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"

Berichte der Landesgeologie
Rapports du Service géologique national
Rapporti del Servizio geologico nazionale
Reports of the Swiss Geological Survey

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Swiss Confederation

Federal Office of Topography swisstopo
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Keywords
Mineral resources, Hard rock aggregates, Explanatory notes, Swiss Federal Geoportal

Recommended citation
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).

Frontcover
Map showing the spatial distribution of the hard rock-bearing geological units (grey areas) and the location of the currently active production sites (orange symbols) in Switzerland (status 2024). Sources: swisstopo, Georesources Switzerland Group, ETH Zurich.

Image page 3
Folded thin-bedded sandstone (Elm Formation, North-Helvetic Flysch Group) in the Eielen hard rock quarry near Attinghausen (UR). Photo: S. Heuberger, Georesources Switzerland Group, ETH Zurich.

pdf file available at www.swisstopo.ch

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Hard rock aggregates play a central role in the construction and maintenance of the national transportation infrastructure.

From a geological point of view, the Swiss subsurface offers many hard rock occurrences. However, most of these occurrences cannot be secured from a spatial planning perspective.

The motivation for producing this document, and the associated geospatial dataset, is to support the relevant authorities, as well as the industrial sector, in the spatial planning process by enabling these users to locate, and possibly safeguard, the most promising hard rock occurrences.

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Disclaimer

This document and the associated geospatial dataset[1] do not claim to contain an absolute and definitive list of all the existing hard rock-bearing geological units occurring in Switzerland. While 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 is 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 units listed in this document have a real geological potential to produce norm-conformal hard rock aggregates at any given location.

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1 Geospatial dataset "Hard rock aggregates: Thickness and quality of geological occurrences" on the Federal Geoportal.

Table of contents

1. Introduction and objectives

Hard rock aggregates play a central role in the construction and maintenance of transport infrastructure [*1*]. Based on the current normative framework (refer especially to the VSS Norms [*2*] and [*3*]) and the many years of experience in the construction industry, hard rock aggregates are employed as the main component of the superstructure of the Swiss railway network (in particular track ballast) as well as for the pavement of highways and other high-performance roads.

With the current and projected growth in rail and road traffic in Switzerland [*4*], the load on the transportation infrastructure and the demand to high-performance hard rock aggregates is expected to increase over the coming decades. Between 2016 and 2022, approximately 0.75 million tonnes of primary hard rock aggregates were used annually for the renewal and maintenance of railway lines. Over the same period, around 0.5 million tonnes per year were used for road surfacing.[2]

To ensure an efficient national transport infrastructure in the future, the Federal Government recognised the importance of high-quality hard rock aggregates and their long-term supply from domestic sources in its Sector Plan on Transport of 2008 [*5*] and 2021 [*6*].

From a geological point of view, the Swiss subsurface offers many hard rock occurrences that could theoretically satisfy the demand of hard rock aggregates over centuries (Figure 1). However, a variety of factors, in particular land-use conflicts, environmental restrictions or difficult logistical access, make most of these occurrences challenging or impossible to exploit, especially if an open pit mining operation is considered [*1*].

The motivation for producing this document and the associated geospatial dataset[3] was to assist the cantonal and federal authorities, as well as the industrial sector, in the spatial planning process by enabling these users to locate the most promising hard rock occurrences. Used in combination, the dataset and this document are valuable instruments to guide planners in obtaining a Swiss-wide, fact-based overview of the geological characteristics of the known hard rock-bearing geological units, such as their spatial extent, their true stratigraphic *thickness,* their estimated *usable thickness* and the *hard rock quality.*

This document and the geospatial dataset are the result of extensive literature research, field investigation and advanced geospatial modelling techniques developed by the Georesources Switzerland Group (FGS) in collaboration with the Swiss Geological Survey (swisstopo) between 2019 and 2024. They enhance and further consolidate the groundwork of various authors and institutions between 1992 and 2012 (in particular [*7*], [*8*], [*9*] and [*10*]).

2 For further information and access to up-to-date data, the reader is invited to consult the website www.mat-min.ch.

3 Geospatial dataset "Hard rock aggregates: Thickness and quality of geological occurrences" on the Federal Geoportal.

A geospatial analysis at a national scale requires the availability of structured vector data and a harmonised stratigraphic framework. This work was only possible thanks to the availability of the geological vector dataset GeoCover and the Lithostratigraphic Lexicon of Switzerland (www.strati.ch).

A particular focus of the investigation was to identify and characterise the geological occurrences located at ground elevations of less than 1300 metres a.s.l. and having an estimated usable thickness exceeding 30 metres. Defined in consultation with the hard rock industry, these boundary conditions allow the users to quickly screen the geological occurrences that (a) are located at a reasonable elevation (from a logistical point of view) and (b) are likely to have a promising volume of usable rock (from a mineral resource development perspective).

"Modifying Factors"[4] such as land use or environmental restrictions have deliberately not been taken into account in constraining the geological occurrences reported here. Identifying these region-specific factors and weighing them against the prospective development of a mining site are the responsibility of the relevant permitting authorities (particularly cantonal and communal) and the industry seeking to develop a mining operation.

4 According to the Pan-European Standard for Reporting of Exploration Results, Mineral Resources and Mineral Reserves (PERC) [*235*], *"Modifying Factors" […] include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governance ('ESG') and regulatory factors.*

2. Structure of the document

Chapter 3 describes the technical requirements, the production process and the application of hard rock aggregates.

Chapter 4 provides a general geological overview of the hard rock-bearing geological units in Switzerland and the location of the current production sites.

Chapter 5 presents the methodology applied to constrain and assess the geological units that are expected to meet the hard rock requirements under the present technical conditions.

Chapter 6 describes the set of parameters that have been collected to describe the hard rock-bearing geological units and how these parameters are organised throughout Chapter 7.

Chapter 7 represents the core of this investigation. It summarises in a structured way the characteristics of promising hard rock-bearing geological units in Switzerland. These characteristics include in particular the lithological and technical properties, the geographic distribution of the occurrences, the estimated thickness and usability ratio of the unit, and the level of geological knowledge and confidence associated with the evaluation of the hard rock potential. The geological units are arranged by stratigraphic age and grouped according to tectonic affiliation (Helvetic, Penninic, Austroalpine or Southalpine).

Chapter 8 provides an overview and a comparison of the compiled thickness, the usability ratio and the usable thickness values of all the geological units.

Chapter 9 gives a statistical overview of the uniaxial compressive strength of all the investigated hard rock-bearing geological units.

Chapter 10 lists and comments on the geological units that were exploited or considered as promising hard rock lithologies in the past but that are today no longer considered suitable to produce hard rock aggregates.

The relevant literature and a selected glossary are appended in *Chapters 11 and 12,* respectively.

Appendix I–XIII contain map extracts showing the spatial distribution of the thickness and usability ratio input values and the interpolated model results for each hard rock-bearing geological unit described in Chapter 7 (without consideration of the boundary conditions described in Chapter 5.4).

3. Technical requirements, production process and application of hard rock aggregates

Hard rock aggregates are produced in three main processing stages involving blasting, crushing and multiple-stage screening. The mined rock material is crushed several times and then sorted into different grain size fractions. The crushing process produces angular and sharp aggregate grains.

To determine the petrographic properties of aggregates and to assess their suitability for specific industrial applications, the norm VSS 70 115 [*11*] is applied. This norm proposes a scheme to classify the hardness of aggregates based on the compressive strength and the proportion of hard minerals[5]. According to this scheme, hard rock aggregates must display a compressive strength greater than 120 N/mm^2 (= 120 MPa)[6] and contain more than 25% (mass) of hard minerals.

The first product to be manufactured in the hard rock aggregate plant is track ballast, the crushed fraction with grain sizes 32–50 mm. According to the VSS norm SN 670 110-NA/EN 13450 [*2*] and the regulation from the Swiss public transport association VöV [*12*], track ballast is subdivided into two classes: Class I and Class II, in which Class I represents the highest quality. Track ballast must have a very high resistance to fragmentation, which is determined using the LA test (Los Angeles test) according to the VSS norm SN 670 903-2C/EN 1097-2 [*13*]. Class I track ballast must have a LA coefficient lower than 16 [*2*].

The next hard rock aggregate product to be manufactured is the fraction with grain sizes 4–32 mm. This fraction is typically used for high-performance road pavements. It must demonstrate a high resistance to fragmentation and to the polishing effect of vehicle tyres. The aggregate requirements for road surfacing are defined in the norm SN 670 103B-NA/EN 13043 [*3*] and the polishing effect is determined using the PSV test (Polished Stone Value test [*14*]). For high-performance roads a PSV greater than 50 is required.

Today, the demand for track ballast is the driving force for steering the extraction and processing of hard rock in Switzerland.

5 Hard minerals are minerals having a Mohs hardness >5 (in particular quartz or feldspar, but also amphibole, olivine, garnet, epidote or volcanic glass) [*11*].

6 It is relevant to note that other authors (e.g. [*8*] and [*24*]) formulated a more restrictive hard rock classification scheme, foreseeing a compressive strength above 140 MPa with a proportion of hard minerals exceeding 25%.

4. General geological overview of the hard rock occurrences and aggregates production in Switzerland

Most of the hard rock-bearing geological units are exposed along the northern Alps between Lake Geneva and Lake Constance or along the southern Alps in the region around and southeast of Lugano. Today, sedimentary rocks such as siliceous limestone, carbonate-rich sandstone and flysch-sandstone/greywacke are extracted to produce Class I track ballast at eight extraction sites, in the cantons of Bern, Nidwalden, Schwyz, Uri, Vaud and Valais.

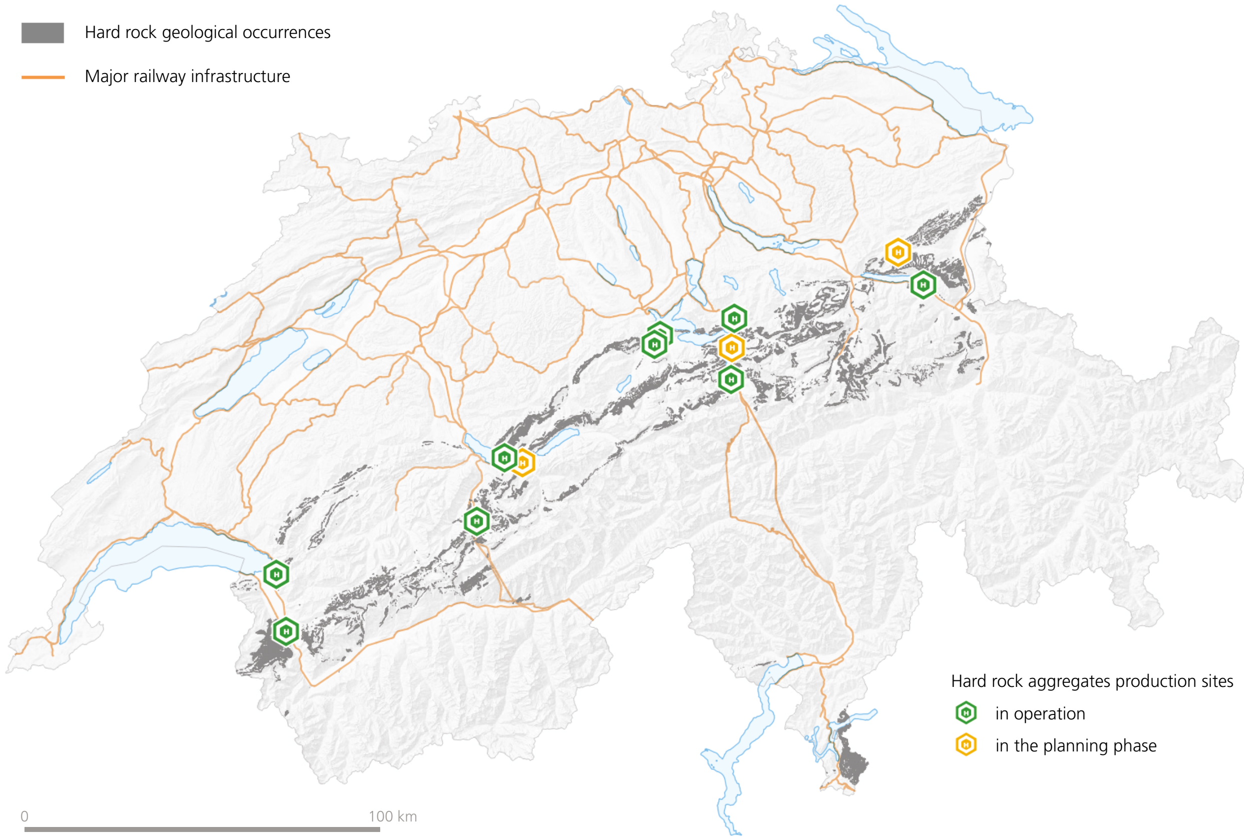

Fig. 1: Overview of the hard rock geological occurrences and the location of the production sites (Status 2024). To explore the details of these features in an interactive way, readers are invited to visit the Federal Geoportal map.geo.admin.ch.

Glauconitic sandstone and fine-grained magmatic rocks with rhyolitic to basaltic composition are known to meet most of the hard rock requirements, but no corresponding extraction site is currently active in Switzerland. This is in contrast with neighbouring countries, where fine-grained magmatic rocks are commonly employed. Lithologies such as granite and gneiss, which are widely exposed in Switzerland, generally do not meet the technical requirements, because the common presence of sheet silicates (mica) has a negative effect on the resistance to fragmentation.

The hard rock-bearing geological units listed in Chapter 7 are mostly situated in regions with diagenetic to sub-greenschist facies Alpine metamorphic overprint that belong to the Helvetic, Penninic, Austroalpine and Southalpine tectonic domains (Figure 2). Low-grade metamorphic overprint appears to play a central role, especially in the formation of hard sandstones and carbonate-rich sandstones. The associated compaction, pressure solution and cementation reduce the porosity of the rock and increase its compressive strength. In greenschist or higher-grade metamorphic rocks, the growth or recrystallisation of minerals and the development of a cleavage or schistosity has a negative effect on the resistance to fragmentation [7]. Therefore, regions with greenschist or higher-grade metamorphic overprint were excluded from this investigation.

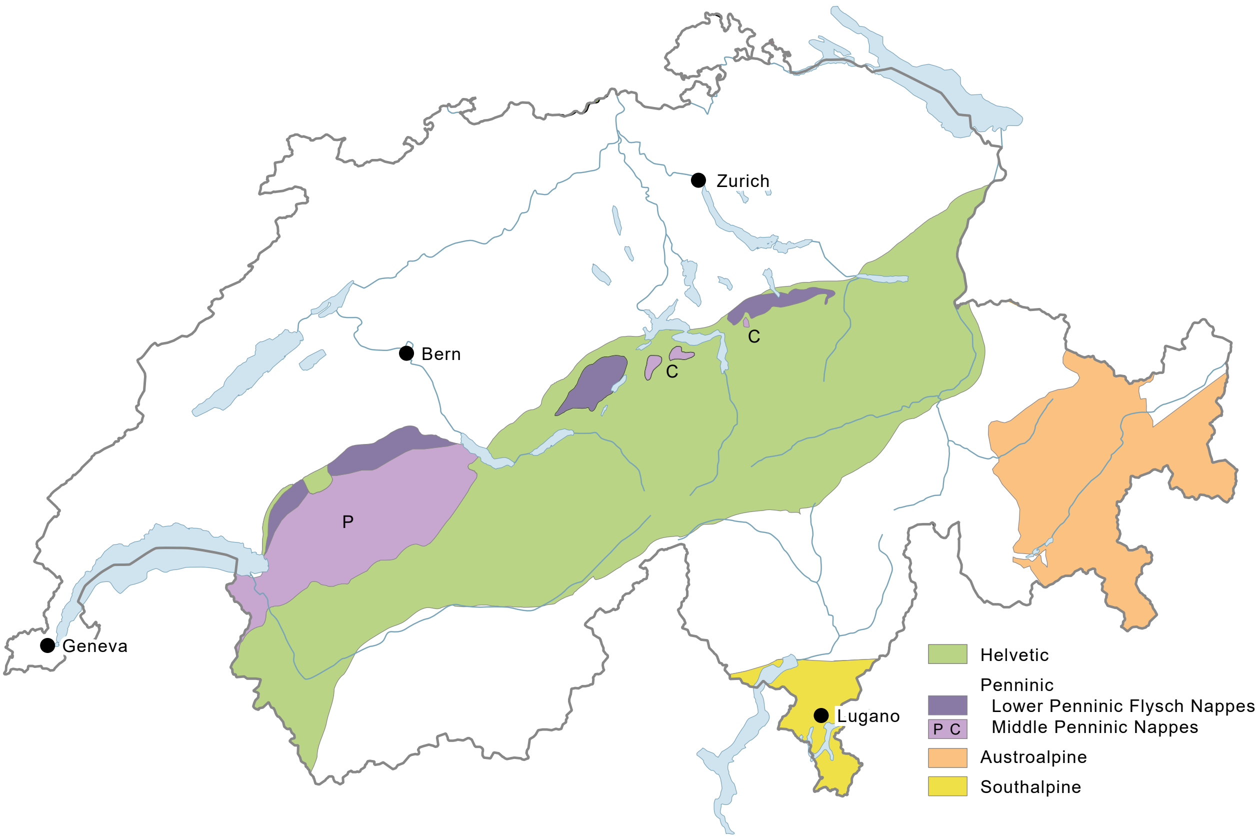

Fig. 2: Schematic overview of the tectonic domains used in this document to group the hard rock-bearing geological units (map simplified after [15], [16] and [236]). P = Préalpes Médianes, C = Klippen of Central Switzerland.

5. Methods and data sources

This chapter summarises the methodology and the input data used to characterise the hard rock geological occurrences and to produce the associated geospatial dataset.

5.1 Definition of the geological potential of a mineral deposit

The geological potential of a mineral deposit is defined by the following three pillars:

1. The *geometry* (i.e. volume) of the deposit or the *thickness* of the geological unit:
   The dimension of the deposit/geological unit must be large enough to justify the substantial financial investment required to access, extract and process the deposit/unit of interest. From an environmental point of view, the exploitation of a thicker deposit/geological unit usually generates a smaller territorial footprint of the extraction site (i.e. smaller impact on the landscape) than the exploitation of a thinner deposit/geological unit.
2. The *quality* (or the grade) of the deposit/geological unit:
   The targeted lithology must meet the technical requirements defined for the intended industrial application. Ideally, a deposit contains large, homogeneous, laterally and vertically continuous volumes of rock with the required quality. Lower quality lithologies within a target geological unit (i.e. interburden) reduce the overall quality of the final product (i.e. dilution effect) and generate higher production costs (i.e. waste rock removal), which in turn can threaten the economic viability of the mining operation.
3. The *accessibility* of the deposit/geological unit:
   The deposit/geological unit must be located at a reasonable distance from the target markets and as close as possible to an efficient transport infrastructure. In addition, the access to the deposit/geological unit must not be impeded by an excessively thick layer of overburden material (e.g. unconsolidated deposits or poor-quality rock).

This document and the method to produce the associated geospatial dataset have been developed according to the above conditions. The geological occurrences identified and described hereafter do not take into account any other "Modifying Factors"[7] such as land use or environmental restrictions. Identifying these region-specific factors and weighing them against the prospective development of a mining site is the responsibility

7 According to the Pan-European Standard for Reporting of Exploration Results, Mineral Resources and Mineral Reserves (PERC) [*235*], *"Modifying Factors" [...] include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governance ('ESG') and regulatory factors.*

of the relevant permitting authorities (particularly cantonal and communal) and the industry seeking to develop a mining operation. This document and the associated geospatial dataset are intended to assist these users in weighing the options in the context of the spatial planning process.

5.2 Criteria for the evaluation of the quality of potential hard rock lithologies

The quality requirements for track ballast and aggregates for road pavements are defined by the normative framework of the VSS (see Chapter 3). To provide the proof whether a geological unit has an effective potential to yield hard rock aggregates of the required quality, a series of industrial tests would have to be carried out. These tests (in particular the LA and PSV tests; see Chapter 3) require the collection and preparation of large sample quantities of fresh rock (~100 kg/sample) with a specific grain size distribution and shape.

The application of this prescribed testing procedure for the evaluation of all the potentially hard rock-bearing geological units occurring in Switzerland would require a substantial financial and logistical effort.

To overcome this limitation, the authors of this document employed a series of inexpensive criteria to rapidly evaluate the quality of potential hard rock lithologies in the field and throughout the literature. These criteria (see list below) build essentially on (a) the technical requirements described in Chapter 3 and (b) the characterisation of the intact rock and the rock mass properties in the field and from the literature.

- *Suitable mineralogy:* a promising lithology must contain more than 25% hard minerals (Mohs hardness > 5, mostly quartz or feldspar) and less than 5% weak minerals such as sheet silicates.
  Information regarding the mineralogical composition was compiled from the literature or from reports provided by the mining operators. In the field, the mineralogical composition and the nature of the detrital grains was estimated by eye whenever possible. However, the identification of the mineralogical composition of a lithology in the field can be challenging, especially in the case of fine-grained siliceous limestone. For some selected samples, X-ray diffraction (XRD) and semi-quantitative microscopic analyses on thin sections were performed.
- *High uniaxial compressive strength (UCS):* the uniaxial compressive strength must be 120 MPa or higher if the lithology contains more than 25% hard minerals.
  In the frame of this investigation, a portable Point Load Test (PLT) device was used to indirectly estimate the compressive strength of fresh rock samples (see Chapter 5.3.3 and Chapter 9 for further details and results).
- *Fine-grained texture:* coarse-grained lithologies are more prone to fracturing along mineral or grain boundaries, meaning a negative effect on the compressive strength and on the resistance to fragmentation. Therefore, a fine-grained texture (< 1 mm) of the sediment grains, the rock-forming minerals or at least the matrix is desirable. Lithologies with a grain size larger than 2 mm were considered to be not usable as hard rock.
- *Isotropic structure of the intact rock:* pervasive parallel structures such as foliation or lamination have a negative effect on the compressive strength and on the resistance to fragmentation. Therefore, an isotropic structure of the intact rock is preferred.

– *Blocky and weakly jointed rock mass:* to optimise the production of track ballast (grain sizes 32–50 mm), a blocky or weakly jointed rock mass (definition according to GSI [*17*]) is preferred. As observed at the mining sites in operation, the thickness of individual beds and/or the spacing between joints are typically 0.3 metres or higher. A lithology with a mean bed thickness or joint spacing less than 0.1 metres was considered to be not usable as hard rock.

The authors are aware that these evaluation criteria alone are not sufficient to prove whether a geological unit listed in this document (or in the associated geospatial dataset) is suitable to produce norm-conformal hard rock aggregates. To obtain such a confirmation, detailed on-site geological investigations (including industrial-scale material testing according to the normative framework) are required.

5.3 Evaluation procedure

5.3.1 Definition of usable and not usable lithologies

A geological unit (i.e. Group, Formation) is a distinct sequence of lithologies typically represented on a geological map. A geological unit may contain a variety of lithologies, which can have by nature very contrasting physical properties. As illustrated in the cross-section in Figure 3, hard rock-bearing geological units contain hard (competent) lithologies that in some places can be intercalated by weak (incompetent) lithologies.

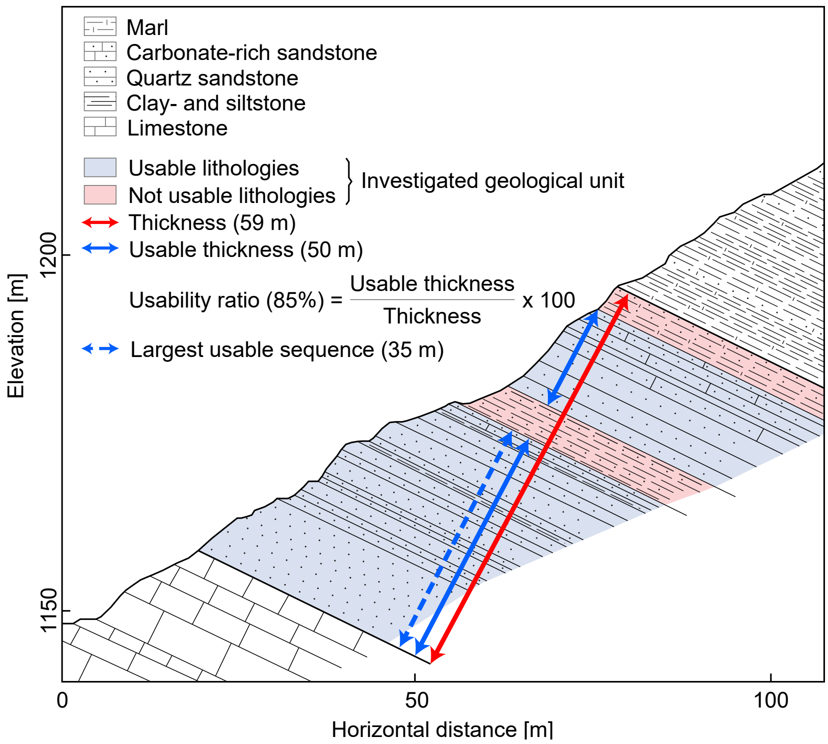

Fig. 3: Schematic example of a cross-section/stratigraphic profile (modified from [*18*]) highlighting the key parameters compiled in this investigation. Example values are given in brackets.

The hard lithologies, such as the sandstone and the carbonate-rich sandstone highlighted in blue in Figure 3, are likely to yield hard rock aggregates according to the evaluation criteria listed in Chapter 5.2. These lithologies are defined in this document as *usable lithologies.*

The weak lithologies, such as the claystone and the siltstone highlighted in red in the cross-section, are not likely to yield hard rock aggregates according to the same evaluation criteria. These lithologies are defined in this document as *not usable lithologies.* If technically and economically feasible, not usable lithologies can be separated during the extraction process (e.g. through scalping).

5.3.2 Literature review, automated thickness analysis and field validation

To evaluate the geometry and to characterise the quality of each potential hard rock-bearing geological unit, more than 350 published articles, theses, technical reports and 47 map sheets of the Geological Atlas of Switzerland 1:25 000 were consulted in detail. In the Geological Atlas of Switzerland 1:25 000 and the corresponding vector dataset GeoCover, the geological units are typically mapped at the Formation level. Therefore, the geological units here were evaluated at the Formation level whenever possible. Geological units of interest not mapped at the Formation level were omitted from the geospatial dataset.

In this data collection and review process, the following numeric parameters were compiled with a spatial reference:

- The *thickness* (or total stratigraphic thickness) represents the distance between the top and the base of a geological unit, normal to the bedding (red arrow in Figure 3).
  More than 1700 thickness data points from around 700 geological cross-sections and 600 stratigraphic profiles or descriptions were compiled from the literature. In order to complement the dataset, especially in areas where no cross-sections were available, more than 10 000 thickness data points and orientation estimates were automatically extracted from the geological vector dataset GeoCover by means of a custom MATLAB routine and Python scripts (see the Technical Documentation [*19*], [*20*] and [*21*] for details regarding the methodology).
- The *Usability ratio* describes the proportion of usable lithologies within a geological unit. This parameter is defined as the ratio between the thickness of all sequences containing usable lithologies (blue arrows in Figure 3) and the thickness of the unit (red arrow in Figure 3). As it reflects both the geometry (thickness) and quality (usability ratio) of a given geological unit, the usable thickness is the main parameter used in the evaluation process: the higher the usability ratio, the larger the proportion of usable lithologies within a geological unit. Estimating the usability ratio or the usable thickness requires a stratigraphic profile, text description or a cross-section including lithostratigraphic information.
  As shown in the cross-section in Figure 3, the usable thickness may not be always stratigraphically continuous, because small intervals of weak lithologies may intercalate the unit.
  In the course of the investigation, approximately 750 estimates of the usability ratio have been compiled.

– The *Largest usable sequence* (blue dashed arrow in Figure 3) describes the thickness of the largest, stratigraphically continuous interval of usable lithologies.
  Based on the experience of mining operators, a sequence of usable lithologies should contain no more than 3 metres of not usable lithologies.
  Approximately 750 estimates of the largest usable sequence have been compiled during this investigation.

At selected locations, the compiled data were validated and supplemented in the field. All active hard rock extraction sites and many natural outcrops located beyond these sites were surveyed between 2020 and 2023 according to the criteria described in Chapter 5.3.2. Besides recording the orientation (dip/dip direction) and the thickness of the beds, the rock mass properties, including the degree of weathering, were classified at the outcrop-scale, according to the Geological Strength Index (GSI) [*22*] and ISRM standards [*17*]. The usability ratio was estimated on site at the outcrop-scale and, whenever possible, at the scale of the entire geological unit as well.

5.3.3 Field testing and compilation of rock properties

During the field visits, rock samples from all the investigated geological units were tested on site using a portable Point Load Test (PLT) device. The PLT is an index field test that gives a rough estimate of the compressive strength by compressing a rock specimen (irregular lump sample) until extensional failure occurs. The advantage of the method is the portability of the testing device and the ability to obtain a statistically and spatially large set of measurements (up to 120 per day), without a time-consuming sample preparation (compared to Uniaxial Compressive Strength (UCS) laboratory testing on drill cores). The authors of this document are aware that the PLT method is not as precise as the standard UCS full-scale laboratory apparatus. The data obtained in this investigation must be seen as complementary to the standard geotechnical procedure involving the collection of samples from exploration drill holes and their testing in a specialised laboratory.

The tested samples were described and investigated with regard to the presence of any potential planes of weakness such as foliation, bedding, joints, or veins. For anisotropic samples, the loading direction (normal or parallel) with respect to the plane of weakness was recorded. The sample size and shape were determined, and the values were used for the size-correction of the test results. The degree of weathering of the samples was also recorded (according to ISRM procedures [*22*]). Here, only the results from fresh or slightly weathered samples were considered (i.e. W2 or W1, according to the ISRM classification [*22*]). At least 15 measurements per geological unit were performed. Finally, the UCS was estimated based on empirical relationships. All tests and calculations were conducted according to the procedure described in the ISRM [*22*] and ASTM D5731-16 standards [*23*] (see Chapter 9 for further details and results).

For the measurements, a "Wille Geotechnics Digital Point Load Tester LP4500", a digital "RocTest PIL-7" device, or a manual "Boart Longyear Interfels no. 431.1000" were used. To ensure that these devices yield comparable results, the same rock samples were tested with all the devices.

Additional rock property data such as the UCS, PSV and LA coefficients were also compiled from the mining operators, the literature or laboratory reports of the Swiss Federal Railways SBB or of the Swiss Federal Laboratories for Materials Science and Technology (EMPA) (e.g. [8], [7], [24], [25]). Note that no new industry-specific tests such as LA or PSV were carried out during the project (see also Chapter 5.2).

Fig. 4: Portable Point Load Test (PLT) device. Photo: T. Galfetti (swisstopo)

5.4 Boundary conditions for locating potentially accessible hard rock occurrences

This project had two main objectives. One was to describe the characteristics of the most promising hard rock-bearing units in Switzerland (this document). This was achieved by means of an extensive literature review, field work and a customised procedure to automatically extract thickness data from GeoCover.

The second objective was to produce a geospatial dataset showing the location of the hard rock-bearing units (a) having a promising usable thickness and (b) that are accessible in terms of transport infrastructure and climatic conditions (snow cover). Since the usable thickness is known to vary laterally, we developed a Python-based, semi-automated modelling method able to predict the usable thickness of any mapped exposure of a promising geological unit in the geological vector dataset GeoCover.

Based on the results of the modelling process, the obtained usable thickness was then constrained by the following boundary conditions:

- Hard rock occurrences with a *usable thickness greater than 30 metres* are considered relevant from a mineral resource development perspective. This lower limit, defined in consultation with the hard rock mining industry, reflects the thickness of the target lithology in some active extraction sites. Note, however, that most extraction sites exploit a geological unit with a usable thickness well above 100 metres.

- Only hard rock occurrences that are situated at a *ground elevation lower than 1300 metres a.s.l.* are considered to be reasonably accessible from a logistical point of view. This upper elevation limit was also defined in consultation with the hard rock mining industry and takes into consideration the duration and extent of the snow cover, assuming an open pit mining operation.

The resulting geospatial dataset, which considers the above-mentioned boundary conditions is published on the Federal Geoportal[8]. The workflow used to constrain the hard rock occurrences is described in the Technical Documentation [*19*], in [*21*] and [*20*].

8 Geospatial dataset "Hard rock aggregates: Thickness and quality of geological occurrences".

6. Description of the attributes describing the hard rock-bearing geological units

Each hard rock-bearing geological unit addressed in Chapter 7 is systematically described by the following attributes:

Attribute	Explanation
Description	General geological description of lithologies (bed thickness, grain size, mineralogy), the proportion and distribution of usable and not usable lithologies within the unit and the total stratigraphic thickness.
Usable lithologies	List of usable lithologies (i.e. competent lithologies with promising hard rock quality) occurring in the geological unit, sorted by abundance.
Not usable lithologies	List of not usable lithologies (i.e. incompetent lithologies) occurring in the geological unit, sorted by abundance.
Geographic distribution	Location and spatial distribution of the unit.
Thickness	Thickness of the unit (as defined in Figure 3, Chapter 5.3.2), with minimum and maximum.
Usability ratio	Usability ratio of the unit (as defined in Figure 3), with minimum and maximum.
Usable thickness	Usable thickness of the unit (as defined in Figure 3), with minimum and maximum.
Largest usable sequence	Largest usable sequence (as defined in Figure 3), with minimum and maximum.
Geological knowledge and confidence	Description of the geological knowledge and the level of confidence regarding the estimation of the usability ratio, the usable thickness, the lateral continuity and quality of potential hard rock lithologies within the unit according to the following categories: *(1) High geological knowledge and confidence:* the unit is currently extracted to produce hard rock aggregates at one or several sites (status 2024) and is likely to contain hard rock quality lithologies also outside these sites. The lithological variability of the unit is rather low, and the lithological lateral continuity is rather high. The quality, distribution, and proportion of usable lithologies within the unit is well known from the existing extraction sites and many stratigraphic descriptions. Not usable lithologies are mostly situated at the base or at the top of the unit. *(2) Medium geological knowledge and confidence:* the unit is or was extracted to produce hard rock aggregates (status 2024). According to stratigraphic descriptions and reports the unit is likely to contain some usable lithologies, also outside these sites. Outside existing or past extraction sites, the usable lithologies cannot be located with precision. Because of the strong tectonic overprint, the high lithological variability or the rather low lithological lateral continuity of the unit, estimates regarding the usable thickness or the usability ratio are generally associated with a high uncertainty. *(3) Low geological knowledge and confidence:* the unit has so far not been extracted to produce hard rock aggregates (status 2024). Stratigraphic descriptions indicate the presence of potentially usable lithologies within the unit. However, whether these lithologies can effectively yield high-quality hard rock aggregates needs to be further investigated. Industrial tests such as LA and PSV are not available. The lithological variability of the unit is high, and the lateral continuity is rather low. Potentially usable lithologies are commonly intercalated with not usable lithologies up to several metres thick. The location of the usable lithologies within the unit is poorly known. Estimates regarding the usability ratio and the usable thickness are generally associated with a high uncertainty.

Technical properties	List of the most relevant hard rock-specific technical properties, expressed, where applicable, as "minimum – (median) – maximum" values: UCS* = Uniaxial Compressive Strength (MPa) LA = Los Angeles coefficient (–) PSV = Polished Stone Value (–) *Results are indirectly estimated from point load tests (PLT, collected within the frame of this investigation) and/or compiled from the literature. Only PLT results obtained from isotropic samples or in the direction normal to anisotropies in the sample are reported here.
Extraction sites	List of the extraction sites exploiting the unit. The currently active sites are highlighted in **bold.** The list may not be exhaustive.
Chronostratigraphy	Chronostratigraphic age of the unit.
Tectonic Position	Affiliation to the present-day tectonic position in the Alpine edifice: – Helvetic domain – Penninic domain (Klippen of Central Switzerland) – Penninic domain (Préalpes Médianes) – Penninic domain (Lower Penninic Flysch Nappes) – Austroalpine domain – Southalpine domain
References	List of the relevant literature pertaining to the described geological unit, sorted by year of publication.
Link to strati.ch	Link to the Lithostratigraphic Lexicon of Switzerland (www.strati.ch).
GeolCode	Numeric code(s) of the GeoCover geological unit(s) (including sub-units, if required). The hierarchically highest-level code (Formation or Group) is highlighted in **bold.**

7. Hard rock-bearing geological units

7.1 Helvetic domain

7.1.1 Spitzmeilen Formation, Early Jurassic

Attribute	Explanation
Description	The Spitzmeilen Formation is composed of a relatively heterogeneous but, overall, very competent succession of fine- to coarse-grained, commonly iron-bearing, carbonate-rich sandstones or siliceous limestones. In places, these lithologies are enriched in echinoderm fragments and ooids [*26*]. Detrital quartz grains and/or the presence of sponge spicules made of amorphous silica result in a quartz content between 15 and more than 30 %. Despite the high lithological variation, the dominantly siliceous limestones or carbonate-rich sandstones of the upper part of the Spitzmeilen Formation can contain lithologies of hard rock quality, for example at the site Fäsch (SG), where the overlying Sexmor Formation is being exploited (see Chapter 7.1.2). The formation also contains relatively incompetent marl and echinoderm-rich, quartz-poor limestone up to several metres thick. According to de Quervain [*24*] and based on our own field work, the sediments of the Spitzmeilen Formation are commonly affected by densely spaced joints and veins. These can be a limiting factor for the production of hard rock aggregates, especially track ballast. The sediments of the Spitzmeilen Formation were deposited in normal fault-bounded basins [*27*] and are characterised by strong lateral thickness variations (5–215 metres, [*26*]), by a high lithological variability and a low lateral continuity. Outside the Fäsch site, the location of the usable lithologies within the unit is poorly known. The presence of irregularly distributed marl- or limestone-dominated intercalations up to several metres thick may hamper the production of hard rock aggregates from this unit. According to stratigraphic descriptions (e.g. [*26*] and [*28*]), the usability ratio is estimated at 40–80 %, the largest usable sequence is mostly less than 40 metres thick, locally up to 80 metres thick.
Usable lithologies	Carbonate-rich sandstone; siliceous limestone
Not usable lithologies	Echinoderm-rich limestone; marl
Geographic distribution	SW–NE striking belt between the Eastern Bernese Oberland and the Glarus Alps (see also Appendix I)
Thickness	5–215 m (see also Appendix Ia)
Usability ratio	40–80 % (see also Appendix Ib)
Usable thickness	3–155 m (see also Appendix Ic)
Largest usable sequence	3–80 m
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* the unit has so far not been extracted to produce hard rock aggregates (Status 2024). Stratigraphic descriptions indicate the presence of potentially usable carbonate-rich sandstone or siliceous limestone within the unit. The lithological variability of the unit is rather high. The potentially usable lithologies can be intercalated with not usable marl or echinoderm-rich limestone up to several metres thick. It is poorly known where the usable lithologies are located within the unit, e.g. [*26*] and [*28*].

Technical properties	UCS: 120–(180)–230 MPa (own PLT measurements) LA: – PSV: –
Extraction sites	– ; –
Chronostratigraphy	Sinemurian–Pliensbachian (Early Jurassic)
Tectonic Position	Helvetic domain
References	Trümpy (1949) [*26*], Spörli (1966) [*28*], de Quervain (1969) [*24*], Schwarz (1969) [*29*], Trümpy & Auberg (1980) [*27*], Tschirky (2009) [*30*], Röthlisberger (2013) [*31*], Ibele et al. (2016) [*32*], Hantke et al. (2019) [*33*], Funk et al. (2020) [*34*], Figi & Grischott (2020) [*35*], den Brok et al. (2021) [*36*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/spitzmeilen-formation
GeolCode	**15202128**, 15202386, 15202387, 15202388

7.1.2 Sexmor Formation, Early Jurassic

Attribute	Explanation
Description	The Sexmor Formation is a heterogeneous succession of siliceous limestone, coarse-grained, quartz-sand-rich limestone, echinoderm limestone, marl and locally some conglomerate [*26*]. Detrital quartz grains and/or the presence of sponge spicules made of amorphous silica result in a quartz content between 15 and more than 30 %. Despite the high lithological variation, large continuous sequences dominated by sand-rich and siliceous limestones can contain hard rock quality material, for example at the site Fäsch (SG), where this unit is being exploited. Relatively weak marls up to several metres thick are present, especially at the base of the formation in the Glarus region [*26*]. These marls, as well as the echinoderm-rich limestones and some locally occurring conglomerate beds do not have hard rock quality. According to de Quervain [*24*], the sediments of the Sexmor Formation are commonly affected by densely spaced joints and veins. These can be a limiting factor for the production of hard rock aggregates, especially track ballast. The sediments of the Sexmor Formation were deposited in normal fault-bounded basins [*27*] and are characterised by high lateral thickness variations (10–170 metres, [*26*]), by a high lithological variability and a low lateral continuity. Outside the Fäsch site, the location of the usable lithologies within the unit is poorly known. The presence of irregularly distributed marl- or limestone-dominated intercalations up to several metres thick may hamper the production of hard rock aggregates from this unit. According to stratigraphic descriptions (e.g. [*26*] and [*28*]), the usability ratio is estimated at 20–95 %. The thickness of the largest usable sequence ranges from less than 10 to 75 metres. The Sexmor Formation is situated on top of the Spitzmeilen Formation (see above), which also contains some hard rock quality material.
Usable lithologies	Carbonate-rich sandstone; siliceous limestone
Not usable lithologies	Echinoderm-rich limestone; marl
Geographic distribution	SW–NE striking belt between the Eastern Bernese Oberland and the Glarus Alps (see also Appendix II)
Thickness	10–170 m (see also Appendix IIa)
Usability ratio	0–90 % (see also Appendix IIb)

Usable thickness	0–75 m (see also Appendix IIc)
Largest usable sequence	0–75 m
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit is currently extracted at one site but not for the production of track ballast of Class I (Status 2024). According to petrological and lab analyses from this site, the unit likely contains some hard rock quality, carbonate-rich sandstone or siliceous limestone. The lithological variability of the unit is rather high. Potentially usable lithologies can be intercalated with not usable marl or echinoderm-rich limestone up to several metres thick (e.g. [*26*] and [*28*]). Outside the extraction sites, the location of the usable lithologies within the unit is poorly known.
Technical properties	UCS: 130–(180)–220 MPa (own PLT measurements), 130–214 MPa [*35*] LA: 12–(14)–16 [*31*], [*35*] PSV: –
Extraction sites	**Fäsch SG**; –
Chronostratigraphy	Pliensbachian (Early Jurassic)
Tectonic Position	Helvetic domain
References	Arbenz (1918) [*37*], Trümpy (1949) [*26*], Spörli (1966) [*28*], de Quervain (1969) [*24*], Schwarz (1969) [*29*], Trümpy & Aubert (1980) [*27*], Tschirky (2009) [*30*], Röthlisberger (2013) [*31*], Ibele et al. (2016) [*32*], Hantke et al. (2019) [*33*], Funk et al. (2020) [*34*], Figi & Grischott (2020) [*35*], den Brok et al. (2021) [*36*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/sexmor-formation
GeolCode	**15202125**, 15202404, 15202405

7.1.3 Torrenthorn Formation, Early Jurassic

Attribute	Explanation
Description	The Torrenthorn Formation represents the lateral equivalent of the Spitzmeilen and Sexmor Formations described in Chapters 7.1.1 and 7.1.2. The unit is, in ascending order, subdivided into the Torrentalp and the Galm Members. Both Members consist of a very heterogeneous succession of medium- to coarse-grained quartz or carbonate-rich sandstone, siliceous limestone, marl, echinoderm-rich limestone and locally some conglomerates [*38*], [*39*], [*40*]. Carbonate-rich sandstone and quartz sandstone typically occur at the base of the Torrentalp and Galm Members [*38*]. The quartz sandstone has a quartz content of up to 80 % [*38*]. These sandstones are typically overlain by echinoderm-rich and sometimes siliceous limestone. Marl commonly dominates towards the top of the Galm Member but can also appear within the rest of the Torrenthorn Formation. The succession and the thickness of the different lithologies described above vary strongly in general. The carbonate-rich sandstone, the quartz sandstone and the siliceous limestone could potentially have hard rock quality and are up to 50 metres thick. Because of the high sheet silicate content and/or the low quartz content, the echinoderm-rich limestone and marl are not suitable as hard rock. Towards the Rhône Valley in the southeast, the unit tends to be increasingly deformed and affected by foliation and/or joints [*40*]. This feature can be a limiting factor for the production of hard rock aggregates. The Torrenthorn Formation only occurs between Leukerbad (VS) and Visp (VS), in the para-autochthonous cover of the Aar Massif. Its sediments were deposited in normal fault-bounded basins [*41*] and are characterised by strong lateral thickness variations (2–325 metres [*38*]), by a high lithological variability and a low lateral continuity.

	The location of usable lithologies within the unit is poorly known from a few detailed stratigraphic descriptions. Potentially usable sandstone and siliceous limestone can contain marly interbeds. The estimated usability ratio within the Torrenthorn Formation varies between 0 and 90 % and is mostly less than 40 %. Especially close to the Rhône Valley, the usable thickness is estimated to be very low as a result of the strong tectonic overprint of the sediments. The unit was extracted in the past at a few sites near Raron (VS) [*40*]. However, no hard rock aggregates were produced from these sites. Important material properties such as the resistance to abrasion, fragmentation etc. are, therefore, not known. Whether portions of the Torrenthorn Formation could fulfil the technical requirements for hard rock aggregates remains to be assessed.
Usable lithologies	Carbonate-rich sandstone; siliceous limestone; quartz sandstone
Not usable lithologies	Echinoderm-rich limestone; marl
Geographic distribution	Leukerbad VS to Visp VS (see also Appendix III)
Thickness	20–325 m (see also Appendix IIIa)
Usability ratio	0–90 % (see also Appendix IIIb)
Usable thickness	0–95 m (see also Appendix IIIc)
Largest usable sequence	0–55 m
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* the unit has so far not been extracted to produce hard rock aggregates (Status 2024). Stratigraphic descriptions indicate the presence of potentially usable carbonate-rich sandstone, siliceous limestone or quartz sandstone within the unit. The lithological variability of the unit is high. Potentially usable lithologies can be intercalated with not usable marl or echinoderm-rich limestone up to several metres thick. It is poorly known, where the usable lithologies are located within the unit.
Technical properties	UCS: 60–(90)–120 MPa (own PLT measurements) LA: – PSV: –
Extraction sites	– ; Raron VS (no hard rock aggregate production)
Chronostratigraphy	Sinemurian–Toarcian (Early Jurassic)
Tectonic Position	Helvetic domain
References	Schläppi (1980) [*38*], Bugnon (1986) [*39*], Loup (1992) [*41*], Sartori et al. (2017) [*40*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/torrenthorn-formation
GeolCode	**15202320**, 15202124, 15202127, 15202516, 15202517, 15202518, 15202519 15202520

7.1.4 Mont-Joly Formation, Early Jurassic

Attribute	Explanation
Description	The Mont-Joly Formation represents the lateral equivalent of the Spitzmeilen, Sexmor and Torrenthorn Formations described in Chapters 7.1.1, 7.1.2 and 7.1.3. The unit consists of a heterogeneous succession of medium to coarse-grained carbonate-rich sandstone, siliceous limestone, echinoderm-rich limestone, and marl [*42*], [*43*]. Typical at the base is a carbonate-rich sandstone, several tens of metres thick, with a high quartz and feldspar content. Above this sandstone, alternating marl and echinoderm-rich limestone with variable detrital quartz content dominate the sedimentary succession and include one or several more competent siliceous limestone sequences. The stratigraphic order and thickness of the different lithologies described above vary laterally. The quartz-feldspar- and carbonate-rich sandstone and the siliceous limestone may have hard rock quality. Especially the sandstone at the base is up to 50 metres thick, while the siliceous limestone sequences are mostly less than 20 metres thick.

	Because of the high sheet silicate content and/or the low quartz content, the echinoderm-rich limestone and marl are not suitable as hard rock. Close to the Rhône Valley, the unit is increasingly deformed and affected by a foliation and/or joints [*42*]. This feature can be a limiting factor for the production of hard rock aggregates. The Mont-Joly Formation only occurs between Col de Balme (VS) in the west and Sierre (VS) in the east, in the para-autochthonous cover of the Aiguilles Rouges and Mont Blanc Massifs. Its sediments were deposited in normal- fault-bounded basins [*44*] and the unit is characterised by strong lateral thickness variations (20–325 metres [*42*], [*43*]), by a high lithological variability and a low lateral continuity. The distribution of usable lithologies within the unit is poorly known from a few detailed stratigraphic descriptions. Especially the siliceous limestone commonly contains marly interbeds. The estimated usability ratio within the formation varies between 0 and 35 %. Especially close to the Rhône Valley, the usable thickness is estimated to be very low as a result of the strong tectonic overprint of the sediments. The unit has not been extracted in the past. Important material properties such as the resistance to abrasion, fragmentation, etc. are, therefore, not known. Whether portions of the Mont-Joly Formation could fulfil the technical requirements for hard rock aggregates remains to be assessed.
Usable lithologies	Carbonate-rich sandstone; siliceous limestone
Not usable lithologies	Echinoderm-rich limestone; marl
Geographic distribution	Col de Balme VS to Sierre VS (see also Appendix IV)
Thickness	20–325 m (see also Appendix IV)
Usability ratio	0–35 % (see also Appendix IVa)
Usable thickness	0–50 m (see also Appendix IVb)
Largest usable sequence	0–50 m (see also Appendix IVc)
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* the unit has so far not been extracted to produce hard rock aggregates (Status 2024). Stratigraphic descriptions and reports indicate the presence of potentially usable carbonate-rich sandstone or siliceous limestone within the unit. The lithological variability of the unit is high. Potentially usable lithologies can be intercalated with not usable marl or echinoderm-rich limestone up to several metres thick. It is poorly known, where the usable lithologies are located within the unit.
Technical properties	UCS: 80–(140)–180 MPa (own PLT measurements) LA: – PSV: –
Extraction sites	– ; –
Chronostratigraphy	Sinemurian–Toarcian (Early Jurassic)
Tectonic Position	Helvetic domain
References	Badoux (1971) [*42*], Epard (1990) [*43*], Bellahsen (2014) [*44*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/mont-joly-formation
GeolCode	**15202126**

7.1.5 Helvetic Kieselkalk, Early Cretaceous

Attribute	Explanation
Description	The Helvetic Kieselkalk is the best studied hard rock-bearing unit in Switzerland and the most exploited to produce hard rock aggregates [*8*], [*45*], [*46*]. The unit is composed of alternating sequences of fine-grained to spathic, mostly very hard siliceous limestone with a variable content of marl and echinoderm-rich limestone [*47*]. The presence of quartz (silica) mainly results from sponge spicules made of amorphous silica and some detrital quartz grains. Where the quartz content is greater than 25–35 %, diagenetic processes and possibly a low-temperature metamorphic overprint, form a densely silicified rock [*8*]. This silification is responsible for the high compressive strength and durability of the Helvetic Kieselkalk. The sedimentary beds of the siliceous limestone are typically 0.1–0.5 metres thick. Locally, the bedding appears massive [*45*], [*46*]. A thin-bedded marly limestone commonly occurs at the base (i.e. "Basisschiefer des unteren Helvetischen Kieselkalkes" [*47*], [*45*], [*46*]) and locally in the middle or near the top of the Helvetic Kieselkalk. At the top, a medium to coarse-grained echinoderm-rich and non-silicified limestone is typically present (i.e. Chriesiloch Echinoderm Limestone [*47*]). These marl-rich and echinoderm-rich limestone-dominated sequences do not have hard rock characteristics. Sequences in which marly intercalations account for more than 10 % of the total volume were considered as not usable as hard rock. The thickness of the Helvetic Kieselkalk varies strongly, especially across nappe boundaries, but also along strike within different Helvetic nappes/tectonic units. The maximum thickness is observed in the Wildhorn-Drusberg and Säntis nappes (up to 1500 m). These thickness maxima are possibly caused by unit-internal folding or thrusting [*46*]. In the Axen nappe, the thickness ranges mostly between 50 and 250 metres. In the Glarus nappe complex and in the Lower Helvetic domain, the thickness is mostly lower than 50 metres, or the unit is entirely absent [*27*]. Overall, the distribution of usable lithologies within the unit is relatively well-known from the many existing extraction sites and stratigraphic descriptions. The estimated usability ratio of the Helvetic Kieselkalk varies between 0 and 100 % but is mostly greater than 50 %. The low-quality sequences mentioned above are mostly confined to the base and/or to the top of the formation. The unit "Calcaire siliceux brunâtre", locally occurring within the Villarbeney Formation of the Ultrahelvetic nappes represents a distal lateral equivalent of the Helvetic Kieselkalk (e.g. [*48*]). Since this siliceous limestone is strongly enriched in marly interbeds, it has not been considered in this investigation.
Usable lithologies	Siliceous limestone
Not usable lithologies	Marl; echinoderm-rich limestone
Geographic distribution	SW–NE striking belt between Vaud-Valais and St. Gallen (see also Appendix V)
Thickness	< 1–1500 m (see also Appendix Va)
Usability ratio	0–100 % (see also Appendix Vb)
Usable thickness	0–670 m (see also Appendix Vc)
Largest usable sequence	0–670 m
Geological knowledge and confidence	*(1) High geological knowledge and confidence:* the unit is currently extracted to produce hard rock aggregates at several sites (Status 2024) and is likely to contain hard rock-quality siliceous limestone also outside these sites. The lithologic variability of the unit is rather low. The quality, distribution, and proportion of usable siliceous limestone within the unit is well known from the existing extraction sites and the many stratigraphic descriptions. Not usable marl or echinoderm-rich limestone is situated mostly at the base or at the top of the unit.

Technical properties	UCS: 115–(150)–195 MPa (own PLT measurements), 90–(160)–285 MPa [24], [49], [7], [50], [51], [52], [53], [54] LA: 11–(14)–24 [24], [49], [7], [50], [51], [52], [53], [54] PSV: ca. 54 (restricted sources)
Extraction sites	**Balmholz BE, Mitholz BE, Kehrsiten NW, Rozloch NW, Zingel SZ**; Därliggrat BE (in planning phase), Läntigen SZ (in planning phase), Starkenbach SG (in planning phase), Amden SG, Brunnen SZ, Collombey VS, Kobelwald SG, and many more.
Chronostratigraphy	Valanginian–Hauterivian (Early Cretaceous)
Tectonic Position	Helvetic domain
References	Kaufmann (1867) [55], Lorenz (1900) [56], Heim (1905 [57], 1910 [58], 1916 [59]), Buxtorf (1910) [60], Arbenz (1911 [61], 1918 [37], 1932 [62]), Beck (1911) [63], Blumenthal (1911) [64], Staub (1911) [65], Keller (1912) [66], Schider (1913) [67], Lugeon (1914) [68], Buxtorf et al. (1916) [69], Mollet (1921) [70], Scabell (1923) [71], Krebs (1925) [72], Bonnard (1926) [73], Loys (1928) [74], Oberholzer (1933) [75], Günzler-Seiffert (1934) [76], Fichter (1934) [77], Schaub (1936) [78], Tavel (1936) [79], Brückner (1937) [80], Furrer (1938 [81], 1946 [82]), Anderegg (1940) [83], Stäger (1944) [84], Collet et al. (1952) [85], Schindler (1959 [86], 1969 [87]), Badoux (1960 [88], 1971 [42], 1991 [89]) Hantke (1961 [90], 2006 [91]), Badoux & Lombard (1962) [92], Herb (1962a [93], 1962b [94]), Mercanton (1963) [95], Nabholz (1964 [96], 1984 [97]), Frey (1965) [98], Godel (1965) [99], Kempf (1966) [100], Funk (1969 [47], 1971 [45]), de Quervain 1969 [24], Ischi (1973) [101], Bieri (1974) [102], Künzi (1975) [103], Ochsner (1975) [104], Schneider et al. (1979) [105], Decrouez & Lombard (1980) [106], Schneider & Keller (1980) [107], Schuler (1980) [108], Trümpy & Aubert (1980) [27], Mojon (1982) [46], Steiger (1982) [109], Mojon & Gerber (1984) [49], Anatra (1986) [48], Friedl & Zurbrügg (1988) [110], Kappes-Taubmann (1988) [111], Schneider (1988) [112], Blant (1989) [113], Jeannin (1989) [114], Gerber (1992 [7], 2010 [54]), Nydegger (1992) [115], Röthlisberger & Vonmont (1992 [50], 1993 [51]), Zwahlen (1993) [116], Huber & Huber (1994) [117], Menkveld (1995) [118], Möri (1995) [119], Hänni (1999) [120], Levi (2001) [121], Gabus et al. (2008) [122], Weber et al. (2010) [123], VersuchsStollen Hagerbach AG (2011 [52], 2012 [53]), Zaugg & Löpfe (2011) [124], Bärtschi (2012) [8], Funk et al. (2013 [125], 2020 [34]), Hantke et al. (2013 [126], 2019 [33], 2022 [127]), Ziegler & Isler (2013) [128], Ibele et al. (2016) [32], Schlunegger et al. (2016) [129], Röthlisberger (2017a) [130], Löpfe et al. (2018) [131], den Brok et al. (2021) [36], Strasky et al. (2022) [132]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/helvetischer-kieselkalk
GeolCode	**15202079**, 15202080, 15202513, 15202081, 15202514, 15202515, 15202537, 15202083, 15202382, 15202082

7.1.6 Garschella Formation, Early Cretaceous

Attribute	Explanation
Description	The Garschella Formation is a succession of glauconite-bearing sandstone, marl and limestone with some phosphatic hardgrounds [133]. In stratigraphically ascending order, the formation is subdivided into the Grünten Member, the Brisi Member and the Selun Member. The Grünten Member consists of silty-sandy, weakly glauconitic, calcareous marls and glauconite-bearing limestone with some sand [134]. At the base, the Brisi Member comprises marly glauconite-rich sandstone overlain by echinoderm-rich limestone and/or glauconite-rich sandstone (Brisi Sandstone). The overlying Selun Member consists of a more heterogeneous sedimentary sequence of sandstone, limestone and marl. The very massive and competent Brisi Sandstone, a glauconitic sandstone, represents the only potential hard rock sequence within the Garschella Formation. The Brisi Sandstone used to be extracted as hard rock at Campiun (SG) [1], [135], where it contains 40–80 % quartz, 3–20 % glauconite and minor calcite.

	The marly sediments situated at the base of the Grünten Member and at the base of the Brisi Member, as well as the limestone, occurring across the entire formation are not suitable to produce hard rock aggregates [*7*]. Because of the high lithologic variability, the entire Selun Member is not suitable as hard rock. The thickness of the formation varies from a few centimetres to more than 150 metres. Overall, the thickness increases from west to east, with two areas of higher thickness in central (Wildhorn nappe) and eastern Switzerland (Säntis nappe). Along the Rhine Valley, near the abandoned extraction site Campiun and in the Meltchtal (OW) area, the thickness of the Brisi Sandstone locally reaches up to 50 metres. In most other regions, especially west of the Melchtal area, its thickness is less than 20 metres (see also Appendix VIa). Overall, the distribution of potential hard rock quality material within the unit is relatively well-known from the existing extraction sites and the stratigraphic descriptions. The estimated usability ratio of the Garschella Formation varies strongly between 0 and 95 % and is mostly less than 30 %. The not usable lithologies mentioned above are mostly above or below the potentially promising Brisi Sandstone.
Usable lithologies	Glauconitic sandstone
Not usable lithologies	Limestone, undifferentiated; marl
Geographic distribution	SW–NE striking belt between Vaud-Valais and St. Gallen (see also Appendix VI)
Thickness	< 1–165 m (see also Appendix VIa)
Usability ratio	0–100 % (see also Appendix VIb)
Usable thickness	0–50 m (see also Appendix VIc)
Largest usable sequence	0–50 m
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit was extracted to produce hard rock aggregates in the past, but none of these extraction sites is currently active (Status 2024). Technical reports from these sites and stratigraphic descriptions indicate the local presence of potentially usable glauconitic sandstone within the unit. The lithologic variability of the unit is rather high. The quality, distribution, and proportion of usable sandstone within the unit are relatively well known and documented from past extraction sites and many stratigraphic descriptions. Not usable echinoderm-rich limestone or marl are abundant, but mostly situated at the top or at the base of the sandstone.
Technical properties	UCS: 100–(160)–220 MPa (own PLT measurements, only sandstones of the Brisi Member considered), 180–340 MPa [*24*], [*7*], [*136*], [*8*] LA: 15–25 [*7*], [*136*] PSV: –
Extraction sites	– ; Campiun SG, Weesen SG, Beckenried NW, Stansstad (NW) [*7*]
Chronostratigraphy	Aptian–Cenomanian (Early Cretaceous)
Tectonic Position	Helvetic domain
References	Escher (1878) [*137*], Mösch (1881) [*138*], Piperoff (1897) [*139*], Arbenz (1905 [*140*], 1918 [*37*], 1932 [*62*]), Heim (1905 [*57*], 1910 [*58*], 1913 [*141*], 1916 [*59*]), Buxtorf (1910) [*60*], Blumenthal (1911 [*64*], 1912 [*142*]), Staub (1911) [*65*], Keller (1912) [*66*], Lugeon (1914) [*68*], Buxtorf et al. (1916) [*69*], Bonnard (1926) [*73*], Loys (1928) [*74*], Oberholzer (1933) [*75*], Fichter (1934) [*77*], Günzler-Seiffert (1934) [*76*], Schaub (1936) [*78*], Furrer (1938 [*81*], 1962 [*143*]), Bentz (1948) [*144*], Collet et al. (1952) [*85*], Korner (1957) [*145*], Badoux et al. (1959) [*146*], Schindler (1959 [*86*], 1969 [*87*]), Hantke (1961) [*90*], Herb (1962a [*93*], 1962b [*94*]), Mercanton (1963) [*95*], de Quervain (1969) [*24*], Badoux (1971) [*42*], Schneider et al. (1979) [*105*], Steiger (1982) [*109*], Zwahlen (1986 [*147*], 1993 [*116*]), Föllmi & Ouwehand (1987) [*133*], Friedl & Zurbrügg (1988) [*110*], Schneider & Keller (1988) [*107*], Badoux & Gabus (1991) [*148*], Gerber (1992) [*7*], Huber & Huber (1994) [*117*], Dietrich & Wahrenberg (1997) [*136*],

	Funk et al. (2000 [*149*], 2013 [*125*], 2020 [*34*]), Linder et al. (2006) [*134*], Zaugg & Löpfe (2011) [*124*], Bärtschi (2012) [*8*], Hantke et al. (2013 [*126*], 2019 [*33*], 2022 [*127*]), Ibele et al. (2016) [*32*], Hodel et al., 2018 [*135*], Röthlisberger (2018a) [*150*], den Brok et al. (2021) [*36*], swisstopo (2021) [*1*], Strasky et al. (2022) [*132*]
Link to strati.ch	www.strati.ch/en/stratigraphic/garschella-formation
GeolCode	**15202052**, 15202053, 15202054, 15202055, 15202056, 15202057, 15202058, 15202059, 15202060, 15202061, 15202062, 15202063, 15202064, 15202065, 15202066, 15202067, 15202068, 15202069, 15202070, 15202071, 15202397, 15202072, 15202424, 15202426

7.1.7 Niederhorn Formation, Middle–Late Eocene

Attribute	Explanation
Description	The Niederhorn Formation is composed of two members, the Hohgant Sandstone at the base and the Gemmenalp Limestone at the top [*151*]. The Hohgant Sandstone is typically dominated by fine- to coarse-grained quartz sandstone and carbonate-rich sandstone with some marly intercalations. Up to four sequences comprising nearly pure quartz sandstone occur between Interlaken and Kemmeribodenbad [*152*], [*153*] and in the Entlebuch region [*18*]. These sandstones typically contain calcite, dolomite and 50–90% quartz [*154*]. The unit was already mentioned as hard rock-bearing in an ASTRA report [*155*]. According to Point Load and Uniaxial Compressive Strength tests conducted in this study [*18*], [*154*], these sandstones have a uniaxial compressive strength of around 185 MPa, thus indicating potential hard rock quality. Lower uniaxial compressive strengths (< 160 MPa) were observed in some well-sorted and coarse-grained sandstones [*154*]. The Gemmenalp Limestone is typically dominated by limestone. Within the Hohgant Sandstone, the potentially usable sandstone sequences described above are commonly separated by marl-rich or calcareous sediments, which do not have hard rock quality. Because of its low quartz content, the Gemmenalp Limestone generally does not have hard rock characteristics [*152*], [*153*], [*151*]. According to Menkveld-Gfeller et al. [*151*], the thickness of the Niederhorn Formation is up to 350 metres, but mostly around 50 metres [*121*] (Appendix VII). The Hohgant Sandstone is up to 280 metres thick [*156*]. Sequences approximately 15–170 metres thick comprising mostly quartz sandstone and carbonate-rich sandstone with potential hard rock-quality are typically intercalated by thin-bedded and not usable marl up to a few metres thick. Depending on the thickness, this marl could be problematic for the production of hard rock aggregates. Stratigraphic descriptions indicate some potentially usable carbonate-rich sandstone or quartz sandstone in the Hohgant Sandstone. Where this member is not mapped, it is difficult to precisely locate the potentially usable lithologies within the unit. The estimated usability ratio of the Niederhorn Formation varies strongly between 0 and 90%, mostly greater than 40%, depending on the abundance of detrital quartz. The Niederhorn Formation has so far not been exploited and important material properties such as the resistance to abrasion, fragmentation etc. are, therefore, not known. Whether portions of the Niederhorn Formation could fulfil the technical requirements for hard rock aggregates remains to be assessed. The Schimberg and Tierberg Members, both part of the Wildstrubel Formation, represent the lateral equivalents to the Hohgant Sandstone (e.g. [*157*], [*92*], [*158*]). These units contain some sandstone but are mostly dominated by marl with variable sand-content and were not considered in this investigation.

Usable lithologies	Carbonate-rich sandstone; quartz sandstone
Not usable lithologies	Limestone, undifferentiated; marl
Geographic distribution	SW–NE striking belt between the Rawil area and Lake Lucerne (see also Appendix VII)
Thickness	< 1–380 m (see also Appendix VIIa)
Usability ratio	0–90 % (see also Appendix VIIb)
Usable thickness	0–170 m (see also Appendix VIIc)
Largest usable sequence	0–170 m
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* the unit has not been extracted to produce hard rock aggregates in the past (Status 2024). Stratigraphic descriptions and reports indicate the presence of potentially usable carbonate-rich sandstone or quartz sandstone within the unit. The lithologic variability of the unit is high. Potentially usable lithologies are commonly intercalated with not usable limestone or marl up to several metres thick.
Technical properties	UCS: 140–(185)–235 MPa (own PLT and UCS measurements, [*18*], [*154*]) LA: – PSV: –
Extraction sites	– ; –
Chronostratigraphy	Bartonian–Priabonian (Middle–Late Eocene)
Tectonic Position	Helvetic domain
References	Beck (1911) [*63*], Boussac (1912) [*157*], Schider (1913) [*67*], Lugeon (1914) [*68*], Mollet (1921) [*70*], Scabell (1923) [*71*], Louis (1924) [*159*], Krebs (1925) [*72*], Schaub (1936) [*78*], Tavel (1936) [*79*], Furrer (1938) [*81*], Müller (1938) [*160*], Tschachtli (1942) [*161*], Badoux & Lombard (1962) [*92*], Eckert (1963) [*162*], Mercanton (1963) [*95*], Ischi (1973) [*101*], Bieri (1974) [*102*], Künzi (1975) [*103*], Breitschmid (1976 [*152*], 1978 [*153*]), Steffen (1978 [*163*], 1981 [*158*]), Steiger (1982) [*109*], Zwahlen (1986 [*147*], 1993 [*116*]), Janssen (1988) [*164*], Blant (1989) [*113*], Badoux & Gabus (1991) [*148*], Hunziker (1992), Menkveld-Gfeller (1994) [*156*], Levi (2001) [*121*], Gerber (2003) [*155*], Funk et al. (2013) [*125*], Menkveld-Gfeller et al. (2016) [*151*], Schlunegger et al. (2016) [*129*], Coray (2021) [*18*], Mayer (2022) [*154*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/niederhorn-formation
GeolCode	**15202020**, 15202021, 15202022, 15202377, 15202023

7.1.8 North-Helvetic Flysch Group, Eocene–Oligocene

Attribute	Explanation
Description	The North-Helvetic Flysch Group comprises a heterogeneous turbiditic sequence of Flysch sandstone/greywacke, clay- and siltstone and some conglomerates ([*151*] and references therein). It is subdivided into the Taveyannaz, Elm and Matt Formations (from stratigraphically old to young [*165*], [*151*]). The top of the North-Helvetic Flysch is typically a tectonic contact to the overlying Helvetic Nappes. At Attinghausen (UR), a more than 50 metres thick sequence dominated by Flysch sandstone/greywacke is exploited to produce hard rock aggregates. The sandstone is typically fine- to medium-grained, the beds are mostly thicker than 0.1 metres and the clay- and siltstone intercalations are very thin. It contains more than 50 % quartz, up to 40 % albite and dolomite and about 10 % calcite [*154*]. Promising sandstone-dominated sequences also can be expected outside the Attinghausen site. However, these are irregularly distributed within the unit and typically intercalated with not usable sequences up to several hundred metres thick, with more abundant siltstone, claystone, or conglomerates [*16*], [*8*].

	The thickness of the North-Helvetic Flysch varies from a few metres to more than 2000 metres, mostly less than 500 metres (e.g. [*166*], Appendix VIII). This thickness cannot be regarded as a true stratigraphic thickness. It rather reflects the cumulative thickness of these sediments in the strongly deformed accretionary wedge [*151*]. Outside the known extraction sites, the distribution of potential hard rock quality material within the unit is poorly known and the proportion of lower-quality clay- and siltstone within the unit can be high. According to stratigraphic descriptions (e.g. [*65*], [*75*], [*167*], [*168*]), the estimated usability ratio varies between 0 and 90 % and is mostly below 45 % (see also Appendix VIII). The largest usable sequence is up to 380 metres thick but mostly below 200 metres. At Attinghausen, the extracted sandstone sequence is stacked as a result of folding and thrusting. This feature gives the advantage of having the hard rock quality material locally concentrated. Because of the deposition on laterally and vertically limited submarine fan systems and the strong tectonic overprint, the resulting geometries of the suitable sandstone successions are very complex and difficult to predict, even at the quarry scale. In the Rhône Valley transect, the North-Helvetic Flysch Group is situated at the base of the Molasse Rouge of Monthey (see Chapter 7.1.9), which also contains hard rock quality lithologies.
Usable lithologies	Flysch sandstone, greywacke
Not usable lithologies	Claystone; siltstone; conglomerate
Geographic distribution	SW–NE striking belt between Valais and Glarus/St. Gallen (see also Appendix VIII)
Thickness	4–3200 m (see also Appendix VIIIa)
Usability ratio	0–90 % (see also Appendix VIIIb)
Usable thickness	0–1450 m (see also Appendix VIIIc)
Largest usable sequence	0–380 m
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit is currently extracted at one site (Status 2024). According to stratigraphic descriptions and reports, the unit is likely to contain usable Flysch sandstone/greywacke also outside this site. The unit is typically very thick, strongly folded and faulted, and the lithological variability within the unit is high. The potentially usable lithologies are commonly intercalated with not usable claystone-, siltstone- or conglomerate-dominated sequences that are up to several hundred metres thick. Outside existing or past extraction sites, the usable lithologies cannot be located precisely within the unit. Given the strong tectonic overprint and lithologic variability of the unit, the estimated usability ratios are associated with a high uncertainty.
Technical properties	UCS: 145–(195)–235 MPa (own PLT measurements), 170–300 MPa [*24*], [*169*] LA: 11–15 [*7*], [*51*], [*170*], [*169*] PSV: 56–58 [*169*]
Extraction sites	**Attinghausen UR**; Bouveret VS, Matt GL, VD, Linthal GL, Seedorf UR, Val d'Illiez VS
Chronostratigraphy	Eocene–Oligocene
Tectonic Position	Helvetic domain
References	Staub (1911) [*65*], Arbenz (1918) [*37*], Scabell (1923) [*71*], Louis (1924) [*159*], Bonnard (1926) [*73*], Loys (1928) [*74*], Oberholzer (1933) [*75*], Brückner (1937 [*80*], 1943 [*171*]), Furrer (1938 [*81*], 1946 [*82*]), Collet (1943) [*172*], Vuagnat (1945 [*173*], 1952 [*174*]), Collet et al. (1952) [*85*], Schröder & Ducloz (1955) [*167*], Badoux et al. (1959) [*146*], Badoux & Lombard (1962) [*92*], Mercanton (1963) [*95*], de Quervain (1969) [*24*], Badoux (1971) [*42*], Siegenthaler (1974) [*165*], Ochsner (1975) [*104*], Ruch (1983) [*175*], Lateltin (1988) [*168*], Badoux & Gabus (1991) [*148*], Gerber (1992) [*7*], Röthlisberger & Vonmont (1993) [*51*], Zwahlen (1993) [*116*], Huber & Huber (1994) [*117*], Menkveld (1995) [*118*], Kündig et al. (1997) [*16*], Gabus et al. (2008) [*122*], Hantke (2011) [*176*], Pfiffner (2011) [*166*], Sartori & Epard (2011) [*177*], Bärtschi (2012) [*8*], Menkveld-Gfeller et al. (2016) [*151*], Röthlisberger (2018) [*170*], Gisler et al. (2020) [*178*], den Brok et al. (2021) [*36*], Mayer (2022) [*154*], www.gasperini.ch (2024) [*169*]

Link to strati.ch	https://www.strati.ch/en/stratigraphic/nordhelvetische-flysch-gruppe
GeolCode	**15202005,** 15292540, 15202541, 15202452, 15202006, 15202007, 15202008, 15202010, 15202009, 15202289, 15202011, 15202512

7.1.9 Molasse Rouge of Monthey, Oligocene

Attribute	Explanation
Description	Along the Rhône Valley, the North-Helvetic Flysch is overlain by hard rock-bearing units of the Lower Marine and the Lower Freshwater Molasse. The stratigraphic attribution and age of these Molasse units are still partly unknown. This shortcoming is also reflected by the somewhat inconsistent geological mapping of these units. On the most relevant geological map "St-Maurice" [*179*], [*180*], these Molasse units are summarised as the Molasse Rouge of Monthey. On this geological map and in Schröder & Ducloz (1955) [*167*], the Molasse Rouge of Monthey is, in stratigraphically ascending order, subdivided into three subunits: (i) the "Schistes marno-micacés" containing mostly claystone and marl, (ii) the "Grès des Carrières" (according to the new lithostratigraphic nomenclature referred to as Massongex Sandstone), a competent fine- to medium-grained carbonate-rich sandstone, mostly less than 40 metres thick, and (iii) the "Molasse rouge", a relatively heterogeneous alternation of marl, limestone, quartz-rich limestone and coarse-grained sandstone. The top of the unit is typically a tectonic contact. The Massongex Sandstone is being exploited at Monthey-Massongex. It contains about 30 % quartz, 35 % feldspar and 30 % carbonate components and has a uniaxial compressive strength of 170–230 MPa (own PLT results and other restricted sources). The underlying "Schistes marno-micacés" and the overlying "Molasse rouge" units do not fulfil the quality requirements for hard rock due to the presence of many sheet silicates and marl. The thickness of the Molasse Rouge of Monthey varies from 50 to 1000 metres but is mostly less than 500 metres (e.g. [*88*], [*167*], Appendix IX). Outside the Monthey-Massongex extraction sites, the position and thickness of the hard rock-bearing Massongex Sandstone is largely unknown, and our estimates may have a high uncertainty. Given the high thickness of the Molasse Rouge of Monthey and the relatively low thickness of the hard rock quality sandstone, the usable thickness at the formation level is mostly below 20 % [*88*]. The not usable lithologies are, however, predominantly situated at the top and at the base of the Massongex Sandstone. At the Monthey-Massongex site, the hard rock quality sequence is stacked through folding and thrusting [*167*]. This feature gives the advantage of having the targeted hard rock quality lithology locally thickened/concentrated. However, the resulting geometries are very complex and difficult to predict, even at the quarry scale. According to Weidmann (1982 [*181*] and 1988 [*182*]), the Massongex Sandstone and the "Schistes marno-micacés" are both attributed to the Vaulruz Formation. The stratigraphic attribution, age and mapping of these units need to be revised and harmonised in the future.
Usable lithologies	Carbonate-rich sandstone
Not usable lithologies	Marl; limestone, undifferentiated
Geographic distribution	Rhône Valley transect (see also Appendix IX)
Thickness	50–1000 m (see also Appendix IXa)
Usability ratio	3–85 % (see also Appendix IXb)
Usable thickness	20–110 m (see also Appendix IXc)
Largest usable sequence	20–60 m

Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit is currently extracted at one site (Status 2024). According to stratigraphic descriptions and reports, the unit is likely to contain some usable carbonate-rich sandstone, also outside this site. Typically, the unit is strongly folded and faulted. The potentially usable sandstone is mostly less than 40 metres thick and is commonly situated within a succession of mostly not usable marl and limestone up to several hundred metres thick. Outside existing or past extraction sites, the sandstone layer of interest cannot be located with precision. Given the strong tectonic overprint and the lithologic variability of the unit, the estimated usability ratios are generally associated with a high uncertainty.
Technical properties	UCS: 170–(220)–265 MPa (own PLT measurements), 200–(205)–230 MPa [*24*], [*183*] LA: 11–15 [*7*], [*51*], [*184*] PSV: 60–62 [*185*]
Extraction sites	**Monthey-Massongex VS**; At least two abandoned sites around the same area, also near Bex VS and Bouveret VS.
Chronostratigraphy	Oligocene
Tectonic Position	Helvetic domain
References	Heim (1917) [*186*], Gagnebin et al. (1928 [*179*], 1934 [*180*]), Collet et al. (1952) [*85*], Schröder & Ducloz (1955) [*167*], Badoux (1960) [*88*], de Quervain (1969) [*24*], Weidmann (1982 [*181*], 1988 [*182*]), Ruch (1983) [*175*], Gerber (1992) [*7*], Röthlisberger & Vonmont (1993) [*51*], Kündig et al. (1997) [*16*], Bärtschi (2012) [*8*], Röthlisberger (2017c [*184*], 2022 [*183*]), www.famsa.ch (2024) [*185*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/molasse-rouge-monthey
GeolCode	**15200549**

7.2 Middle Penninic Nappes (Klippen of Central Switzerland)

7.2.1 Obflue Formation, Early Jurassic

Attribute	Explanation
Description	The Obflue Formation is restricted to the Penninic Klippen of Central Switzerland. It is mostly composed of fine-grained siliceous limestone with variable content of echinoderm fragments and with subordinate marly intercalations (e.g. [*187*]). The siliceous limestone beds are mostly thicker than 0.2 metres and separated by marly interbeds up to 5 cm thick. The presence of quartz (silica) in the limestone mainly results from sponge spicules made of amorphous silica and some detrital quartz grains. When the quartz content is greater than 25–35 %, diagenetic processes and eventually a low-temperature metamorphic overprint form a densely silicified rock [*8*]. This silification is responsible for the high compressive strength and durability of the siliceous limestone. In the Stanserhorn (OW/NW) area, in the uppermost part of the formation, these marly interbeds can be up to 1 metre thick. In the Arvigrat (OW/NW) area, these marly interbeds appear to be absent so that the entire Obflue Formation is made of siliceous limestone. The thickness of the marly intercalations is variable [*187*]. Sequences in which marly intercalations account for more than 10 % of the total thickness were considered as not usable for the production of hard rock aggregates. The sediments of the Obflue Formation were deposited in normal fault-bounded basins [*125*] and are characterised by strong lateral thickness variations (2–50 metres, mostly around 30 metres), by a high lithological variability and a low lateral continuity. In the absence of present or past extraction sites, the hard rock potential of the Obflue Formation is rather poorly known and difficult to estimate because of the variable marl content. According to stratigraphic descriptions (e.g. [*187*]), the usability ratio is estimated at 60–100 %. Important material properties such as the resistance to abrasion, fragmentation etc. are not known. Whether the siliceous limestone of the Obflue Formation could fulfil the technical requirements for hard rock aggregates remains to be assessed. The Petit-Liençon and the Chauderon Formations described in Chapters 7.1.1 and 10.3.2 represent the lateral equivalents of the Obflue Formation.
Usable lithologies	Siliceous limestone
Not usable lithologies	Marl
Geographic distribution	South of Stans NW (see also Appendix X)
Thickness	2–50 m (see also Appendix Xa)
Usability ratio	65–100 % (see also Appendix Xb)
Usable thickness	2–45 m (see also Appendix Xc)
Largest usable sequence	2–45 m
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* the unit has not been extracted to produce hard rock in the past (Status 2024). Stratigraphic descriptions show evidence for the presence of potentially usable siliceous limestone within the unit. The usable siliceous limestone can contain not usable marly interbeds up to several centimetres thick.
Technical properties	UCS: 90–(135)–160 MPa (own PLT measurements) LA: – PSV: –
Extraction sites	– ; –
Chronostratigraphy	Pliensbachian (Early Jurassic)
Tectonic Position	Middle Penninic Nappes (Klippen of Central Switzerland)
References	Christ (1920) [*187*], Bärtschi (2012) [*8*], Funk et al. (2013) [*125*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/obflue-formation
GeolCode	**15203078**

7.3 Middle Penninic Nappes (Préalpes Médianes)

7.3.1 Petit-Liençon Formation, Early Jurassic

Attribute	Explanation
Description	The Petit-Liençon Formation represents the lateral equivalent to the Obflue and Chauderon Formations described in Chapters 7.1.1 and 10.3.2. It occurs in the Middle Penninic Nappes (Préalpes Médianes), between Lac Léman and Lake Thun. In the literature, the Petit-Liençon Formation is described as a fine-grained relatively homogeneous succession of siliceous limestone (e.g. [*188*], [*189*], [*190*], [*191*], [*192*]). The beds are 0.2–1 metre thick and locally separated by thin marly intercalations, which mostly do not exceed 5 cm. The siliceous limestone banks have a quartz content of 20–60 %, locally even more [*8*]. The presence of quartz (silica) in the limestone mainly results from sponge spicules made of amorphous silica and detrital quartz grains. A quartz content greater than 25–35 % leads to densely silicified rock [*8*]. This silification is responsible for the high compressive strength and durability of the siliceous limestone. Given the high proportion of competent siliceous limestone in the unit, it appears justified to consider the Petit-Liençon Formation as a hard rock-bearing unit. However, the petrophysical properties are not known in detail and as such, hard rock characteristics are not proven. The thickness of the marly intercalations is variable (e.g. [*190*]). Sequences in which marly intercalations account for more than 10 % of the total volume were considered as not usable as hard rock. The sediments of the Petit-Liençon Formation were deposited in normal fault-bounded basins [*189*] and are characterised by strong lateral thickness variations (2–440 metres, mostly around 100 metres, [*191*], [*188*], Appendix XI), by a high lithological variability and a low lateral continuity. According to stratigraphic descriptions, the usability ratio is estimated at 75–100 %. In the absence of data from the past extraction sites, important material properties such as the resistance to abrasion, fragmentation etc. are not known. Whether the siliceous limestone of the Petit-Liençon Formation could fulfil the technical requirements hard rock aggregates remains to be proven.
Usable lithologies	Siliceous limestone
Not usable lithologies	Marl
Geographic distribution	Between Lac Léman and Lake Thun (see also Appendix XI)
Thickness	2–440 m (see also Appendix XIa)
Usability ratio	75–100 % (see also Appendix XIb)
Usable thickness	2–330 m (see also Appendix XIc)
Largest usable sequence	2–260 m
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit was extracted to produce hard rock aggregates in the past but none of these sites is currently active (Status 2024). Stratigraphic descriptions and reports show strong evidence for the presence of potentially usable siliceous limestone within the unit. The usable siliceous limestone can be interbedded in places with not usable marl up to several centimetres thick.
Technical properties	UCS: 145–(190)–250 MPa (own PLT measurements), 170–(175)–185 MPa [*8*] LA: – PSV: –
Extraction sites	– ; Stocken-Höfen BE, Spiez BE
Chronostratigraphy	Pliensbachian (Early Jurassic)
Tectonic Position	Middle Penninic Nappes (Préalpes Médianes)

References	Thury (1973) [*188*], Heinz (1980) [*193*], Mettraux (1989) [*189*], Weidmann (1993) [*194*], Borel (1997) [*190*], Pasquier (2004) [*195*], Bärtschi (2012) [*8*], Braillard (2015) [*191*], Plancherel et al. (2020) [*195*], Heinz & Burkhalter (2023) [*192*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/petit-liencon-formation
GeolCode	**15203052**

7.3.2 Rossinière Formation, Early to Middle Jurassic

Attribute	Explanation
Description	The Rossinière Formation contains siliceous limestone, echinoderm limestone and marl (e.g. [*196*]). The siliceous limestone is rather coarse grained and enriched in echinoderm fragments. The relatively high quartz content, typically more than 30 %, results from the presence of sponge spicules made of amorphous silica and detrital quartz grains [*8*], [*196*]. The beds are mostly more than 0.1 and up to 0.6 metres thick and separated by thin marly intercalations. In the upper part of the Rossinière Formation, the silica is observed as concretions or the beds are entirely silicified. At Arvel (VD), the uppermost part of the Rossinière Formation, a regularly bedded alternation of siliceous limestone with sub-centimetre marly interbeds, is currently exploited to produce hard rock aggregates. The lower part of the Rossinière Formation (e.g. the part that was earlier extracted in the lower, now abandoned part of the Arvel site, s. Chapter 10.3.1) is dominated by echinoderm-rich limestone. Given its low quartz content and coarse-grained texture, this part does not have hard rock quality. The thickness of the marly intercalations is variable [*190*]. Where these intercalations account for more than 10 % of the total volume, the entire sequence is considered not usable to produce hard rock aggregates. This is commonly the case towards the top of the formation. The sediments of the Rossinière Formation were deposited in normal fault bounded basins [*189*] and are characterised by strong lateral thickness variations (up to 550 metres in the Arvel area but mostly less than 200 metres, e.g. [*191*], [*188*], see also Appendix XII), by a high lithological variability and a low lateral continuity. It is difficult to estimate the usability ratio of the Rossinière Formation outside the Arvel site. The main reasons are the high lithological variability, the irregularly distributed marly beds and the variable quartz content. According to stratigraphic descriptions, the usability ratio is estimated at 40–80 %, the largest usable sequence is near the Arvel site more than 300 metres thick.
Usable lithologies	Siliceous limestone
Not usable lithologies	Echinoderm-rich limestone; marl
Geographic distribution	between Lac Léman and Lake Thun (see also Appendix XII)
Thickness	2–660 m (see also Appendix XIIa)
Usability ratio	40–80 % (see also Appendix XIIb)
Usable thickness	2–375 m (see also Appendix XIIc)
Largest usable sequence	2–300 m
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* the unit is currently extracted at Arvel (VD) (Status 2024). According to stratigraphic descriptions and reports, some usable siliceous limestone is expected to occur outside this site. Potentially usable siliceous limestone prevails in this unit, but it can contain marly interbeds up to several centimetres thick. Not usable echinoderm-rich limestone up to several decametres thick is mostly situated at the base of the unit or can even be the dominant lithology within the unit. The absence of clear markers and/or formation boundaries cause a high degree of uncertainty in the estimated thickness values.

Technical properties	UCS: 120–(170)–220 MPa (own PLT measurements), 100–(142)–198 MPa [*7*], [*51*], [*197*], [*198*] LA: 16 [*7*], [*51*], [*199*] PSV: 52 (restricted sources)
Extraction sites	**Arvel VD**; Rossinière VD
Chronostratigraphy	Toarcian–Aalenian (Early–Middle Jurassic)
Tectonic Position	Middle Penninic Nappes (Préalpes Médianes)
References	Jeannet (1918) [*200*], Badoux (1965) [*201*], Thury (1973) [*188*], Mettraux (1989) [*189*], Weidmann (1991) [*194*], Gerber (1992) [*7*], Cuccodoro (1993) [*202*], Röthlisberger & Vonmont (1993) [*51*], Borel (1997) [*190*], Pasquier (2004) [*195*], Bärtschi (2012) [*8*], Braillard (2015) [*191*], Geomin (2016 [*197*], 2020a [*203*], 2020b [*204*]), Röthlisberger (2017b) [*199*], Plancherel et al. (2020) [*196*], Violay & Sandrone (2022) [*198*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/rossiniere-formation
GeolCode	**15203047**

7.4 Southalpine domain

7.4.1 Moltrasio Formation, Early Jurassic

Attribute	Explanation
Description	The Moltrasio Formation is a grey, massive, well-bedded succession of predominantly siliceous, partially echinoderm-rich, nodular and bituminous limestones that is rich in silex concretions and marl beds. East of the major N–S striking Lugano Fault (Faglia di Lugano) and within the Generoso Basin, it reaches a thickness between 1300 and up to 5000 metres (e.g. [*205*], see Appendix XIII). The base of the formation is tectonic and hardly exposed (Castellaccio, above Melano). The top is typically eroded or can display a stratigraphic hiatus (Alpe di Mendrisio). West of the Lugano Fault (Rancate–Arzo–Viggiù area), the thickness increases from 10 metres near Arzo to 150 metres at the Swiss-Italian border and reaches up to 1500 metres in the Monte Nudo Basin further west in Italy [*205*]. The siliceous limestones have a quartz content of 12–50 %, mostly around 35 % [*8*]. The relatively high quartz content results from the presence of sponge spicules made of amorphous silica and detrital quartz grains. From a mineralogical point of view, the siliceous limestone commonly appears suitable for the production of hard rock aggregates. According to Bernoulli [*205*], who has tried to subdivide the formation into 6 subunits, subunit no. 5 contains the most suitable lithologies. However, this subdivision has not been mapped on the respective geological map sheets 69 (Lugano) and 152 (Mendrisio). Marly interbeds are mostly less than 5–10 cm thick. At the base of the formation, the marls appear to be more abundant [*205*]. Where these intercalations account for more than 10 % of the total volume, the entire sequence is not considered usable as hard rock. The Moltrasio Formation locally also contains calcareous conglomerates, which are not suitable to produce hard rock aggregates. The thickness of the beds generally varies between 0.2 and 1 metre. This highly competent unit is widely used as dimension stone for several applications in Ticino and northern Italy. Based on the visited outcrops and literature analyses, the usability ratio is estimated from 0 to 90 %, but is mostly between 70 and 90 %.
Usable lithologies	Siliceous limestone
Not usable lithologies	Marl; echinoderm-rich limestone; calcareous conglomerate
Geographic distribution	East of Lugano Fault: between Lugano and Como (I) West of Lugano Fault: between Rancate and Arzo (see also Appendix XIII). The unit extends westwards in Italy to Lago Maggiore and eastward to the Lago d'Iseo.
Thickness	East of Lugano Fault: 1300–5000 m West of Lugano Fault: 10–150 m (in Switzerland) (see also Appendix XIIIa)
Usability ratio	0–90 % (see also Appendix XIIIa)
Usable thickness	0–2600 m
Largest usable sequence	–
Geological knowledge and confidence	*(2) Medium geological knowledge and confidence:* in the past, the unit was extracted at several sites to produce hard rock aggregates for road construction but not for railway ballast. Stratigraphic descriptions and reports show strong evidence for the presence of potentially usable siliceous limestone within the unit, also outside these old extraction sites. The siliceous limestone deposits are up to several kilometres thick and, overall, relatively continuous. However, the highest quality lithologies cannot be located precisely within the unit. The unit also contains some not usable marl, echinoderm-rich limestone and calcareous conglomerate. Because of the absence of clear geological markers, the estimated usability ratios have a high uncertainty.

Technical properties	UCS: 110–(180)–235 MPa (own PLT measurements), 174–(210)–342 MPa [*8*] LA: – PSV: –
Extraction sites	**Cave di Saltrio (Italy, west from Arzo)**; Cava Sasséi near Salorino (TI), Cava Ronchetti near Caprino (TI) and a site near Gandria close to the Swiss/Italian border.
Chronostratigraphy	Hettangian–Pliensbachian (Early Jurassic)
Tectonic Position	Southalpine domain
References	Wiedenmayer (1963) [*206*], Bernoulli (1964) [*205*], Reinhard et al. (1964) [*207*], Bärtschi (2012) [*8*], Bernoulli et al. (2018) [*208*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/moltrasio-formation
GeolCode	**15205040**, 15205041

7.4.2 Permian volcanics: Granophyre

Attribute	Explanation
Description	The granophyres of the Lugano area are exposed from the area north of Varese (I) via Porto Ceresio to Carona (TI), together with many other Permian volcanic rocks (see also Chapter 7.4.3). Granophyre, also known as quartz-porphyry is microscopically characterised by a very robust intergrowth of quartz and feldspars in a micro-crystalline glassy matrix. The texture is weakly porphyritic. The typical red colour is due to small hematite inclusions in the feldspars [*24*]. Phenocrysts (mostly feldspar, quartz and some biotite) are typically less than 1–3 mm in diameter. At the visited sites on the Monte Arbostora (Soresello, Madonna d'Ongero), the rock mass is dissected by variably spaced sub-planar joints and faults, which are commonly covered by secondary pyrite, chalcopyrite or galena [*209*]. The granophyre is affected by various degrees of alteration, vertically and laterally, and can contain millimetre-size vesicles filled with various secondary minerals. The alteration and the vesicles have a negative effect on the intact rock strength. In southern Ticino and Lombardia (I), dimensioned granophyre ("porfido rosso") is commonly used as a building material (as natural wall stone, road kerbstone or for pavements) but also as aggregates. Historic extraction sites are located on and around the Monte Arbostora (TI). In Italy, a quite large mining site is operated near Porto Ceresio (Cuasso al Monte). Another large mining site is located North of Varese (Rasa di Varese), but it has been recently decommissioned. According to our field investigations, weakly altered granophyre can be very competent (UCS up to 200 MPa, [*24*] and own measurements) and may have hard rock quality. However, test results also show that strongly altered granophyre are much weaker (UCS < 100 MPa). Given the poor exposure of the top and base contacts, the thickness of the unit cannot be estimated precisely. It is assumed to be 100–160 metres thick, reaching up to 300 metres in some areas. Because of the sparse available data, especially the degree and extent of the weathering and alteration, it is not possible to reasonably estimate the usability ratio for this unit. As a result of these uncertainties, the unit is currently not considered in the geospatial dataset.
Usable lithologies	Granophyre (quartz-porphyry)
Not usable lithologies	When strongly altered, faulted or jointed the granophyre may not be usable
Geographic distribution	The granophyres strike SW-SE and are exposed from north of Varese (I) via Porto Ceresio to Carona (TI) [*209*]
Thickness	100–300 m
Usability ratio	–
Usable thickness	–

Largest usable sequence	–
Geological knowledge and confidence	*(3) Low geological knowledge and confidence:* In Switzerland, the unit was extracted in the past for dimension stone production. In northern Italy, the rock is also processed to obtain hard rock aggregates. Our own and third-party testing results indicate that the unit can have a high performance in terms of compressive strength. However, the granophyre can be strongly altered and commonly contains vesicles. The alteration and the vesicles have a negative effect on the physical properties and its extent is largely unknown. Based on the existing data, it is not possible to estimate a usability ratio. Therefore, this geological unit is not included in the present version of the geospatial dataset.
Technical properties	UCS: 80–(130)–185 MPa (own PLT measurements), 200 MPa [*24*] LA: – PSV: –
Extraction sites	**Cuasso al Monte** (Italy, nearby the Swiss border); Soresello near Figino (TI), south of Carona (Madonna d'Ongero, TI), Rasa di Varese (Italy)
Chronostratigraphy	Permian
Tectonic Position	Southalpine domain
References	de Quervain (1969) [*24*], Buletti (1985) [*209*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/lugano-vulkanite-granophyr
GeolCode	**15205066** (attribution in GeoCover is not definitive, may change in the future)

7.4.3 Permian volcanics: Other (undifferentiated)

Attribute	Explanation
Description	A variety of volcanic rocks of Permian age are exposed between Porto Ceresio (I), Riva San Vitale (TI) and Campione d'Italia (I). Rhyolites, andesites and dacites with a mostly porphyritic texture are most common. Altogether, the volcanics form a complex up to 600 metres thick at the base of the Mesozoic sediments. At Cava Campioli, north of Melide (TI), such porphyritic andesites/dacites were extracted to produce track ballast, road base aggregates and as backfill for the Melide Dam (Ponte Diga) [*210*]. Slope stability concerns [*211*] led to the site being closed and recultivated in the 1970's. The dark red to violet to green andesite/dacite has a dense and glassy matrix and contains feldspar phenocrysts 1–3 mm long [*24*]. Other elongated phenocrysts (originally likely amphibole or pyroxene) were altered to mostly epidote, chlorite, carbonates and iron oxides or hydroxides [*209*]. Quartz is commonly present as phenocryst or within the matrix. At the visited site in Melide, the rock mass is dissected by irregularly spaced and oriented faults and joints. The unit is affected by various degrees of alteration, vertically and laterally, and this results in a low strength of the intact rock. However, many outcrops of the rhyolites are strongly weathered [*209*]. Given the historic production of hard rock aggregates at Melide in the past, some of the competent and weakly altered volcanics are assumed to be suitable for hard rock aggregates production. This is also indicated by UCS values of up to 235 MPa or more at the Melide site (own measurements). However, because of the sparse available data, especially the degree and extent of the weathering and alteration, the location of the faults and the variable mineralogy, it is not possible to reasonably estimate the usability ratio for this unit. As a result of these uncertainties, the unit is currently not considered in the geospatial dataset.
Usable lithologies	Dacite, rhyolite, andesite
Not usable lithologies	Not usable if strongly altered, faulted or jointed

Geographic distribution	Monte Arbostora between Morcote and Melide, northern foot of the Monte San Giorgio between Pojana and Porto Ceresio, and western foot of the Monte Generoso between Campione d'Italia and Melano.
Thickness	Up to 600 m in total [*24*]
Usability ratio	–
Usable thickness	–
Largest usable sequence	–
Geological knowledge and confidence	*(2) Medium level of confidence:* At Melide (TI), the unit was extracted in the past to produce hard rock aggregates. Our own and third-party testing results indicate that the unit can have a high performance in term of compressive strength. However, the Permian volcanics are locally strongly altered. This alteration has a negative effect on the physical properties and its extent is largely unknown. Based on the existing data it is not possible to estimate the usability ratio for the volcanics. Therefore, this geological unit is currently not included in the geospatial dataset.
Technical properties	UCS: 120–(195)–235 MPa (own PLT measurements) LA: – PSV: –
Extraction sites	– ; Campioli, near Melide (TI)
Chronostratigraphy	Permian
Tectonic Position	Southalpine domain
References	de Quervain (1955 [*210*], 1969 [*24*]), Bersier (1965) [*211*], Buletti (1985) [*209*]
Link to strati.ch	https://www.strati.ch/en/stratigraphic/lugano-vulkanite
GeolCode	**15205065** (attribution in GeoCover is not definitive, may change in the future)

8. Overview of the thickness and usable thickness values

This chapter describes the variability of the thickness and the usable thickness values obtained for each hard rock-bearing geological unit shown in the geospatial dataset. The ca. 6400 thickness values (blue boxplots in Figure 5) include both literature-derived and automatically extracted estimates. The 635 estimates of the usable thickness (red boxplots in Figure 5) were compiled from the literature.

The geological units can be assigned to three thickness clusters:

The units with the highest thickness are the *Helvetic Kieselkalk, the North-Helvetic Flysch, the Molasse Rouge of Monthey as well as the Rossinière and Moltrasio Formations* (see Figure 5 and Appendix Va, VIIIa, IXa, XIIa and XIIIa). In these units, median thickness values between 115 and 500 metres are observed, with a large variability. In the Molasse Rouge of Monthey, the median usable thickness amounts to 30 metres with little variation (see Appendix IXc), which corresponds to a median usability ratio of less than 10%. The Helvetic Kieselkalk, the Rossinière and Moltrasio Formations as well as the North-Helvetic Flysch have a median usable thickness of 100–125 metres, again with a large variability (see Appendix Vc, VIIIc, IXc and XIIIc). This corresponds to a usability ratio between 45 and 75%.

Median thickness values between 50 and 110 metres are estimated for the *Spitzmeilen, Sexmor, Torrenthorn, Mont-Joly and the Petit-Liençon Formations* (see Figure 5 and Appendix Ia–IVa and XIa). In the Petit-Liençon Formation, the median usable thickness (110 metres, see Appendix XIc) is almost as much as the thickness of the unit. The Spitzmeilen and Sexmor Formations have a median usable thickness of 40–60 metres (see Appendix Ic and IIc), which corresponds to a median usability ratio around 65%. Lower median usable thicknesses (< 20 metres, see Appendix IIIc and IVc) are observed in the Mont-Joly and Torrenthorn Formations. The corresponding median usability ratios are less than 25%. The lower usable thickness in these formations may reflect more and thicker marly interbeds combined with a stronger tectonic and metamorphic overprint.

The *Garschella, Niederhorn and Obflue Formations* are characterised by low thickness values with a median between 25 and 50 metres (see Figure 5 and Appendix VIa, VIIa and Xa). The Garschella Formation has a median usable thickness of less than 15 metres. However, usable thicknesses greater than 30 metres are locally observed in central and eastern Switzerland (see Appendix VIc, VIIc and Xc). In the Obflue and Niederhorn Formations, the median usable thickness amounts to 30 and 50 metres, respectively.

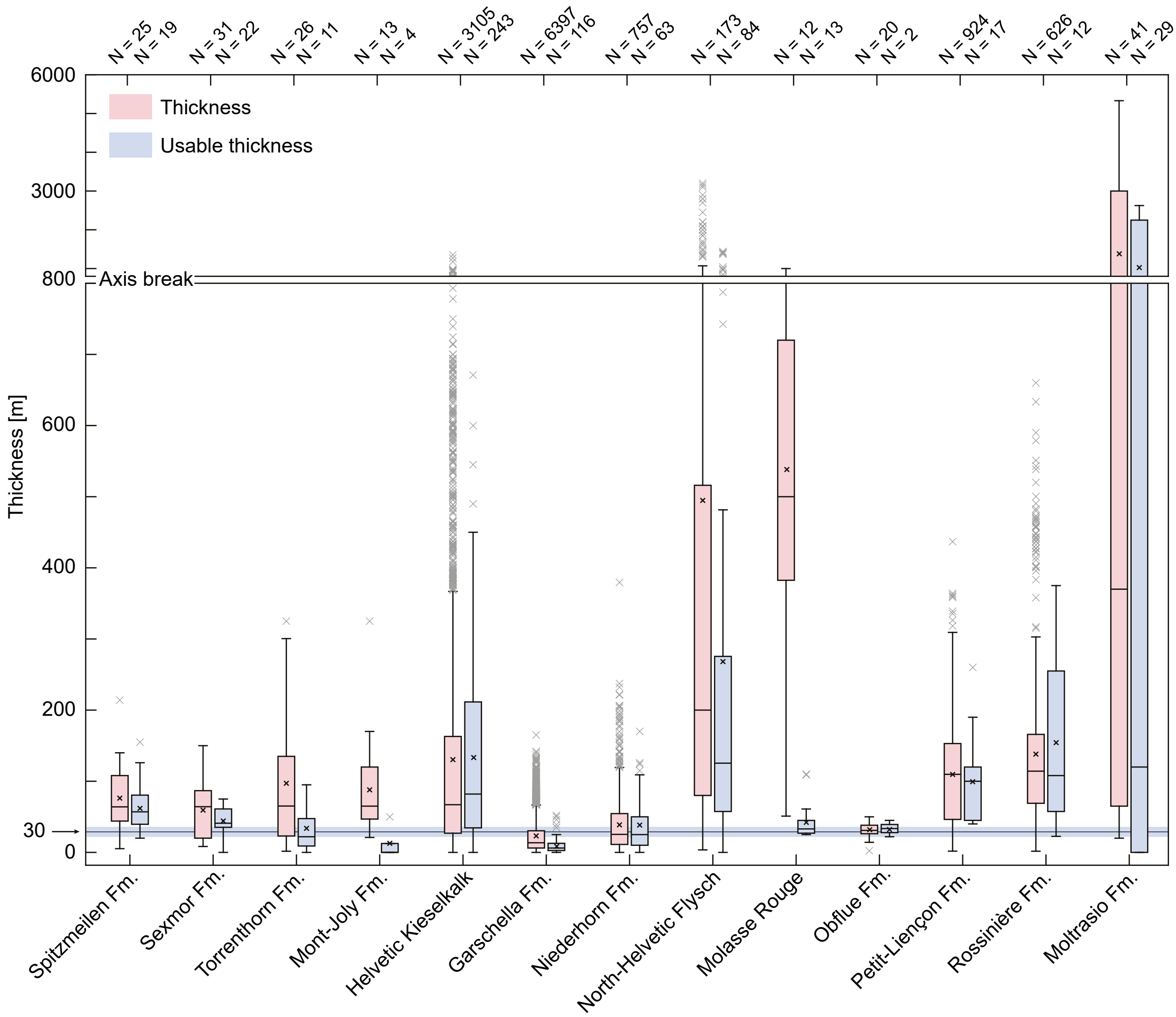

Fig. 5: Boxplots showing the variability of the thickness and the usable thickness values obtained in this investigation for each hard rock-bearing geological unit. The black line and the black cross in the middle of each box highlight the sample median and mean, respectively. N = number of data points used per geological unit. The height of the boxes represents the lower and upper quartiles. The whiskers extend to the 5% and 95% levels of the data set, respectively. Data points beyond the whiskers are outliers (grey crosses). The blue horizontal line represents the lower limit of the usable thickness of 30 metres (see Chapter 5.4).

9. Compressive strength of the hard rock-bearing units

This chapter provides a statistical overview of the approximately 1300 compressive strength results, which were obtained from samples of the geological units listed in Chapter 7 and tested using a portable Point Load Test device (see and Chapter 5.3.3, Figure 4). Most of the tests involved isotropic samples. Foliated or laminated samples were tested in the direction normal or parallel to the anisotropy. Only the tests conducted normal to the anisotropy are reported in Figure 6. Not usable lithologies such as marl, limestone, silt- or claystone, which commonly occur within the investigated geological units, were also investigated, but these results are not shown here.

In the box and whisker plot, it can be observed that the median compressive strength of all tested units, except the Torrenthorn Formation, exceeds the lower limit of 120 MPa defined in the norm VSS 70 115 [*11*] (see also Chapter 3). Depending on the geological unit, the variability of the results can be high (± 50 MPa in the interquartile range). This variability can be explained by the lithological variability, the presence of sheet silicates or discontinuities such as joints or veins or the degree of weathering of the tested rocks. To some degree, this variability may also reflect the measurement accuracy.

Samples from the Sexmor, Spitzmeilen, Niederhorn, Petit-Liençon Formations, the North-Helvetic Flysch, the Massongex Sandstone (Molasse Rouge of Monthey) and other tested Permian volcanics of the Southalpine domain show a median compressive strength greater than 180 MPa. The Helvetic Kieselkalk, Mont-Joly, Garschella, Obflue, Rossinière and Moltrasio Formations as well as the Permian Granophyre of the Southalpine domain display a median compressive strength between 120 and 180 MPa.

The results obtained in the frame of this investigation fall in the range of values that have been obtained from the literature or from the mining operators (if available).

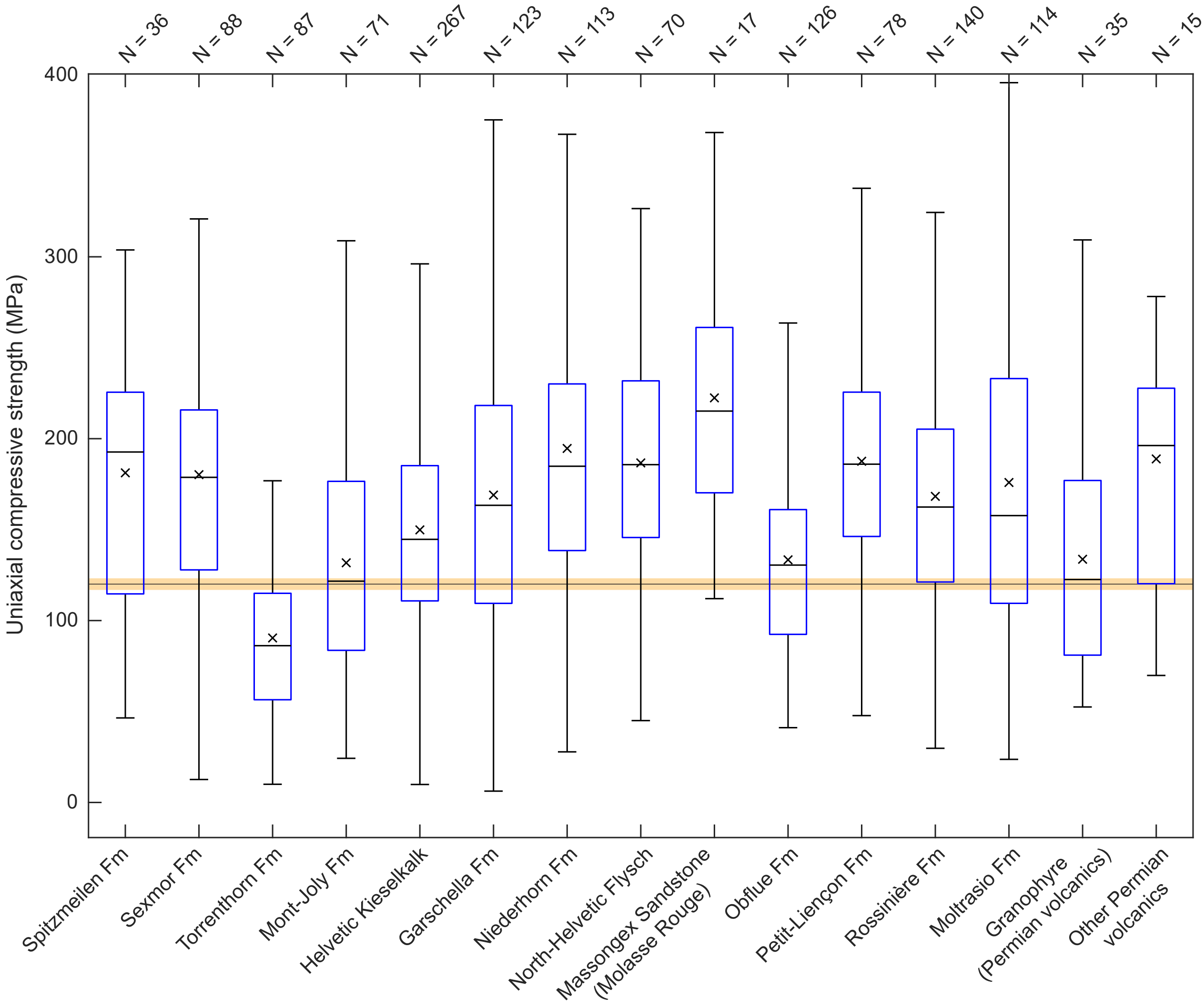

Fig. 6: Box and whisker plots showing the variability of the uniaxial compressive strength determined for the hard rock-bearing geological units listed in Chapter 7. The black horizontal line and the black cross in the middle of each box highlight the sample median and mean, respectively. N = number of data points collected per geological unit. The height of the blue box represents the lower and upper quartiles. The whiskers represent the minimum and maximum. Only the results of potentially usable lithologies are shown. When only a selected subunit (i.e. member) was tested, the superordinate unit is shown in brackets. The orange horizontal line at 120 MPa represents the lower limit defined in the norm VSS 70 115 [*11*] (see also Chapter 3).

10. Geological units not considered in the geospatial dataset

This chapter lists the geological units that were extracted or were considered as promising hard rock lithologies in the past but are no longer considered suitable to produce hard rock aggregates. The reasons that led to the exclusion of these units from the geospatial dataset are provided in the following subchapters. The most common reasons that led to the exclusion of a given geological unit are (i) the more restrictive normative quality requirements for hard rock aggregates and (ii) the refinement of the lithostratigraphic framework of the mapped geological units during the harmonisation process of the GeoCover dataset.

10.1 Helvetic domain

10.1.1 Formations of the Early Jurassic

In older geological maps, the Early Jurassic sediments of the Helvetic domain are commonly mapped as one large undifferentiated unit. Previous hard rock investigations included all Early Jurassic sediments, because these containing some usable lithologies (e.g. [*7*], [*8*], [*9*] and [*10*]). In more recent geological maps (e.g. [*32*]), the lithostratigraphic classification is refined and the Early Jurassic sediments are subdivided into several formations. This subdivision enables to locate the usable lithologies more precisely in the Spitzmeilen, Sexmor, Torrenthorn and Mont-Joly Formations (see Chapters 7.1.1–7.1.4). Moreover, other less promising formations can be excluded based on this refined attribution. In this investigation, the Early Jurassic sediments were re-evaluated at the formation level.

Formations that do not contain relevant amounts of usable lithologies are not considered in the geospatial dataset. These formations are listed and described in the following table:

Prodkamm Formation	The Prodkamm Formation is exposed between Engelberg (OW) and Sargans (SG). It is dominated by marls having some competent sandstone beds [*26*]. Because of the abundance of marls or marly interbeds, it is unlikely that the Prodkamm Formation is suitable for the production of hard rock aggregates.
Brunnistock Formation	The Brunnistock Formation locally occurs in the Engelberg (OW) region. According to Spörli [*28*], the unit is dominated by sand-rich, coarse-grained echinoderm-rich limestone, including up to cm-sized dolomite pebbles. Owing to the coarse-grained texture of the sediments, it is unlikely that the Brunnistock Formation is suitable to produce hard rock aggregates.
Bachalp Formation	The Bachalp Formation locally occurs in the Leuk (VS) region. It is dominated by marl and limestone with rather low quartz content (e.g. [*212*]). Because of the low quartz content, it is unlikely that the Bachalp Formation is suitable to produce hard rock aggregates.
Tierces Formation	The Tierces Formation occurs between Col de la Forclaz (VS) and Sion (VS). It is composed of an alternation of marl and limestone with relatively low quartz content [*213*]. Because of the low quartz content, it is unlikely that the Tierces Formation is suitable to produce hard rock aggregates.

Monts Rosset Formation	The Monts Rosset Formation occurs between Col de la Forclaz (VS) and Sion (VS). The unit comprises marls with beds of echinoderm-rich limestone [*213*]. Therefore, the Monts Rosset Formation is unlikely to be suitable to produce hard rock aggregates.
Gryonne Formation	The Gryonne Formation, historically known as "Lias des Mines", occurs in the Ultrahelvetic nappes between Bex and Lenk [*92*]. It constitutes marls with a variable content of silex. Overall, the marls dominate and hence it is unlikely that this formation will be suitable to produce hard rock aggregates.

10.1.2 Formations of the Middle Jurassic

The following table contains two formations of Middle Jurassic age from the Helvetic domain. In the past, these formations were either exploited to produce hard rock aggregates or assumed to contain relevant amounts of usable lithologies. The following table explains why these formations are not included in the geospatial dataset.

Reischiben Formation	The Reischiben Formation is exposed between Martigny (VS) and Sargans (SG) and it is mostly composed of echinoderm-rich limestone [*214*]. It can also contain quartz-rich limestone and iron oolites (Blegi-Eisenoolith). The limestone was previously extracted to produce hard rock aggregates, for example at its type locality south of Walenstadt (SG) [*7*]. At this site, the quartz content, and the degree of silification of the rock is relatively low. Owing to the low content of quartz and other hard minerals (mostly < 25 %) in the limestone, the Reischiben Formation is unlikely to meet today's requirements for hard rock aggregates.
Hochstollen Formation	The Hochstollen Formation is exposed between Martigny (VS) and the Reuss Valley (UR). It contains carbonate-rich sandstone, siliceous limestone and marl. Marly interbeds are common and thicker than 5 cm in many places (e.g. [*118*]), so that large continuous sequences of usable lithologies are unlikely to occur.

10.1.3 Formations of the Early Cretaceous

In the past, the Betlis Formation, the Sichel Limestone and the Diphyoides Limestone, in the older German literature often referred to as "Valanginien-Kalk" or "Valanginien-Kieselkalk", were considered as hard rock-bearing units (e.g. [*7*], [*8*], [*9*] and [*10*]). These formations are exposed between the Rhône Valley (VS) and the Rhine Valley (SG). The three formations have a comparable stratigraphic age and represent lateral facies domains of the former Helvetic continental shelf from proximal (Betlis Formation), to intermediate (Sichel Limestone) and to distal (Diphyoides Limestone). After re-evaluation, these formations have been excluded from the geospatial dataset.

Betlis Formation	The Betlis Formation is dominated by competent limestone, having minor silica and in places of sandstone on top up to a few metres thick (i.e. Pygurus Member [*215*], [*46*]). The quartz content of the limestone is low and the thickness of the sandstone near the top of the formation (Pygurus Member) is mostly less than 20 metres (e.g. [*75*], [*59*], [*148*]). Therefore, the Betlis formation is unlikely to be suitable to produce hard rock aggregates.
Sichel Limestone	The Sichel Limestone contains siliceous and sand-rich limestone with a variable contents of echinoderm fragments and generally thin marly interbeds [*215*], [*46*]. The unit is up to 200 metres thick (e.g. [*215*], [*147*], [*216*]) and was earlier exploited to produce hard rock aggregates at Ringgenberg (BE). There, the echinoderm limestone is not sufficiently silicified [*7*] and does not fulfil some of the quality requirements (according to the mining operator, the resistance to the fragmentation is not sufficiently high to produce track ballast of Class I).

Diphyoides Limestone	The Diphyoides Limestone contains mostly fine-grained micritic limestone and some marl (e.g. [*215*], [*90*], [*217*]). It contains some quartz, mostly originating from silica-bearing sponge needles. However, the quartz content is mostly less than 20 %, so that the limestone is not considered as a potential hard rock-bearing unit.

10.2 Lower Penninic Flysch Nappes

The Lower Penninic Flysch Nappes include, from west to east, the Gurnigel-, Schlieren- and Wägital-Flysch series, situated between Lac Léman and Walensee (Figure 2). These nappes contain a 50–200 metres thick sedimentary sequence, which is dominated by competent, quartz-rich Flysch Sandstone (e.g. [*218*]). Near Alpnach (OW), Sarnen (OW) and Flühli (LU), the sandstone is extracted to produce dimension stone, but not for hard rock aggregates (i.e. Guber and Schoni Sandstones). The Guber Sandstone has a UCS of 187 MPa [*219*].

In the Gurnigel area, comparable sandstones (i.e. "Flysch 2b with sandy turbidites", according to the Lithostratigraphic Lexicon of Switzerland [*220*]) occur together with some silt- and claystone as well as conglomeratic beds. The sandstone was extracted near Zollhaus (FR), where UCS values of 160–240 MPa and 90–175 MPa are reported in the literature [*221*] and own PLT measurements, respectively.

Although the compressive strength of the sandstones from these Flysch Nappes is mostly greater than 120 MPa, there is no record that hard rock aggregates have been produced or employed as track ballast. This may be due to the relatively coarse-grained texture and the presence of sheet silicates, both of which have a negative impact on the resistance to fragmentation. For now, the unit is not included in the geospatial dataset.

The Prättigau Schists are interpreted often to represent the lateral equivalents to the Flysch Nappes discussed above [*222*], [*236*]. The unit is more than 1500 metres thick and contains up to 350 metres thick sandstone-dominated sequences such as the Klus, Pfävigrat, Gyrenspitz and Ruchberg Formations. However, according to Winkler [*223*], not usable marly interbeds or coarse-grained sandstone to conglomeratic beds are relatively abundant in these formations. Furthermore, the sheet silicate content in many of the sandstone beds is relatively high [*223*]. Therefore, the formations are not included in the geospatial dataset.

10.3 Middle Penninic Nappes (Klippen of Central Switzerland, Préalpes Médianes)

Previous investigations (e.g. [*7*], [*8*], [*9*] and [*10*]) mention the occurrence of promising hard rock lithologies in the Early Jurassic and Middle Jurassic as well as parts of the Late Jurassic sediments of the Penninic Klippen. In more recent geological maps (e.g. [*125*], [*191*], [*196*], [*192*]), the lithostratigraphic classification has been refined and the Early to Middle Jurassic sediments have been attributed to several formations. This subdivision allows to locate the usable lithologies of the Obflue, Petit-Liençon and Rossinière Formations more precisely (see Chapter 7.2) and to discard the less promising ones from the geospatial dataset. The latter units are described hereafter.

10.3.1 Formations of the Early Jurassic

Horngraben Formation	The Horngraben Formation is exposed in the Klippen of central Switzerland, between Alpnach (OW) and Beckenried (NW). It contains a very heterogeneous succession of limestone, sand-rich limestone, siliceous limestone, marl and dolomite-bearing breccias [*187*], [*125*]. Because of the low silica content and the heterogeneity of the succession, no relevant amounts of hard rock-quality lithologies are expected within the unit.
Brand Formation	The Brand Formation is exposed in the Klippen of Central Switzerland, between Sörenberg (LU) and Beckenried (NW). It is dominated by echinoderm-rich limestone with some silicified beds or concretions and marl [*187*], [*125*]. Given its low silica content, the Brand Formation is unlikely to be suitable to produce hard rock aggregates.
Stanserhorn Formation	The Stanserhorn Formation occurs in the Klippen of central Switzerland, between Sörenberg (LU) and Beckenried (NW). It contains some clay-rich marls at the base. These are overlain by intercalated marl and limestone [*224*], [*125*]. The unit, which was considered as a promising hard rock unit in previous investigations, contain silica originating from sponge needles. Following a re-evaluation of the literature and based on field investigations, it appears that that the marly interbeds are too thick and too abundant, so that the unit is unlikely to be suitable to produce hard rock aggregates.
Vudalla Formation	The Vudalla Formation is exposed in the Préalpes Médianes. It contains limestone, which can be sand-rich especially at the base of the formation. The limestone beds are commonly separated by marly intercalations [*189*], [*190*], [*196*]. Overall, the silica content is too low, and the marly intercalations are too abundant, so that no relevant hard rock lithologies are to be expected within the unit.
Chauderon Formation	The Chauderon Formation occurs in the Préalpes Médianes. It is characterised by an alternance of siliceous limestone with glauconite and echinodermal fragments and marls [*225*], [*190*], [*195*]. Overall, the marly intercalations are too abundant and too thick. Therefore, no relevant amounts of hard rock-quality lithologies are to be expected within the unit.
Grande Bonavau Formation	The Grande Bonavau Formation occurs in the Préalpes Médianes. It is dominated by echinoderm-rich limestone with minor silex, marl, detrital quartz and dolomite components, especially at the base [*189*], [*190*], [*195*]. Given the overall relatively low quartz content, the unit is unlikely to be suitable to produce hard rock aggregates.
Arvel Formation	The Arvel Formation is part of the Préalpes Médianes. It is dominated by coarse grained echinoderm-rich limestone with minor marl or quartz [*226*], [*189*]. In the past, the unit was extracted at Arvel (VD). Given the relatively low quartz content, the production at the Arvel site has shifted to the stratigraphically younger, finer-grained and more silicified Rossinière Formation (see Chapter 7.3.2). A re-evaluation of the literature and field investigations indicate that the Arvel Formation does no longer fulfil the present-day hard rock requirements.
Combe du Pissot Formation	The Combe du Pissot Formation outcrops in the Préalpes Médianes. The formation is dominated by an intercalation of siliceous limestones and marls [*227*], [*228*], [*189*], [*196*]. Overall, marl or marly interbeds are too thick and too abundant, so that the unit appears unsuitable for the production of hard rock aggregates.
Heiti Formation	The Heiti Formation is exposed in the Préalpes Médianes. The unit contains siliceous limestone with marly intercalations and marls [*190*], [*189*], [*225*], [*188*], [*191*], [*192*]. Although the siliceous limestone beds are abundant in quartz, the marly interbeds are too thick and too abundant, making the unit apparently unsuitable to produce hard rock aggregates.

10.3.2 Formations of the Middle Jurassic

Stanserhorn Formation	The Stanserhorn Formation is exposed between Sörenberg (LU) and Beckenried (NW). It contains some marls at the base. These are overlain by a thick succession of marl and limestone [*224*], [*125*]. The limestone beds contain silica derived from sponge needles and the unit was, therefore, considered in previous hard rock investigations (e.g. [*10*]). Following a re-evaluation of the literature and based on field investigations it appears that the marly interbeds are too thick and too abundant, so that the unit is unlikely to be suitable to produce hard rock aggregates.

10.3.3 Formations of the Late Jurassic

The Late Jurassic of the Penninic Klippen contains some competent limestones. In the past, some of these limestones were extracted to produce hard rock aggregates or considered as promising hard rock lithologies (e.g. [*7*], [*8*], [*9*] and [*10*]). In this investigation, these units have been re-evaluated with regard to the increased quality requirements for hard rock aggregates.

Moléson Formation	The Moléson Formation is exposed in the Préalpes Médianes. The unit is dominated by competent limestone with some silicified beds or concretions and marl [*229*], [*230*], [*191*]. Given the low quartz content, the unit is unlikely to be suitable to produce hard rock aggregates.
Dorfflüe Formation	The Dorrflüe Formation occurs in the Préalpes Médianes, is dominated by limestones and represents the lateral equivalent to the Moléson Formation. Given the low quartz content [*192*], the unit is unlikely to be suitable to produce hard rock aggregates.

10.4 Penninic basement units

The calc-silicate unit (Kalksilikatfels), also known as “Castione Nero”, is ca. 600 metres thick and located close to Castione (TI). It was extracted to produce aggregates for road pavements especially after the 1950’s. Several investigations (e.g. [*25*]) were performed to determine whether the unit has a potential to produce Class I track ballast, but the results were negative. The metamorphic foliation of the rock and the presence of sheet silicates and coarse-grained calcite appear to have a negative impact on the resistance to fragmentation of the aggregates. The unit is therefore not included in the geospatial dataset.

10.5 Austroalpine basement units

In the Silvretta Nappe between Filisur and Bergün (GR), a meta-rhyolite (Ruina Formation, in the German literature also known as “Quarzporphyr” [*231*]) is exposed. At the Farrirola site (GR), this meta-rhyolite was extracted to produce some hard rock aggregates until the early 2010’s [*232*]. It contains phenocriysts (ca. 16% quartz, 16% feldspar, 4% white mica and other minerals) and ca. 60% of fine-grained matrix. The feldspars in particular are strongly altered into sheet silicates [*8*]. According to a technical report [*232*], the meta-rhyolite does not fulfil the present-day criteria for a Class I track ballast. However, no information regarding the physical properties of the unit is currently available. Additional data may be helpful to establish whether the unit should be included in the geospatial dataset.

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12. Selected glossary

Term	Explanation
Hard rock aggregates	Hard rock aggregates play a central role in the construction and maintenance of the transport infrastructure. Based on the current normative framework (refer especially to [*2*] and [*3*]) and the many years of experience in the construction industry, hard rock aggregates are employed as the main component of the rail network as well as the road-base of highways and main roads. They are characterised by a fine-grained texture, a high proportion (>25 %) of hard minerals (Mohs hardness >5, especially quartz and feldspar [*11*]), by a very high compressive strength and by a high resistance to abrasion and weathering.
Thickness (total stratigraphic thickness)	The thickness, or the total stratigraphic thickness, is an estimate of the interval, expressed in metres, between the top and the base of the unit, measured perpendicular (normal) to the bedding plane.
Usable lithologies	Usable lithologies are lithologies that are likely to be suitable for the production of hard rock aggregates according to the criteria described in Chapters 3 and 5.3.1.
Usability ratio	The usability ratio is the estimated ratio between the thickness of the usable lithologies and the thickness of a given geological unit (in %). This value is based on published or unpublished stratigraphic descriptions and profiles.
Usable thickness	The usable thickness is the sum of the thickness of all usable lithologies within a given geological unit (see Chapter 5.3.1 and Figure 3).
Geological unit	In this document, a geological unit is a lithostratigraphically ordered unit (i.e. formation, group) that is mapped in the Geological Atlas of Switzerland 1:25 000 and the related vector dataset GeoCover (see also the Lithostratigraphic Lexicon of Switzerland for definitions). Geological units can contain a variety of lithologies. However, only lithologies fulfilling the quality criteria (see Chapter 3) are suitable today to produce hard rock aggregates.
Point Load Test/ strength (PLT)	The Point Load Test (PLT) is an index field test that allows to predict the intact rock strength by compressing a rock specimen until extensional failure occurs. Key physical strength parameters, such as the Uniaxial Compressive Strength (UCS, see below), can be estimated based on the point load index strength. The portability of the apparatus allows a large number of measurements (up to 120 per day) to be performed without sample preparation. The test follows the procedure described in the ASTM standard D5731-16 [*23*] and ISRM [*233*].
Uniaxial Compressive Strength (UCS)/Uniaxial Compression Test	The Uniaxial Compressive Strength (UCS) is one of the most important mechanical properties of intact rock, widely used in different engineering related project including mining. Expressed in MPa or in N/mm², it represents the maximum load that a rock specimen can carry when a unidirectional stress is applied. The test method is performed in a dedicated laboratory and requires a cylinder-shaped sample (e.g. a core sample) with flat, carefully-machined surfaces. The test follows the procedure described in the ASTM standard D7012 [*234*] and ISRM [*22*]. According to the norm VSS 70 115 [*11*], a hard rock lithology must have a UCS of 120 MPa or more and contain more than 25 % (mass) of hard minerals.

Los Angeles Test/ Coefficient (LA)	The Los Angeles Test (LA) is a laboratory method widely used in the aggregate industry to estimate the resistance to fragmentation and abrasion of track ballast or road base aggregates. It measures the degradation of a given mass of aggregates, which is subjected to abrasion and impact in a rotating steel drum with an abrasive charge of steel balls. After a specific number of rotations, the sample is retrieved from the drum and sieved. The Los Angeles Coefficient (LA) is proportional to the mass of the sample that passes through a 1.6 mm sieve. The lower the LA value, the more resistant to fragmentation is the aggregate. According to the norm SN 670 110-NA/EN 13450 [*2*], a track ballast aggregate is classified as Class I if LA ≤ 16 and Class II if LA ≤ 24.
Polished Stone Value (PSV)	The Polished Stone Value (PSV) indicates the resistance of an aggregate sample to the polishing action of vehicle tires on a road surface. The value is determined through a standardised test method (SN 670 903-8B/EN 1097-8, [*14*]), in which a sample is subjected to a polishing action in a high-speed polishing machine. The achieved polished condition is determined by means of a skid resistance measurement. The higher the PSV value, the greater the resistance to the polishing action. For the road bases of highways and main roads, the PSV must be greater than 50 (SN 670 103B-NA/EN 13043 [*3*]).

13. Acknowledgments

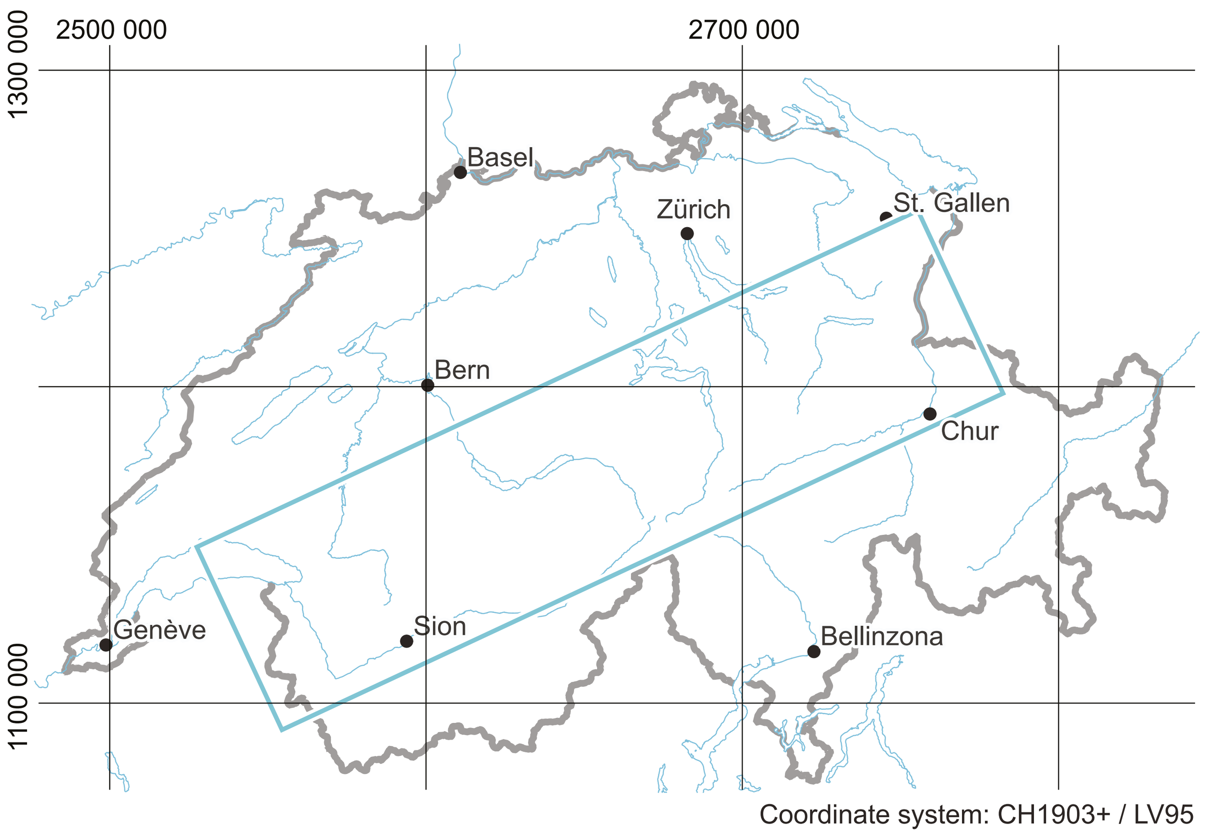
The authors kindly thank the hard rock-quarry operators, affiliated with the “Verband Schweizerischer Hartsteinbrüche (VSH)”, for providing access to their mining sites and facilities as well as for openly sharing their vast technical knowledge. The authors are also grateful to M. Beres (swisstopo) for proofreading the English version as well as the many reviewers who provided valuable suggestions that helped to improve the quality and content of the manuscript.

14. Appendix

The following Appendix contains map extracts showing the spatial distribution of the input data and the interpolated model results for each hard rock-bearing geological unit described in Chapter 7. Each Appendix contains three maps highlighting (a) the thickness, (b) the usability ratio and (c) the usable thickness of the corresponding geological unit without consideration of the boundary conditions described in Chapter 5.4 (i.e. ground elevation less than 1300 metres a.s.l., usable thickness higher than 30 metres).

Spitzmeilen Formation: Input values and model results

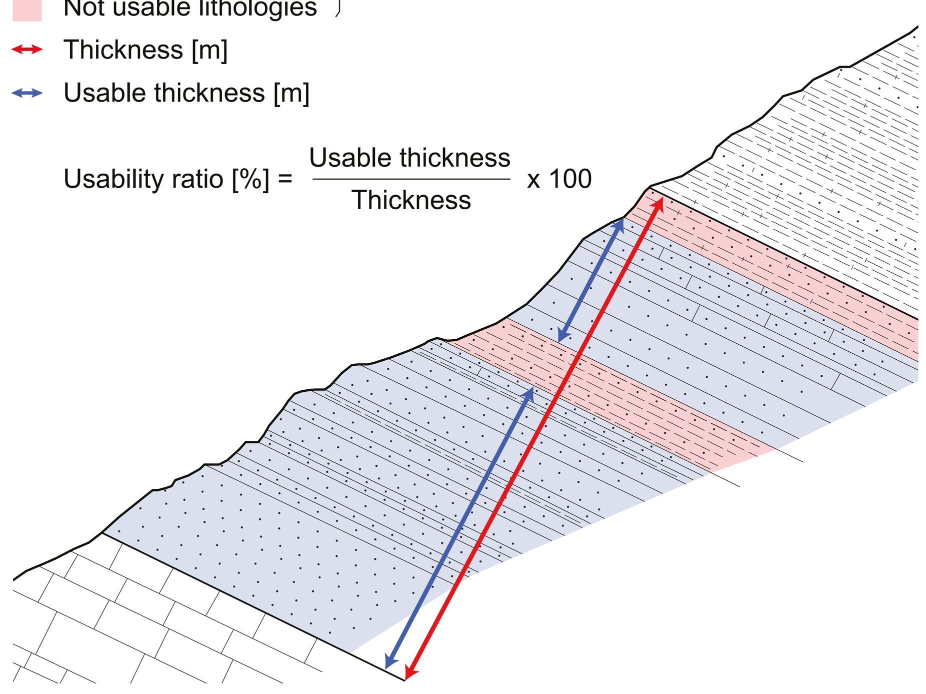
Extent of map views A – C



Terminology (schematic cross-section view)

- Topography
- Usable lithologies
- Not usable lithologies
- Investigated geological unit
- Thickness [m]
- Usable thickness [m]

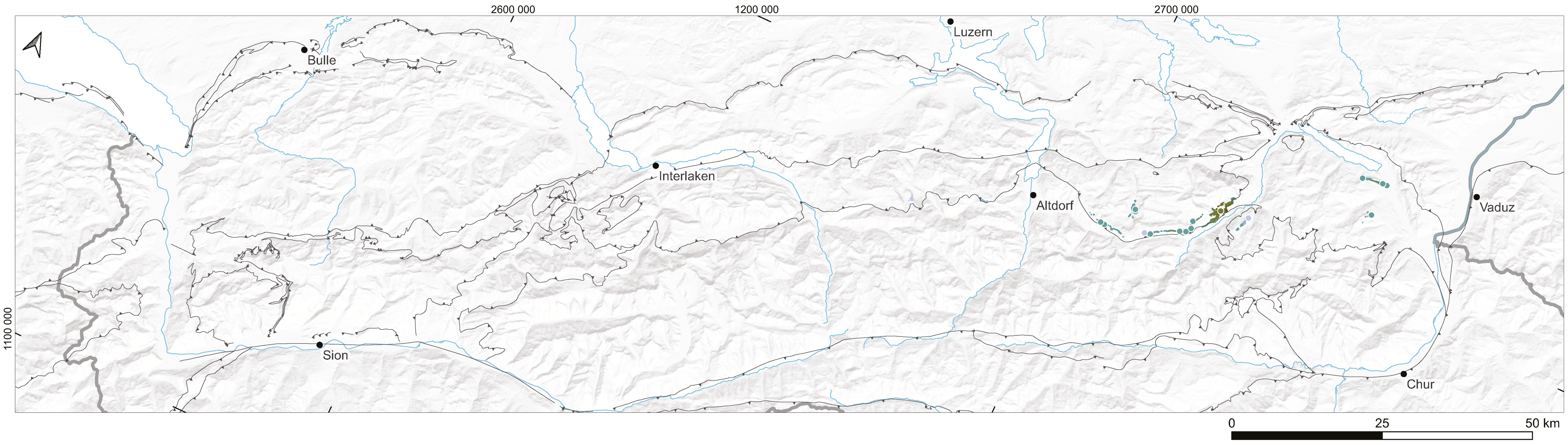
Usability ratio [%] = $\frac{\text{Usable thickness}}{\text{Thickness}}$ x 100



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

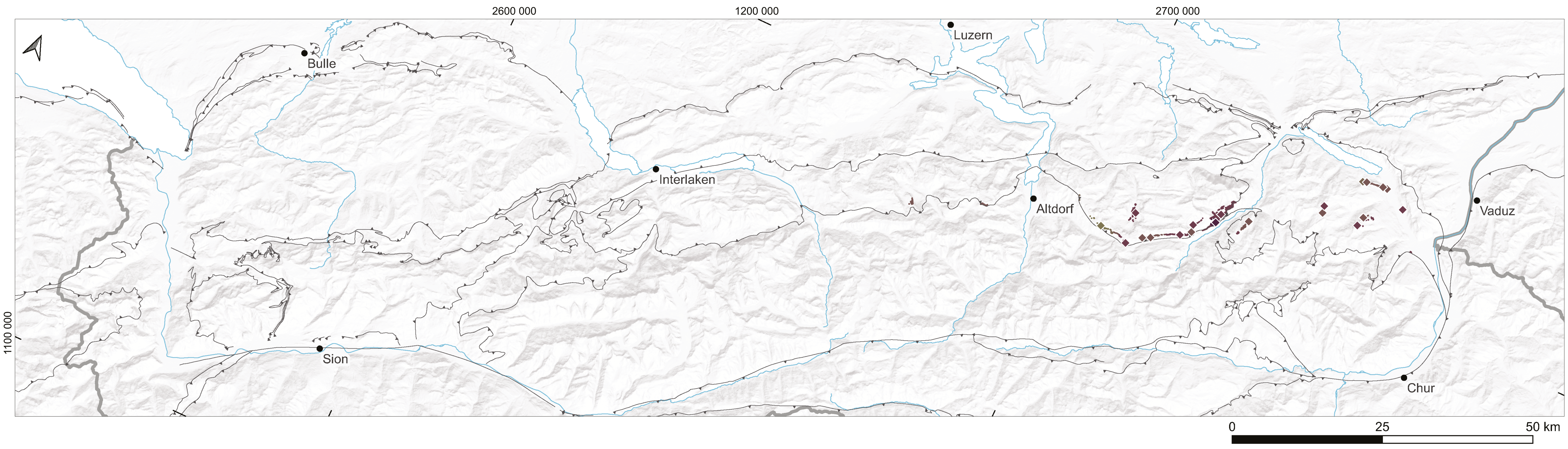
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

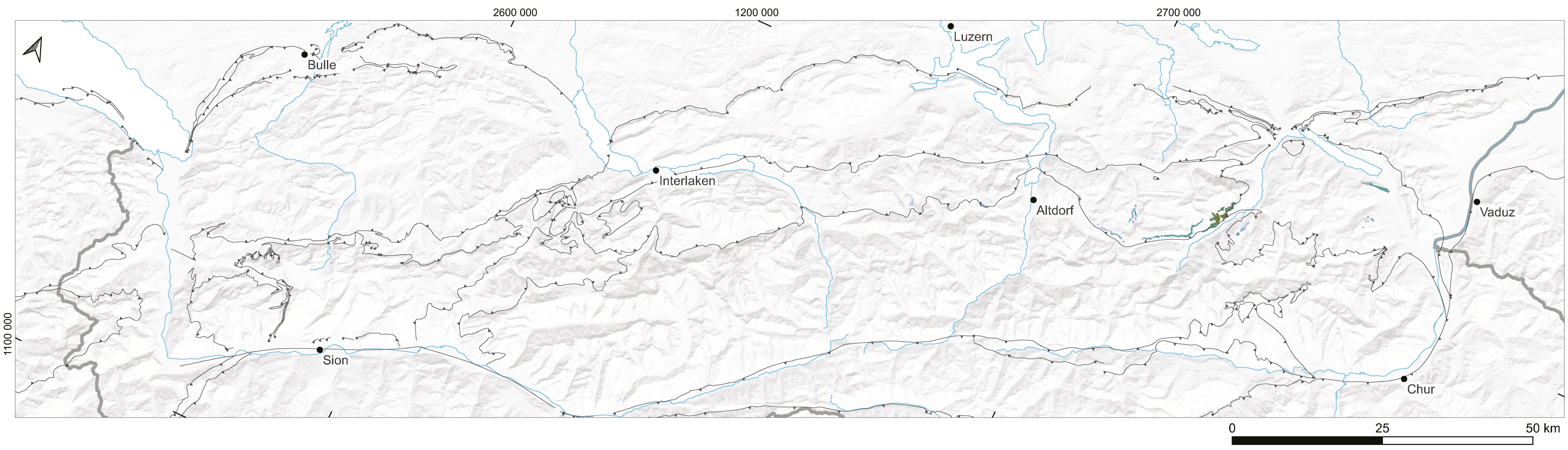
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

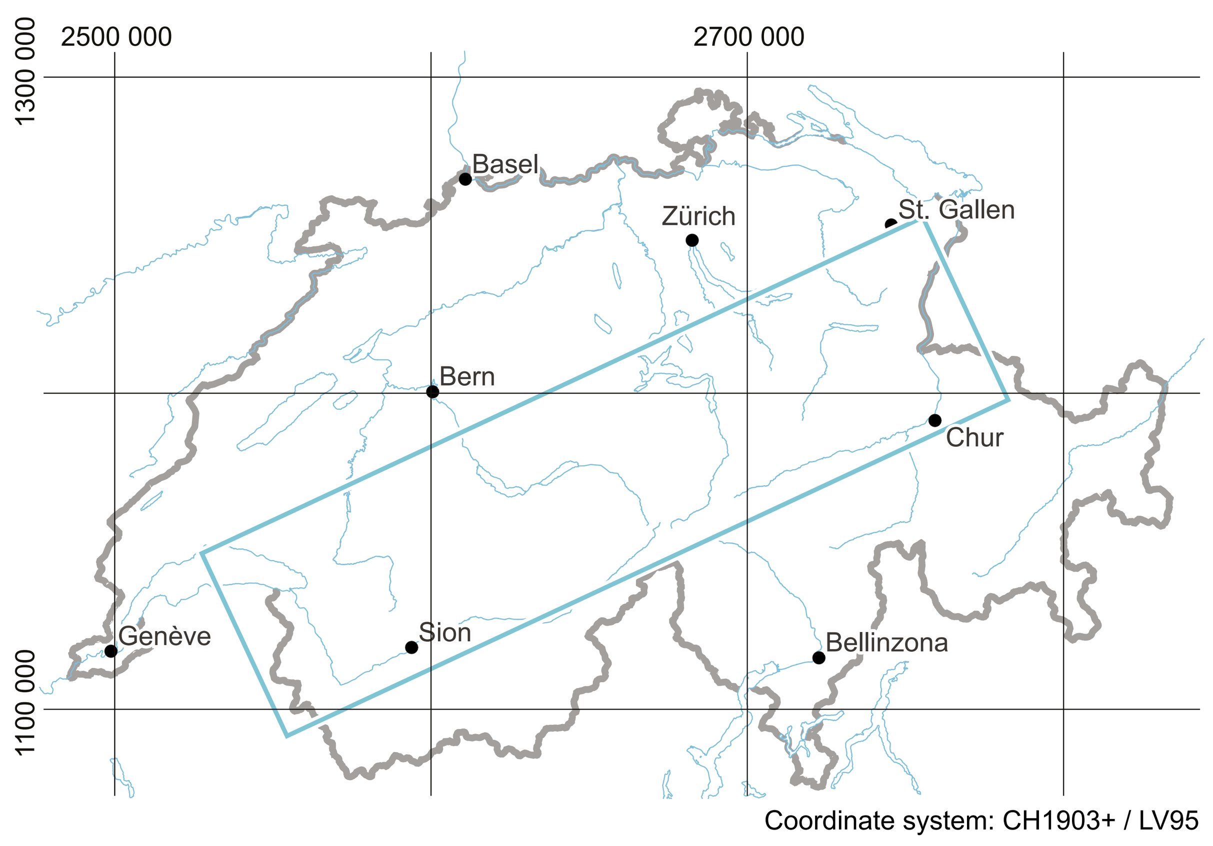
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

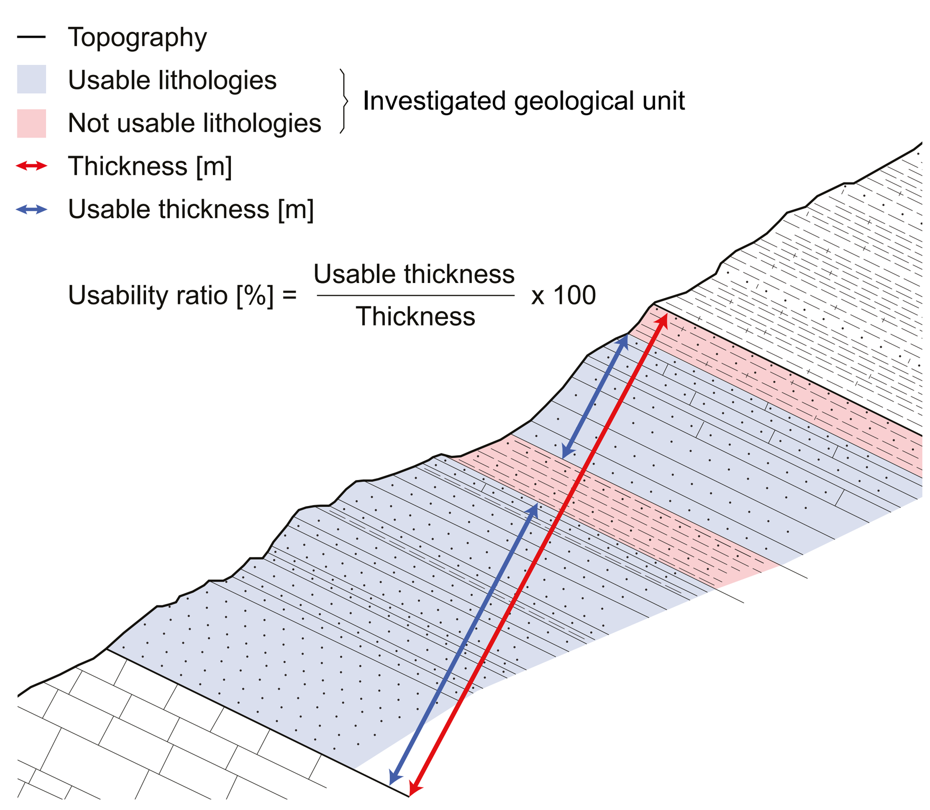


Sexmor Formation: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



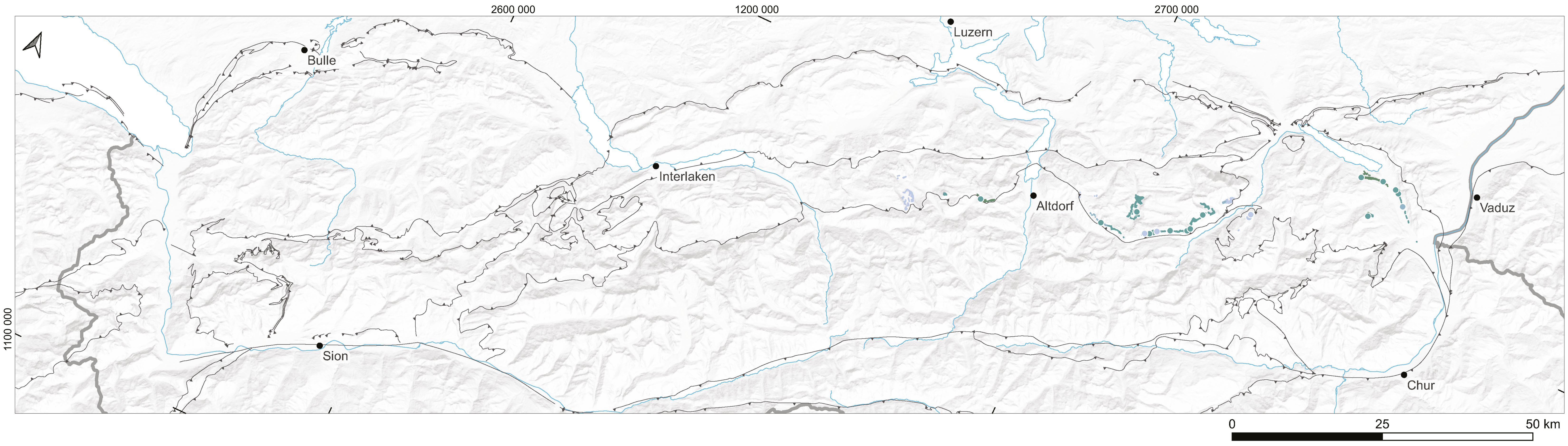
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



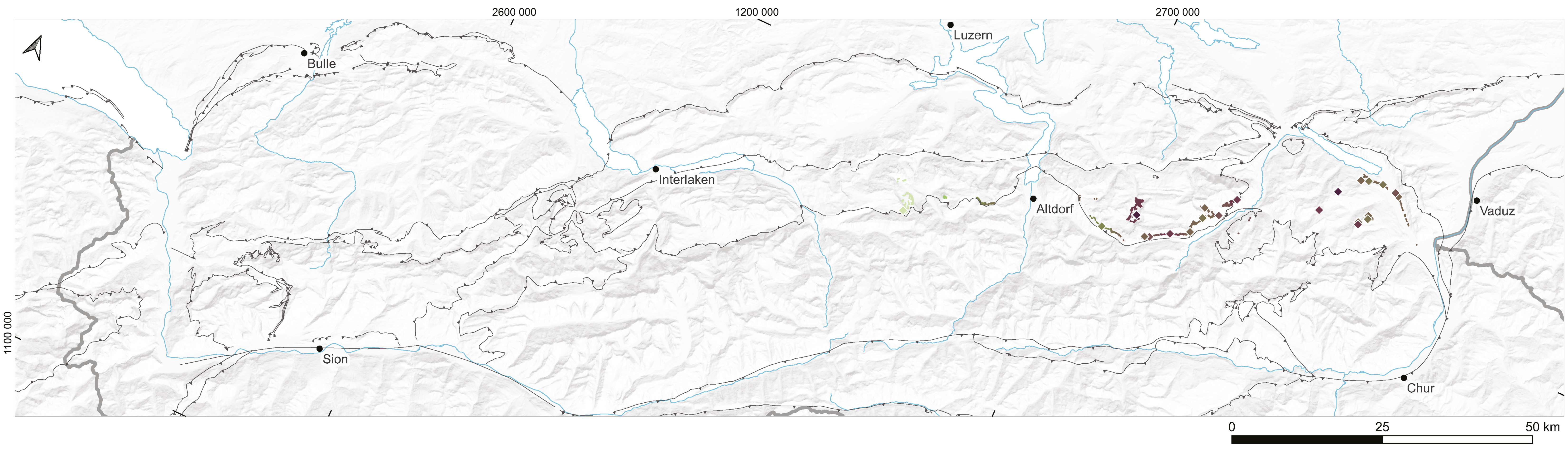
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%

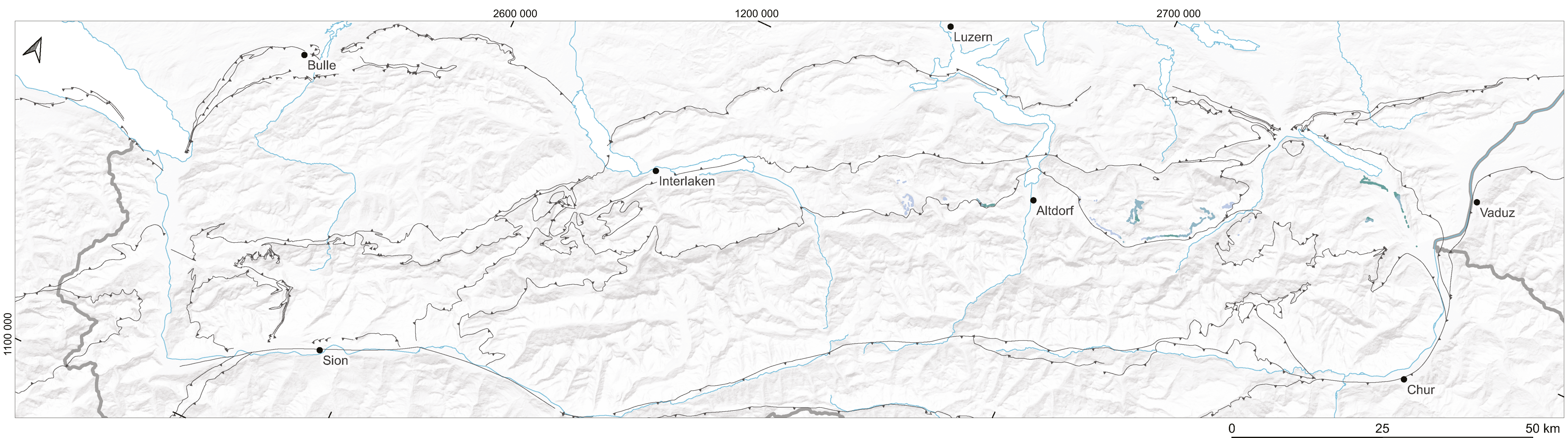


(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

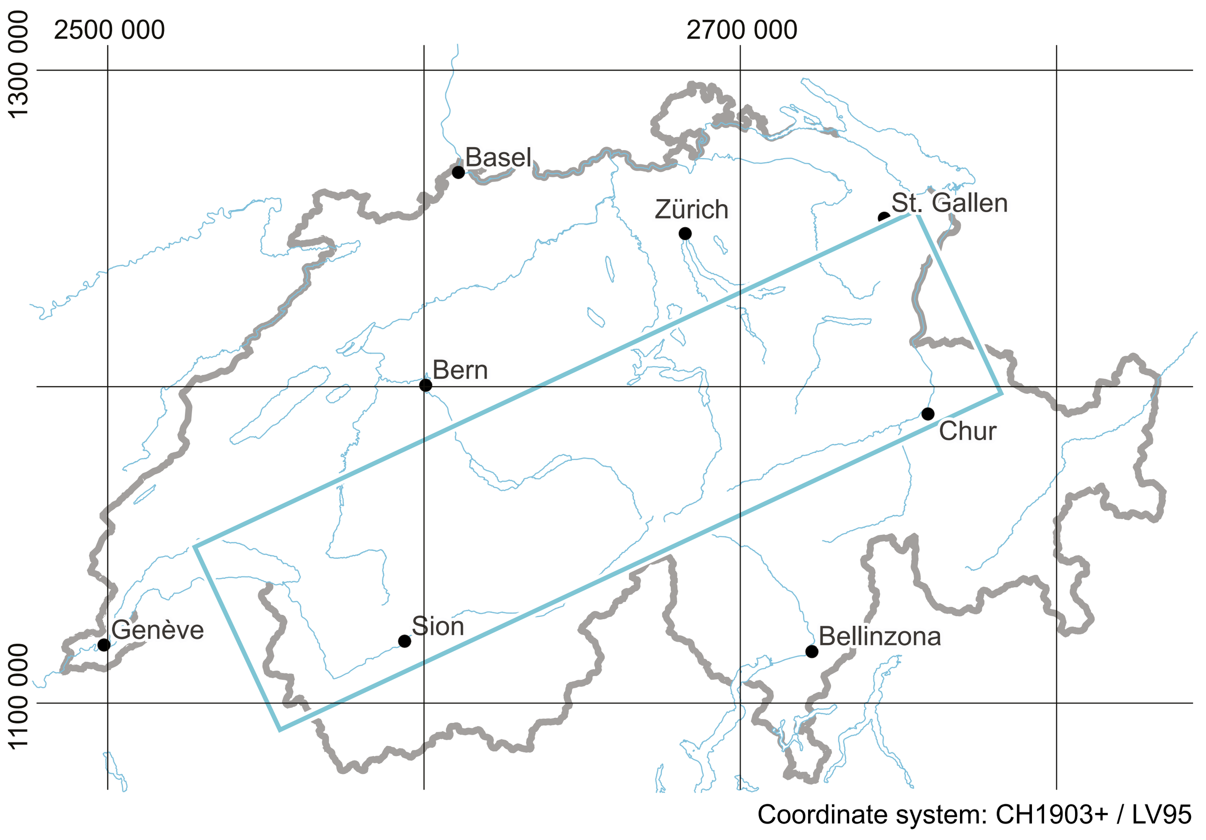
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



Torrenthorn Formation: Input values and model results

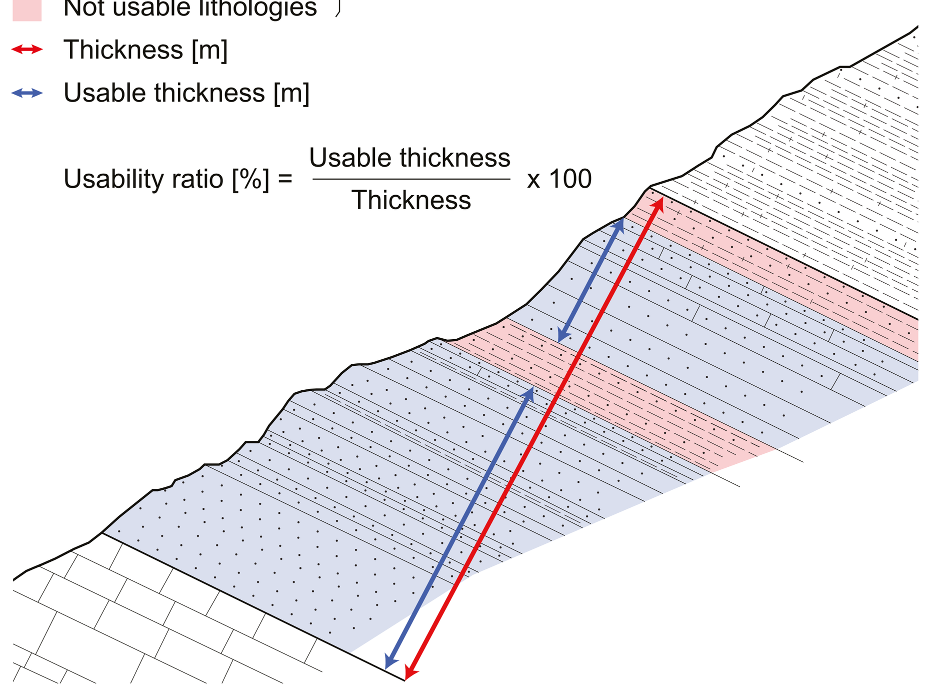
Extent of map views A – C



Terminology (schematic cross-section view)

- Topography
- Usable lithologies
- Not usable lithologies
  } Investigated geological unit
- Thickness [m]
- Usable thickness [m]

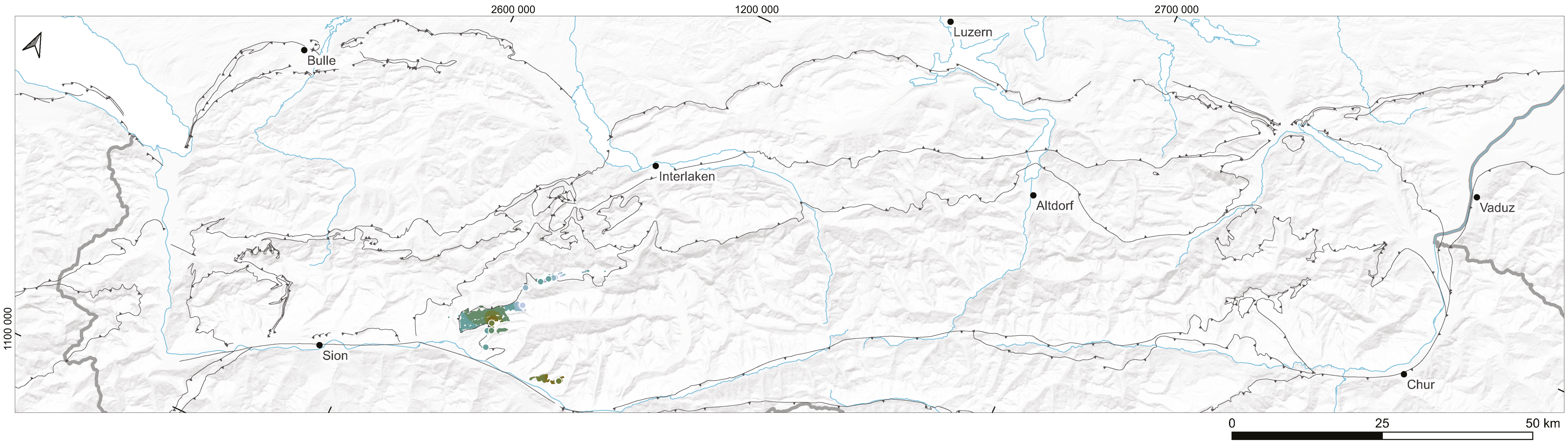
$$\text{Usability ratio [\%]} = \frac{\text{Usable thickness}}{\text{Thickness}} \times 100$$



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

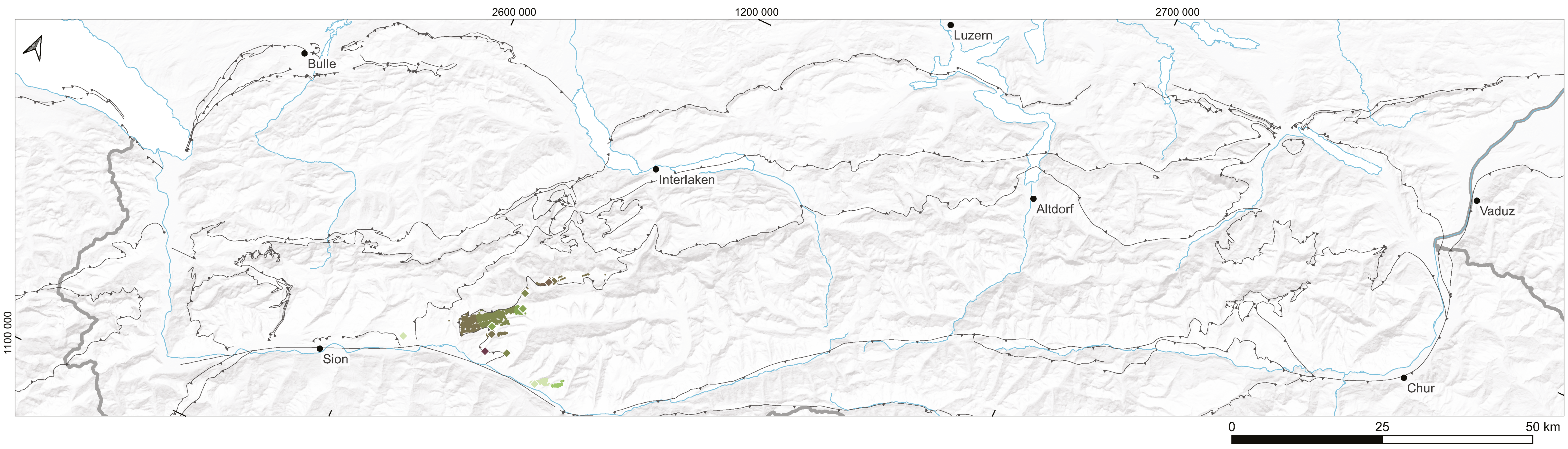
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

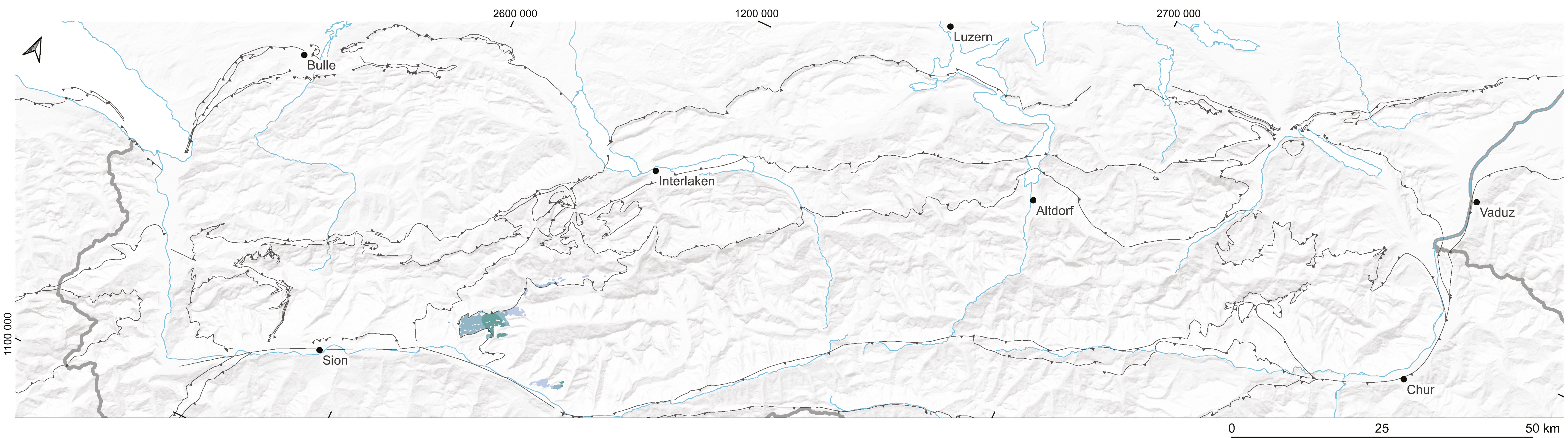
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

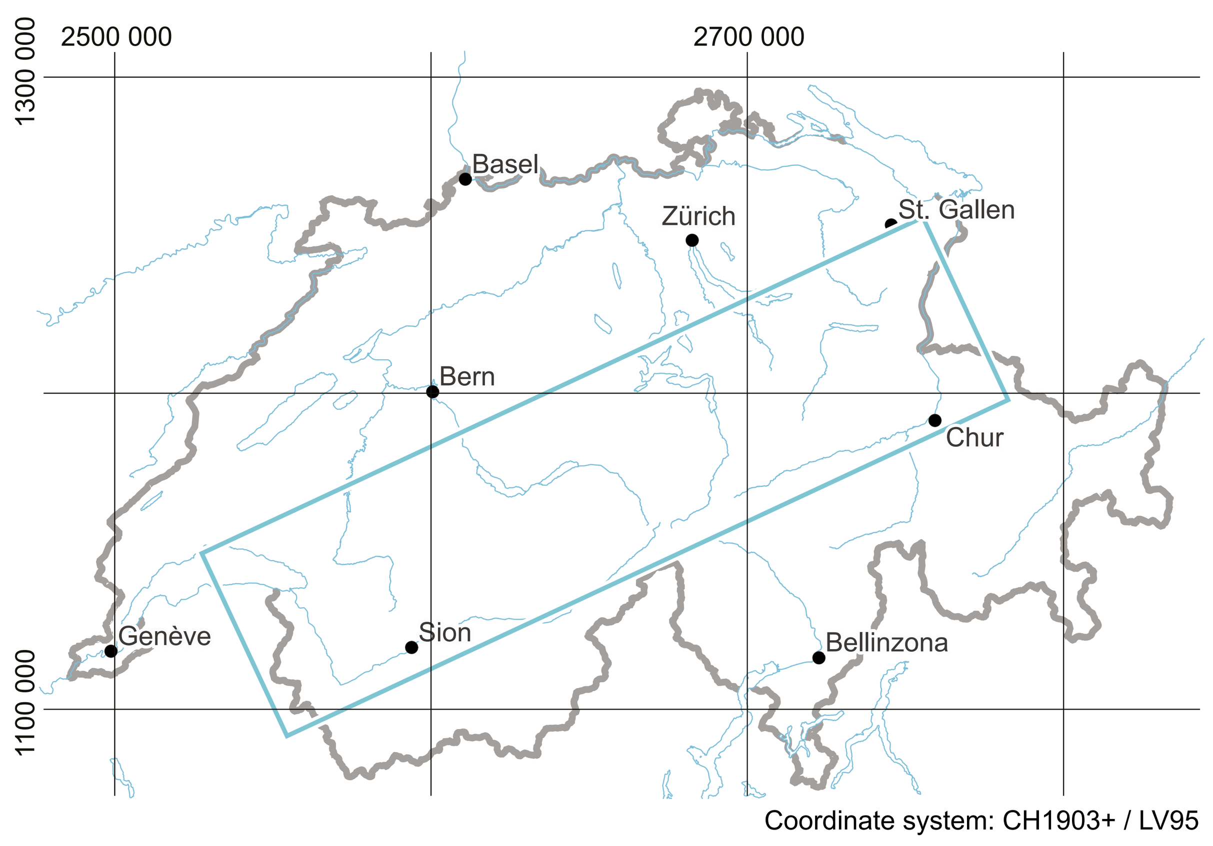
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



Mont-Joly Formation: Input values and model results

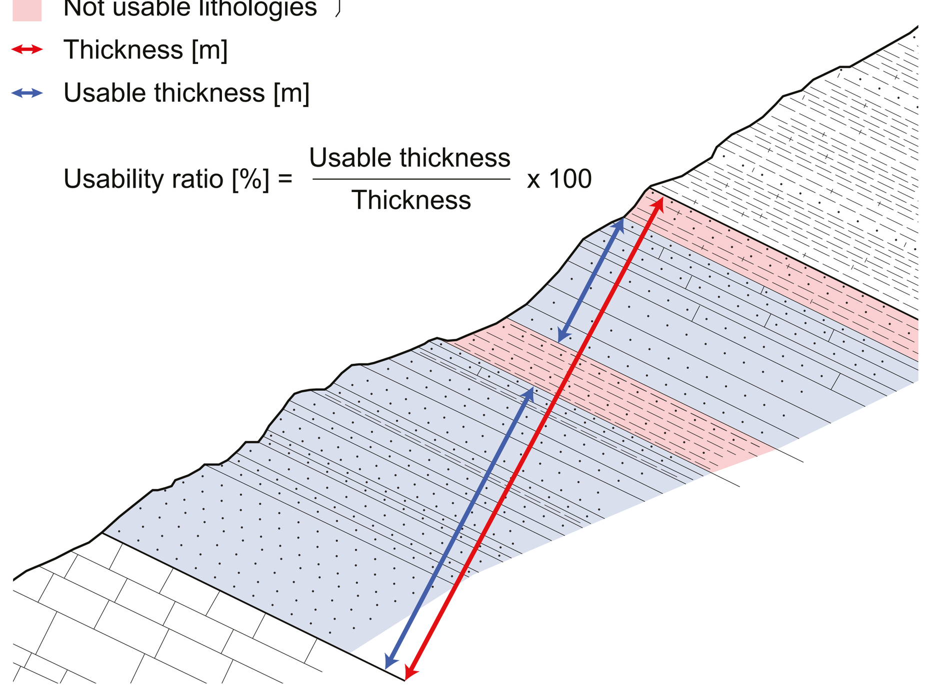
Extent of map views A – C



Terminology (schematic cross-section view)

- Topography
- Usable lithologies
- Not usable lithologies
- } Investigated geological unit
- Thickness [m]
- Usable thickness [m]

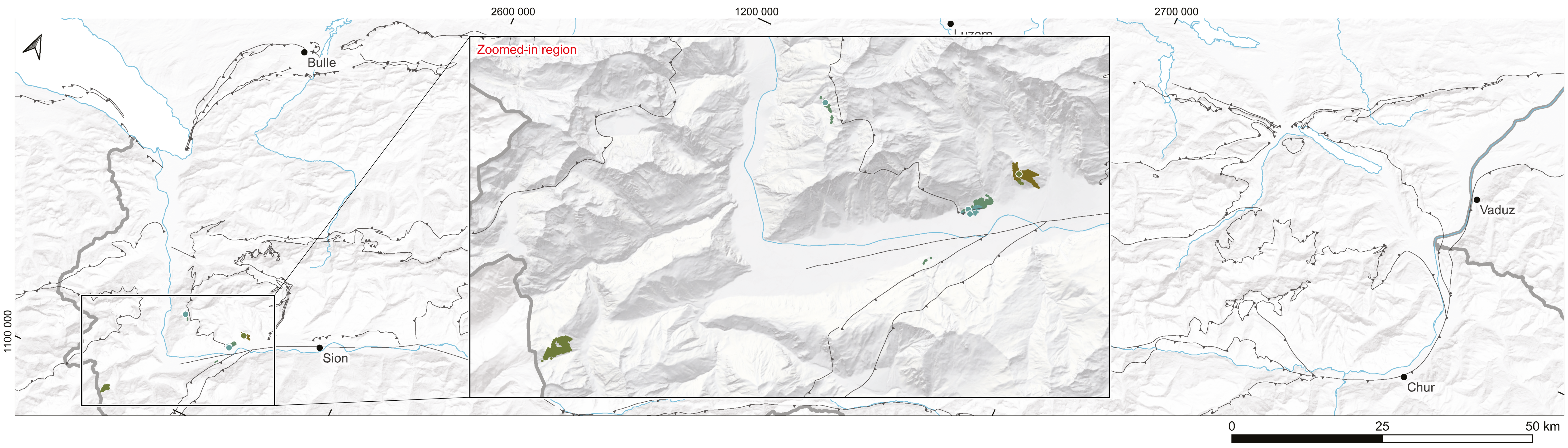
$$\text{Usability ratio [\%]} = \frac{\text{Usable thickness}}{\text{Thickness}} \times 100$$



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

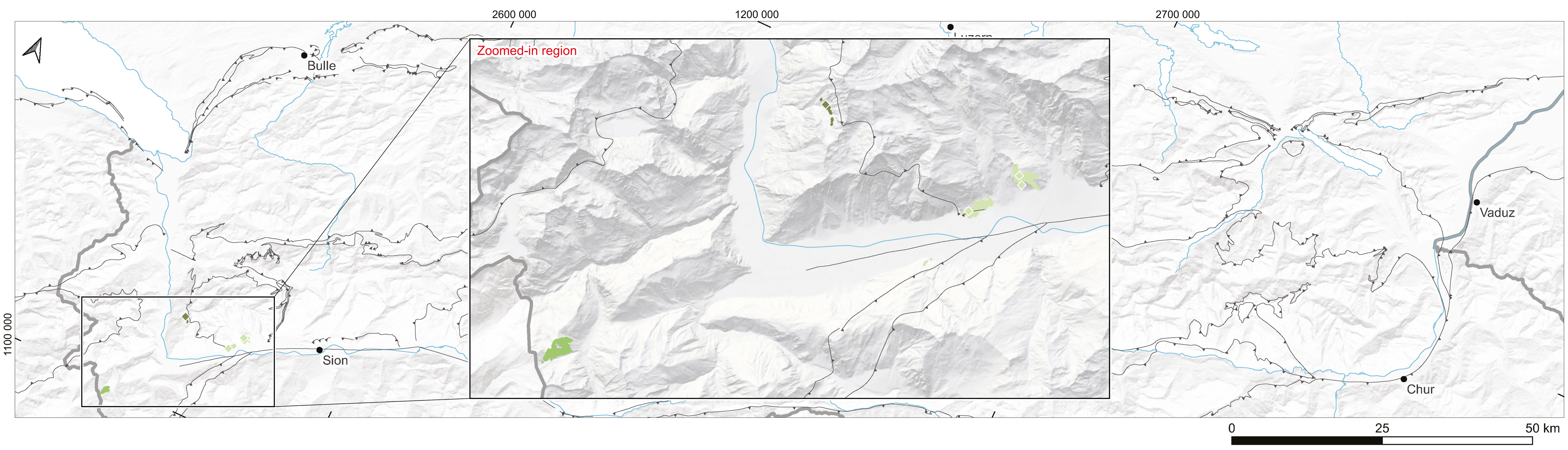
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

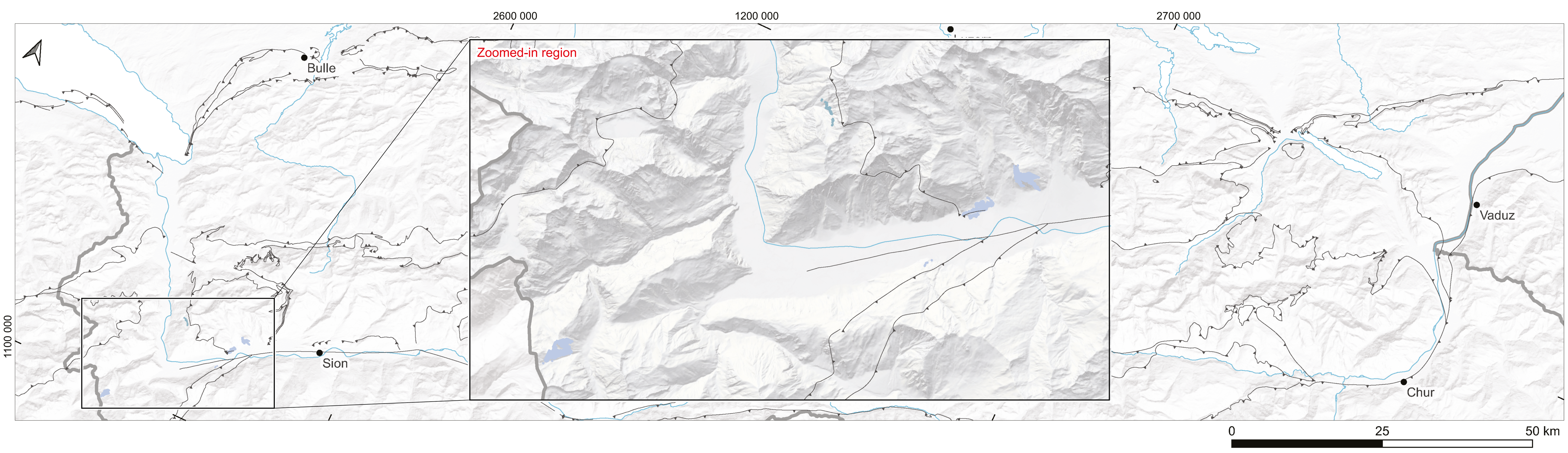
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

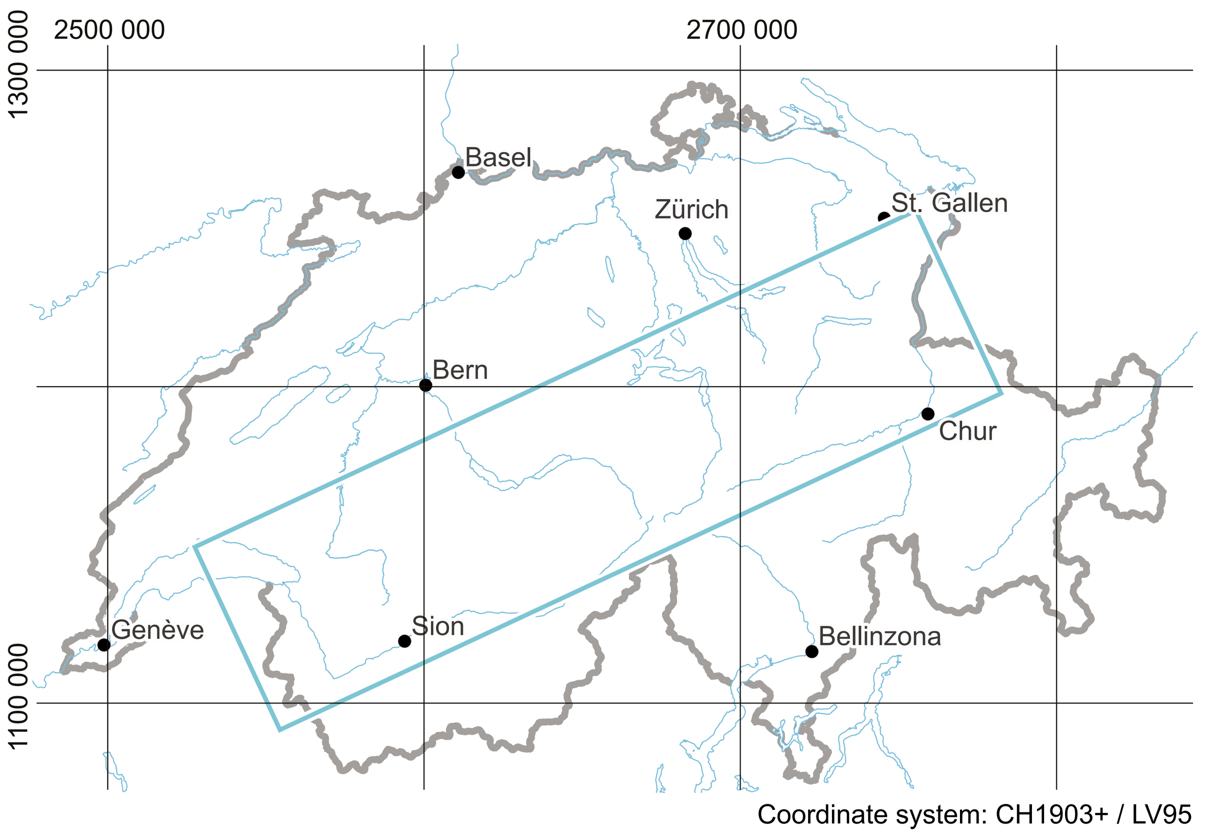
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

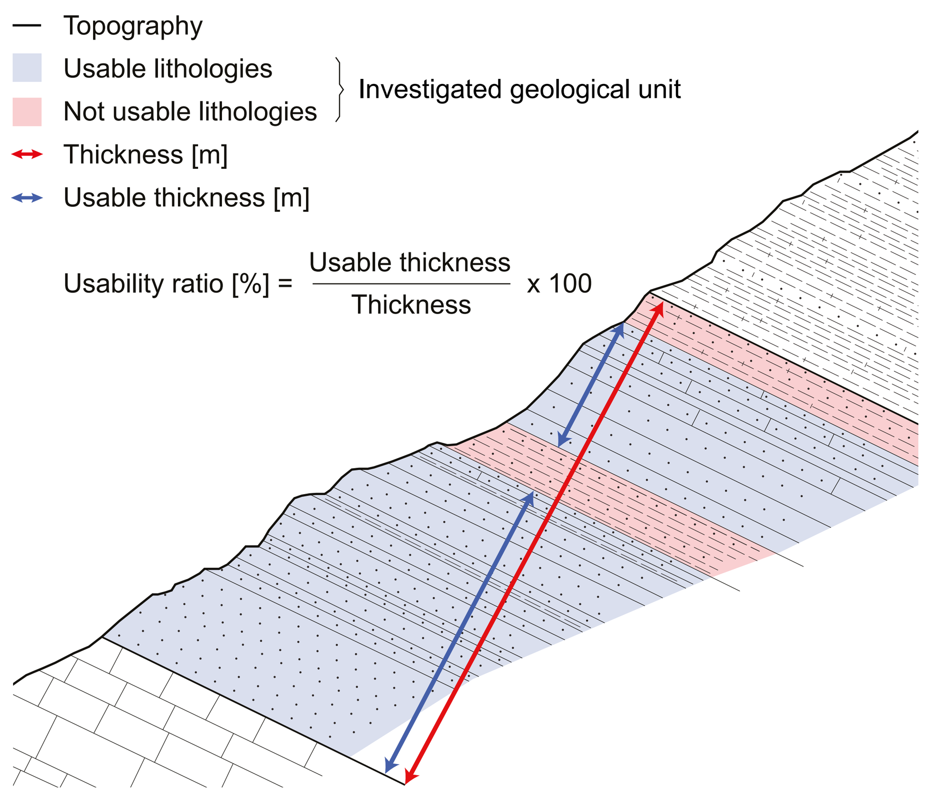


Helvetic Kieselkalk: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



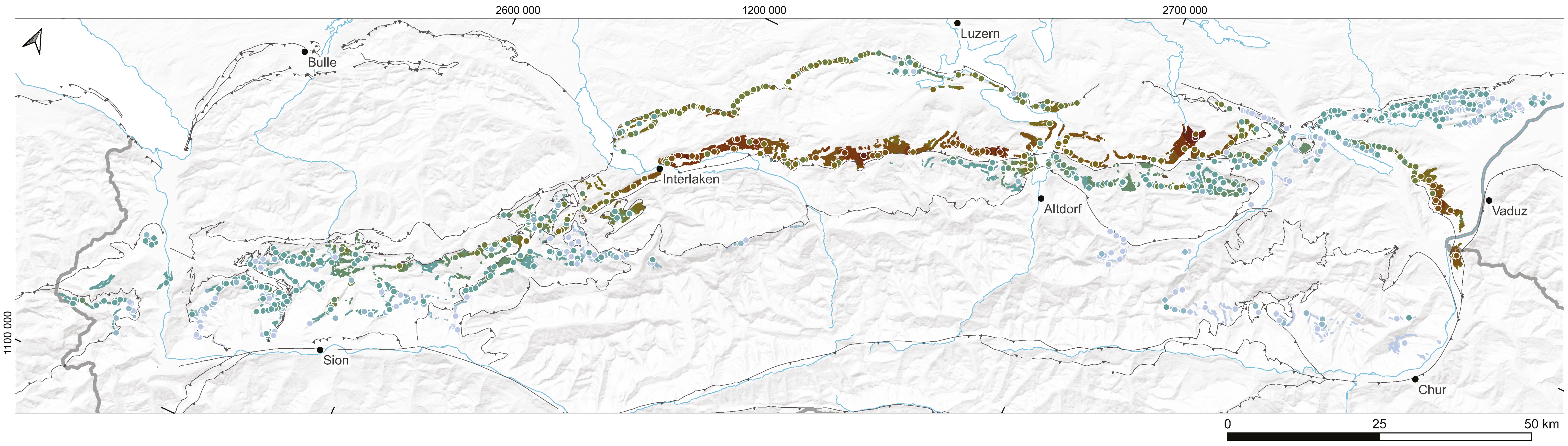
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



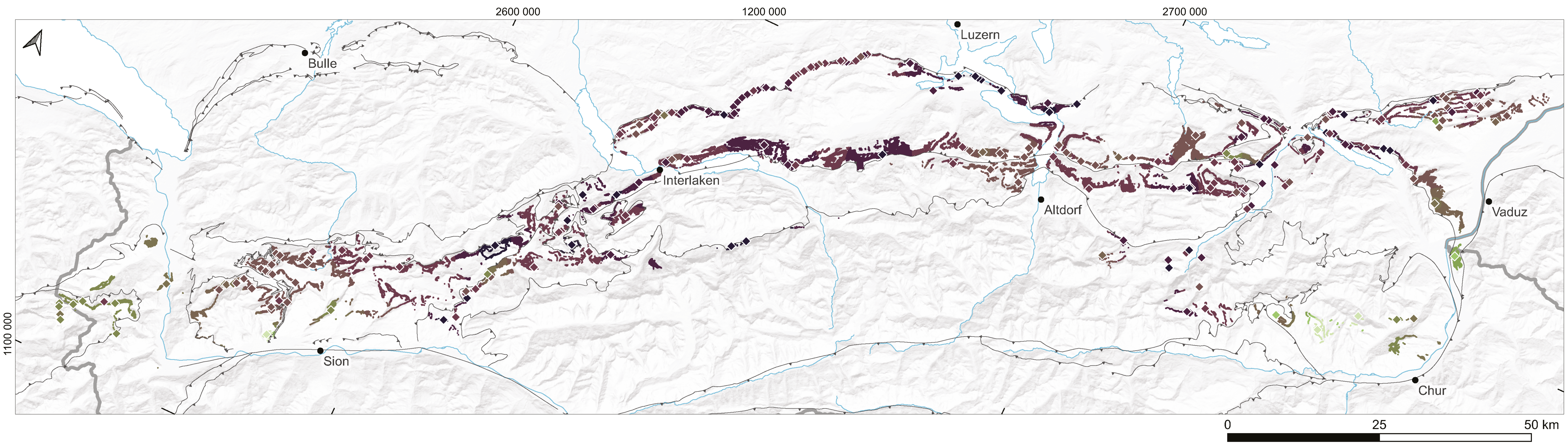
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%

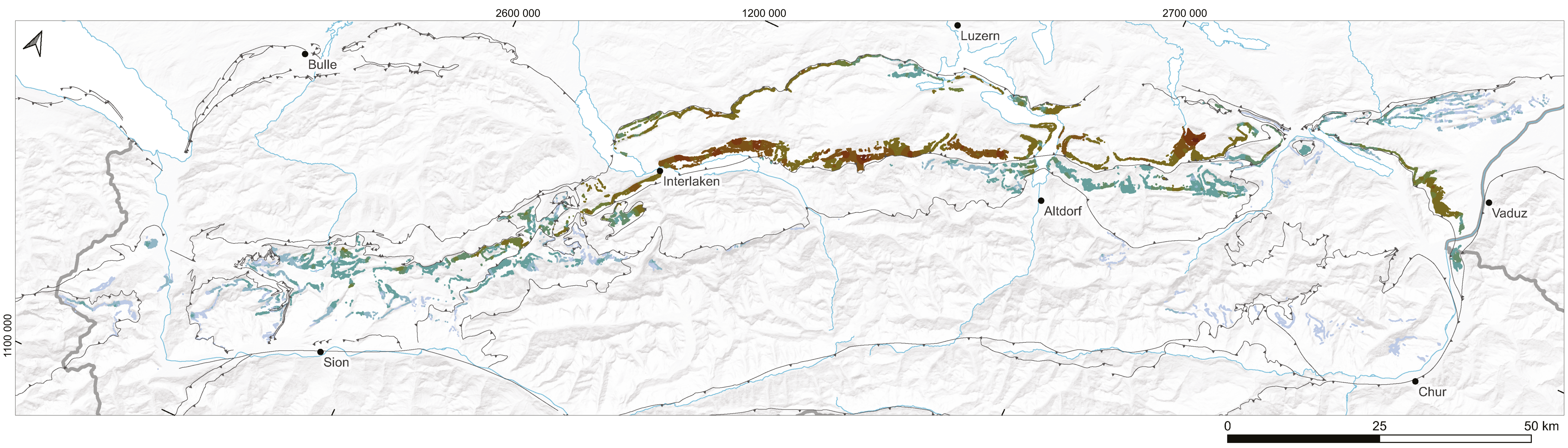


(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

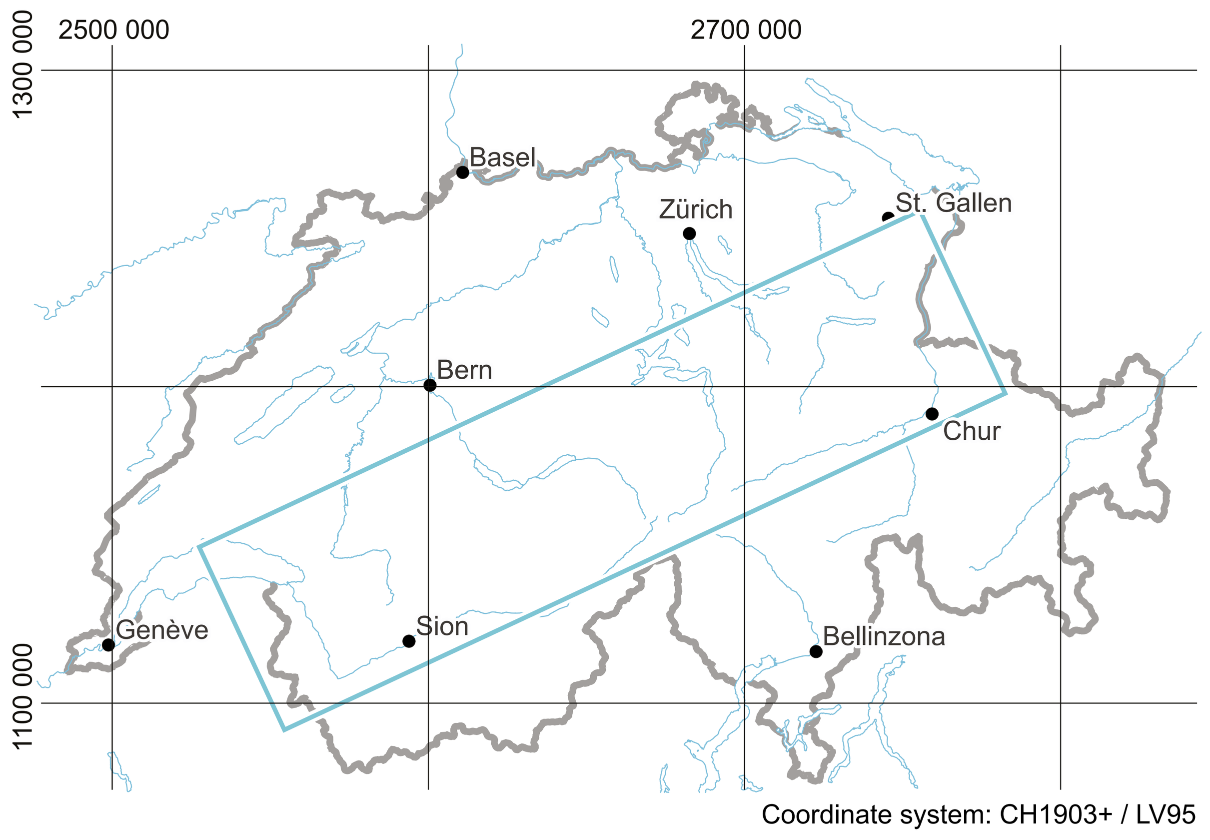
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

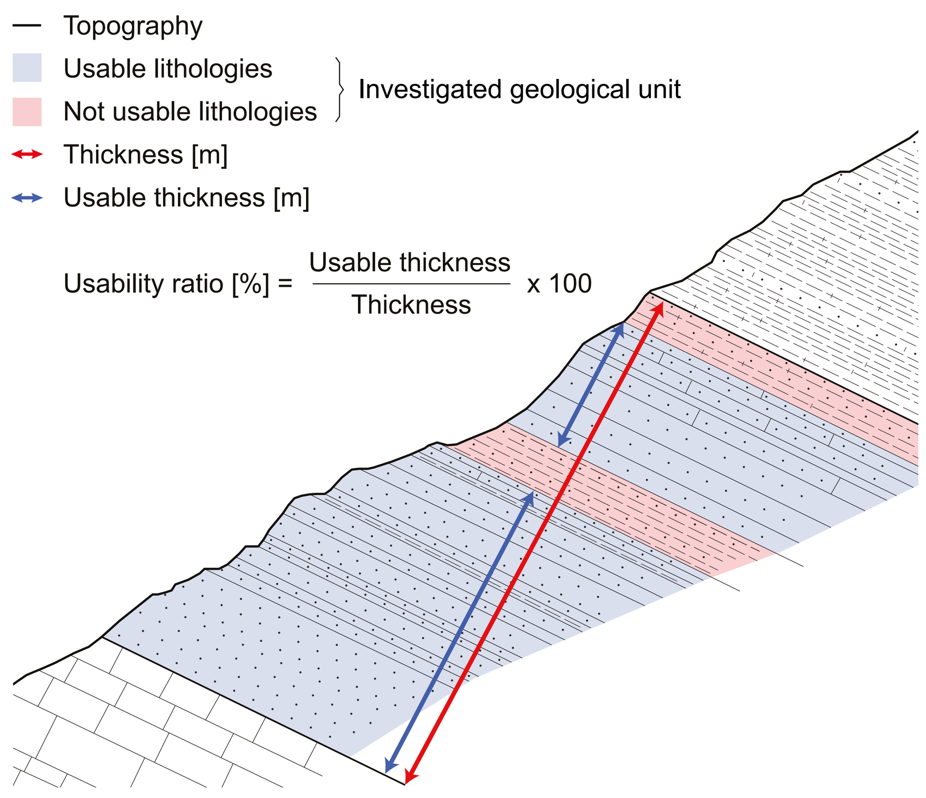


Garschella Formation: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



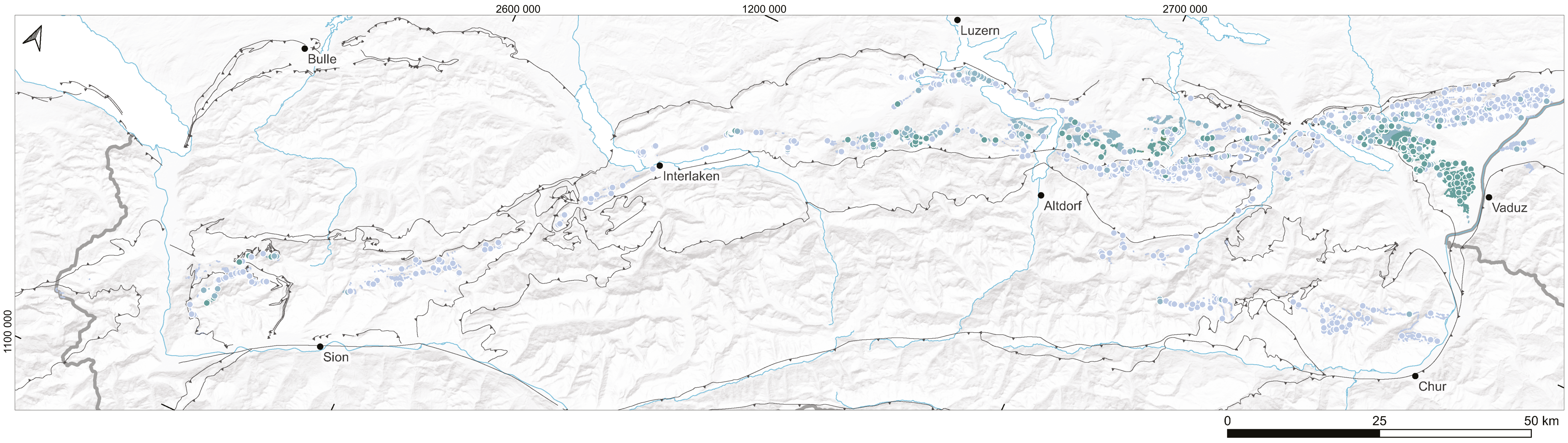
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



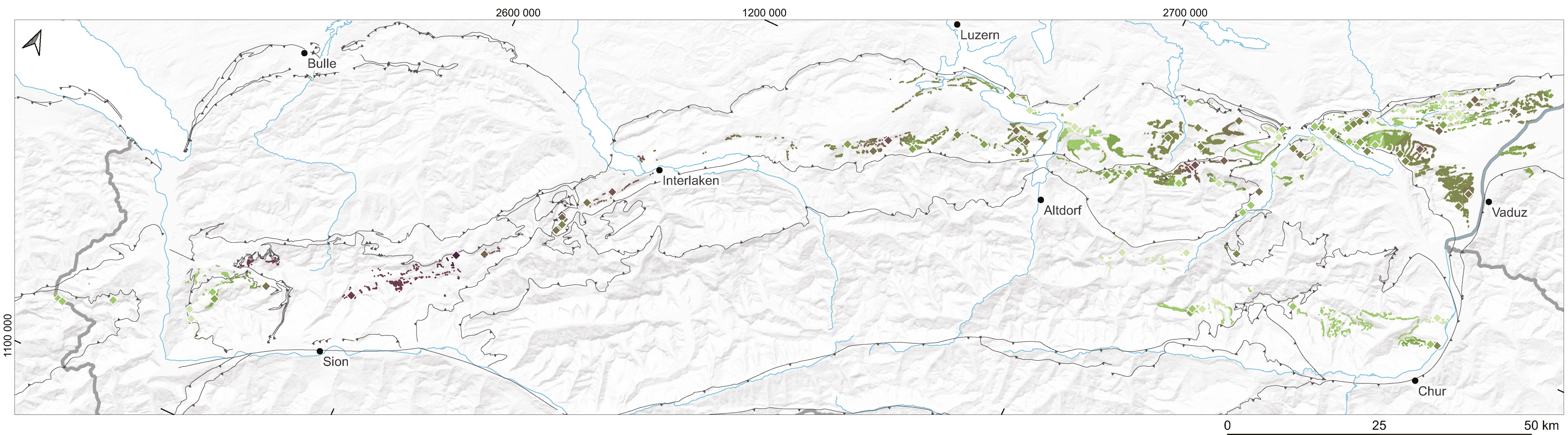
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15]))

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%

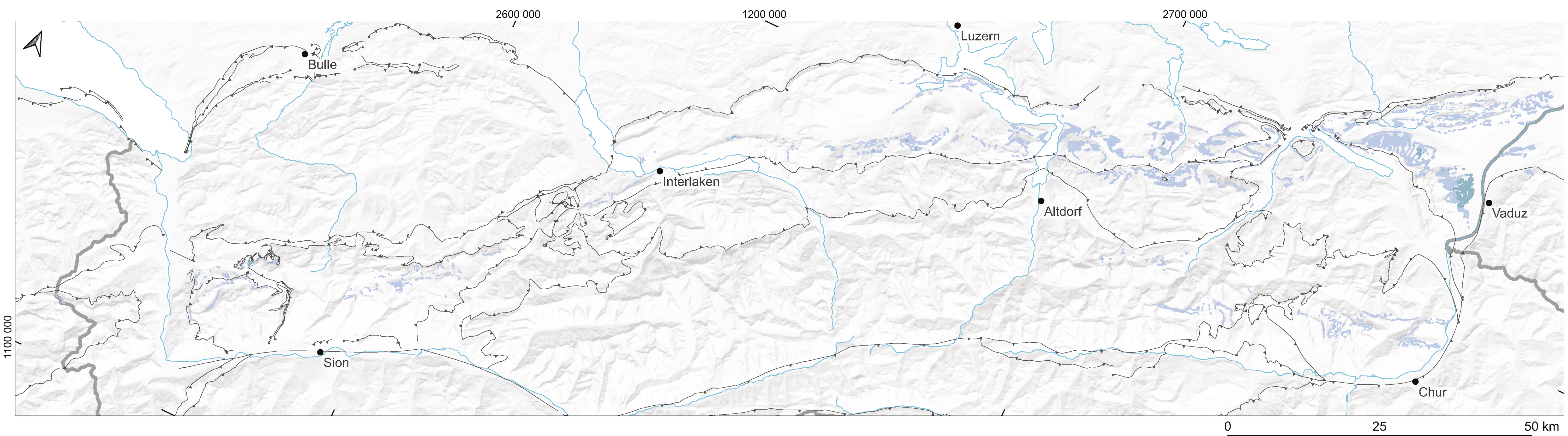


(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15]))

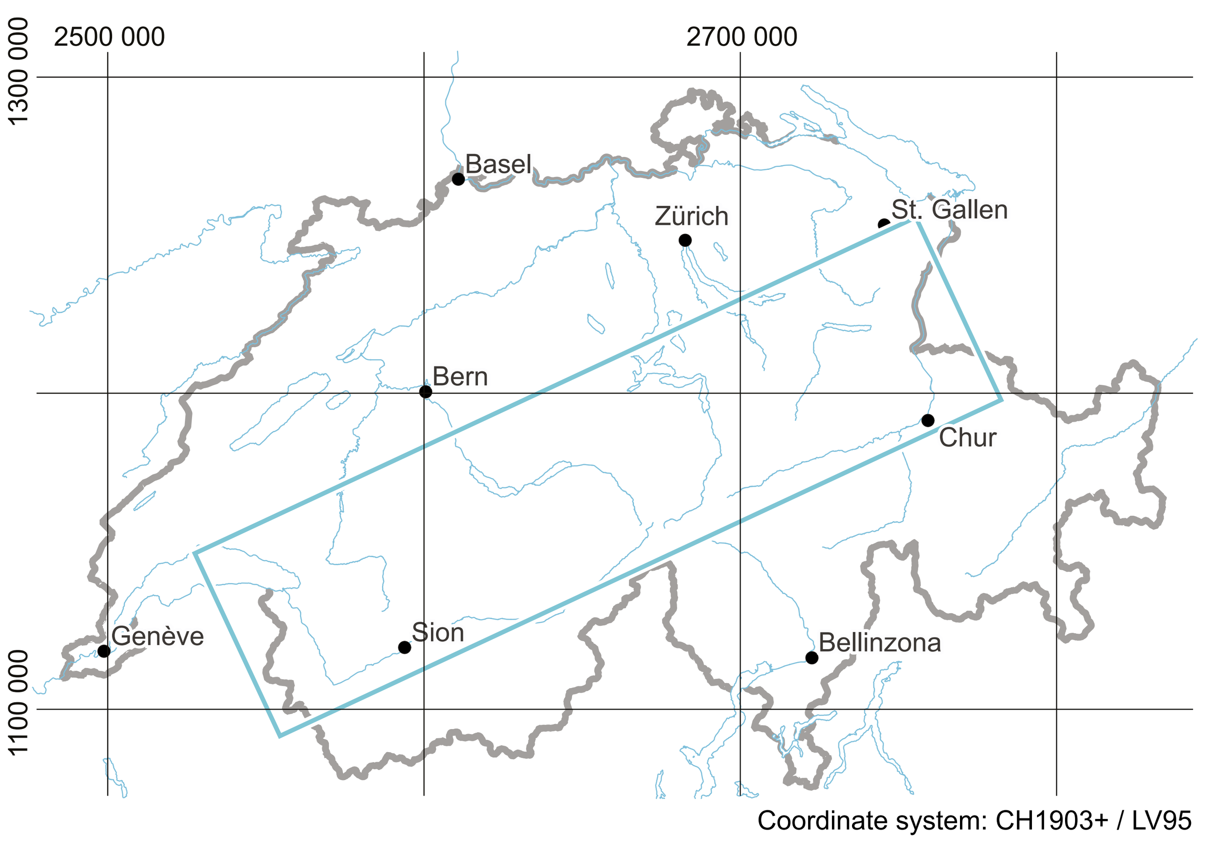
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

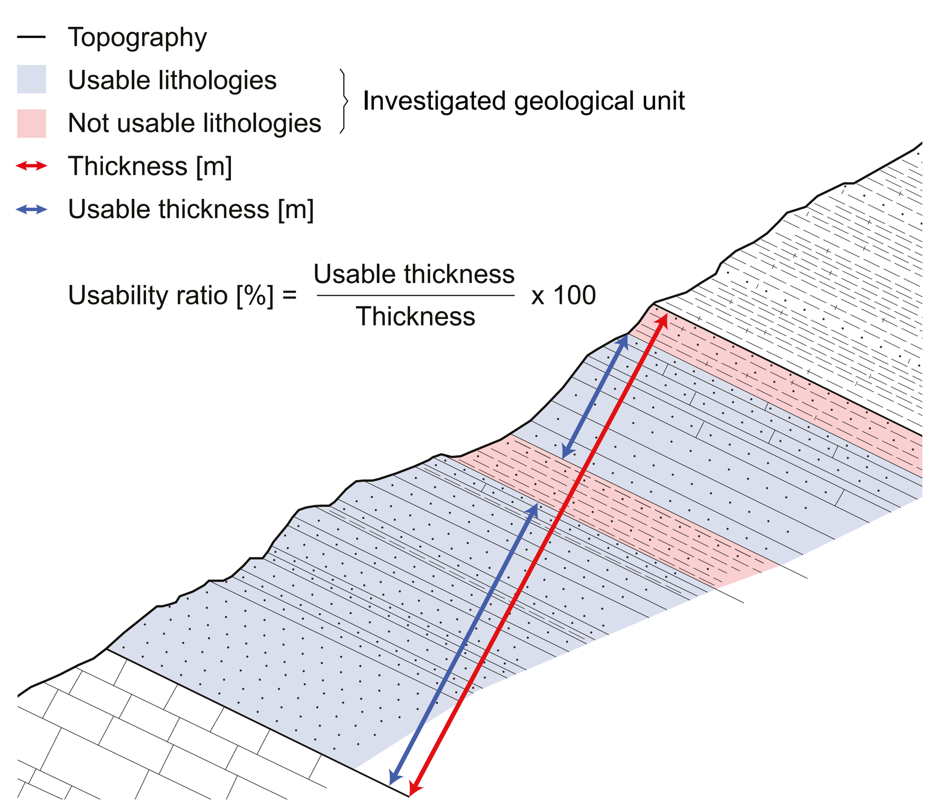


Niederhorn Formation: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



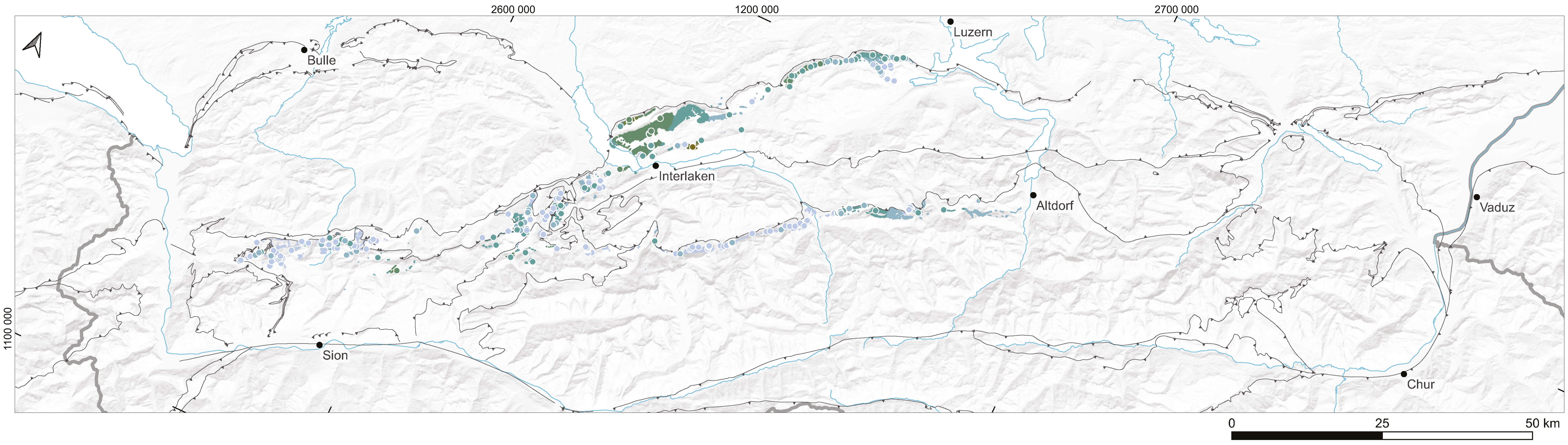
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



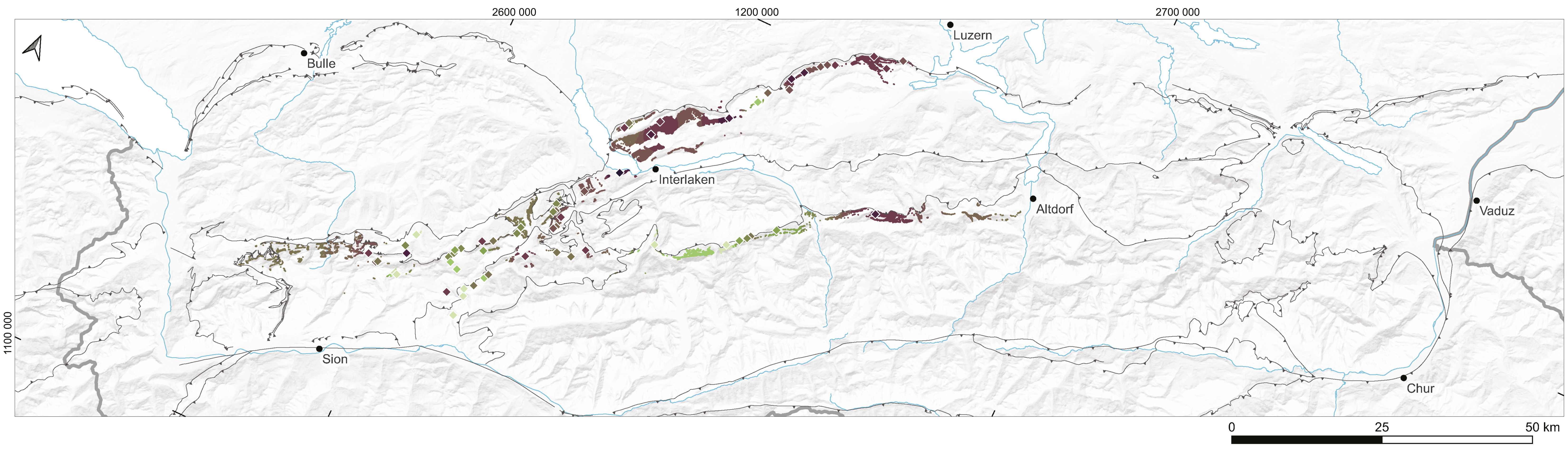
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%

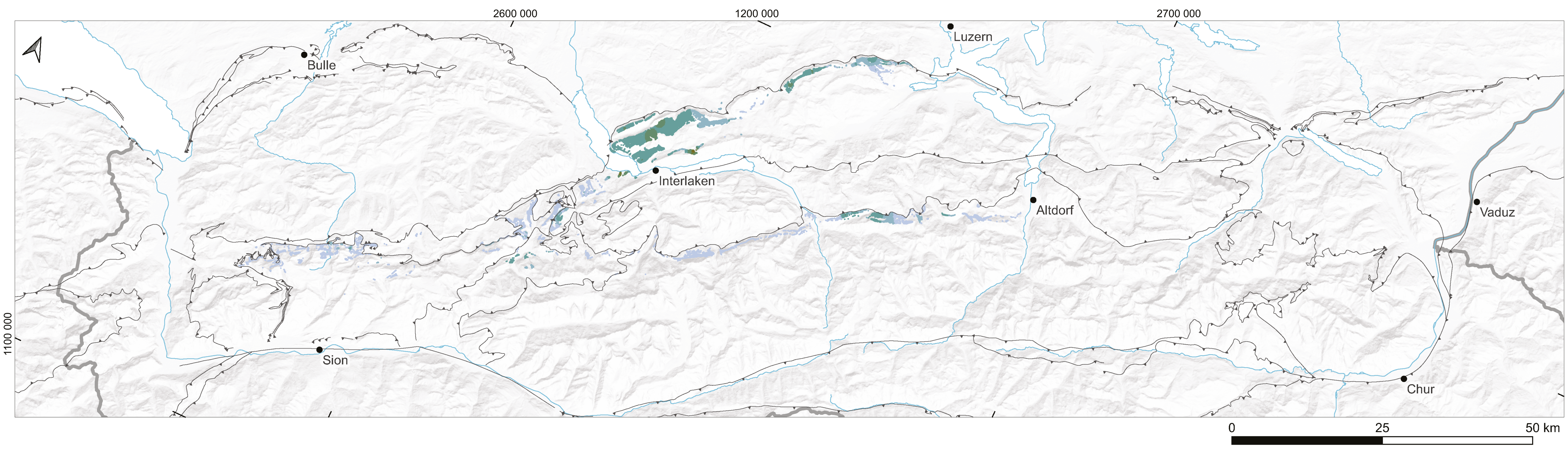


(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

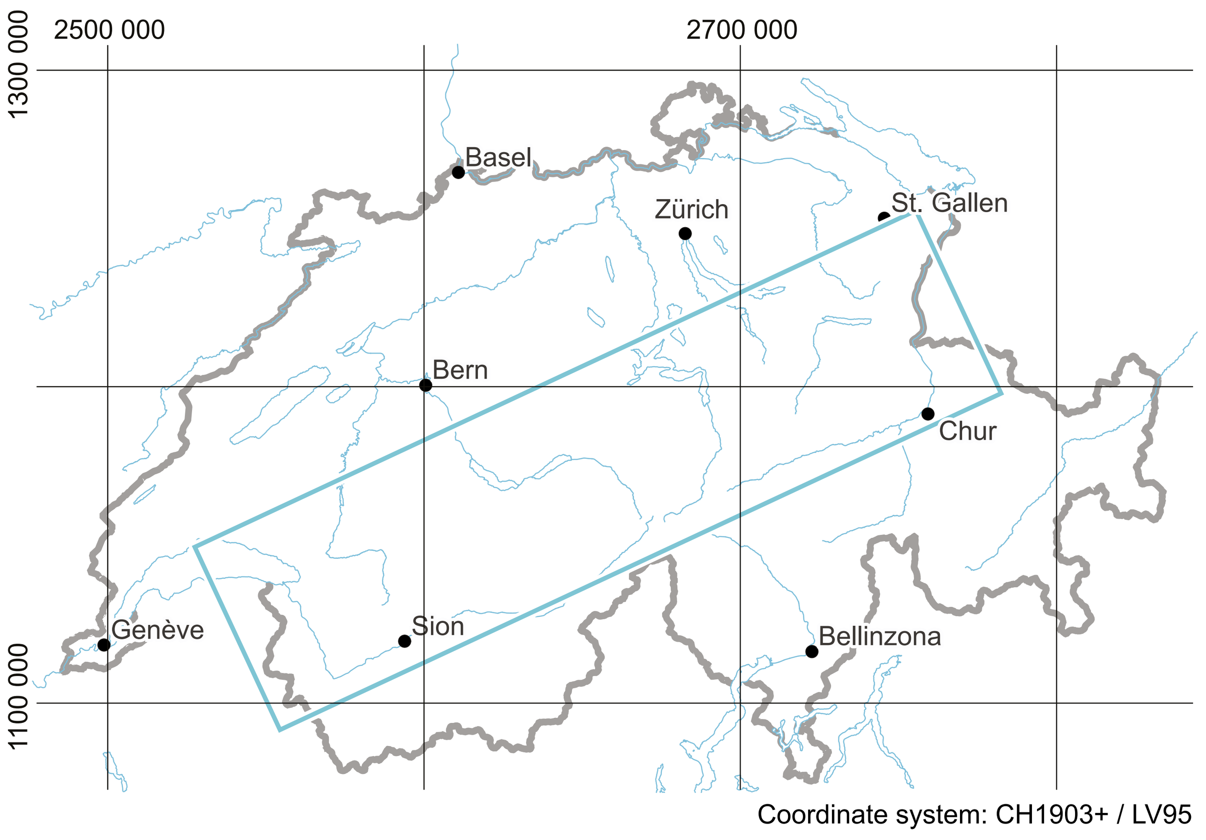
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

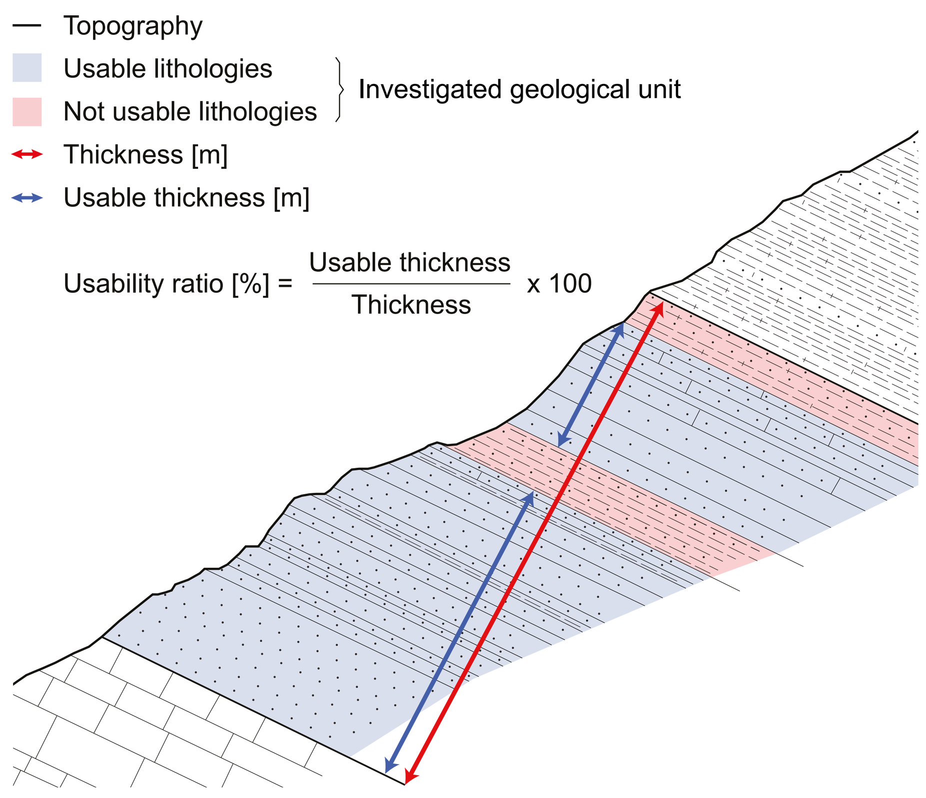


North-Helvetic Flysch Group: Input values and model results

Extent of map views A – C



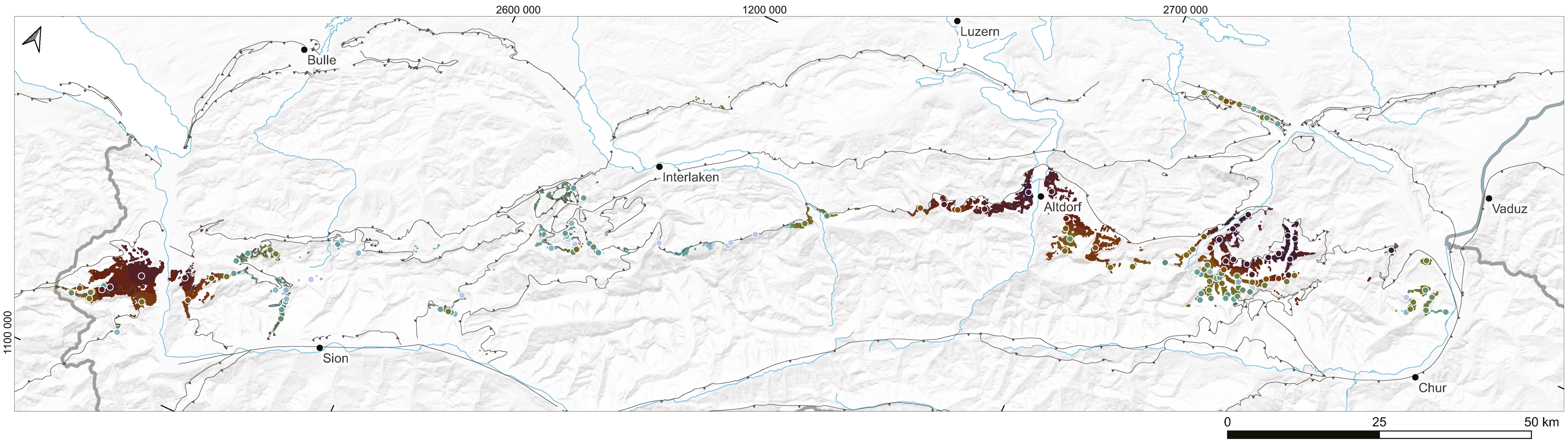
Terminology (schematic cross-section view)



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

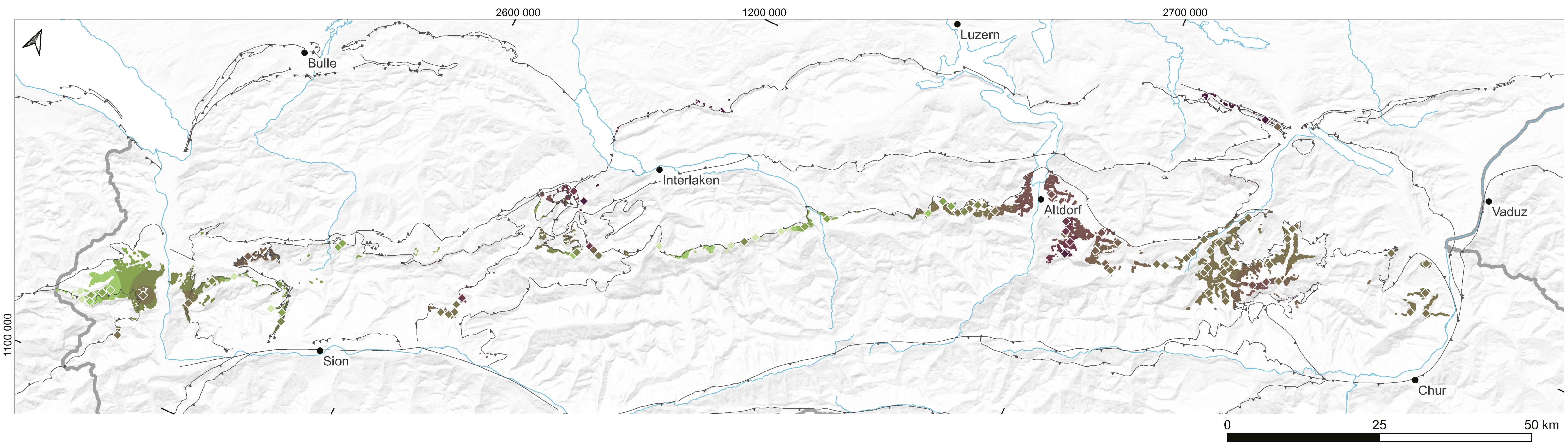
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

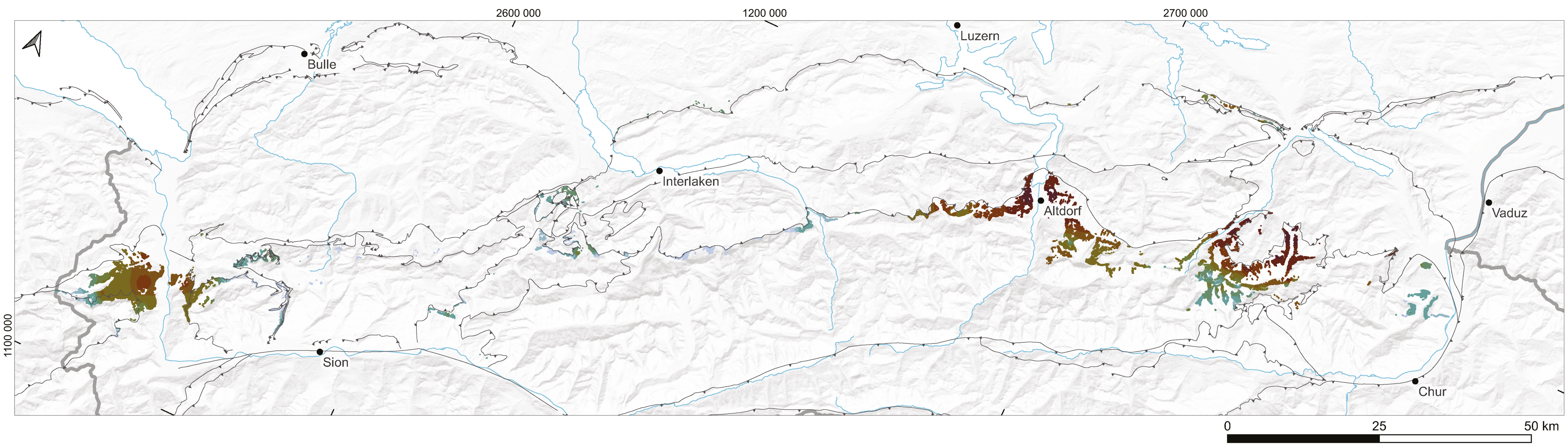
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

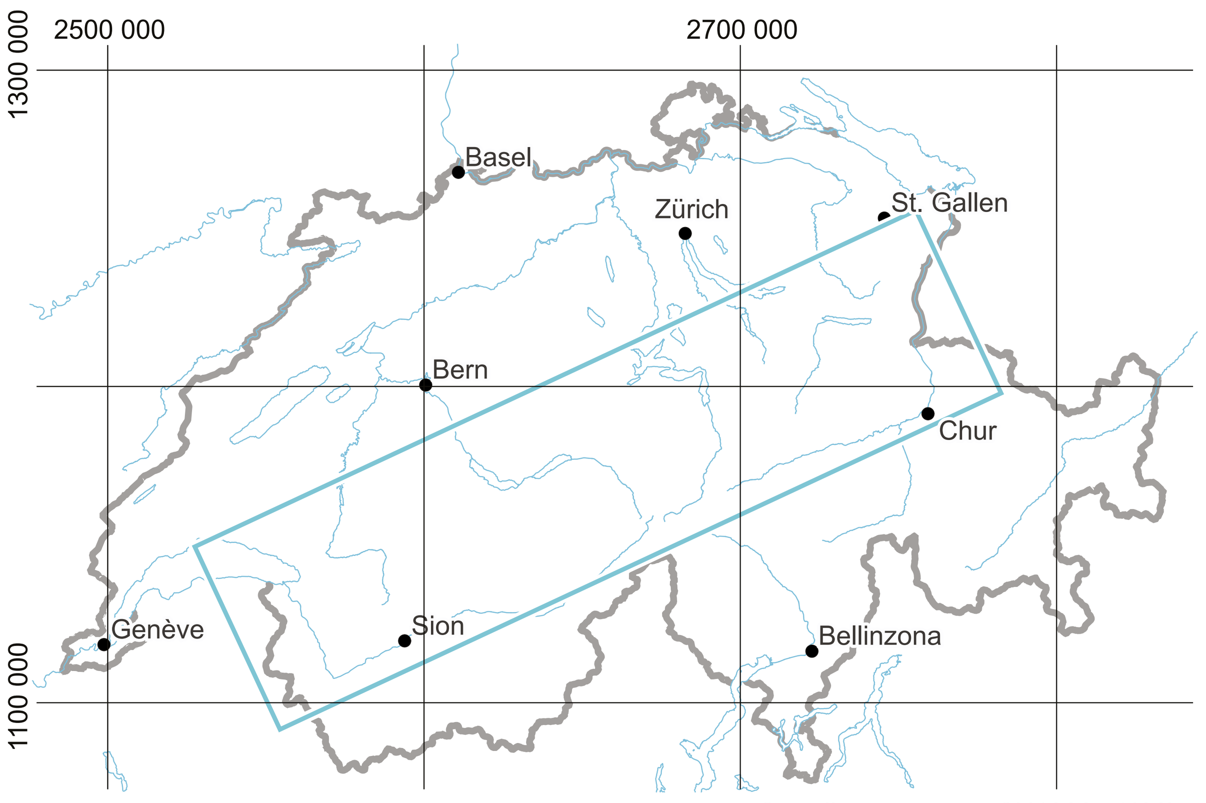
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

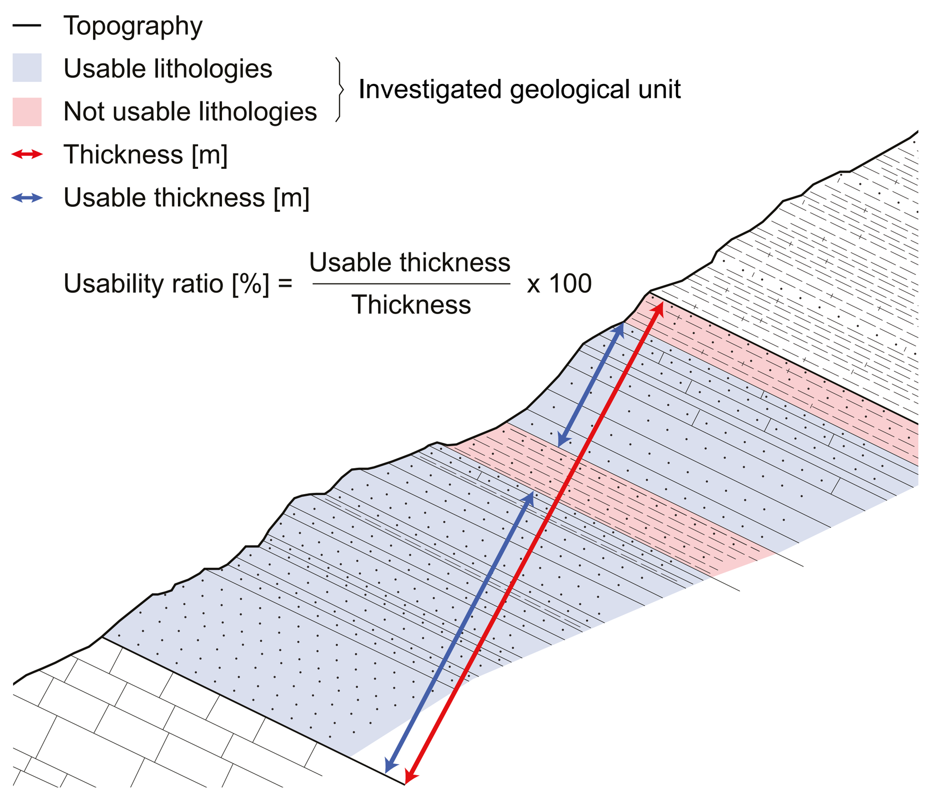


Molasse Rouge of Monthey: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



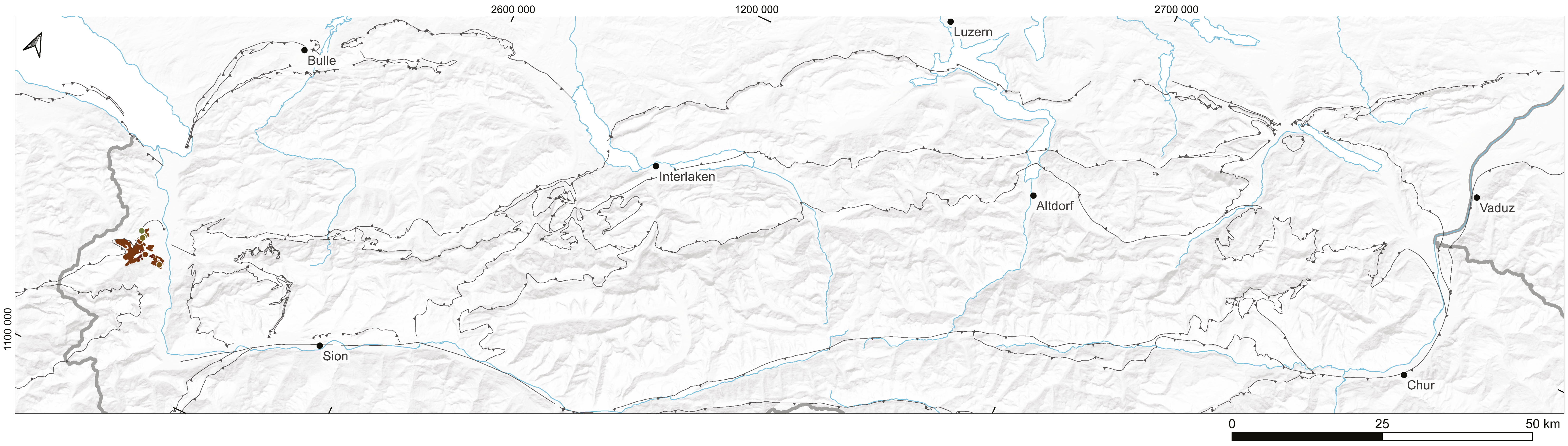
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



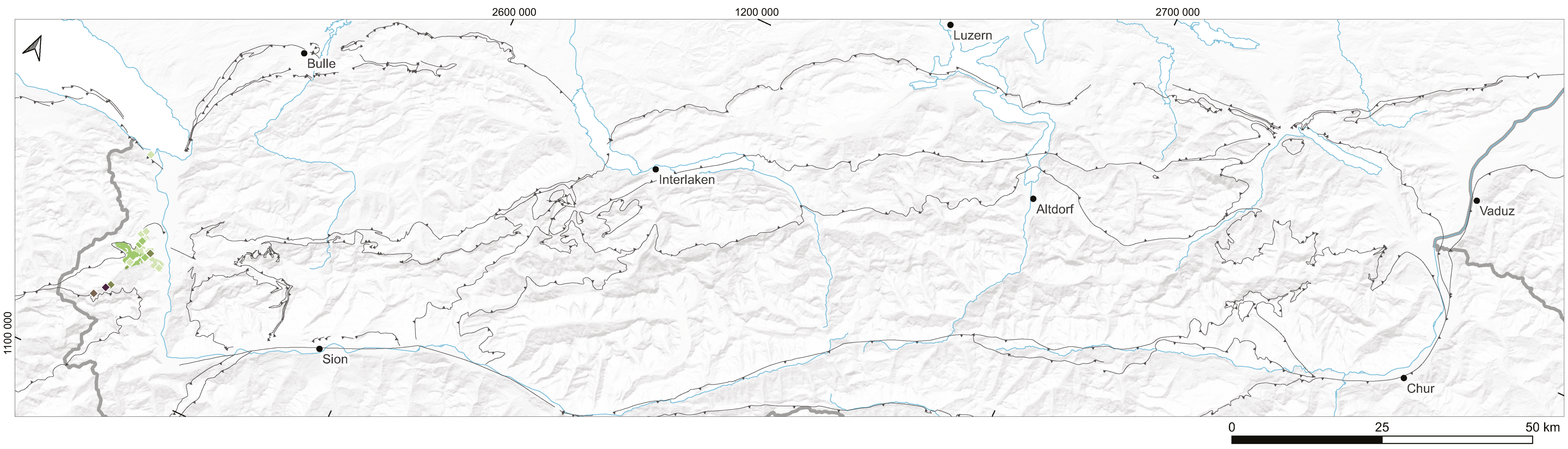
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%

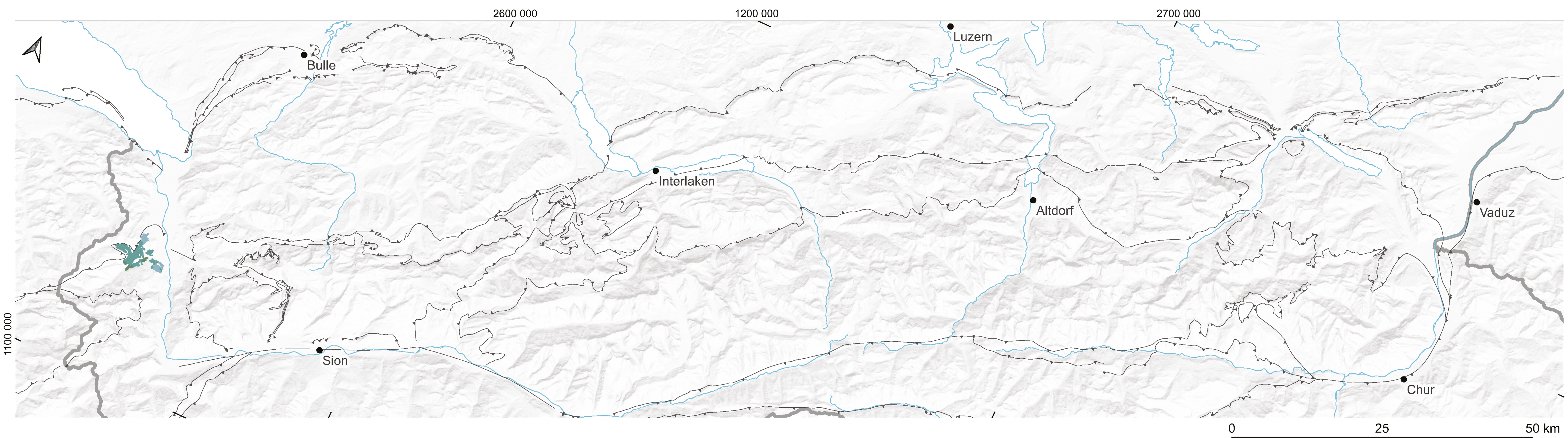


(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

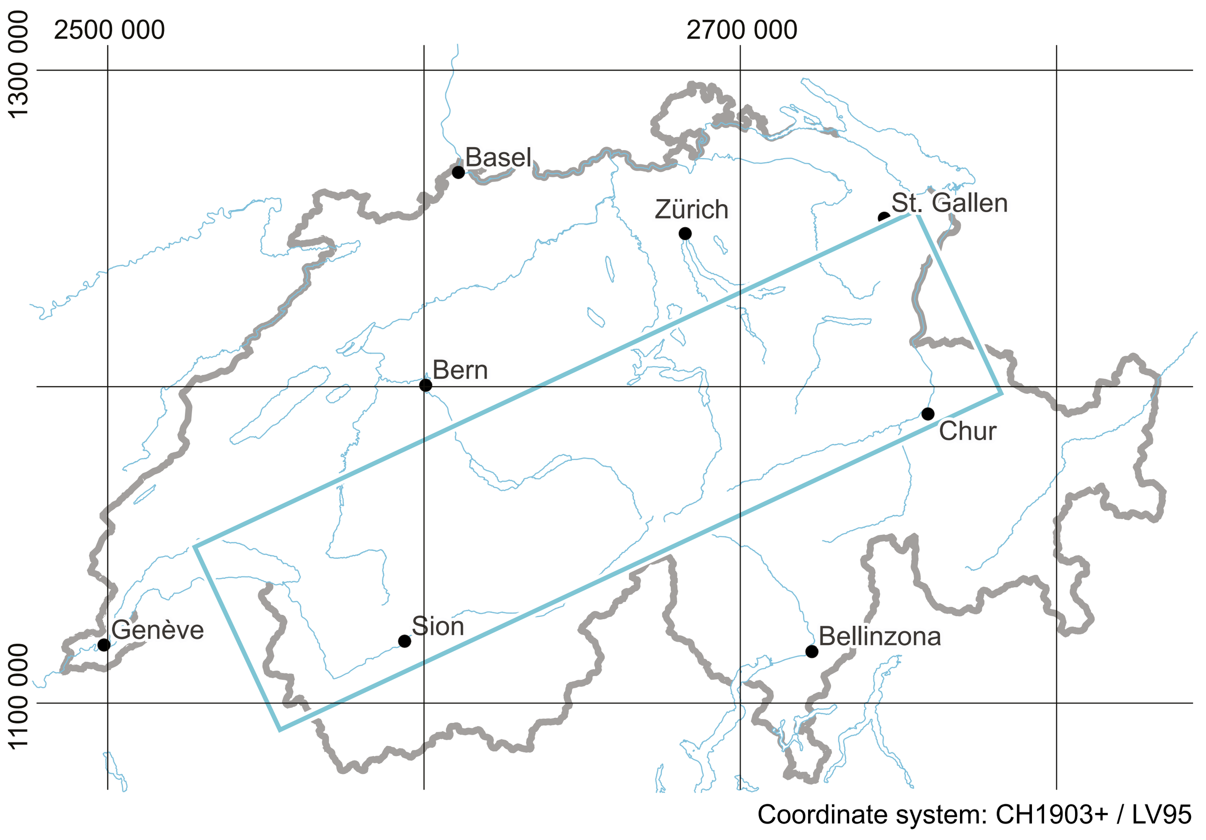
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

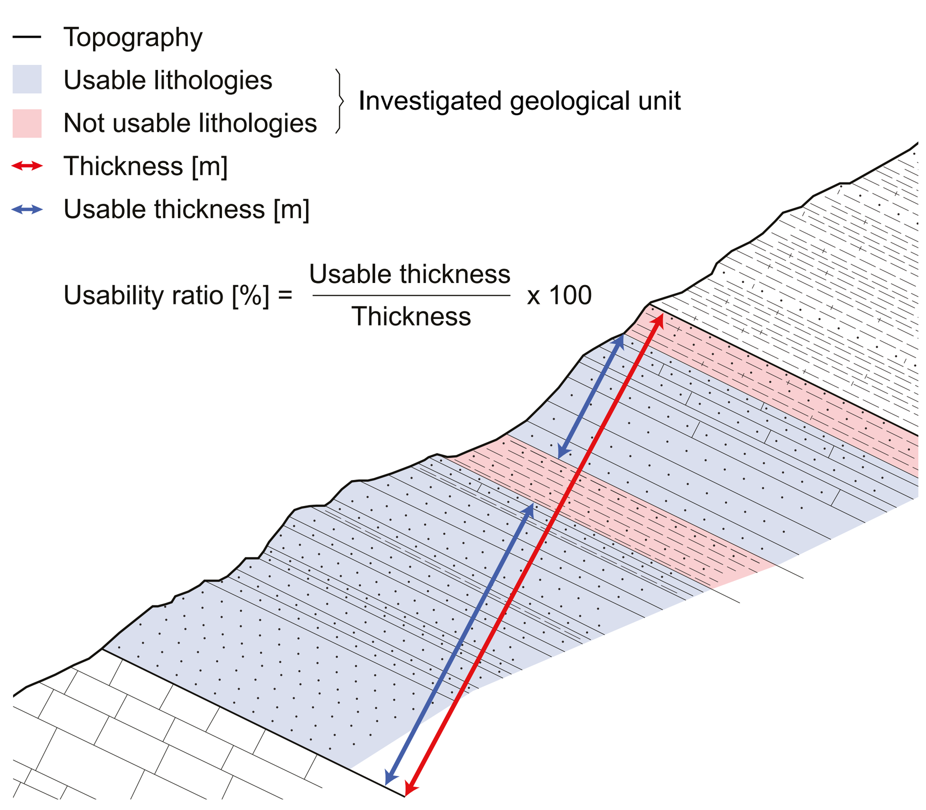


Obflue Formation: Input values and model results

Extent of map views A – C



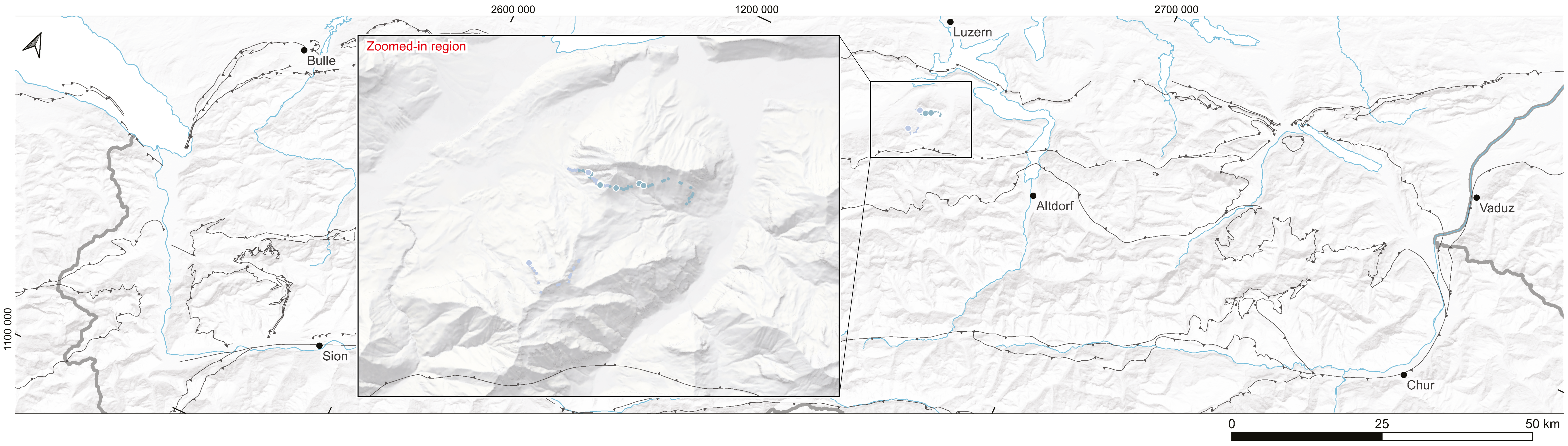
Terminology (schematic cross-section view)



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

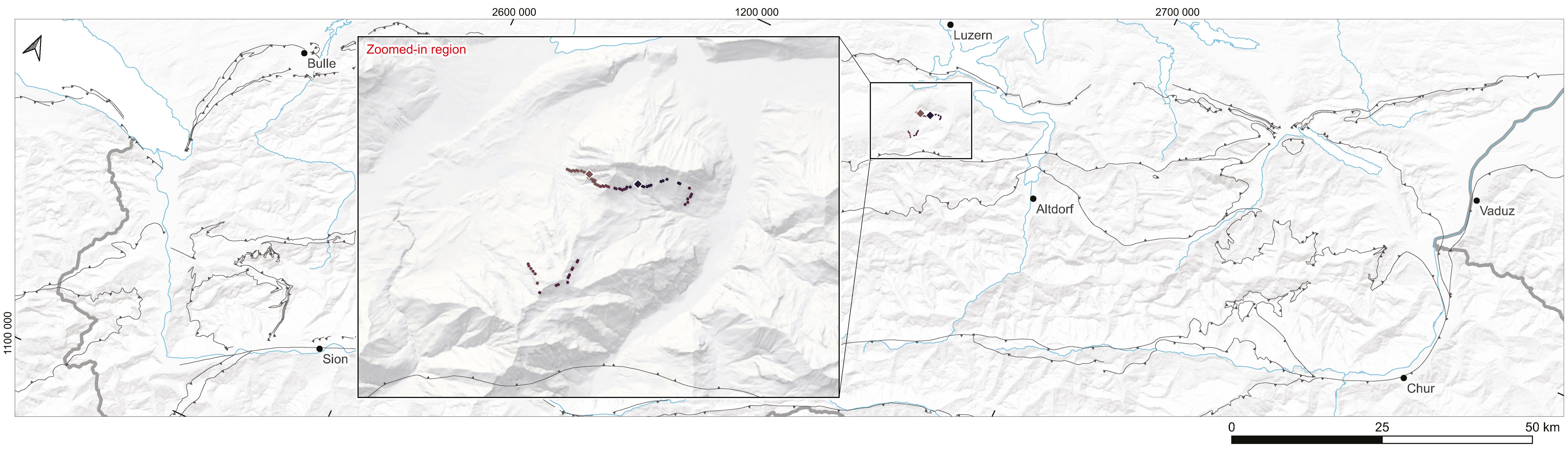
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

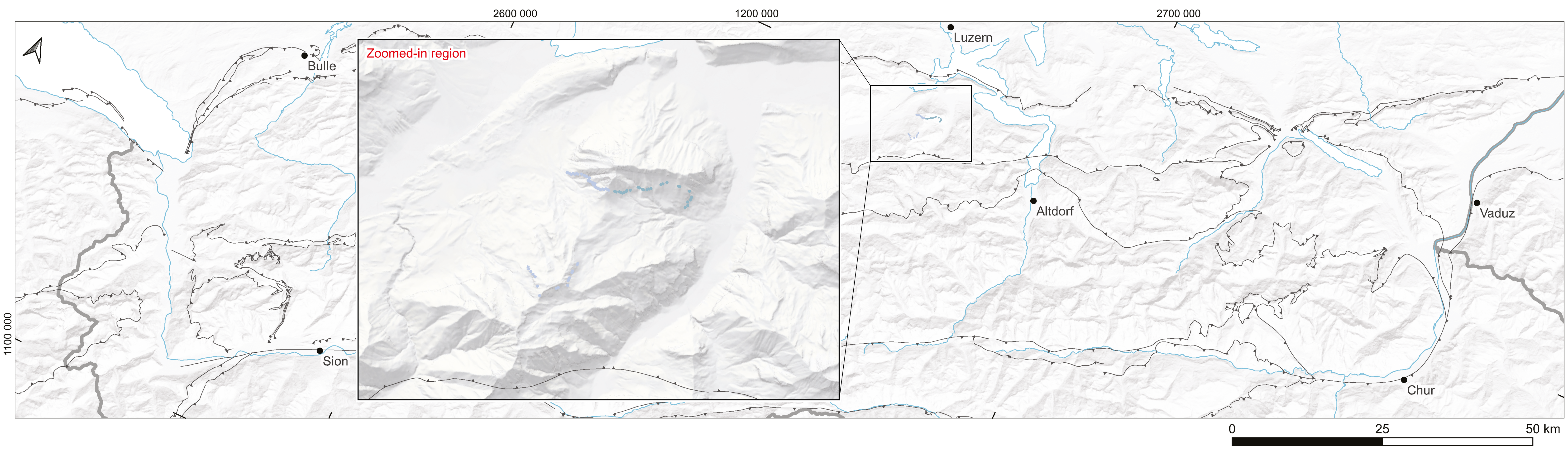
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

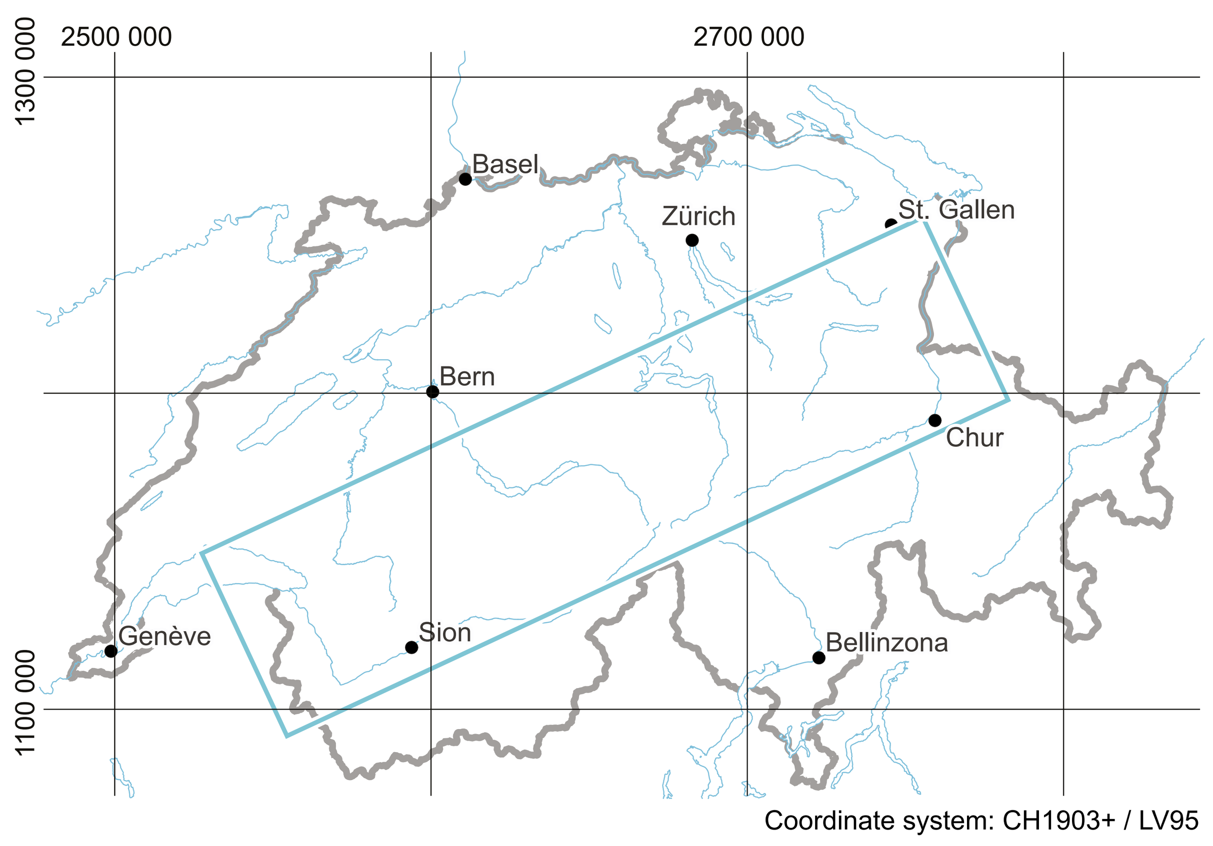
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



Petit-Liençon Formation: Input values and model results

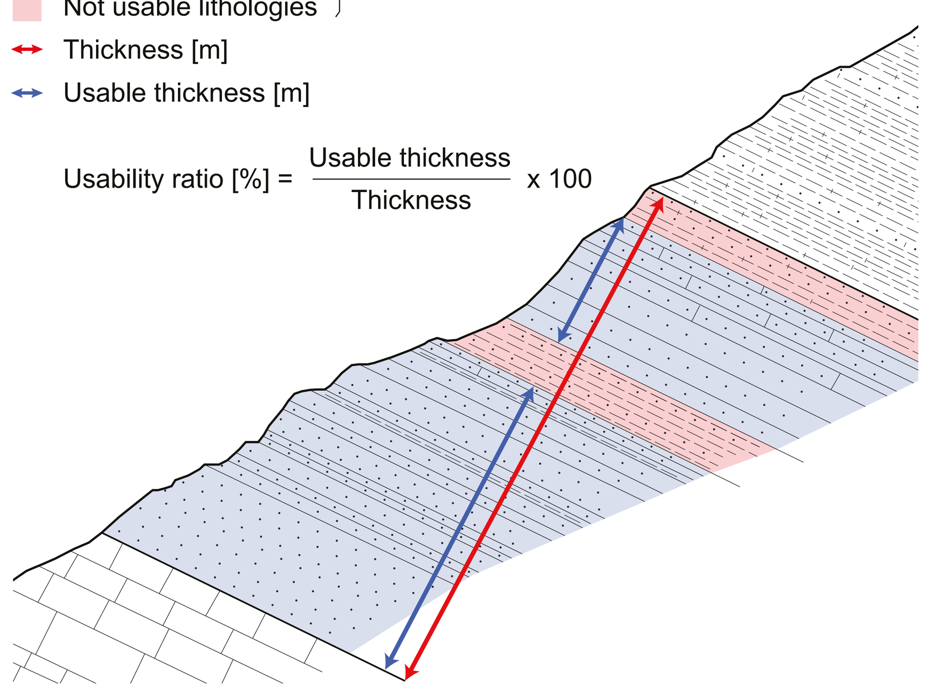
Extent of map views A – C



Terminology (schematic cross-section view)

Topography
Usable lithologies
Not usable lithologies
Investigated geological unit
Thickness [m]
Usable thickness [m]

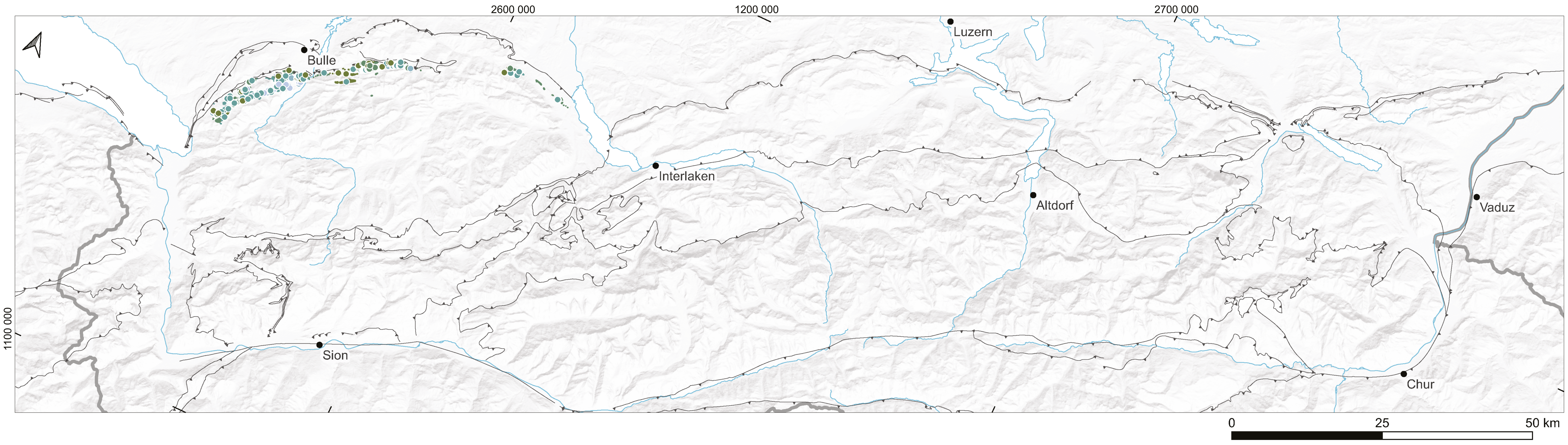
$$\text{Usability ratio [\%]} = \frac{\text{Usable thickness}}{\text{Thickness}} \times 100$$



(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
Estimated Thickness (raster cell size 50x50 m)

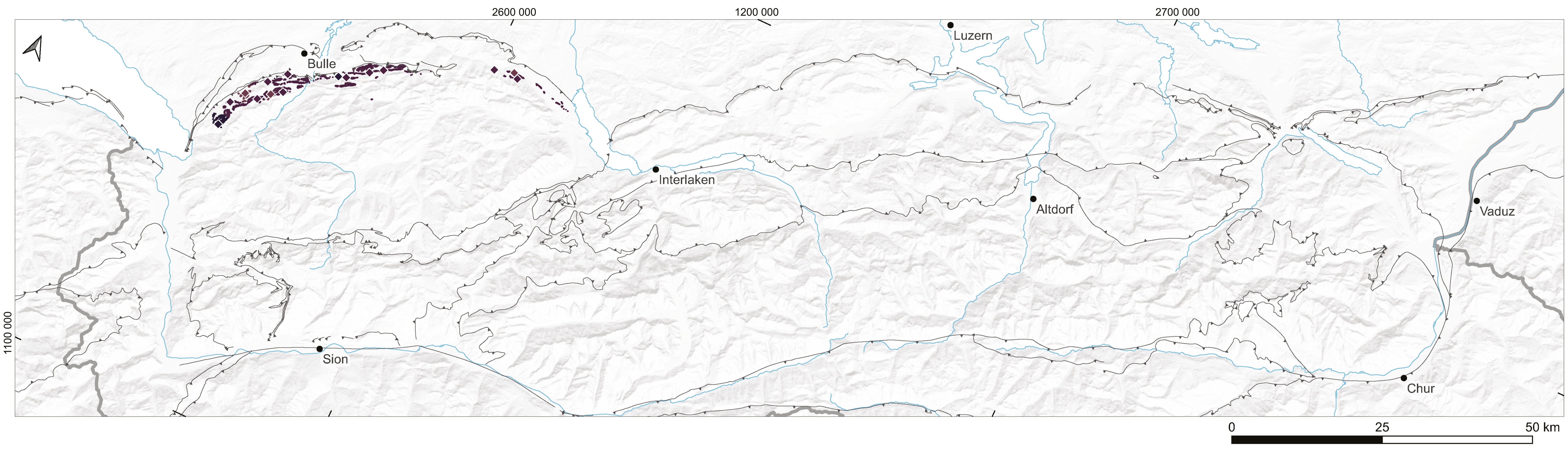
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
Usability ratio input values (compiled from the references listed in Chapter 7)
Estimated usability ratio (raster cell size 50x50 m)

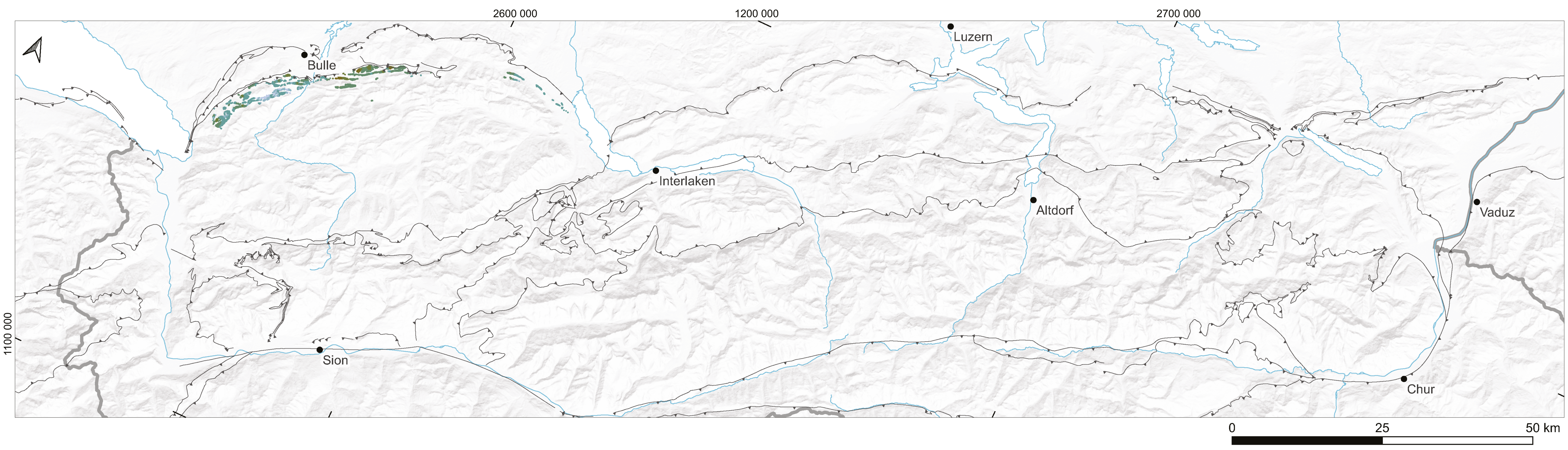
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

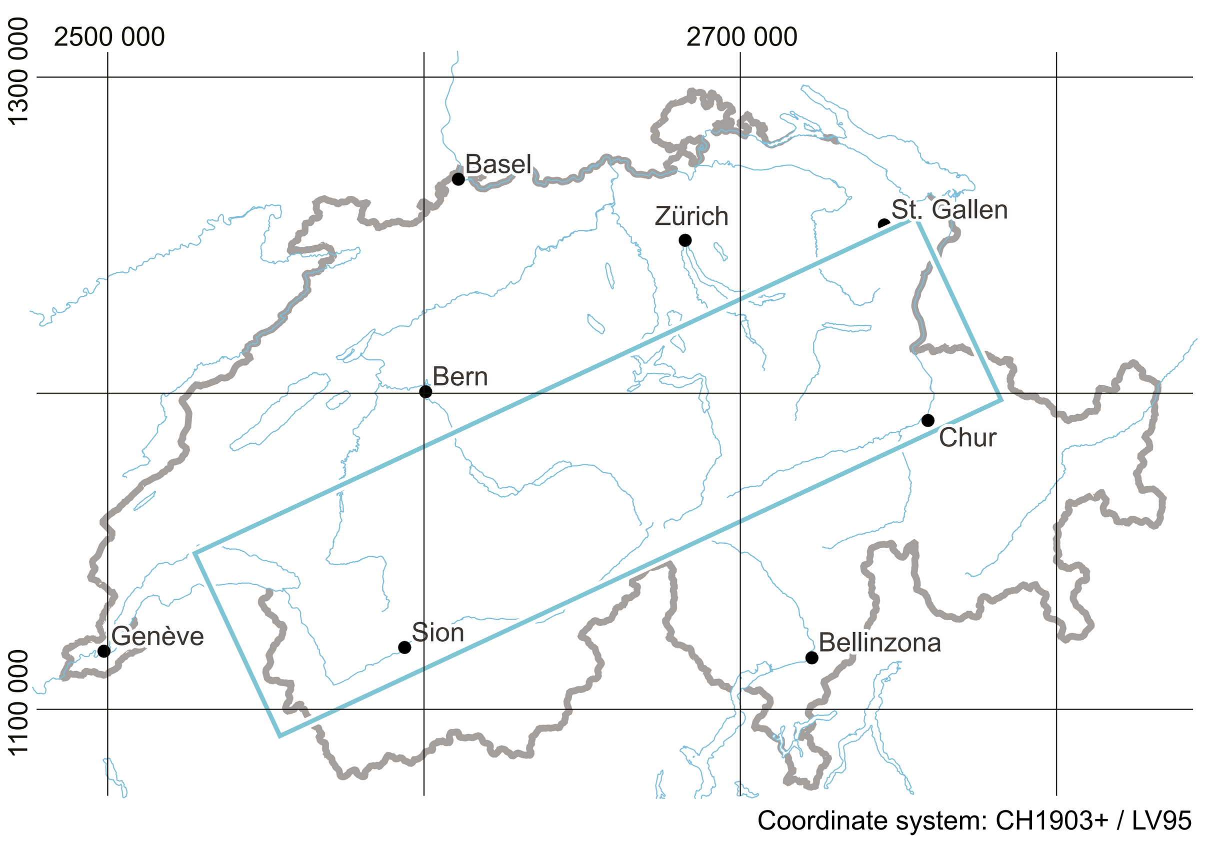
Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

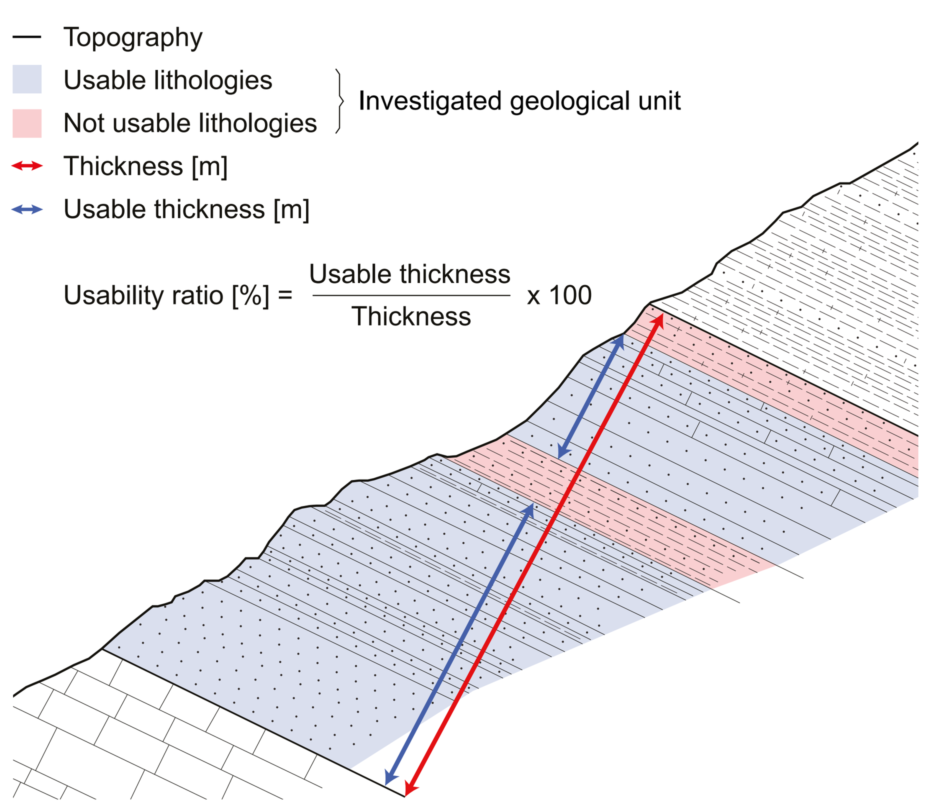


Rossinière Formation: Input values and model results

Extent of map views A – C



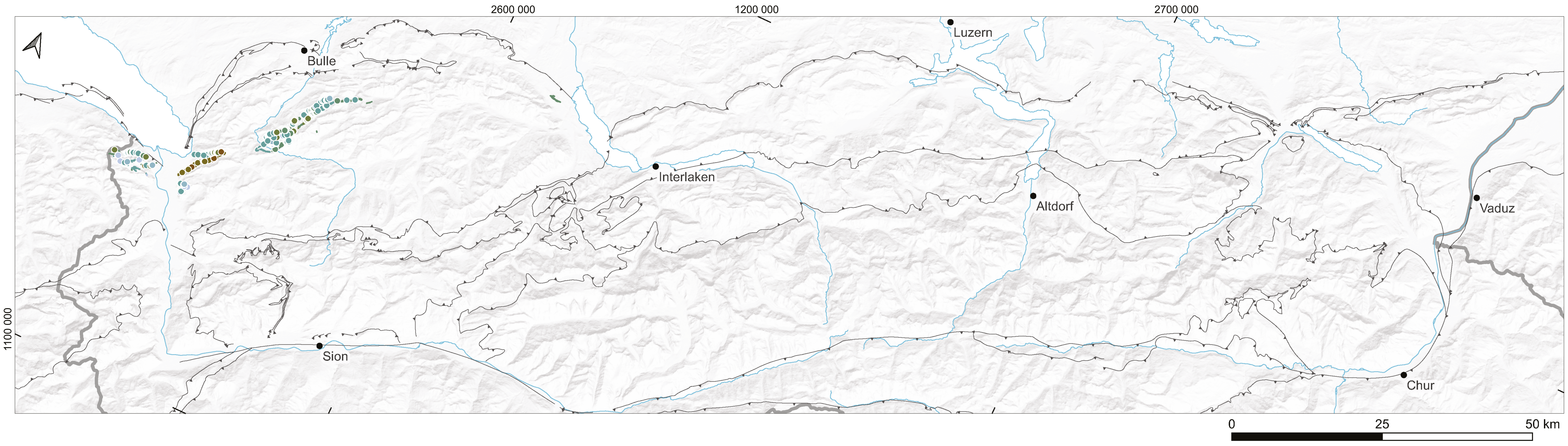
Terminology (schematic cross-section view)



(A) Thickness

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])
- Estimated thickness (raster cell size 50x50 m)

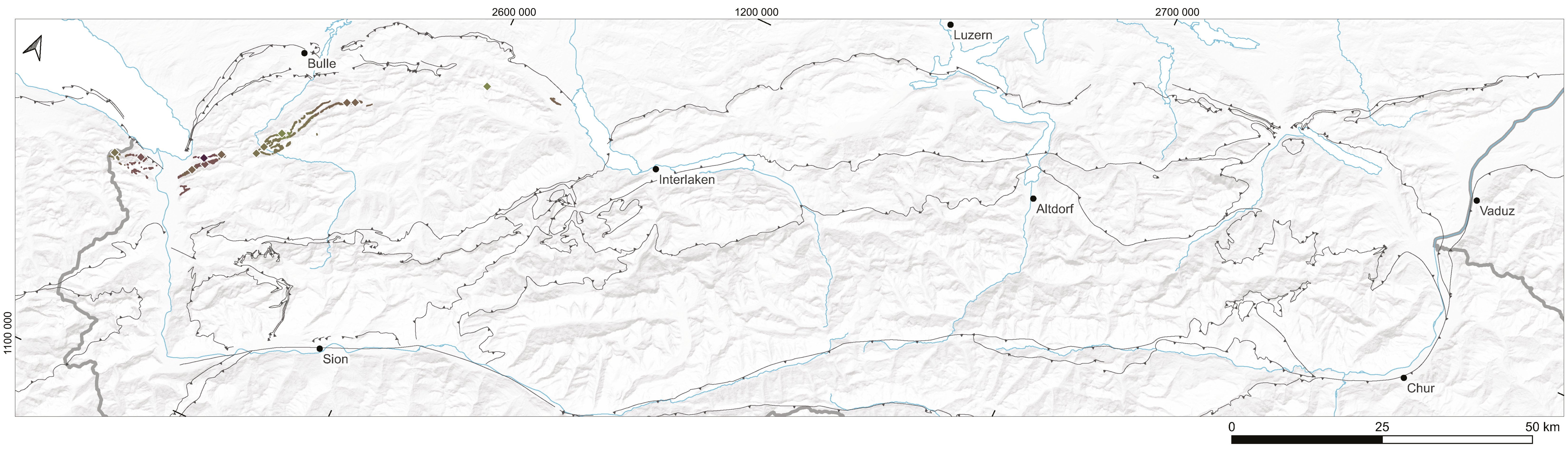
0 30 50 100 150 200 350 500 750 1250 2000 6000 m



(B) Usability ratio

- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Usability ratio input values (compiled from the references listed in Chapter 7)
- Estimated usability ratio (raster cell size 50x50 m)

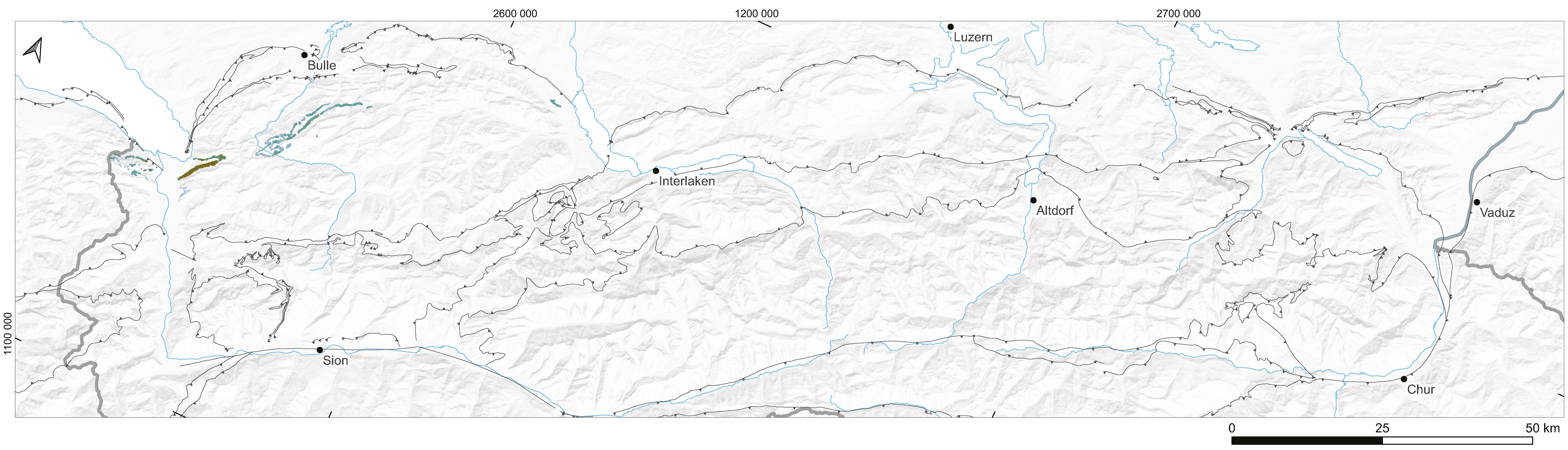
0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

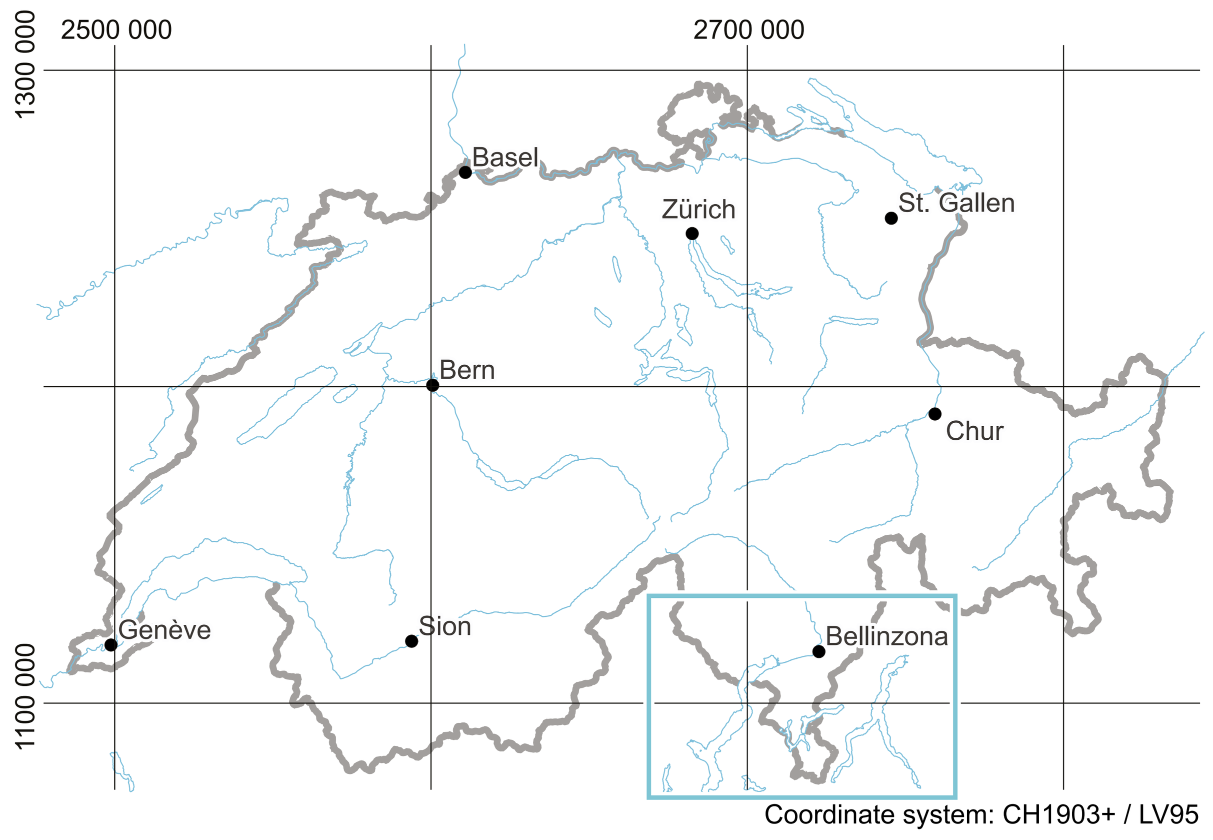
- Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])
- Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m

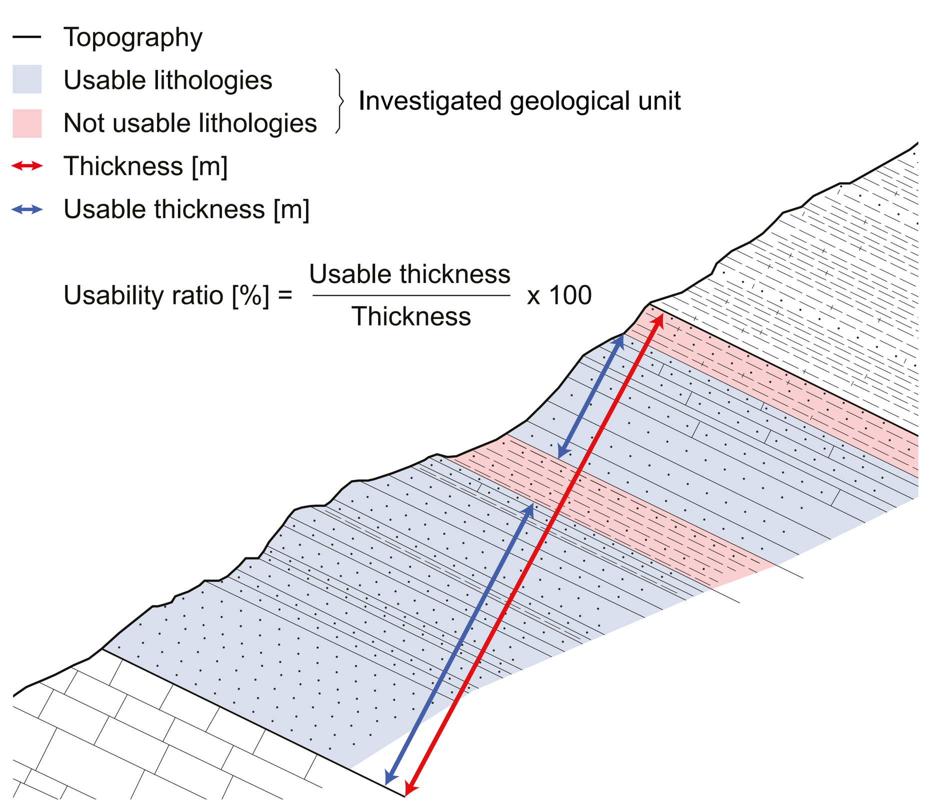


Moltrasio Formation: Input values and model results

Extent of map views A – C



Terminology (schematic cross-section view)



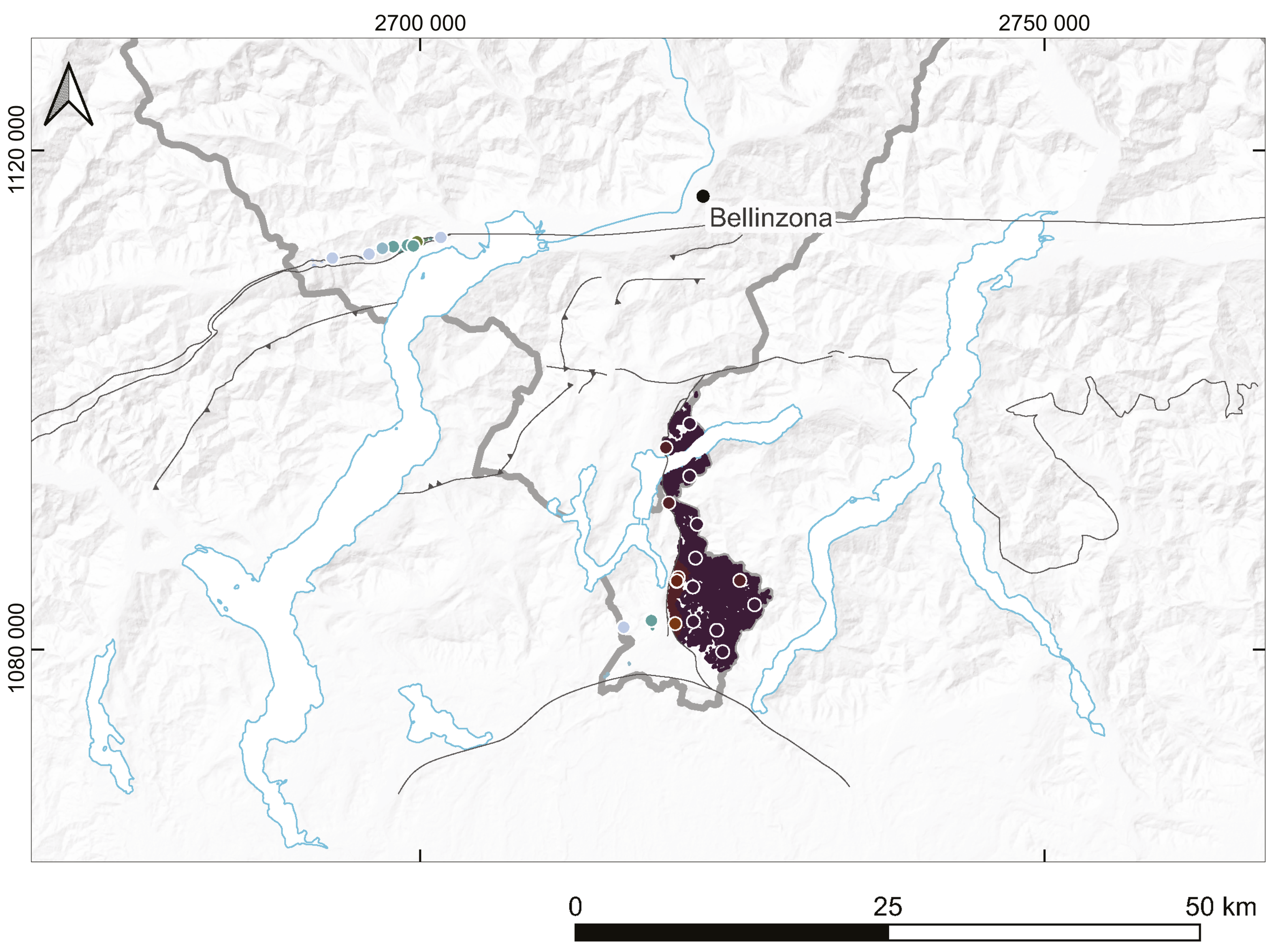
(A) Thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Thickness input values (compiled from the references listed in Chapter 7, automatically extracted using the methods described in Nibourel et al., 2023 [19] and Juchler, 2022 [20])

Estimated thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m



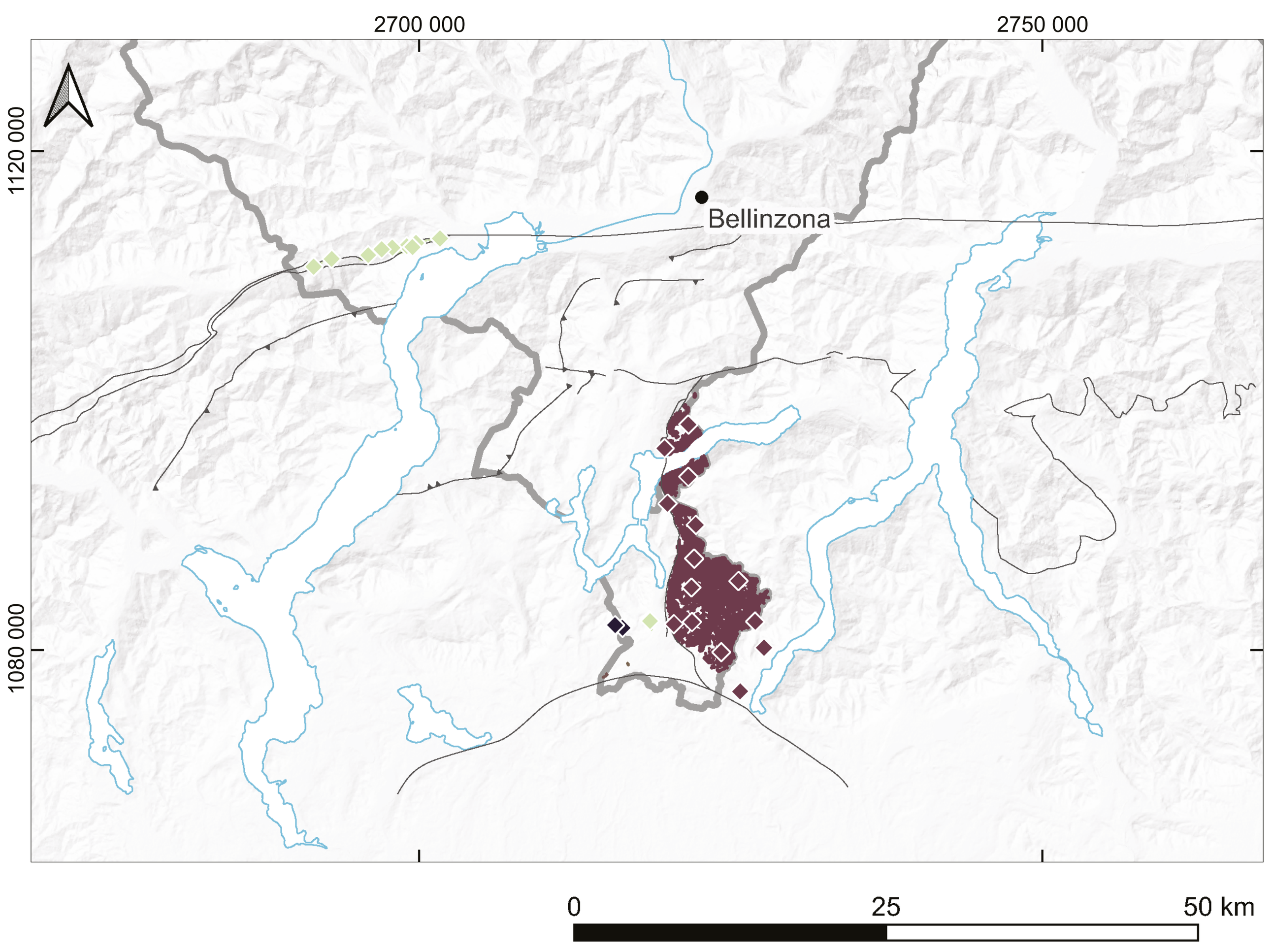
(B) Usability ratio

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Usability ratio input values (compiled from the references listed in Chapter 7)

Estimated usability ratio (raster cell size 50x50 m)

0 10 20 300 40 50 60 70 80 90 100%



(C) Usable thickness

Major tectonic boundaries (modified from the Tectonic Map of Switzerland, swisstopo, 2024 [15])

Estimated usable thickness (raster cell size 50x50 m)

0 30 50 100 150 200 350 500 750 1250 2000 6000 m