Zeitschrift: Swiss bulletin für angewandte Geologie = Swiss bulletin pour la géologie appliquée = Swiss bulletin per la geologia applicata = Swiss bulletin for applied geology

Herausgeber: Schweizerische Vereinigung von Energie-Geowissenschaftern; Schweizerische Fachgruppe für Ingenieurgeologie

Band: 21 (2016)

Heft: 1

Artikel: 3D model of the Swiss Molasse Basin : a first step towards a national geological 3D model

Autor: Baumberger, Roland / Allenbach, Robin

DOI: https://doi.org/10.5169/seals-658183

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Mehr erfahren

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. En savoir plus

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. Find out more

Download PDF: 11.02.2026

ETH-Bibliothek Zürich, E-Periodica, https://www.e-periodica.ch

Swiss Bull. angew. Geol. Vol. 21/1, 2016 S. 17-28

3D model of the Swiss Molasse Basin – A first step towards a national geological 3D model

Roland Baumberger[1], Robin Allenbach[1]

Keywords: 3D modelling, Molasse basin, fault zones, data management, uncertainty

1 Introduction

Today, 80% of political and economic decisions are related to – mostly 2D – spatial data. In these decision-making processes, the characterization and visualization of the subsurface in three dimensions plays only a minor role. In Switzerland, the usage of the underground for energy production, waste disposal, assessment and mining of mineral resources and infrastructural planning are key topics regarding the security of supply, civil protection and mobility. Consequently, competing claims in the subsurface and related conflicts (3D property, 3D spatial planning), are potentially one of the main societal conflict areas of the future. In general, 3D spatial planning plays a key role in future use of the subsurface, which in turn requires reliable data to meet advances in technology (e.g. unmanned cargo transport) and the consequences of population growth (e.g. deep cities). Today, public interest in Switzerland is focusing on subsurface potentials (e.g. hydrocarbons, raw materials), the unsolved contemporary energy supply problems (e. g. radioactive waste disposal), the challenges of the energy transition (e.g. geothermal energy production) and climate change (e.g. CCS). It's becoming evident that with these upcoming challenges the usage of the subsurface will further increase and needs to be planned accordingly.

From a geoscientific point of view, these challenges have, in combination with increasing computing capacity and software functionality, turned the 3D geoscientific description of the subsurface into an eye-catcher discipline over the course of the last few years. This change does not only impact our understanding of the subsurface and its potentials, but it also forces geoscientists to supply their highly complex and extensive three-dimensional products to non-specific target groups. Thus, the main challenge is not only to construct precise and informative 3D geological models, but preferably to make geological data in general accessible to a wide range of potential end-users (Baumberger et al. 2015).

2 Motivation

Within the context presented above, geological data and information have become increasingly important to decision makers, planning authorities and even the public – with the geosciences being tasked with supplying concrete solutions and coherent explanations. However, quick and easily accessible data of this kind are presently not readily available. Accessible basic 3D datasets in particular are generally missing today. It therefore becomes obvious that a

[1] Federal Office of Topography, Swiss Geological Survey, Seftigenstrasse 264, CH-3084 Wabern, Switzerland

3D geoscientific model is urgently needed to assess and plan the usage of the underground and that the accessibility of geological data in general needs to be improved.

The Swiss Geological Survey (SGS) distinguishes between modelling unconsolidated and consolidated sediments (Baumberger et al. 2015).

- Unconsolidated sediments: This model type comprises Quaternary deposits (Volken et al. 2016, this volume).
- Consolidated sediments: Modelling focuses on Tertiary and Mesozoic horizons, including the base of the Mesozoic deposits.
- Numerical models: Modelling of Thermo-Hydro-Mechanical processes, parameter estimations, interpretation of measurements and predictions.

Existing 3D models currently do not cover the entire country. The SGS aims to 1) regionally enlarge the models, 2) improve them from a geological (e.g. additional stratigraphic units) and content (e.g. parametrization) point of view and 3) combine them to become the National Geological 3D model of Switzerland in the foreseeable future (see below). Additional models are going to be developed and integrated with the already

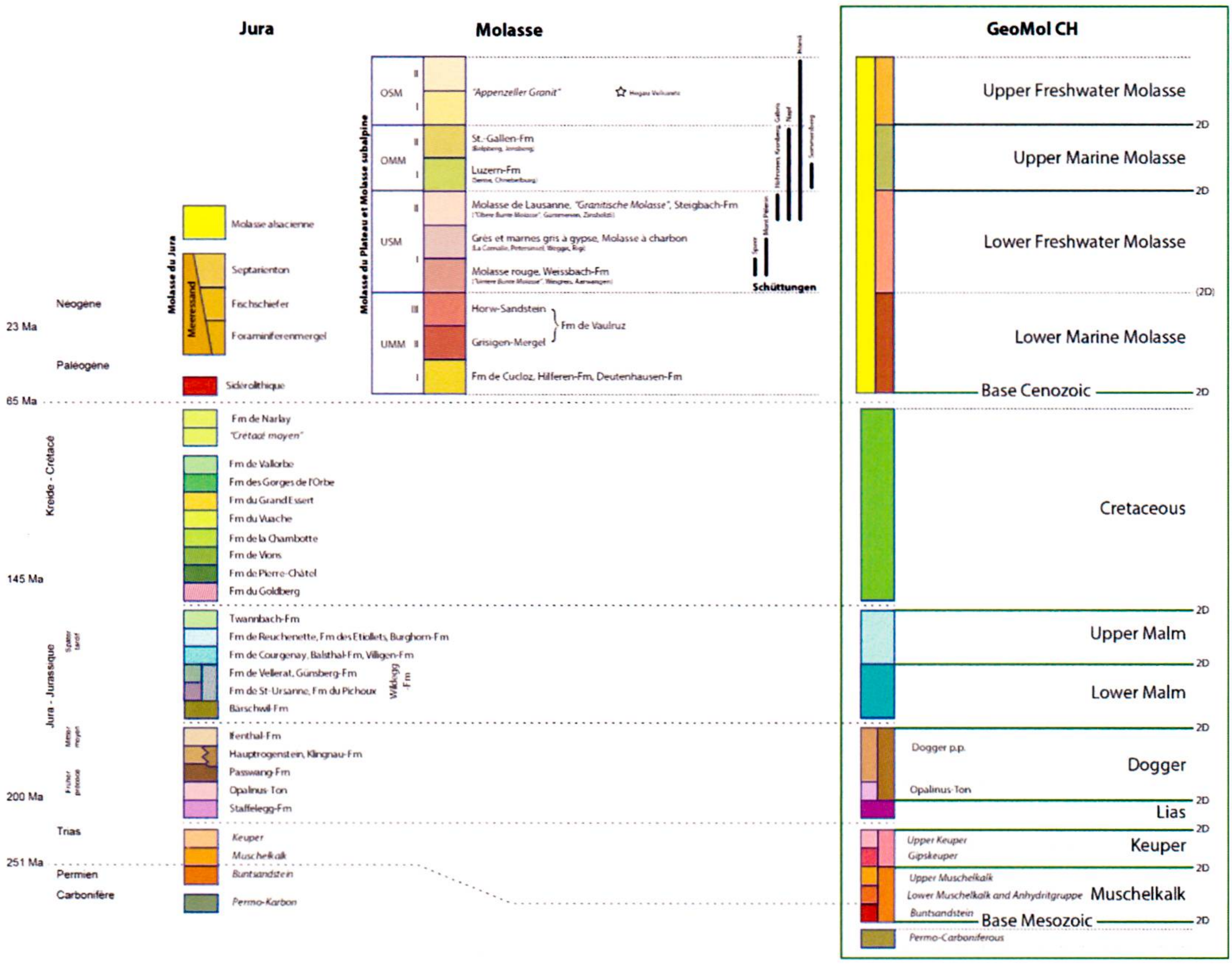

Fig. 1: The stratigraphic resolution of the 3D geological models of the Swiss Molasse basin comprises 12 horizons (Upper Freshwater Molasse, Upper Marine Molasse, Lower Freshwater Molasse, Lower Marine Molasse, Cretaceous, Upper Malm, Lower Malm, Dogger, Lias, Keuper, Muschelkalk, and Base Mesozoic) as well as the horizon «Base Cenozoic». The high resolution model (see text) contains additional horizons in selected regions (Opalinus Clay, Upper Keuper, Gipskeuper, Upper Muschelkalk, Lower Muschelkalk and Anhydritgruppe, Buntsandstein, Permo-Carboniferous).

existing products. Finally, all of this data will be accessible by the public (see below).

More than 50% of the Swiss population work and live in the central plateau and the geological resources in this region have already been intensively explored and/or exploited. In 2011, the SGS began planning the first comprehensive 3D geological model of the Swiss Molasse basin.

3 The 3D geological model of the Swiss Molasse basin

3.1 A brief history

After two years of intensive planning and fund raising, the development and production of the basin-wide large-scale 3D geological model started in January 2013. Since then, the SGS has been developing two layer cake national framework models for the consolidated sediments. They exist in different resolutions and cover the same area, but show differences in terms of stratigraphic units (Fig. 1) and structural elements.

3.2 Framework model 200 (FM200)

This large-scale model is based mainly on the interpretations published in the Seismic Atlas of the Swiss Molasse Basin (Sommaruga et al. 2012). However, the framework model differs in three major points from Sommaruga et al. (2012):

- Additional well data from Switzerland and Germany were integrated, mainly to develop an updated basin-wide interval velocity model for the time-to-depth conversion of seismic interpretations.
- Large-scale and simplified fault zones were added to build up a complete structural model.
- Cenozoic horizons were added in order to display the most important geological layers in the Swiss Molasse basin.

The FM200 model has a resolution of 200 m grid size, which compares to scale of approximately 1:200'000. The purpose of the FM200 is to provide a comprehensive overview of the geology and structures of the Swiss Midlands on a large-scale. The model was published in December 2015.

3.3 Framework model 50 (FM50)

This model was largely built from scratch. It cannot be compared to the framework model, since a large number of previously unused datasets were integrated:

- Already available seismic interpretations were enhanced and completed. Seismic lines without available interpretations were loaded, interpreted and added to the data repository. A few dozen lines initially only available on paper were vectorized and converted to digital data.
- In addition to the deep wells, a large number of new wells of intermediate depth were integrated.
- In contrast to the framework model, a large number of surface data (geological maps, dip measurements, cross-sections etc.) were used.

The FM50 features a 100 m grid size (approximately 1:50'000) and focuses on more detailed representations of smaller scale structural elements than the FM200. The modelling was done by the SGS and five partners (Universities of Basel, Bern, Fribourg and Geneva as well as the museum of geology of the canton of Vaud) in a joint endeavor. The work will be completed in late 2016.

4 Input data

Such a complex project could not have been accomplished without the support of the owners of seismic and well data in Switzerland. The SGS gratefully acknowledges Nagra, SEAG (AG für Schweizerisches Erdöl), Swissgas, St.Galler Stadtwerke, many Federal and cantonal administrations, the Swiss Federal Railways and research partners at the Swiss universities for generously providing access to their data and know-how. This also applies to ExxonMobil, which provided access to well data in southern and south-eastern Germany.

5 Data treatment

The SGS is tasked with providing comprehensive, complete and harmonized datasets and is commissioned to produce more than simple 3D geological models. The application of standards (e.g. data models, stratigraphy), the parametrization of the models and the assessment of the inherent uncertainty of 3D data denotes a fundamental step to achieving this goal. Therefore, the characterization of data for both the FM200 and FM50 models comprises three domains: 1) semantic description, 2) rock properties and 3) uncertainty (Baumberger et al. 2015).

5.1 Harmonization

In terms of a 3D geological model, the semantic description turns out to be a very difficult task. A 3D model is not only based on the interpretations of different kinds of data (seismics, boreholes, cross sections, maps, etc.), but this data is also of varying vintages, quality, detail and acquisition purposes. Additionally, type and vintage of the input data also reflect different interpretations and geological knowledge at the time of data acquisition. Furthermore, uncertainties related to exact spatial location of these data sets may adversely influence the final results. Last but not least, the final model is based on many different data sets, which were not coordinated initially. In order to achieve the goal mentioned above, the SGS applied its suite of interdependent minimal data models (e.g. 2D geology, 3D geology, boreholes) to the models of the Swiss Molasse basin. Therefore, the input data was not only formally harmonized (e. g. naming, formats etc.), but a huge effort was also put on the semantic harmonization of the input datasets based on the stratigraphy shown in Fig. 1 and the minimal data models (Baumberger & Michael 2013, Strasky et al. 2012).

5.2 Rock properties

The parametrization of models with rock properties such as lithology, density, permeability, porosity, heat flow, rock classifications, etc. is the most obvious way to increase the value and application of 3D data. Despite the fact that the 3D geological models of the consolidated sediments currently do not contain any rock parameters, they are already prepared to receive additional data. With the addition of new data (e. g. boreholes) the structural model can be enhanced with petrological and petrophysical information.

5.3 Uncertainty

Discussing the uncertainty of different characteristics (e. g. data density, data quality, lithology) is going to be a mandatory chapter of any 3D model developed at the SGS. Consequently, the increasing demand for quantifying the reliability of subsurface models will be addressed. Currently, indications of the density of input data will be added in order to supply an initial model reliability index (see below). In the future, the model quality will be assessed by concentrating on the detail of investigation, the quality of documentation and the age of the input data as well as an uncertainty estimation regarding the lithology at a certain location.

6 Results

For the first time, a comprehensive 3D geological model of the Swiss Molasse basin is available for public access (see above and

Fig. 2). It covers the area between the Jura Mountains and the Penninic and Helvetic Nappes in the N-S transect and from Lake Geneva to Lake Constance in W-E direction. It comprises Cenozoic (Plateau and Subalpine Molasse) and the major Mesozoic units (Fig. 1). Total area at the surface is approximately 11,000 km^2. With 12 geological horizons, each model covers a total of 140,000 km^2 of modelled stratigraphic horizons and fault zones (comparable to over 3 times the surface area of all of Switzerland or 13 MM football stadiums)!

6.1 3D structures

Both models contain fault zones, which were adapted and simplified to the resolution of the particular models. Within the FM200 a total of 22 fault zones were modelled, including the triangle zone of the Alpine frontal thrust. Approximately half of the fault zones crop out at the surface (red lines, Fig. 3), whereas the rest can only be mapped at the level of the base Cenozoic (grey lines, Fig. 3). For the FM200, fault zone modelling was differentiated into major fault zones and conceptual fault zones. The former is based on the interpretation by Sommaruga et al. (2012) and modelled both in time and depth domains. In contrast, modelling the latter took into account geological profiles and conceptual interpretations and was completed exclusively in the depth domain. In general, large-scale structural features, such as the basal thrust of the Subalpine Molasse, the back thrust of the Triangle Zone and the basal detachment fault, belong to the conceptual fault category (no. 20, 21 and 22 in Figs. 3, 4). Any other fault zones within the FM200 (no. 1 to 19 in Fig. 3) belong to the major fault zones group.

6.2 Top Bedrock

The «Base Quaternary» or «Top Bedrock» horizon denotes the delimitation between the models of the different domains defined by the SGS (see above). This important boundary horizon was modelled based on

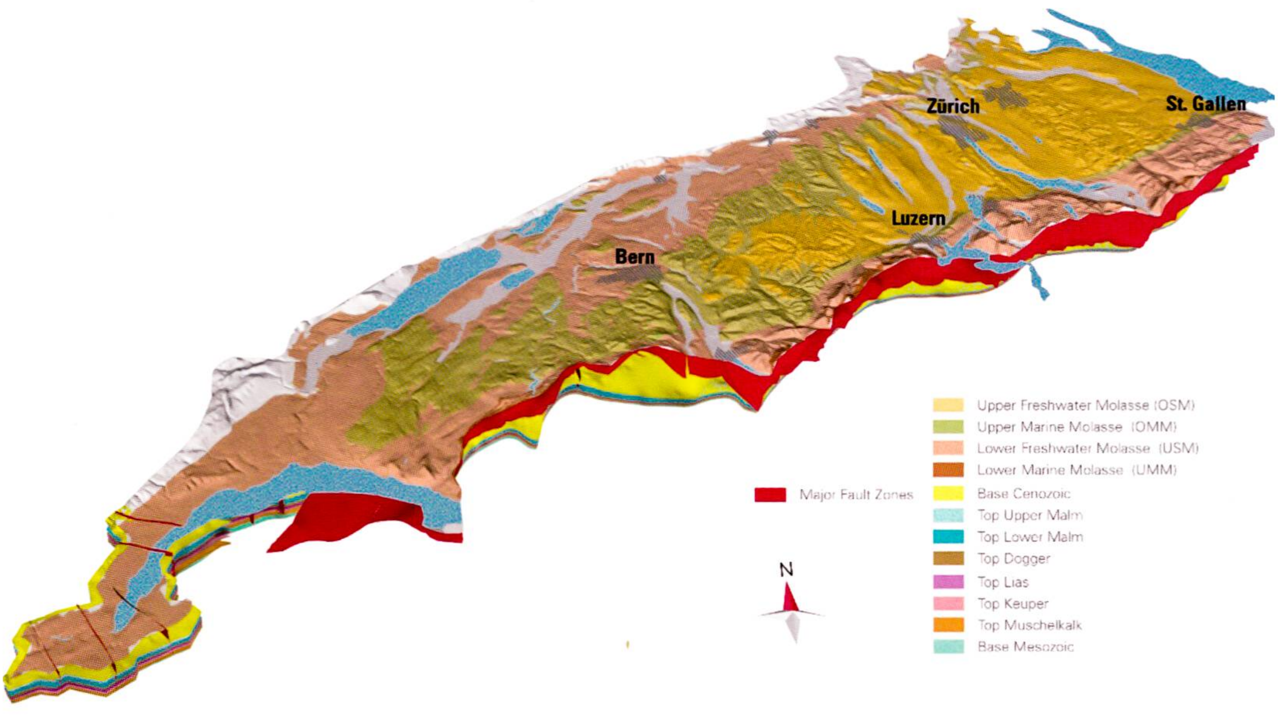

Fig. 2: Three-dimensional view of the FM200. In western Switzerland, the major fault zones are clearly visible as well as the extent and location of the triangle zone along the northern margin of the Alps. The Cenozoic and Mesozoic units can be recognized again in the greater Geneva area (representative for the entire Swiss Plateau) and throughout the Molasse Basin.

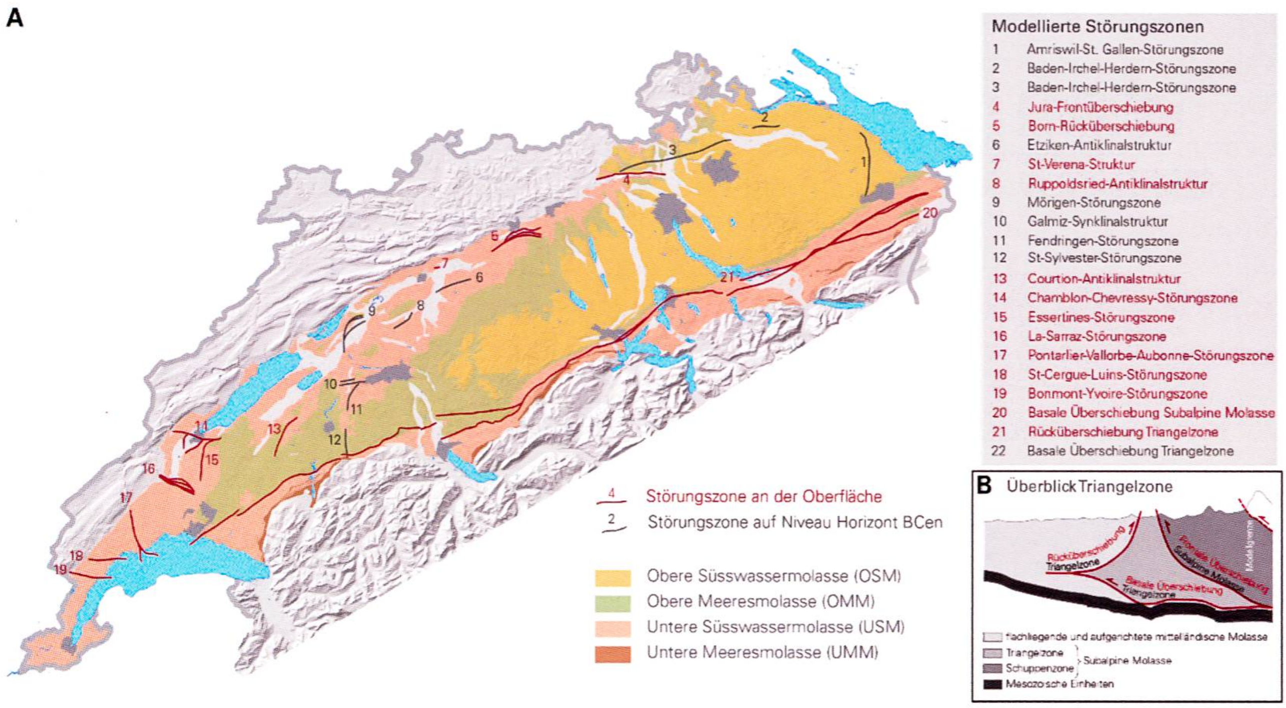

Fig. 3: Fault zone map of the FM200. A] Red lines indicate the traces of the fault zones visible at the surface, grey lines illustrate fault zones, which can be mapped at the level of Base Cenozoic. B] Schematic illustration of the conceptual fault zone of the Triangle Zone.

already existing maps and models (e.g. Dürst Stucki & Schlunegger, F. 2013; Fiore, J. 2007; Jordan, P. 2007, 2010; Pietsch & Jordan, 2014; Schälli, L. 2012; Wagner et al. 2001), contour maps (e.g. Graf, 2007; Graf & Willenberg, 2011a, 2011b, 2012, 2014) and cross-sections (e.g. Graf, 2009). Additionally, approximately 50,000 drillholes were used to complement this new data set which includes the base Quaternary in the Swiss Midlands and the large alpine valleys (Aare, Linth, Rhein, Reuss, Rhône and Ticino). As a complementary data set, the thickness of the «unconsolidated sediments» was also

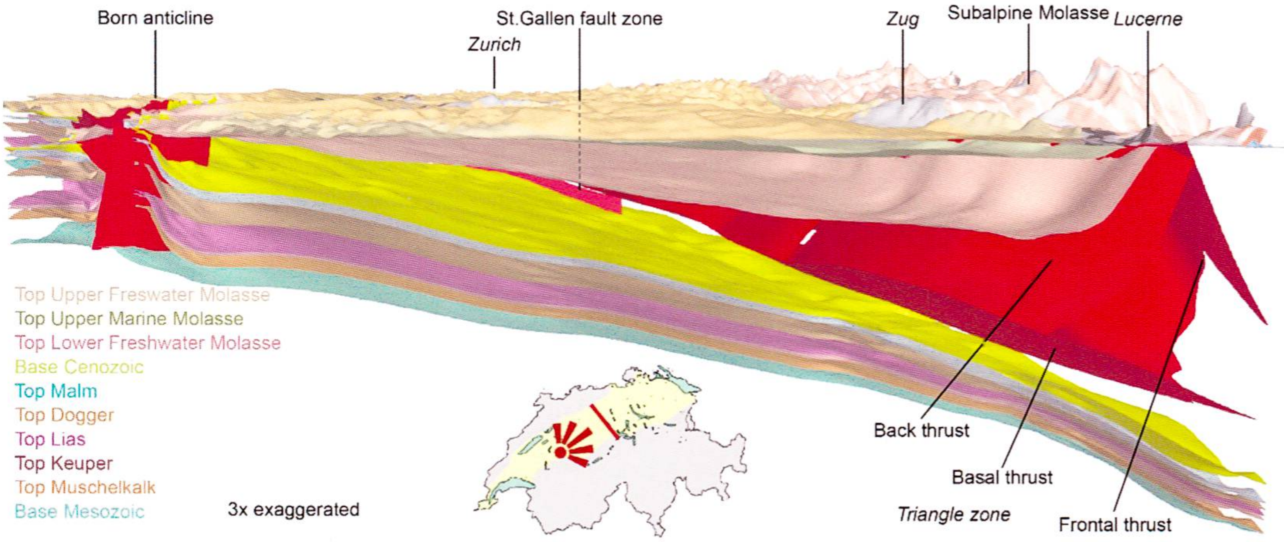

Fig. 4: NW-SE trending cross section through the central Swiss Plateau. The south-dipping modelled stratigraphic units are clearly visible as well as some selected major fault zones (Born anticline, St.Gallen fault zone) and the conceptual faults of the triangle zone (view to the NE, 3× exaggeration).

modelled. Grids of both the base Quaternary and the thickness of the unconsolidated sediments are available at 25 × 25 m resolution (Fig. 5).

6.3 CO_2 sequestration

The CO_2 storage potential in Switzerland was estimated in a 2D study by Diamond et al. (2010). In that study, regions with high storage potentials were identified and their theoretical storage capacities were calculated. Based on the models shown in the present study, a detailed 3D structural model for the area showing the highest potential for CO_2 sequestration identified was produced (Fig. 6). Due to lack of data at great depth as well as inconsistencies in the geological input data, a quantified potential distribution in three dimensions could not be modelled without further investigations and data acquisition. Nevertheless, the 3D structural model can be used for future projects and more detailed investigation.

6.4 Data Coverage Maps

The quality of any geological study, be it in 2D or 3D, directly depends on the amount and quality of input data available. Since a 3D geological model always denotes an approximation and simplification of the real geological settings, special requirements regarding the amount, quality and distribution of the input data need to be fulfilled. The Data Coverage Maps (DCM, Fig. 7) serve as an instrument to visualize these basic characteristic values. In this sense, the DCM provide a simple model-reliability index (see above) to assess the uncertainty of 3D geological model in a first step. Besides data harmonization and quality control, the DCM represents a fundamental instrument of the quality assurance for 3D geological model-

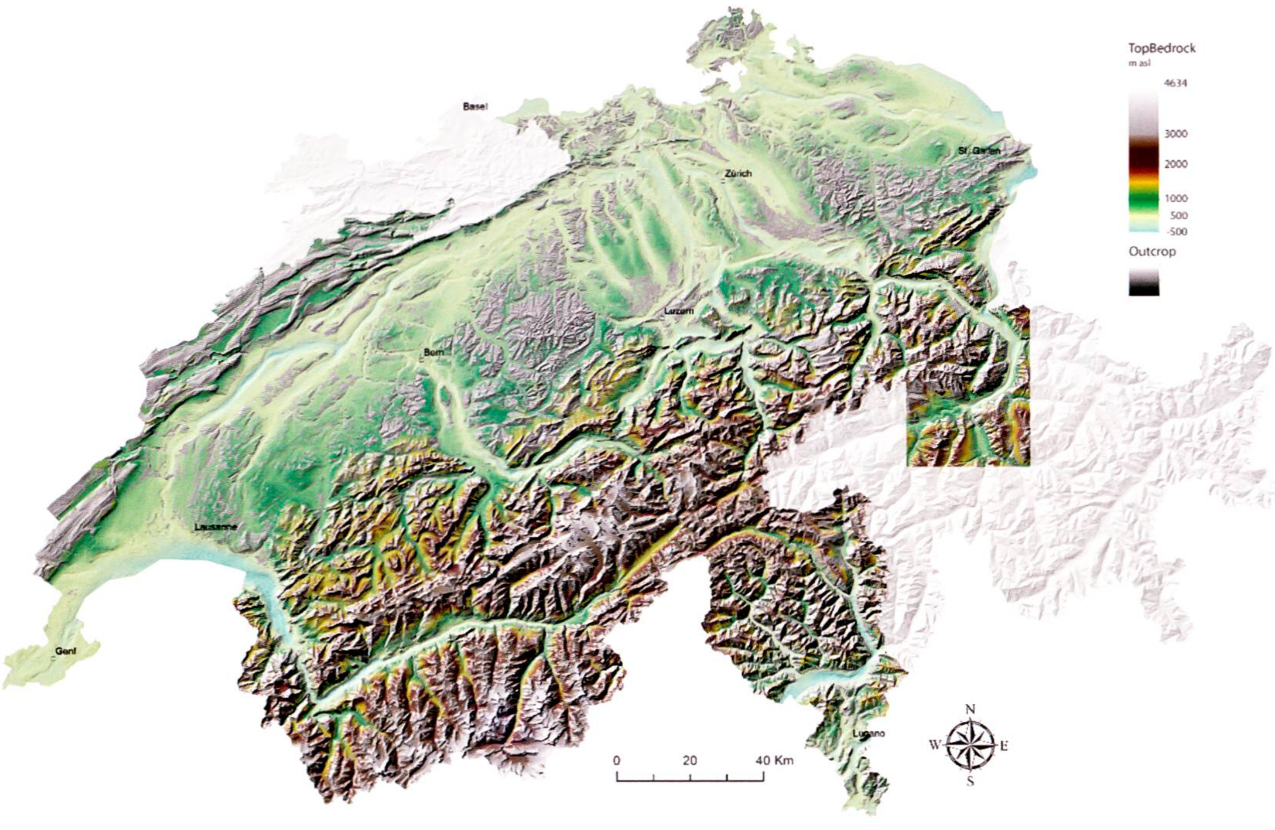

Fig. 5: Elevation map of Top Bedrock (base Quaternary) covering the Swiss Plateau and the large valleys in the alps. Colored areas denote regions where consolidated sediments are covered by Quaternary deposits. Greyish colors indicate a lack of quaternary deposits (= outcropping bedrock).

ling for the FM200 and FM50 models. They 1) illustrate the available input data of any kind per modelled horizon and 2) are also based on a detailed data model, which finally allows to filter and correlate all the data used.

6.5 Summary

These newly developed 3D geological models of the Swiss Plateau describe the deep underground of the Swiss Molasse Basin based on a standardized stratigraphic section. Relying on two different resolutions, they provide harmonized data for the most important horizons and the major fault zones. The FM200 is available for public access in a BETA version of SGS's 3D viewer (see below), the FM50 is currently still under development and will be finished by the end of 2016. There already exist written reports for the FM200 and the detailed structural model for CO_2 sequestration in the Swiss Midlands (see above), which were both developed within the European GeoMol project (http://www.geomol.eu). Please visit http://www.geomol.eu/report/ for the FM200 report and other national reports related to the GeoMol project.

7 Access and benefit

7.1 Visualization

The visualization of complex geological topics for professionals and non-professionals alike is challenging. On the other hand, simplified models enable non-professionals to recognize geological correlations to support e. g. decision making processes. This will become increasingly important in the future, when upcoming challenges (see above) related to the subsurface need to be trans-

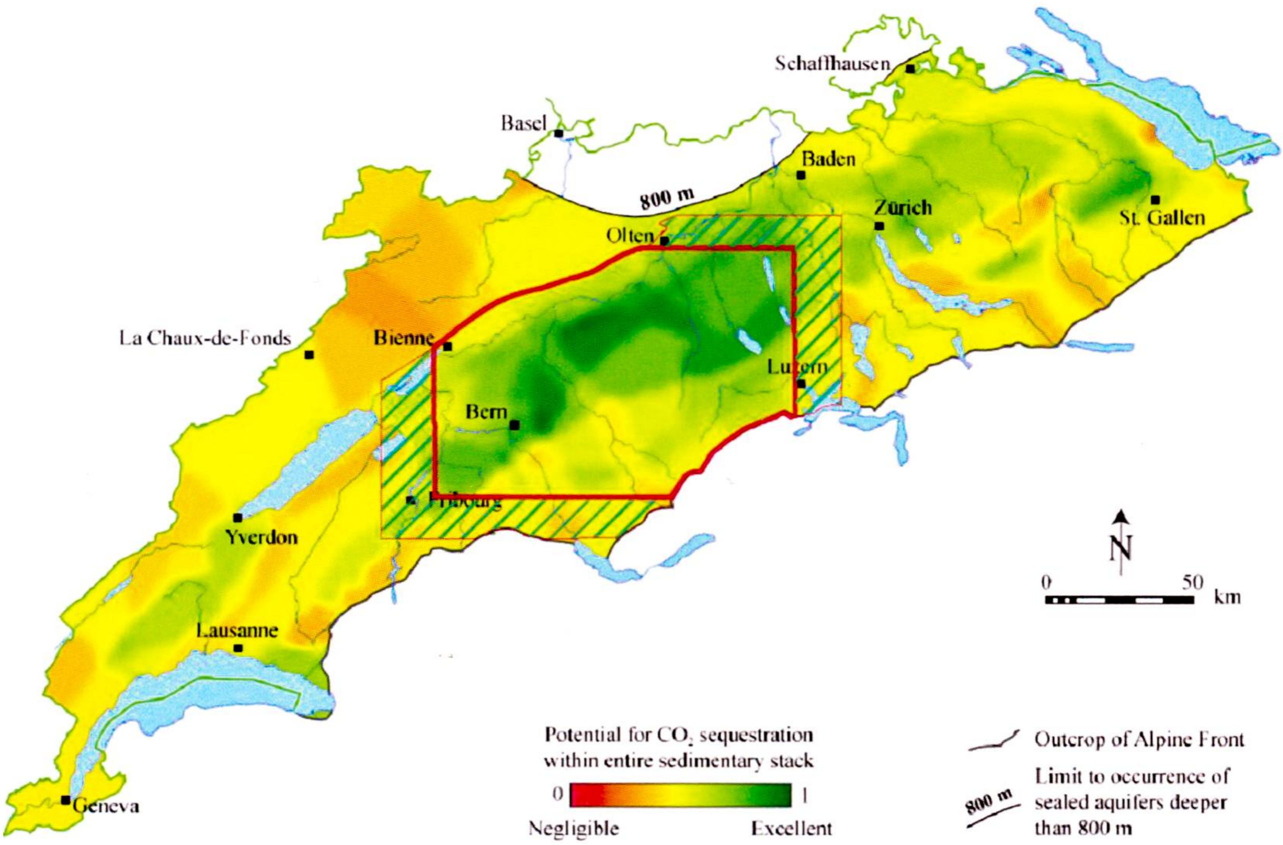

Fig. 6: Potential for CO_2 sequestration in Switzerland within the entire sedimentary stack. Red polygon denotes the boundary of the structural model. Model resolution is 100 ×100 m, which equals approximately the scale of 1:50'000 (modified from Diamond et al. 2010).

ferred from geoscientists to laymen (Baumberger et al. 2015). Therefore, the SGS offers various approaches for the distribution of 3D models and the corresponding data transfer. For non-experts, geological data is available on the federal geodata portal (http://map.geo.admin.ch). The FM200 3D geological model will be available in 3D PDF format, soon. For the experts, the SGS provides full access to the FM200 via a web based 3D viewer (https://viewer.geomol.ch, BETA version). The users may query the models in 3D view (rotating, slicing, Web Map Service [WMS] overlay, attributes histogram). Virtual boreholes and cross sections (vertical, horizontal, dogleg) can be constructed live with the possibility of saving the produced images to the user's device (Baumberger et al. 2015).

7.2 Benefit

Although the visualization of the third dimension offers fascinating perspectives to earth sciences, the limitations of 3D models (e. g. approximation to real settings, simplification) have to be kept in mind. In contrast to the 3D models of the unconsolidated sediments (Volken, this volume), the number of possible utilizations of the 3D models of the deep underground is considerably lower. However, the role of these models will be key to face future challenges as was already mentioned above. They provide a three-dimensional impression of the deep-seated structural framework, which is an important pre-requisite for any work related to the production of geothermal energy or CO_2 storage. Currently, with the tools available to the public, prognosis studies of the underground at a certain location can be easily

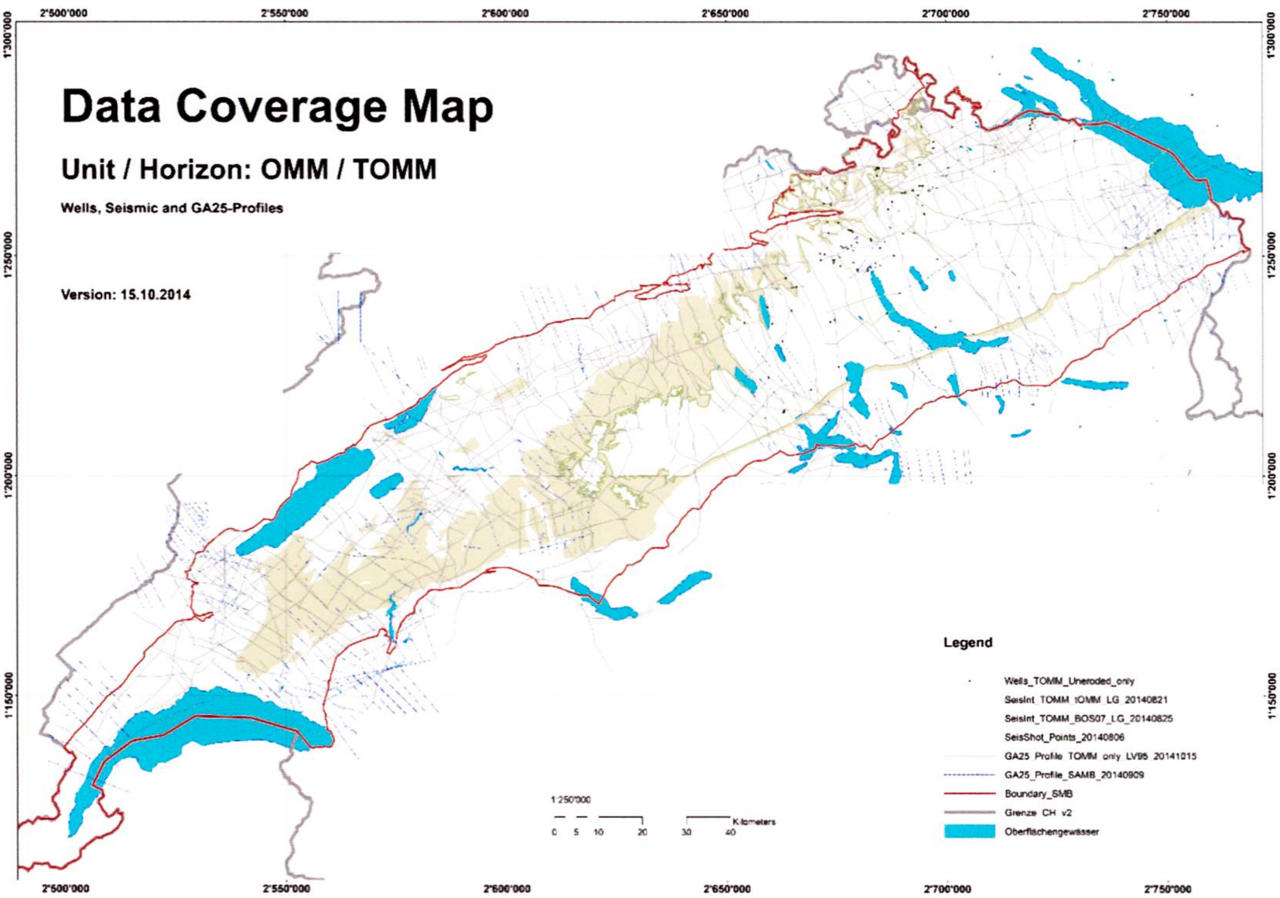

Fig. 7: Data Coverage Map (DCM) of the Horizon Upper Marine Molasse / Top Upper Marine Molasse. Every well, seismic line and cross section, which documents the occurrence of a modelled horizon (Upper Marine Molasse in example shown) is highlighted in these representations.

made. Although such data must not be used for any detailed study or construction work, it supports the geologists and engineers involved in such projects and may help to save considerable amounts of time and money. The future combination of the models with rock properties or other datasets as e.g. infrastructural data or 3D spatial planning zones allows an increase in value of the available models and will also be in line with an overall economic benefit. Incorporating rock properties finally leads to property based and value constraint 3D visualizations (distribution of a distinct parameter on a regional extent) or even depth serialized maps of geopotentials (e. g. temperature distribution at a certain depth or at a certain horizon), which can easily be produced. Combining 3D models with infrastructural or spatial planning data allows for preliminary investigations ahead of larger civil engineering projects or political or economic decisions.

8 Outlook – The national geological 3D model

In a following development step, the model existing at the SGS will be consolidated into a 3D knowledgebase which also contains retrievable attributes to be used in practical applications as well as research.
Mathers et al. (2014) and van der Meulen et al. (2013) outline the concept for such national geological models for the United Kingdom and the Netherlands, respectively. Fig. 8 illustrates the approach followed by the British Geological Survey (Mathers et al. 2014) using cross sections as replacements for 3D geological models. One large-scale model serves as a foundation for the nationwide three-dimensional representation of the subsurface. Regional-scale models can be seamlessly integrated into this framework model at clearly defined boundaries and are additionally enhanced themselves by even more detailed models on a smaller-scale. It is also possible to integrate high resolution regional scale and local models into

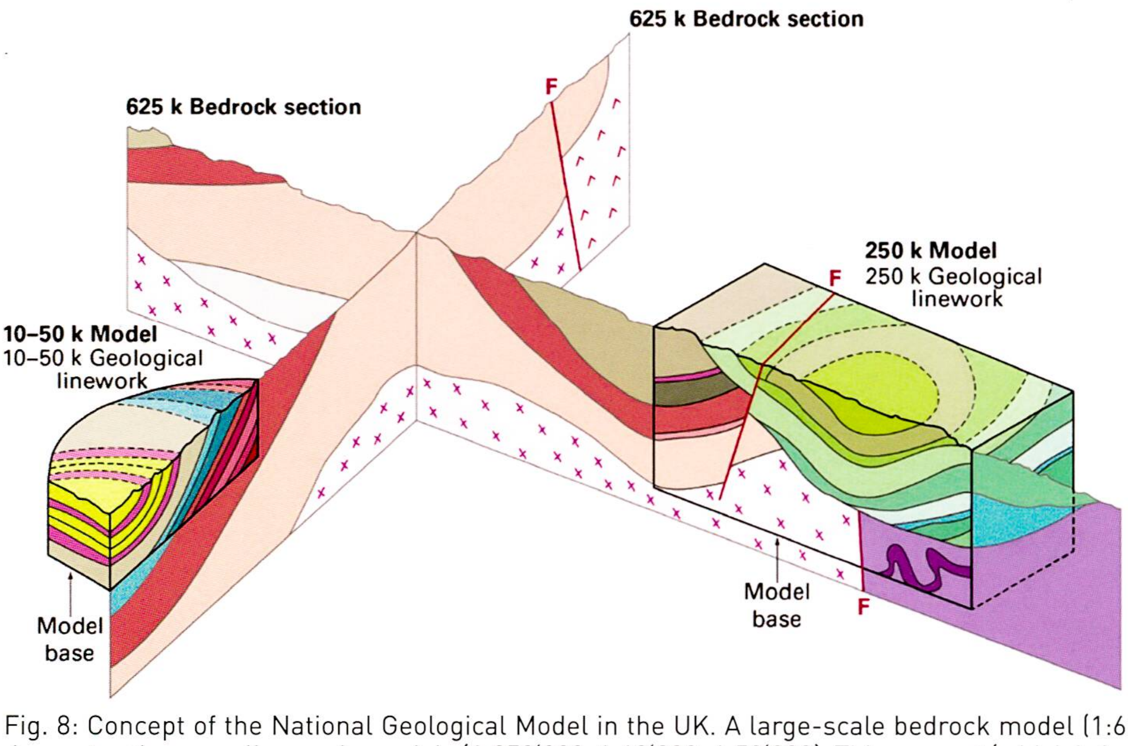

Fig. 8: Concept of the National Geological Model in the UK. A large-scale bedrock model (1:625'000) fundaments other, smaller-scale models (1:250'000, 1:10'000–1:50'000). This concept (which is in operation in the UK) shows varied and heterogeneously distributed detail at different levels of resolution. All the models need to mandatorily fit at predefined horizons (Mathers et al. 2014).

models showing a lower resolution, which 1) leads to different levels of details and 2) illustrates the regional data density in lateral or vertical extents.
Currently, no similar integration exists in Switzerland, but the approach presented by Mathers et al. (2014) serves as a key guideline for our country. However, the existing or currently developed models at the SGS (consolidated, unconsolidated sediments [Volken, this volume] and numerical models) are separated by a boundary horizon defined by the base of the Quaternary (see above), which exists as a separate dataset. Each model provides knowledge about the specific purpose it was constructed for. The models rely on different basic data, are produced partly using different software tools and are stored in different environments. As mentioned above, the integration (and subsequent publication) of all models produced by the SGS in such a national data store is a mandatory task of the SGS (Baumberger et al. 2015). To achieve this goal, the SGS will

- strengthen its current national framework models to serve as a starting point for the deviation of new products (e.g. block models, depth serialized maps);
- enlarge the modelling areas to cover the entire country;
- develop the technical basics to store and publish very large datasets;
- build up 3D geological models from the nationwide geological surface mapping at a 1:25'000 scale;
- develop online applications (e.g. 3D resource knowledge bases, geothermal energy, consolidated and unconsolidated sediments, numerical models) and services (e.g. Web Map Service [WMS], Web Map Tile Service [WMTS]);
- consolidate different 3D geological models built for a variety of purposes into one National Geological 3D model.

Starting with 3D geological modelling in 2010, the SGS follows adapted schedules to achieve the above-mentioned goals. The National Geological 3D model will be introduced by 2020. Within ten years' time, an initially dismissed and ridiculed technology will have turned into an influencing and strategically important eye-catcher.

Acknowledgements

The SGS thanks the Federal Office of Energy (OFEN), the Federal Office of the Environment (FOEN), the Federal Office for Spatial Planning (ARE), the Federal Office of Topography (swisstopo) and the cantons of Aargau, Fribourg, Geneva, Lucerne, Solothurn, Vaud and Zürich for project funding. The Nagra, SEAG (AG für Schweizerisches Erdöl), Swissgas and St. Galler Stadtwerke are thanked for providing access to their data. Besides the cantons mentioned above, the cantons of Appenzell Innerrhoden, Appenzell Ausserrhoden, Bern, Glarus, Neuenburg, Thurgau, Schaffhausen, Schwyz, St. Gallen, Wallis and Zug granted access to their data archives. ExxonMobil also kindly granted access to their data. Special thanks go to our modelling partners located at the Universities of Basel, Bern, Fribourg and Geneva as well as at the Geological Museum of the canton of Vaud.

References

Baumberger R., Allenbach R. & Volken, S. 2015: From wallflower to eye-catcher: 3d geological modelling in Switzerland – more than XYZ, less than a Swiss Army knife. 3D mapping workshop at the Annual Meeting of the Geological Society of America, Baltimore, 2015.

Baumberger, R. & Michael, C. S. 2013: Datenmodell 3D-Geologie, Erweiterung zum Datenmodell Geologie, Version 2.0, Hrsg.: Bundesamt für Landestopografie (swisstopo), Wabern.

Diamond, L. W., Leu, W., Chevalier, G., Burlini, L., Deichmann, N., Naef, H., Pini, R. & Wyss, R. 2010: Studie zur Abschätzung des Potenzials für CO2-Sequestrierung in der Schweiz (Potential for geological sequestration of CO_2 in Switzerland), Report for the Swiss Federal Office of Energy, pp. 23.

Dürst Stucki, M. & Schlunegger, F. 2013: Identification of erosional mechanism during past glaciations based on a bedrock surface model of the central European Alps. EPSL.

Fiore, J. 2007: Quaternary Subglacial Processes in Switzerland: Geomorphology of the Plateau and Seismic Stratigraphy of Western Lake Geneva. In: Terre et Env. 69. Université de Genève, Switzerland, pp. 169.

Graf, H. R. 2007: Isohypsenkarte der plio-pleistozänen Rinnen und Becken im Gebiet von Atlasblatt Baden, Tafel 2. In: Bitterli-Dreher, P., Graf, H. R., Naef, H., Diebold, P., Matousek, F., Burger, H. & Pauli-Gabi, T. 2007: Blatt 1070 Baden. Geol. Atlas Schweiz 1:25'000, Erläuterungen 120.

Graf, H. R., 2009: Stratigraphie von mittel- und Spätpleistozän in der Nordschweiz. Beiträge zu Geologischen Karte der Schweiz, 168.

Graf, H. R. & Willenberg, H. 2011a: Isohypsenkarte der pleistozänen Rinnen und Becken im Gebiet von Atlasblatt Aarau, Tafel 3. In: Jordan, P., Graf, H. R., Eberhard, M., Jost, J., Kälin, D., Bitterli-Dreher, P. H., 2011: Blatt 1089 Aarau. Geol. Atlas Schweiz 1:25'000, Erläuterungen 135.

Graf, H. R. & Willenberg, H. 2011b: Isohypsenkarte der pleistozänen Rinnen und Becken im Gebiet von Atlasblatt Murgenthal, Tafel 2. In: Bitterli, T., Jordi, H. A., Gerber, M. E., Gnägi, C. & Graf, H. R. 2011: Blatt 1108 Murgenthal. Geol. Atlas Schweiz 1:25'000, Erläuterungen 113.

Graf, H. R. & Willenberg, H. 2012: Isohypsenkarte des Felsuntergrunds im Gebiet von Atlasblatt Schöftland, Tafel 3. In: Graf, H. R., Jost, J., Eberhard, M., Kruysse, H. & Kempf, O. 2012: Blatt 1109 Schöftland. Geol. Atlas Schweiz 1:25'000, Erläuterungen 150.

Graf, H. R. & Willenberg, H. 2014: Isohypsenkarte der pleistozänen Rinnen und Becken im Gebiet von Atlasblatt Balsthal und Nordteil von Atlasblatt Solothurn, Tafel 3. In: Bläsi, H. R., Gygi, R., Gnägi, C., Graf H. R., Jordan, P., Laubscher, H. P., Herold, T., Schlanke, S., Burkhalter, R. & Kälin, D. 2014: Blatt 1107 Balsthal. Geol. Atlas Schweiz 1:25'000, Erläuterungen 139.

Jordan, P. 2004: Felsisohypsenkarte am Jurasüdfuss zwischen Oberbuchsiten SO und Lenzburg AG. Nagra NIB.

Jordan, P. 2007: Digitales Höhenmodell der Basis des Quartärs (DHM B_QU, «Felsmodell»). NAGRA Arbeitsbericht NAB 07-12.

Jordan, P. 2010: Analysis of overdeepened valleys using the digital elevation model of the bedrock surface of northern Switzerland. Swiss J. Geosci. 103, 375–384.

Mathers, S. J., Terrington, R. L., Waters, C. N. & Leslie, A. G. 2014: GB3D – a framework for the bedrock geology of Great Britain. Geosci. Data J. 1: 30–42 (2014), doi: 10.1002/gdj3.9.

Pietsch, J. & Jordan, P. 2014: Digitales Höhenmodell Basis Quartär der Nordschweiz – Version 2013 (SGT E2) und ausgewählte Auswertungen. NAGRA Arbeitsbericht NAB 14-02.

Schälli, L. 2012. The diffluence of the Rhine glacier at Sargans in connection to the solid-rock surface model of the Rhine and Seez valley. Unpublished Master Thesis, University of Zürich, Switzerland.

Sommaruga, A., Eichenberger U. & Marillier, F. 2012: Seismic Atlas of the Swiss Molasse Basin, in: Beiträge zur Geologie der Schweiz – Geophysik Band 44, Bundesamt für Landestopografie swisstopo (Hrsg.), Wabern, 2012.

Strasky, St., Baland, P., Michael, C. S. & Oesterling, N. 2012: Datenmodell Geologie, Beschreibung im UML-Format und Objektkatalog, Version 2.1, Hrsg.: Bundesamt für Landestopografie (swisstopo), Wabern.

Van der Meulen, M. J., Doornenbal, J. C., Gunnink, J. L., Stafleu, J., Schokker, J., Vernes, R. W., van Geer, F. C., van Gessel, S. F., van Heteren, S., van Leeuwen, R. J. W., Bakker, M. A. J., Bogaard, P .J .F., Busschers, F. S., Griffioen, J., Gruijters, S. H. L. L., Kiden, P., Schroot, B. M., Simmelink, H. J., van Berkel, W. O., van der Kroogt, R. A. A., Westerhoff, W. E. & van Daalen, T. M. 2013: 3D geology in a 2D country: perspectives for geological surveying in the Netherlands, Netherlands Journal of Geosciences 92-4, 217–241.

Wagner, U., Huggenberger, P., Schaub, D. & Thater, M. 2001: Erkundung der Grundwasserleiter und Böden im Hochrheintal – Abschlussbericht zum INTERREG II-Projekt. Landratsamt Waldshut.