idx	int	Index number of PQ-line
geometry	geom(line)	Line between nearest neighbors P-Q

Datasets associated with interpolation

Associated scripts (in the order they should be run):

1. Domains_Interpol_ThicknessData.py (*_euler.py for euler)
2. Combining_TU_rasters.ipynb

Interpolation Domains (.gpkg)		
Global per target unit: (..\1_data_preprocessed\0_per_targetunit\<TargetUnit>\<Targ		
Field	Type	Description
Ordnung_1	string	Helvetikum, Penninikum, ect.
geometry	geom(polygon)	Tectonic domain with relatively uniforma thickn

Target unit / GeolCode (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
thickness	float	Interpolated thickness within interpolation dom

Interpolated thickness map (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
thickness	float	Interpolated thickness within interpolation dom

Interpolated rel. thickness map (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
rel_thickness	float	Interpolated usable thickness within interpolati

Interpolated usable thickness map (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
extr_thickn	float	Interpolated usable thickness within interpolati

Usable thickness masked (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04c_Restrict		
Band	Type	Description
extr_thickn	float	Interpolated usable thickness within interpolati

Variability / Uncertainty of thickness inputs (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
Uncertainty_thickness	float	Weighted mean representing the variability of t

Variability / Uncertainty of usability inputs (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
Uncertainty_rel_thick	float	Weighted mean representing the variability of t

Variability / Uncertainty of usable thickness (.tif)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
Uncertainty_extr_thic	float	Calculated uncertainty based on the two attribu

Elevation of occurrence (.tif)		
Global: (..\2_output_global\DHM25_2056_cellsize_50.tif)		
Band	Type	Description
Elevation	float	Elevation (at centroid of each raster cell, m a.s.l

Input data density thickness (.geotiff)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
density_extr_thickn	float	Point density thickness data within 10 km radius

Input data density usability ratio (.geotiff)		
Global per target unit and per domain: (..\2_output_global\<TargetUnit>\04b_Interp		
Band	Type	Description
density_extr_thickn	float	Point density usable thickness data within 10 km

Occurrences (.geotif)		
Global per target unit: (..\2_output_global\<TargetUnit>\<TargetUnit>_<Domain>_oc		
Band	Type	Description
GeolCode	int	Numeric code for lithostratigraphic unit (see als
Thickness	float	Inter- / extrapolated thickness data (m)
Rel_thickness	float	Inter- / extrapolated relative extractable thickne
Extr_thickness	float	Estimated extractable thickness (Band1*Band2)
Extr_thickness_maske	float	Estimated extractable thickness, masked accord
Uncertainty_thickness	float	Weighted mean representing the variability of t
Uncertainty_rel_thick	float	Weighted mean representing the variability of t
Uncertainty_extr_thic	float	Calculated uncertainty based on the two attribu
Elevation	float	Elevation (at centroid of raster cell, m a.s.l.)
Reliability_thickness	float	Nnumber of thickness data points within 10 km
Reliability_rel_thickne	float	Nnumber of data points within 10 km radius

Dataset vectorisation and attribution

Associated scripts (in the order they should be run):

1. Vectorise_rasters.ipynb
2. Correct_Recalculate_Thickness_Data_Uncertainties.ipynb
3. Join_Concat_Final_Dataset.ipynb

Optional scripts:

4. Final_Corrections_only_string_data.ipynb

Hard rock units string information (.geotiff)		
Global per target unit: (..\0_input_global\0_data_raw\HSt_unit_info.xlsx)		
Field	Type	Description
Please_note_*	string	Important note, regarding the reliability of the pre-
Unit_*	string	Name of the lithostratigraphic unit, according to the
Usable_lithologies_*	string	List of usable lithologies (i.e. competent lithologies
Not_usable_lithologies_*	string	List of not usable lithologies (i.e. incompetent lithol
Level_of_confidence_*	string	Description of the geological knowledge and the lev
Legend_*	string	Path to legend file on swisstopo repository, includin
Thickness_boxplot_filenar	string	Path to thickness boxplot file on swisstopo reposito
Thickness_boxplot_descr_	string	Caption text to boxplot
swissgeol_link	string	Link to swissgeol
Strati_ch_link	string	Link to the Lithostratigraphic Lexicon of Switzerland
Mat_min_link	string	Link to the website www.mat-min.ch containing up
HSt_catalog_link	string	Link to the hard rock catalog, describing the charac
Tech_doc_link	string	Link to the technical documentation (this document
Auto_thickness_paper_lin	string	Nnumber of thickness data points within 10 km rad
Thickness_concat	string	Combined string including the thickness and the est
Usability_ratio_concat	string	Combined string including the usability ratio and th
Usable_thickness_concat_	string	Combined string including the usability thickness ar

Occurrences (.gpkg)		
Global per target unit: (..\2_output_global\hard_rock_occurrences_final_240610.gpkg)		
Band	Type	Description
GeolCode	int	Numeric code for lithostratigraphic unit (see also St
Thickness	float	Inter- / extrapolated thickness data (m)
Rel_thickness	float	Inter- / extrapolated relative extractable thickness c
Extr_thickness	float	Estimated extractable thickness (Band1*Band2) (m)
Extr_thickness_masked	float	Estimated extractable thickness, masked according
Uncertainty_thickness	float	Weighted mean representing the variability of the E
Uncertainty_rel_thickness	float	Weighted mean representing the variability of the L
Uncertainty_extr_thickne	float	Calculated uncertainty based on the two attributes
Elevation	float	Elevation (at centroid of raster cell, m a.s.l.)
Reliability_thickness	float	Nnumber of thickness data points within 10 km rad
Reliability_rel_thickness	float	Nnumber of data points within 10 km radius
Please_note_*	string	Important note, regarding the reliability of the pre-
Unit_*	string	Name of the lithostratigraphic unit, according to the
Usable_lithologies_*	string	List of usable lithologies (i.e. competent lithologies
Not_usable_lithologies_*	string	List of not usable lithologies (i.e. incompetent lithol
Level_of_confidence_*	string	Description of the geological knowledge and the lev
Legend_*	string	Path to legend file on swisstopo repository, includin
Thickness_boxplot_filenar	string	Path to thickness boxplot file on swisstopo reposito
Thickness_boxplot_descr_	string	Caption text to boxplot
swissgeol_link	string	Link to swissgeol
Strati_ch_link	string	Link to the Lithostratigraphic Lexicon of Switzerland
Mat_min_link	string	Link to the website www.mat-min.ch containing up
HSt_catalog_link	string	Link to the hard rock catalog, describing the charac
Tech_doc_link	string	Link to the technical documentation (this document
Auto_thickness_paper_lin	string	Nnumber of thickness data points within 10 km rad
Thickness_concat	string	Combined string including the thickness and the est
Usability_ratio_concat	string	Combined string including the usability ratio and th
Usable_thickness_concat_	string	Combined string including the usability thickness ar