CHART Scientific Report

Geology 3D Model 2

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DATA BASE AND GEOLOGICAL STUDIES IN SUPPORT OF THE FCC FEASIBILITY STUDY

Project KE5790

FINAL REPORT

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1. Introduction

This activity report presents the key results of the collaborative work carried out by the Geo-Energy Group (GE-RGBA) of the University of Geneva in support of the CERN's FCC feasibility study from 2023 to 2025 (project KE5790). The primary objective of this partnership was to support the *Future Circular Collider (FCC)* project through advanced geological, geophysical, and geospatial investigations of the Geneva Basin and its cross-border subsurface domains.

The research activities documented in this report combine subsurface modelling, data harmonization, and borehole analysis to enhance understanding of the geological framework relevant to the FCC tunnel design. The work builds upon previous regional initiatives (e.g., GeoMol, Geothermie 2020, HARMOS) and extends them through the creation of a unified, cross-border subsurface database, U-SOLSTISS, integrating Swiss and French datasets.

Between 2023 and 2025, the GE-RGBA team focused on five key areas of research and technical development:

- **3D Geological Modelling:**
    - Integration of 2D and 3D seismic reflection data, borehole information, and geological maps to construct a high-resolution 3D geological model of the FCC corridor.
- **U-SOLSTISS Database Development:**
    - Harmonisation of geological datasets between Switzerland (SOLSTISS) and France (BRGM InfoTerre) to establish a unified, cross-border subsurface database.
- **Database Management and Data Transfer:**
    - Implementation of a data management plan and data specification requirements to ensure traceability, quality control, and secure transfer of datasets between UniGe and CERN.
- **Borehole Data Analysis:**
    - Detailed sampling and petrographic analysis of core materials (e.g., MAND_02), focusing on the Molasse–Cretaceous transition to refine stratigraphic interpretation.
- **Collaboration and Knowledge Transfer:**
    - Continuous engagement with CERN's geology and engineering teams to ensure consistency across geological models, data structures, and analytical workflows.

2. 3D Modelling

2.1 Methodological Framework

The initial step in developing a realistic and fit-for-purpose 3D geological model involved the establishment of a robust workflow, aligned with globally recognized best practices for subsurface characterization and modelling (Figure 2.1). At UNIGE, SLB's Petrel® software (version 2022–2024) was employed to build a subsurface database and to interpret a comprehensive suite of datasets. These included:

- 2D and 3D seismic reflection surveys,
- Borehole data,
- Geological maps, and
- The FCC trace provided by CERN.

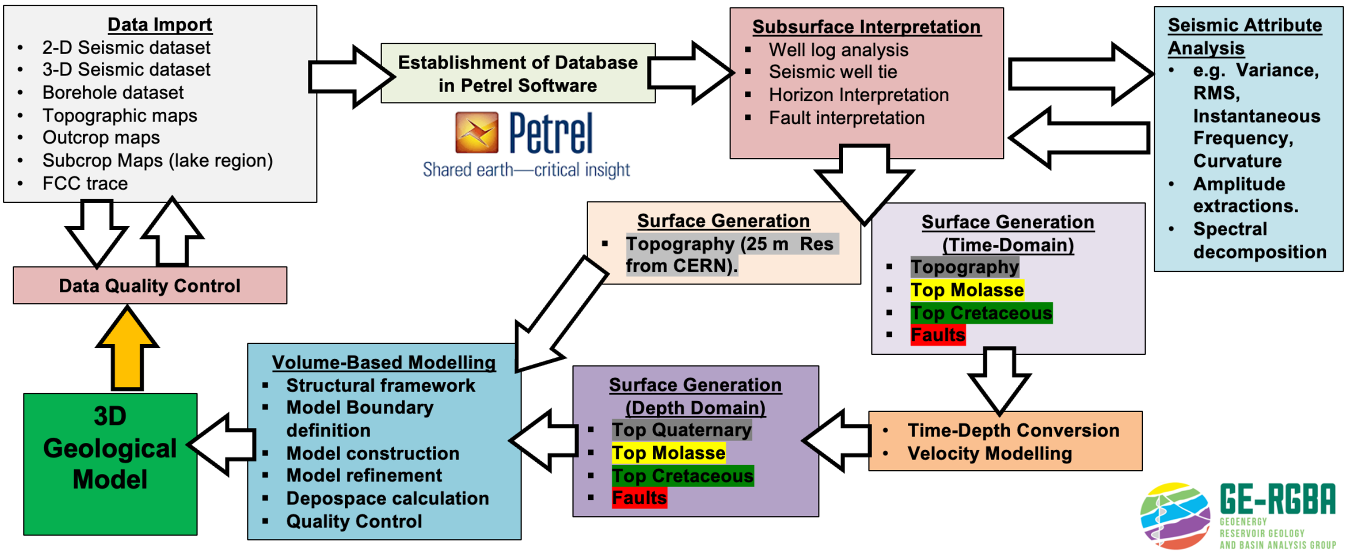


Figure 2.1. Revised methodological workflow adopted to create the updated geological model for the CERN FCC project.

The database has been progressively updated with additional datasets received from CERN, such as survey shapefiles from the proposed 2D seismic campaign, as well as planned boreholes and shaft locations with their respective trajectories.

2.2 Seismic Integration and Horizon Interpretation

The 2D seismic reflection dataset was integrated with the recently acquired 3D seismic survey and calibrated against borehole data from the Geneva Basin. This integration enabled the interpretation of key horizons relevant to the FCC geological model:

- Topography,
- Top Molasse (Base Quaternary), and
- Top Cretaceous.

The 3D seismic dataset, although limited in spatial coverage around the FCC trace, provides superior resolution (Figure 2.2). This significantly improved the quality of the model in the covered areas. Similarly, the structural framework of the area of interest was established from mapping the faults from the seismic dataset and eventually them with the key horizons using the volume base modelling and depogrid The final deliverables included grid-resolution products at 100 m × 100 m scale.

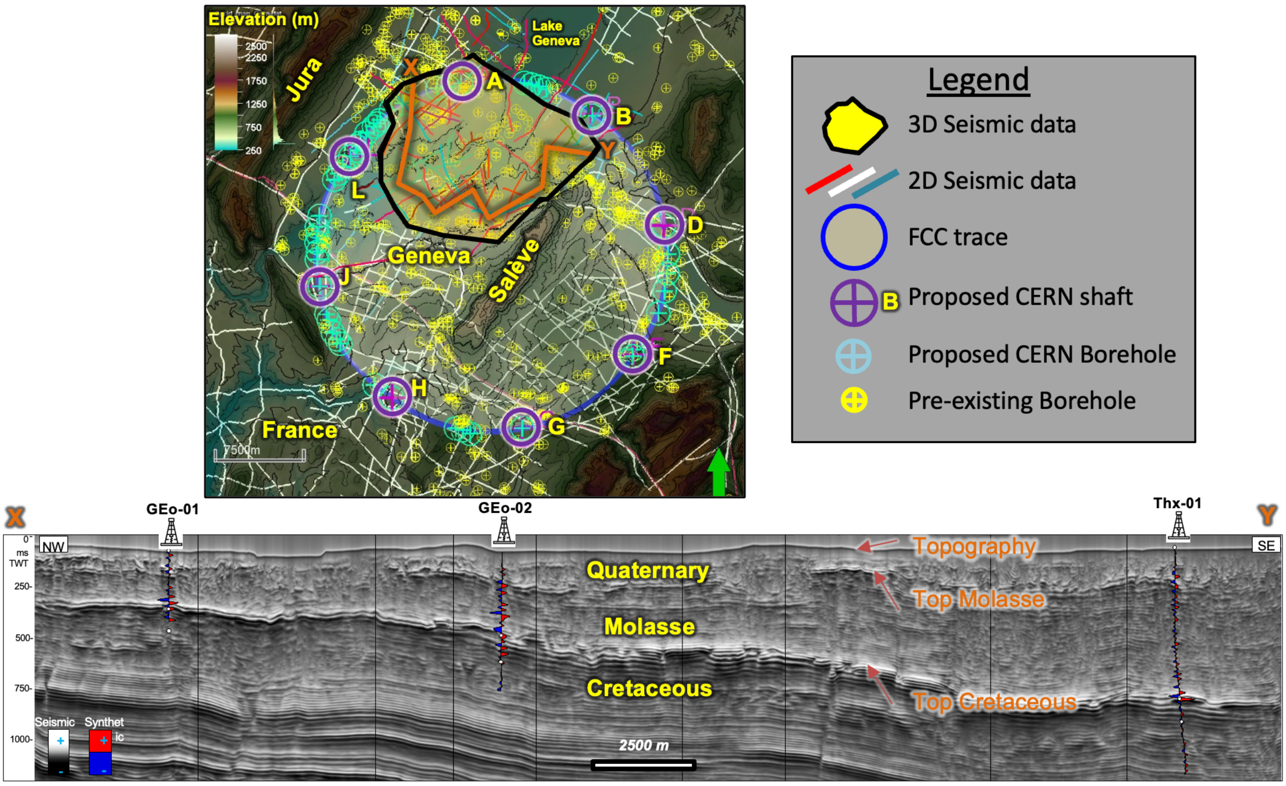


Figure 2.2. (Above) Updated database including the 3D seismic reflection dataset, FCC trace, and proposed shaft/borehole locations. (Below) Composite seismic line extracted from the 3D survey, calibrated to key boreholes, highlighting the three principal units of interest and interpreted horizons.

2.3 Model Deliverables

Several iterations of the Top Molasse and Top Quaternary models were delivered to CERN, with the most recent version illustrated in Figure 2.3. Notably, areas where the 3D seismic dataset was integrated exhibit higher resolution and improved geological accuracy. Additionally, a subsurface geological profile was developed along the FCC trace, illustrating key horizons and the associated fault system in relation to the proposed shafts (Figure 2.4). Continuous collaboration with CERN's modelling team has been maintained. Comparative analyses were carried out between UNIGE's Petrel-based model outputs and CERN's in-house tool GEOPROFILER, ensuring consistency in geological model definitions and shaft-to-shaft correlations (Figure 5).

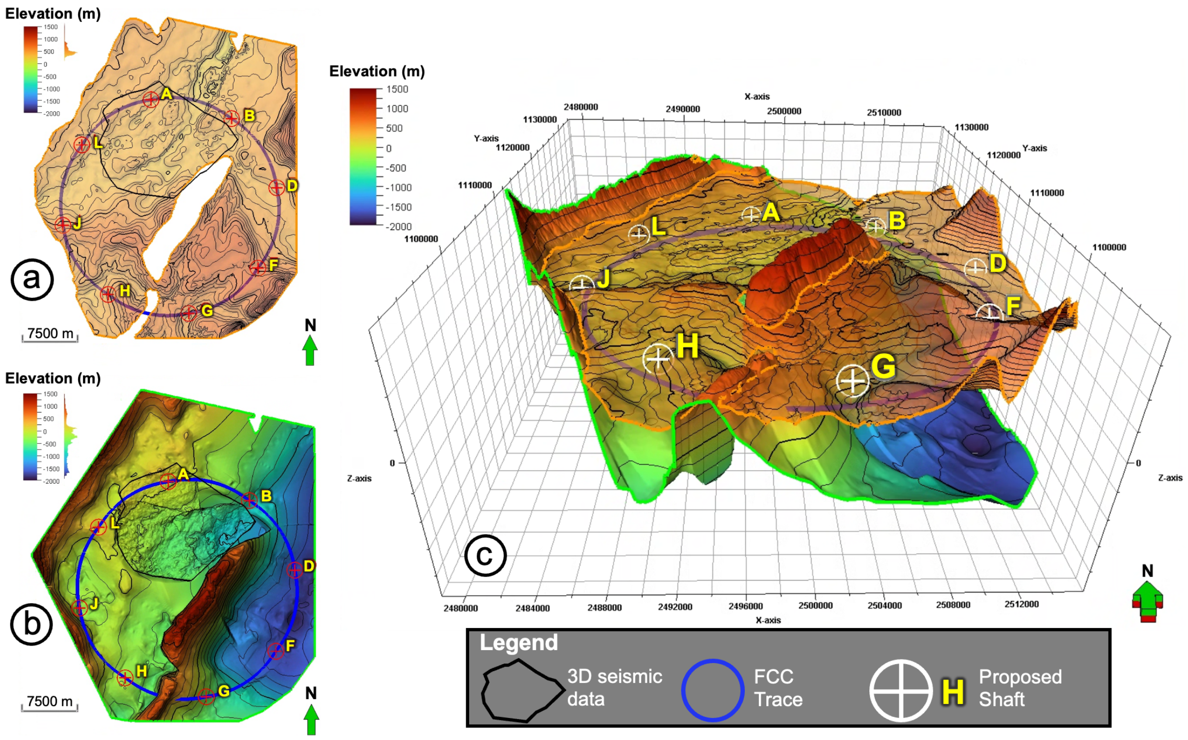


Figure 2.3. Latest FCC geological model: (a) Top Molasse, (b) Top Cretaceous, (c) 3D visualization including the latest FCC trace.

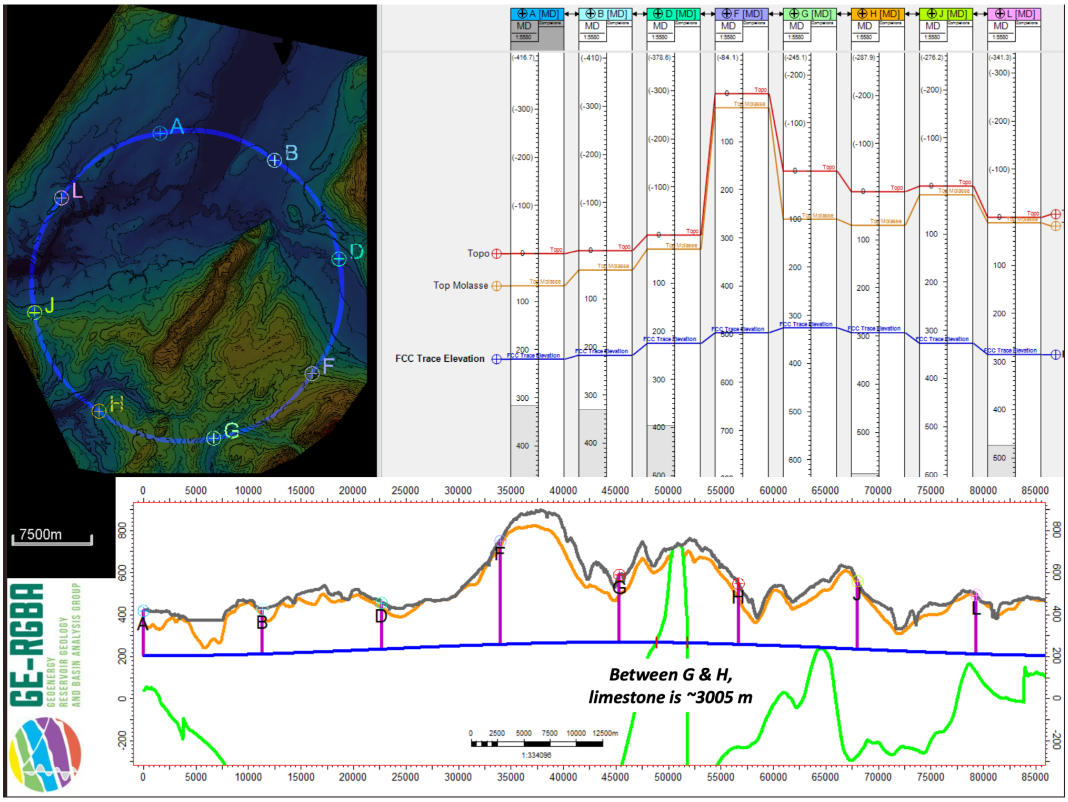


Figure 2.4. (Above) Elevation model for proposed shaft locations along the FCC trace. (Below) Geological profile extracted along the FCC trace, showing interpreted horizons and fault systems.

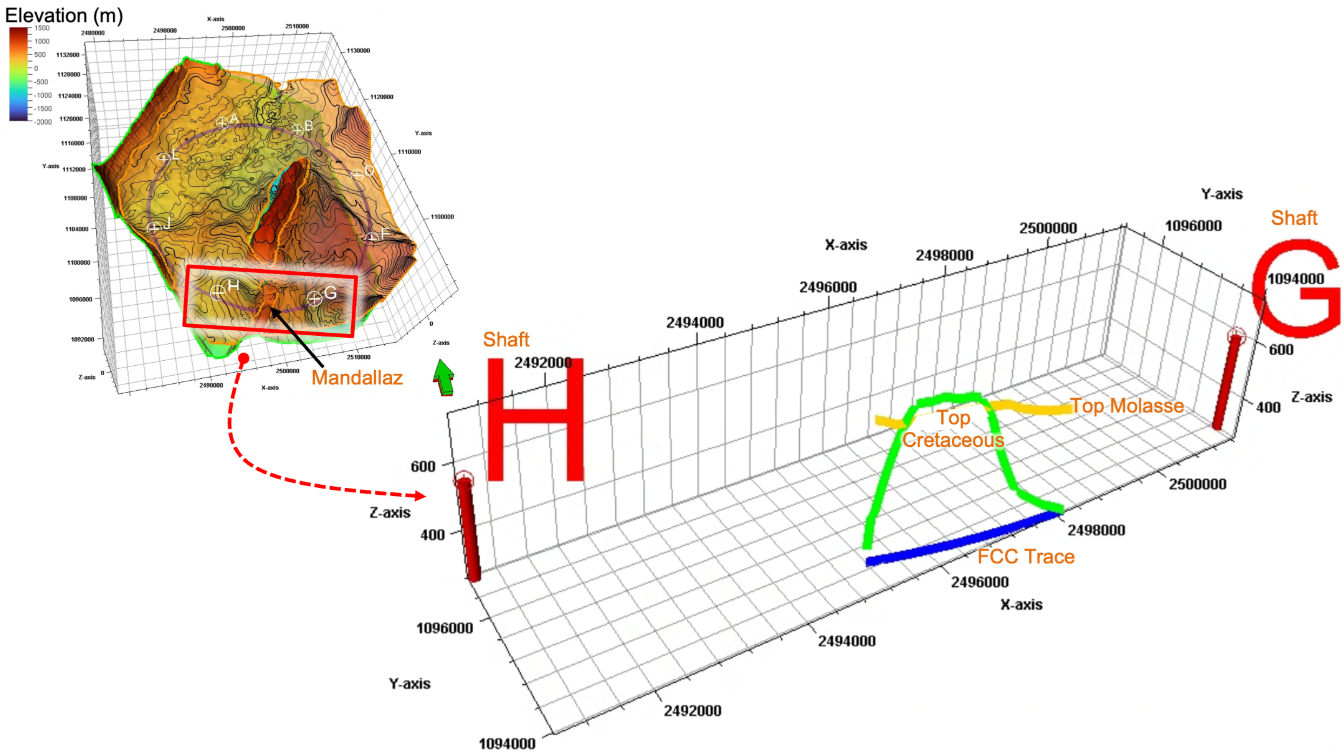


Figure 2.5. Comparative analysis of the FCC geological model in the Mandallaz area between shafts H and G, highlighting differences between Petrel and GEOPROFILER outputs.

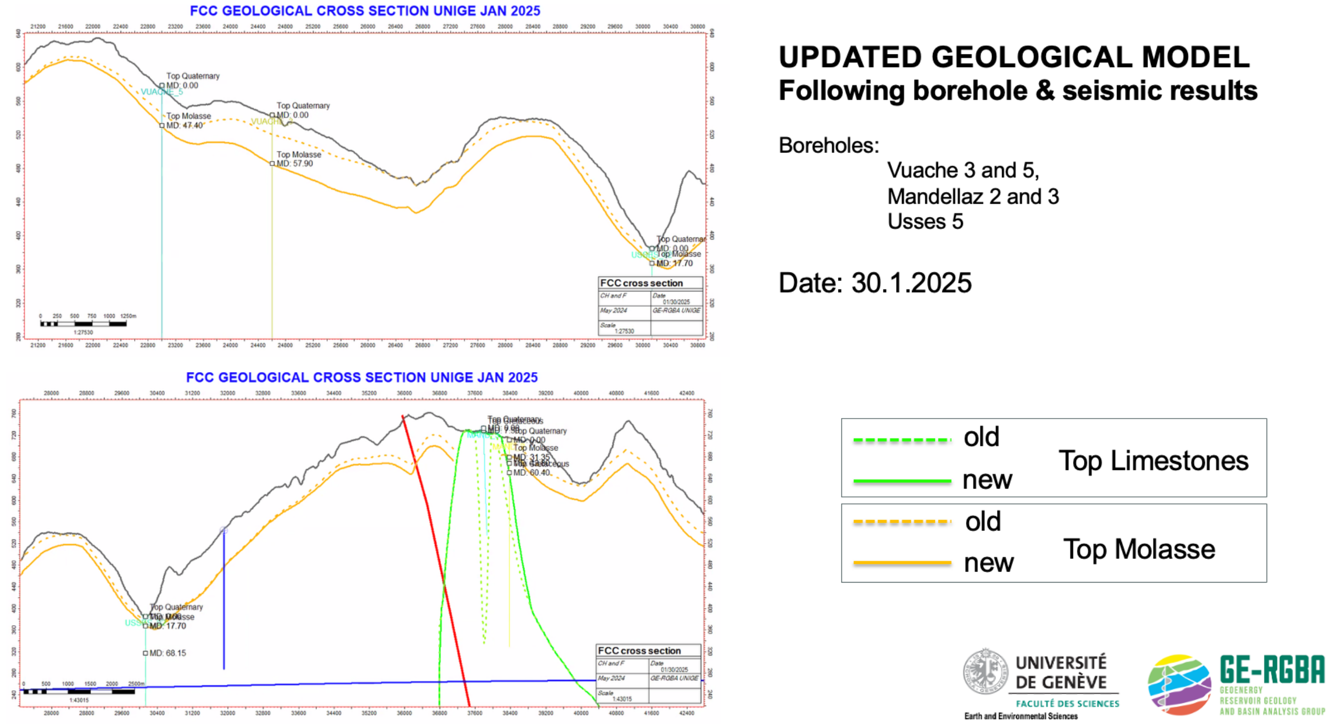


Figure 2.6. Cross section showing the Top Molasse and Top Limestone before and after the drilling campaign. Pre-drilling interpretations were based on limited constraints, whereas post-drilling geometries are refined using well-top data, providing a more accurate positioning of both units.

In the cross section (Fig. 2.6), the traces of the Top Molasse and the Top Limestone are visible both before and after the drilling campaign. Prior to drilling, these surfaces were interpreted on the basis of limited subsurface constraints, resulting in a more speculative geometry. Following the drilling campaign, the interpretation has been refined by incorporating well-top data, allowing a more accurate positioning of both the Top Limestone and the overlying Molasse units.

The most significant modifications to the structural model are observed in the Mandallaz area, where subsurface knowledge had previously been very limited. The new well data have made it possible to substantially revise the geological model and to define a more realistic configuration of the Top Limestone surface. In particular, the geometry and extent of the limestone units are now better constrained, reducing previous uncertainties in this critical area.

Further improvements to the interpretation are expected in the near future through the integration of the available 2D seismic lines. The incorporation of these seismic data will allow a more detailed and continuous imaging of the subsurface, leading to an even more robust delineation of the key stratigraphic horizons, especially the critical top surfaces of the Limestone and Molasse formations.

3. U-SOLSTISS

The development of a harmonized cross-border subsurface geological database is essential for projects like CERN's Future Circular Collider (FCC), which proposes a 90.7 km underground tunnel crossing the Swiss French border four times (Fig. 3.1). Reliable 3D models for feasibility and design require consistent stratigraphic frameworks, yet differences in nomenclature, data formats, and coordinate systems between Switzerland and France pose major challenges (Strasky et al., 2016). This study addresses these issues by integrating borehole data from BRGM's InfoTerre platform with the Geneva-based SOLSTISS database to create a unified system, U_SOLSTISS, focusing on the complex Quaternary succession. Building on earlier initiatives such as GeoMol, Geothermie 2020, and HARMOS, the harmonized database provides a consistent lithostratigraphic framework across the Geneva Basin and neighbouring France. This is particularly critical for understanding shared groundwater systems such as the Genevois aquifer, jointly managed by Swiss and French authorities but still poorly characterized in its cross-border extent (Fig. 3.2). The resulting harmonized dataset supports updated 3D geological models of the Base Quaternary surface, guiding FCC tunnel design while also strengthening groundwater management and future geological analyses.

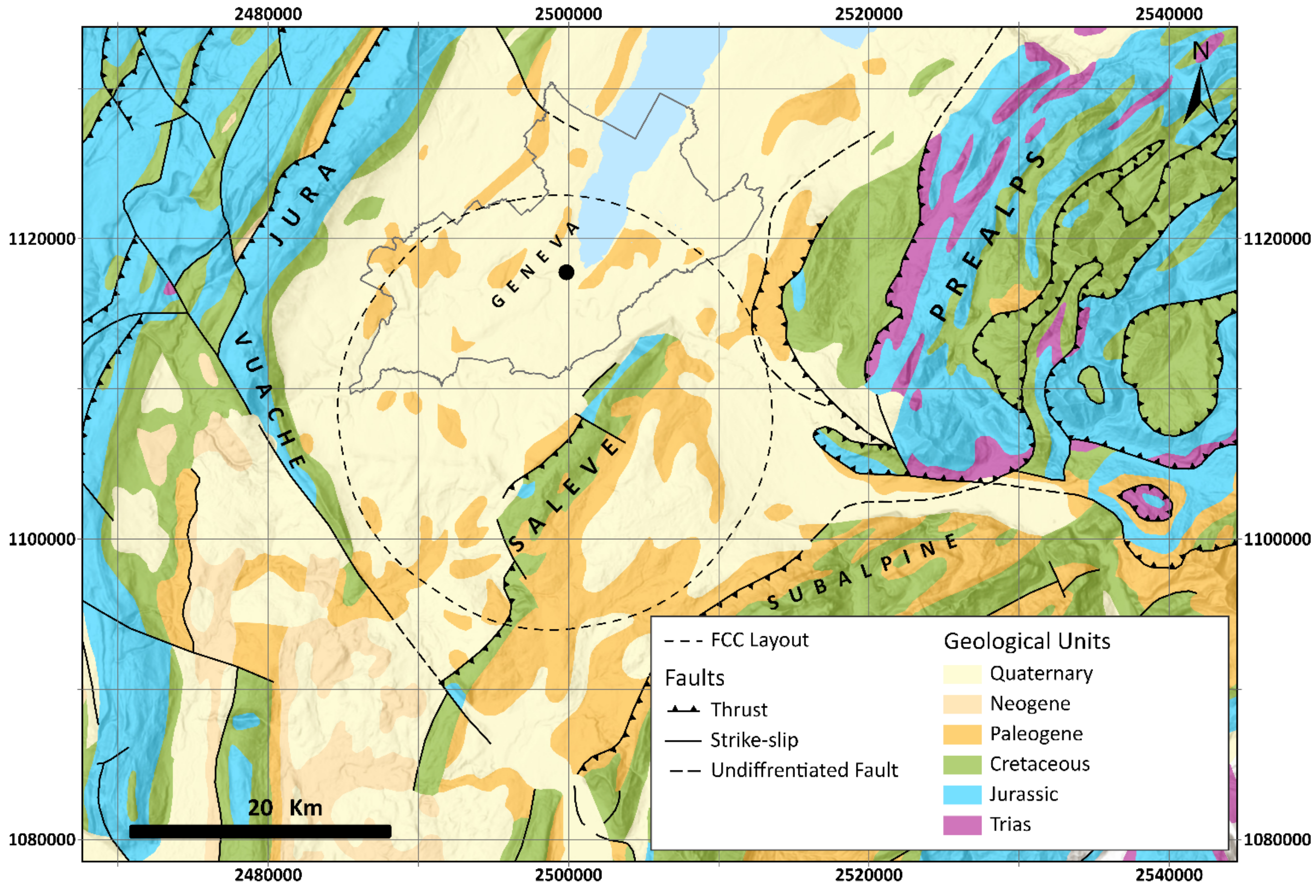


Fig. 3.1. Overview map showing outcropping geological units and simplified structural elements in the study area crossed by the FCC layout, modified from BRGM (La Carte Géologique Métropolitaine à 1/1 000 000, 2003)(Meftah & Moscariello, 2025).

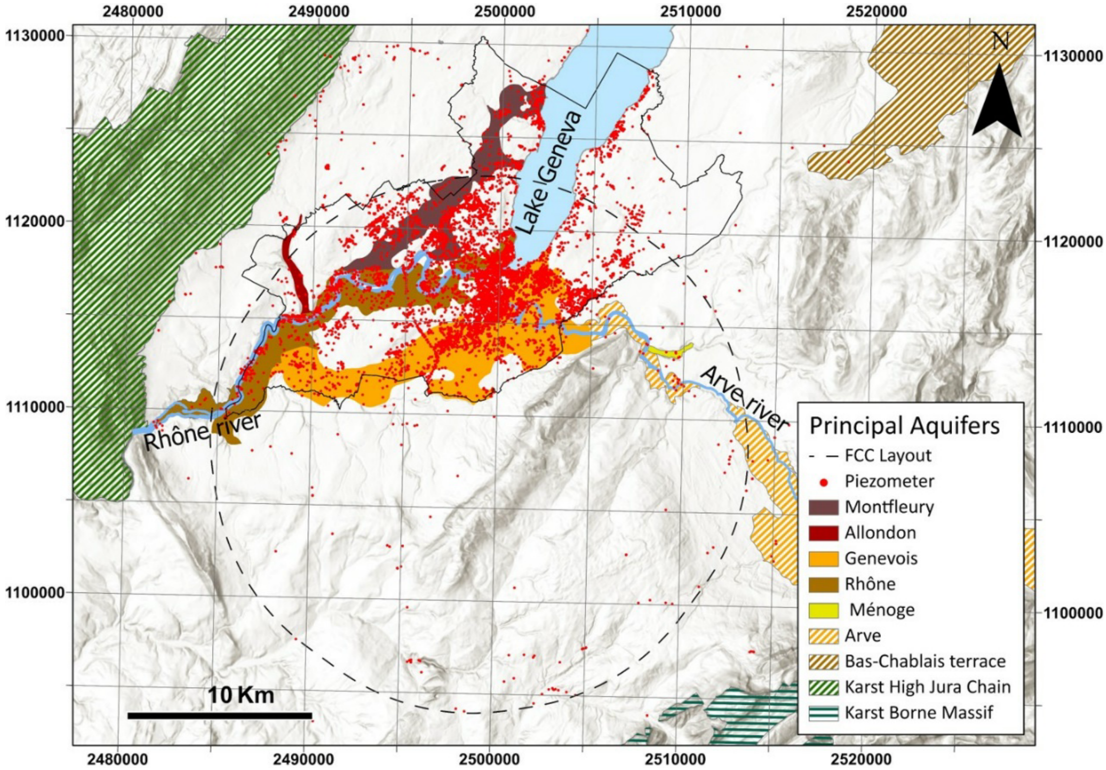


Fig. 3.2. Principal cross-border aquifers of Geneva canton and neighbouring France (SITG, 2023; BDLISA, 2024) (Meftah & Moscariello, 2025).

3.1. Datasets

The data set used for harmonisation in this work is represented by borehole records acquired from neighbouring France and Switzerland in the Canton of Geneva. The sources of these data are: (i) GESDEC (Catalogue |SITG (ge.ch)) and (ii) BRGM (InfoTerre Platform: https://infoterre.brgm.fr/page/i-infoterre).

3.1.1. InfoTerre open data source from BRGM

InfoTerre contains "La Banque du Sous-Sol: BSS of BRGM" (Fig. 3.3), which is a database that stores and manages the geological and technical descriptions of underground structures (drillings, boreholes, underground structures, or excavation work) on the French territory. This database is not relational. Hence, all the shape files are formed by flat attribute tables. To understand the BSS data structure, several classifications (labels) of boreholes, related to the availability of documents and the verification by the BRGM geological team (Table 3.1), have been introduced. The documents include logs, drilling reports, or just descriptions of different lithologies, geophysical logs, soil analyses, photographs, or any other type of technical documentation, etc.

Table 3.1. BRGM database layer classification and corresponding number of boreholes present in the study area, see Fig. 3 for spatial distribution of boreholes by layer classification

Class	Layer classification	Number of boreholes
1	With verified geology and documents	484
2	With verified geology and no documents	105
3	Without geology documents available	621
4	Initial geology with documents	1175
5	Initial geology without documents	902
6	Without geology or documents	1791
	Total Boreholes in the study area	5078

A borehole is labelled as "verified" when the associated report (information, stratigraphy, location...) has been examined, confirmed, and found to be reliable and consistent by experts, geologists, or BRGM engineers. Some boreholes can be verified without formal written documentation once the experts have confirmed the information directly in the field or using other reliable methods (BRGM, 2013), which, however, are not specified in the InfoTerre documentation. A borehole is labelled as "unverified" when the verification described above is missing. This data originates from initial, unverified sources. The label "No documents" means that no information (e.g., written report, drawing, etc.) is available for this borehole. The "initial geology" label refers to a classification of data that presents initial observations and information on the geological setting of a site before any detailed analysis or verification is carried out. In this work, we focus on a selection of a borehole (in blue in Fig. 3.6) from the BRGM datasets (Fig. 3.3), which have been classified between 1 to 4 (See Table 1 and Fig. 3.3). In addition to the classification criteria, the selected boreholes are among the deepest and specifically include the top of the Molasse formation, which was essential for defining the Quaternary base. Unfortunately, among the collected boreholes, the number of boreholes per classification was not recorded, as this information is not explicitly provided with each borehole in the InfoTerre database. The boreholes classified as 5 and 6 were excluded from the analysis due to insufficient geological information (See Table 3.1).

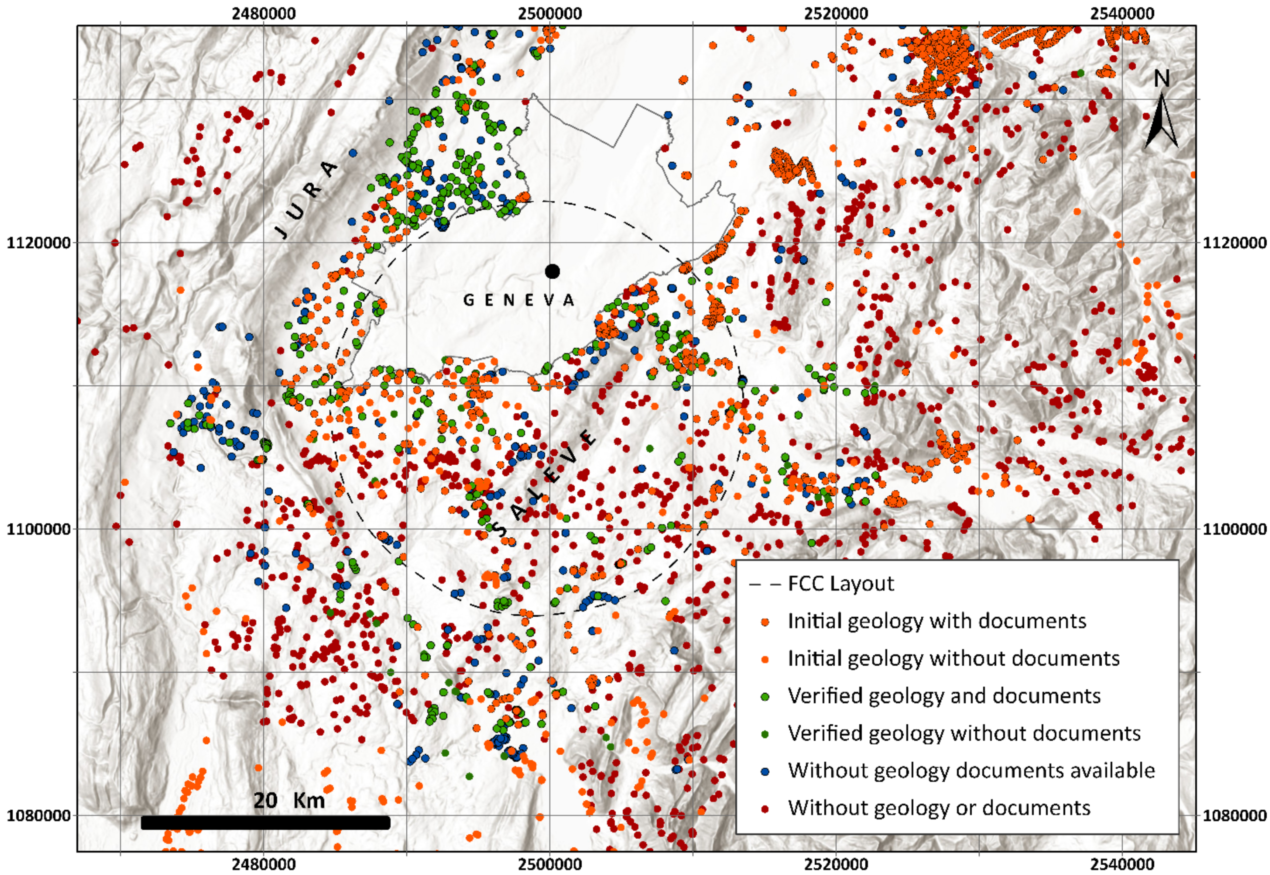


Fig. 3.3. BSS database layer classification from InfoTerre platform (Visualiseur InfoTerre, 2024) (Meftah & Moscariello, 2025).

3.1.2. SOLSTISS Database architecture

The SOLSTISS (Système d'Information Territorial du Sous-Sol) serves as the present subsurface information system for the Canton of Geneva. Its database is made accessible through the website SITG platform (ge.ch, 2022) that allows for the centralisation of all data related to geological projects, whether they involve geothermal energy, soil and subsurface studies, or construction in general. The data processed by GESDEC is stored in relational geodatabases and file tree systems.

In the SOLSTISS database, data are classified and described using object catalogue tables. For each table, various data attributes (such as name, ID, type, and description) are detailed (Favre, 2018; Brentini, 2018; ge.ch, 2022; SITG, 2023). The SOLSTISS database is accompanied by a structured metadata catalogue (in Excel sheet format), which is distinct from the database itself. This catalogue documents the content and structure of the database, detailing table schemas, field names, data types, and descriptions, thereby ensuring clarity, consistency, and traceability in data management.

For each geological project (geothermal energy, hydrogeology, geo-engineering), data are collected, centralised, and stored in SOLSTISS. The development of a data model allows the definition of the structure of the relational database through a modelling process (Fig. 3.4) (Favre, 2018). It also gathers all the data on geological objects, i.e., status of borehole (producing, abandoned, equipped, etc). Another dataset, such as seismic and electric survey lines, outcrops, and geothermal installations of both open and closed system types, is not yet implemented and is planned for inclusion in upcoming development work (Favre, 2018; ge.ch, 2022). The conceptual model of SOLSTISS demonstrates how the data is stored and archived in a centralised and indexed system to ensure quick access to information for government officials, planners, and the public alike (Favre, 2018).

The GESDEC manages the geological, hydrogeological, geophysical, geothermal, polluted sites, gravel pits, soil, and waste (ge.ch, 2022). Therefore, data originated from diverse types of sources, mostly from prospection (i.e., boreholes, geophysics surveys) associated with geotechnical, hydrogeological, exploitation (sand and gravel pit), and recently geothermal projects. The data are entered through a web-based interface developed by GESDEC, following a quality control process. The geological information of the borehole database is used to produce maps and subsurface geological models. The SOLSTISS database allows dynamic infill with access to the latest subsurface data from projects across the Geneva canton. The SOLSTISS also includes data inherited from an older cantonal borehole database, which contained fewer attributes. Older borehole records are being progressively reviewed and enhanced using original logs, equipment details, and status reports to meet current SOLSTISS standards.

Through the SITG platform, the public can access borehole data (more than 20,800 boreholes as of May 2024), as well as maps displaying isolines and depth models of key Quaternary stratigraphic units, such as the Top Riss and the Base Quaternary/Top Molasse (LFM), etc. (Fig. 3.5) (SITG, 2023).

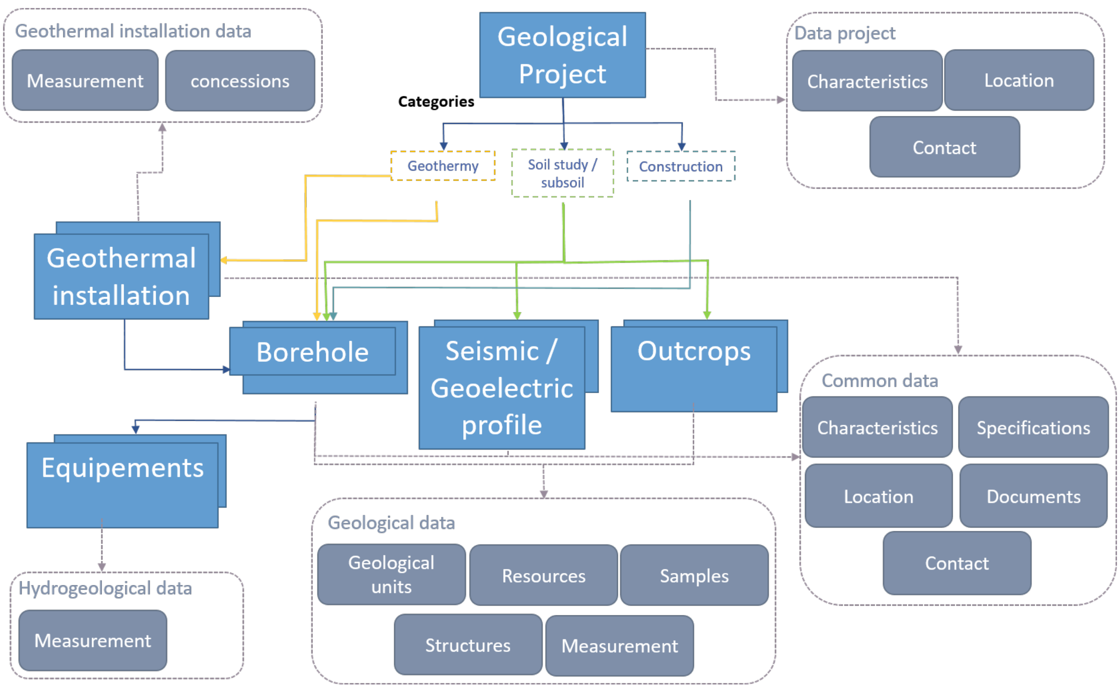


Fig. 3.4: Simplified relational model of the SOLSTISS Database (Système d'information Du Sous-Sol, ge.ch, 2022) (Meftah &

Moscariello, 2025).

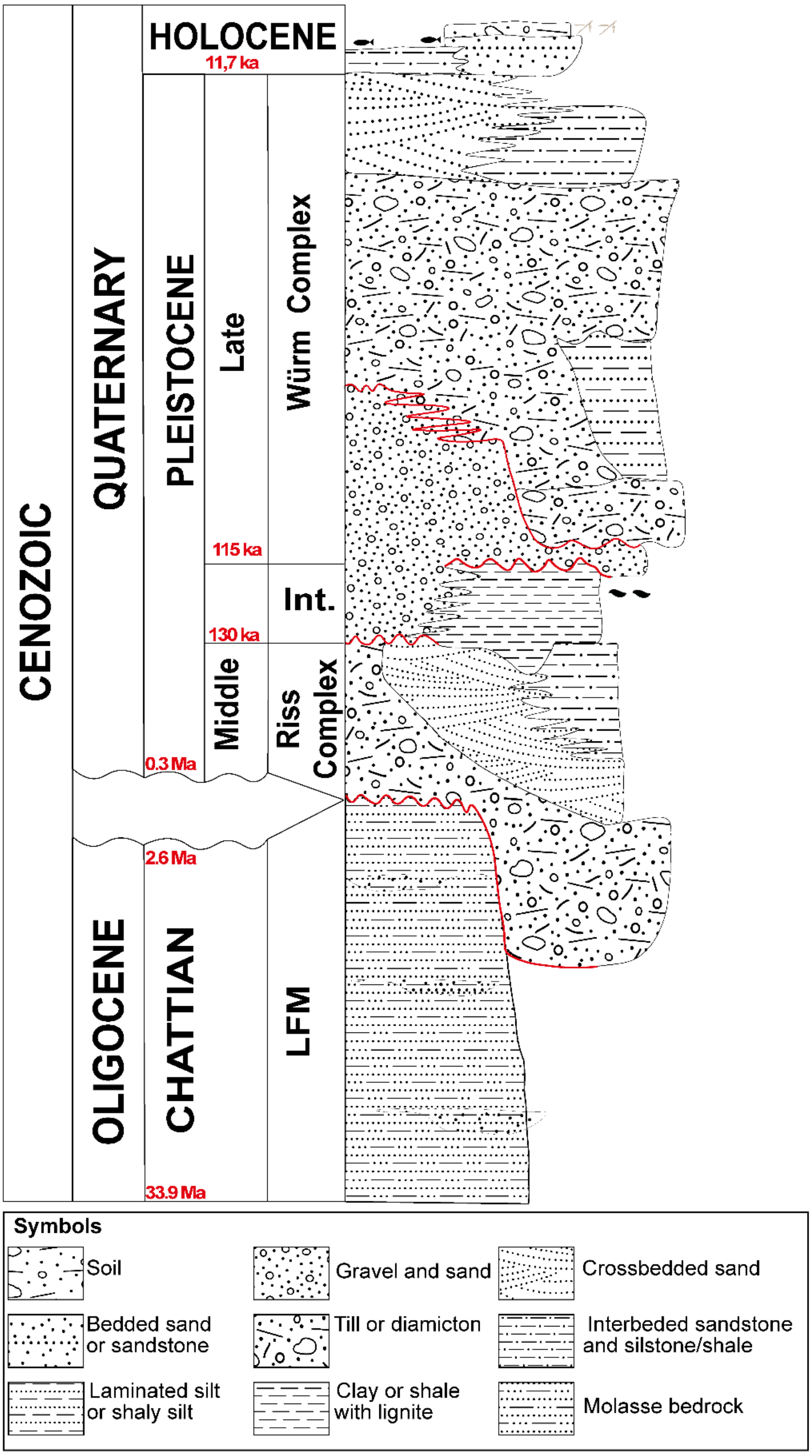


Fig. 3.5. Chronostratigraphic Column of the Geneva Basin showing the Riss and Würm complexes separated by an Eemian-Interglacial (Int), overlying the lower freshwater Molasse unit (LFM) (Meftah & Moscariello, 2025). The age framework for Quaternary stratigraphy follows Gibbard & Cohen (2019) for ages and the stratigraphic units to the SOLSTISS database (ge.ch, 2022).

3.1.3. U_SOLSTISS database

The U_SOLSTISS presents the same database architecture and content as the SOLSTISS database, except that it also contains data from the BRGM InfoTerre. The U_SOLSTISS is stored in a local environment at the University of Geneva (hence the prefix "U_" (Fig. 3.6), and it represents the key database for the FCC project. The UNIGE database is disconnected from the original SOLSTISS database of GESDEC, which is not populated with data from the nearby French territory and collected from the BRGM database. The infill of U_SOLSTISS started in January 2022 with 19,419 boreholes. For this study, U_SOLSTISS is defined to be the environment of data storage and collection of data approved by CERN, and therefore, it is defined as the only source of data in support of the FCC project.

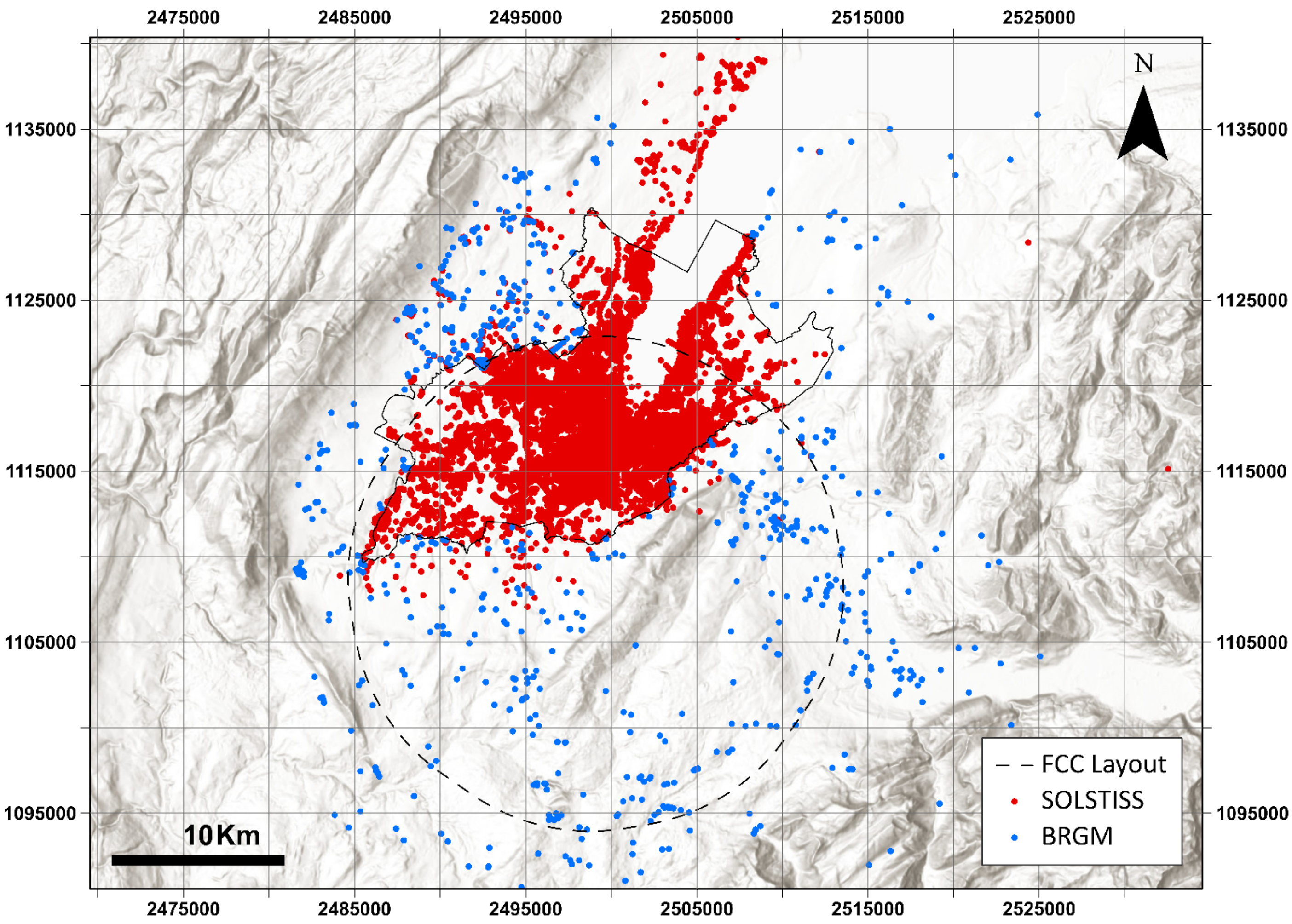


Fig. 3.6. Boreholes from the U_SOLSTISS database include SOLSTISS boreholes (red) and BRGM boreholes (blue) (Meftah & Moscariello, 2025).

3.2 Methodology

The Research by UNIGE started by collecting data from the deep and shallow boreholes containing information on the Base Quaternary/Top Molasse, which represents a well-recognised surface and was recorded by boreholes in both Swiss and French territories (Fig. 3.5). The project also requested integrating and harmonising data (i.e., stratigraphic naming convention, etc.) from multiple subsurface boreholes stored in the InfoTerre open data source into U_SOLSTISS. The adopted workflow consisted of two tasks: (1) establish a Geodatabase using ArcGIS Pro software, (2) transfer and interpret datasets on a modelling software, Petrel™ (2014).

In detail, the workflow of the first task was organised as follows: (i) bulk data collection from the BRGM is performed following verification of information within the supporting documents, (ii) Primary storage of required data into a flat ArcGIS database in the format of. Shp or Excel for geoprocessing steps, (iii) selection of the boreholes according to their depth, presence of geological units of interest, validity of information, and relevance for the specific project of interest, in this case, the FCC. (iv) Infill and harmonise the data into the U_SOLSTISS database as final storage using the SOLSTISS catalogue as a guide. These steps are summarised in the workflow reported in Fig. 3.7.

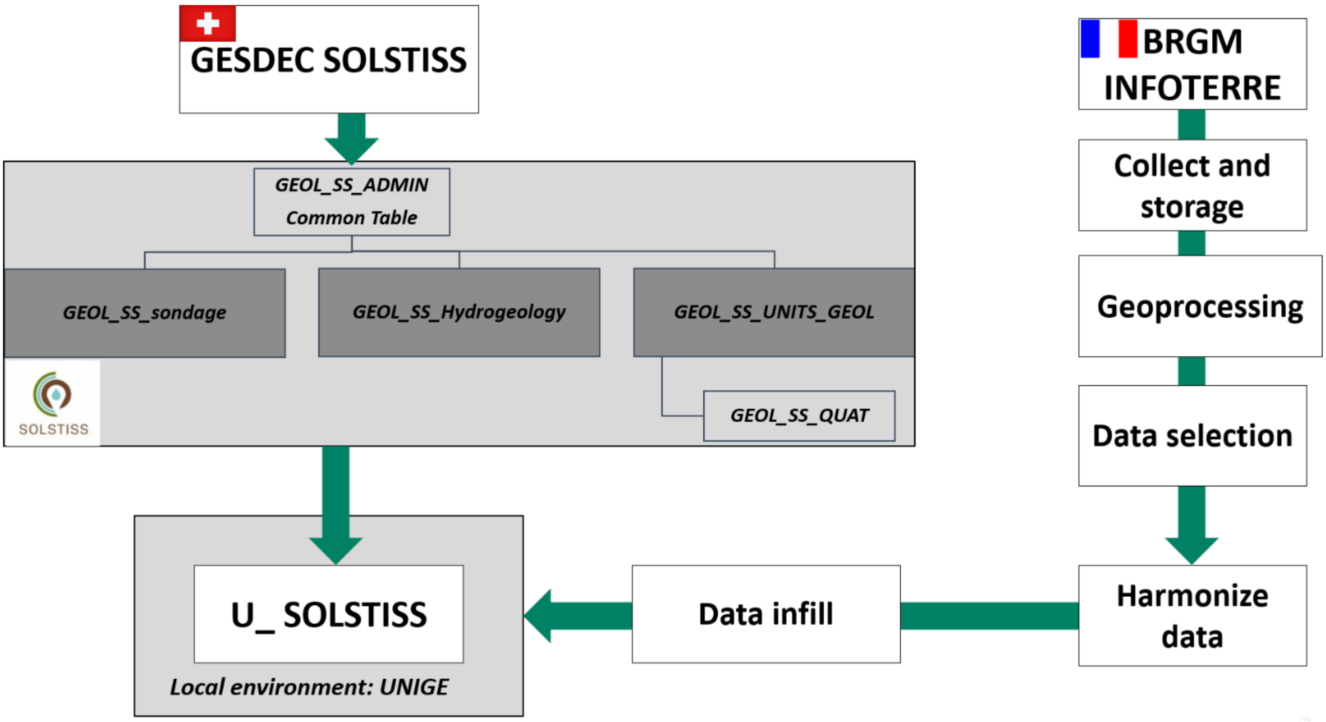


Fig. 3.7. Workflow for harmonising borehole data from BRGM (InfoTerre) into the U_SOLSTISS system (Meftah & Moscariello, 2025).

3.2.1. Geoprocessing steps

The data collection was carried out over eight months through the open database InfoTerre, during two distinct work phases: the first, from October 2020 to April 2021, to collect all the required boreholes, and the second in July 2023 for more recently drilled boreholes. The U_SOLSTISS is supplied with 842 boreholes from BRGM. At the present day, U_SOLSTISS contains exactly 20,100 Boreholes (Fig. 3.6).

The Collection of bulk geographic datasets from BRGM of several types is loaded and stored in a common file system folder in shapefile format and an Excel sheet. The database is created on the ArcGIS software and is intended for the management, storage, updating, infilling, and consultation of data and their different attributes. This allows for the comparison of information from the French and Swiss datasets side by side. This visual and organised setup helps quickly spot which data represents the same attributes (Total depth, groundwater level, etc.), even if they have different names. After this comparison, the harmonisation process can standardise these attributes, ensuring both datasets use the same terms. This step-by-step approach simplifies integrating and analysing the combined data.

In the verification process, 161 boreholes were found in both the SOLSTISS and BRGM databases. Most of these boreholes were drilled during the construction of the earlier CERN colliders and were originally sourced from an outdated cantonal boreholes database that lacked comprehensive geological and hydrogeological details. Out of these, 132 reached the top of the Molasse formation, yet they possess only partial or no geological and hydrogeological data in the SOLSTISS database. Currently, these records are being progressively updated by re-evaluating original borehole logs to fill in the missing attributes, ensuring alignment with the current database structure.

The geometric harmonisation of the coordinate reference system (CRS), an essential part of the geoprocessing steps, was carried out to avoid data heterogeneity (Gedrange *et al.*, 2011). The SOLSTISS is projected in the Swiss coordinate system (Projects spatial system CH1903+_LV95). Subsequently, boreholes integrated in U_SOLSTISS database are projected using a projection tool from ArcGIS to convert the X and Y from the French system (Lambert 93 projection, (BRGM, 2013)) to the Swiss coordinate system using specific parameters and rules (CRS-EU, 2014). For boreholes with missing or incorrect coordinate values, the projection tool in ArcGIS Pro was used to accurately correct and assign their spatial position.

If elevation values were absent or incorrect, either in the U_SOLSTISS or the BRGM database, corrected values were derived from the boreholes report and manually input into the database. The elevation information could be extracted from the digital elevation model (DEM) from two different sources: (i) “BD ALTI” from France (BD ALTI® | Géoservices (ign.fr)) with a resolution of 25 m. (ii) MNT25 from Switzerland, generated by the Swisstopo (MNT25 (admin.ch)), also with a resolution of 25 m (Fig. 3.8).

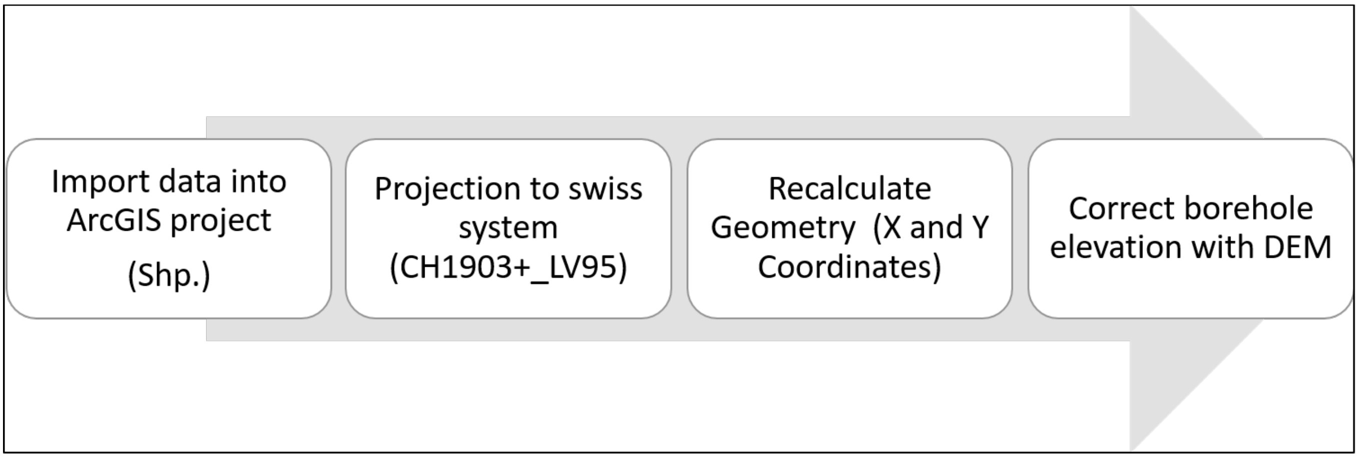


Fig. 3.8: Geoprocessing steps (Meftah & Moscariello, 2025)

Some deep boreholes do not encounter the Top Molasse, indicating a locally thick Quaternary succession. These boreholes are essential for better constraining the Base Quaternary / Top Molasse boundary, which is required for developing a more accurate 3D geological model along the planned FCC trajectory. Ongoing work and subsurface investigations within the FCC project aim to refine this surface. Boreholes on either side of the French-Swiss border often show inconsistent stratigraphic descriptions, highlighting the need for harmonised data to improve geological modelling.

3.2.2 Database Harmonization

The harmonisation of borehole data into the U_SOLSTISS database required a systematic infill of attributes already defined in the initial cantonal SOLSTISS database (Favre, 2018). These consist of five attribute tables (Fig. 3.9) which aim to ensure consistency of the geological information associated with each borehole, regardless of its origin (i.e. France or Switzerland). The five attributes are the following:

- “GEOL_ ADMIN” (object’s unique identifier) is a common table and links to all the attribute tables. This forms a central table of the database and corresponds to the ‘administration table'.
- “UNITE_GEOL” (Geological units): This table describes the different geological layers. The information is based on the documentation provided (from the borehole report).
- “GEOL_SONDAGE” (Geological borehole) is a shapefile format as a point type. It provides a technical description of the borehole survey.
- “GEOL_ QUAT”: this table describes in detail the lithology of the Quaternary units. The "classification des sols genevois" was developed by GADZ for the Geneva Quaternary successions (Deriaz, S.A & Ruchat, 1997). Local authorities and stakeholders use this geomechanical classification for subsurface characterisation and engineering applications.
- “GEOL_ HYDROGEOLOGY”: This table describes the hydrogeological units. It contains the piezometer, depth of the aquifer, and geological units of the reservoir.

All these attribute tables are related to the Geological borehole through the admin ID from the GEOL_ADMIN attribute table. Therefore, all these attributes' tables adopt “Geol” as a prefix.

The integration of data from the borehole into these attribute tables is a manual process. Each borehole is filled individually by adding all information from the borehole reports and logs. The data infill is controlled and well guided by the domain already set up in SOLSTISS and detailed in the catalogue. Any other description not included in the catalogue is not considered and is deleted by the system.

The stratigraphy encountered in the boreholes ranges from the base of the Jurassic to the Holocene. All the names of geological units are established by GESDEC based on the local geology of the Canton of Geneva and are applied to the UNITE_GEOL attribute table of SOLSTISS (Table 2). Many geologists have studied the Quaternary deposits in the Geneva Basin and neighbouring France, starting with Necker (1841) and Favre (1878, 1879). Favre was the first to compile borehole data in his geological description of the Canton of Geneva. Later, Penck and Brückner (1909) proposed an early glacial stratigraphy for the region. Subsequent work by Joukowsky (1920, 1927) and Paréjas (1938), and Jayet (1946) further described the stratigraphic variability of the Quaternary successions (Fig. 3.5). The stratigraphic units are systematically coded based on the SOLSTISS database conventions, with full documentation provided in the associated documentation within the SOLSTISS catalogue (Table 3.2).

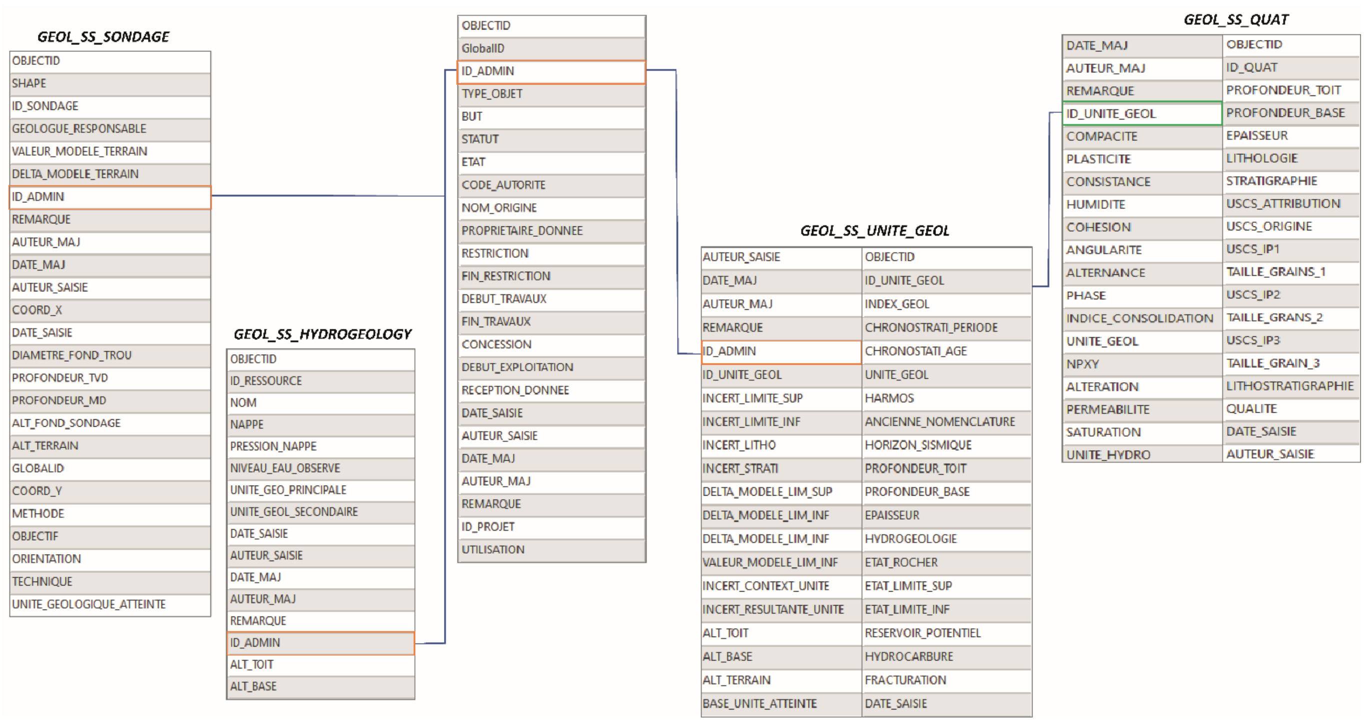


Fig. 3.9. Attribute Tables from the SOLSTISS database. The connections enable efficient linking and sharing of data across tables (Data extracted from the SOLSTISS database and modified using ArcGIS Pro) (Meftah & Moscariello, 2025)

Table 3.2. Description of the Quaternary geological units from the SOLSTISS database catalogue (Translation from the original French version of the SOLSTISS catalogue)

Period	Age	Geological unit	Code SOLSTISS
Quaternary	Holocene	Terrains de couverture/cover soil	1-2
		Colluvions ; Terre végétale/colluvial and vegetal soils	1
		Remblais hétérogènes / backfill	2
		Ruissellements ; Colluvions/ Runoff; Colluvium	3
		Dépôts palustres/ Palustrine deposits	3
		Alluvions récentes/ Recent alluvium	4
		Alluvions indifférenciées/ Undifferentiated alluvium	4-9
		Dépôts lacustres/ Lacustrine deposits	5
		Tourbe/ Peat	5
	Pleistocene	Retrait glaciaire indifférencié/ Undifferentiated glacial withdrawal	6-11
		Retrait würmien / Würmian withdrawal	6
		Moraine indifférenciée/ Undifferentiated moraine	7-12
		Moraine würmienne/ Würmian moraine	7
		Dépôts intra morainiques/ Intra moraine deposits	8
		Alluvion ancienne/ Ancient alluvium	9
		Interglaciaire Riss-Würm/ Interglacial Riss-Würm	10
		Retrait rissien/ Rissian withdrawal	11
		Moraine rissienne/ Rissian moraine	12
		Dépôts intra morainiques/ Intra-formational deposits	13
		Non renseigné /Unknown	N/A
		Autre/ Other	N/A

The BRGM database presents differences in the nomenclature of Quaternary geological units, and in some boreholes, this information is missing because the geological descriptions focus more on lithology than on stratigraphic units. This inconsistency between the Swiss and French datasets, especially in lithological descriptions, poses a key challenge for harmonisation and complicates automated correlation.

To address this, lithological descriptions have been systematically reinterpreted to distinguish geological units and enable data harmonisation. Where Quaternary units were not identified or remained unclear, they were classified as 'unidentified'. This approach was applied to several boreholes that, despite lacking direct Quaternary data, encountered the Base Quaternary/Top Molasse boundary.

Using lithological and stratigraphic information from the SOLSTISS database, it has been possible to harmonise the geological units across datasets. Figure 3.10 outlines a simplified workflow for harmonising BRGM borehole data using lithological descriptions and the SOLSTISS stratigraphic framework. Lithological descriptions from BRGM boreholes are reinterpreted using the GADZ (1965) classification criteria. These units are then standardised to the SOLSTISS framework using the SOLSTISS catalogue to ensure consistency in the geological framework of this database (Table 3.2). The harmonisation is validated by correlating with adjacent boreholes, where available, to confirm stratigraphic coherence (Fig. 3.5). However, in the French records, both the Riss complex and the interglacial interval are not present in the BRGM nomenclature and may be absent or unidentifiable. In some cases, these units can be identified using neighbouring boreholes.

Similarly, individual advances within glacial cycles, such as Riss or Würm, are not documented (Fig. 3.5); typically, only a single advance is described. This contrasts with the geological understanding of the Geneva Basin, where multiple advances are expected based on stratigraphic and geomorphological evidence (Moscariello, 1996). Due to these limitations, classification of Quaternary units in French boreholes relied on thematic interpretation of lithological descriptions, aligned with the stratigraphic framework applied by GESDEC.

In some instances, boreholes contain both lithological and stratigraphic descriptions, facilitating direct correlation with adjacent records. These cases simplify the harmonisation process by providing internal stratigraphic anchors that enhance consistency across the regional geological framework.

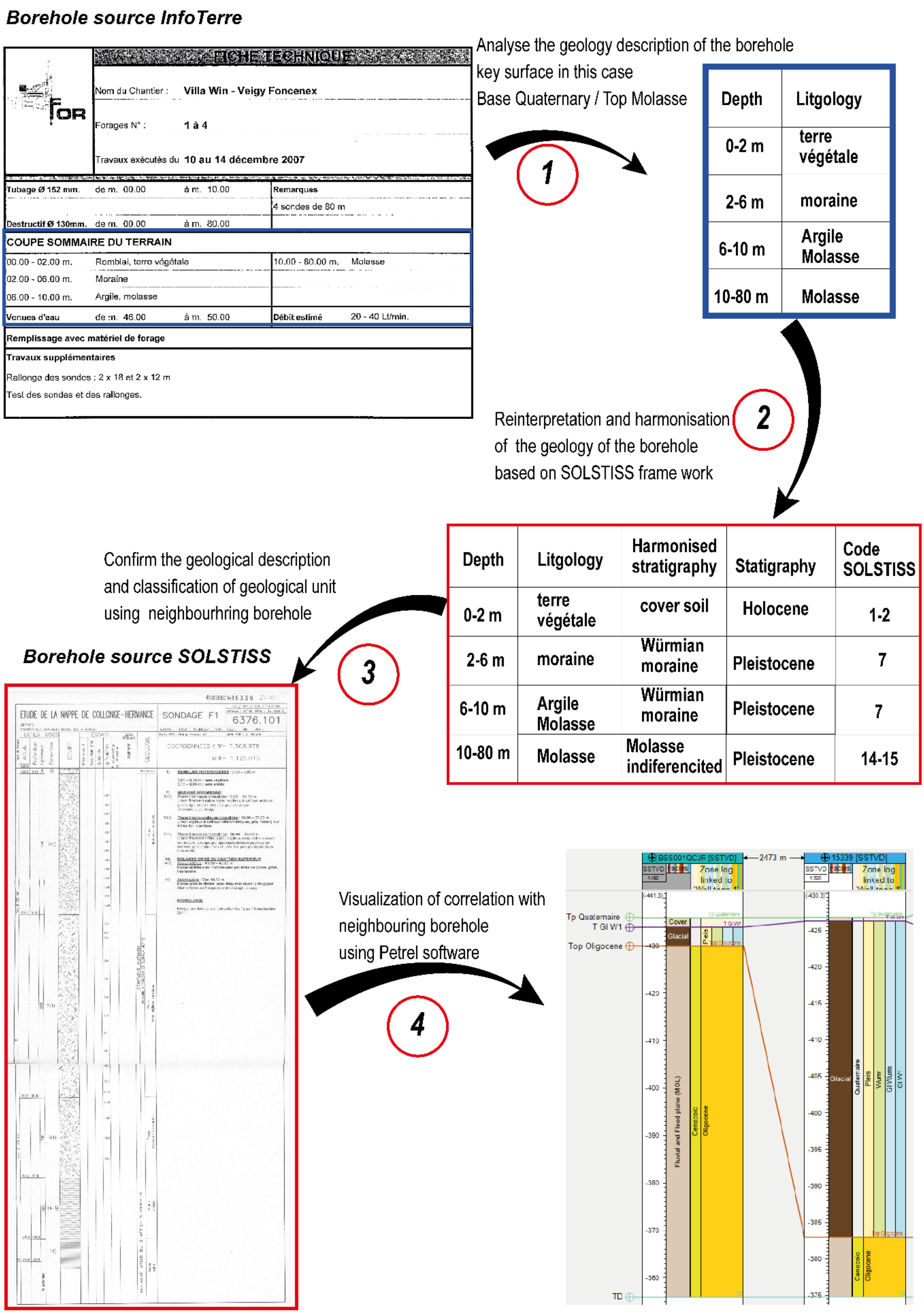


Fig. 3.10. Simplified workflow of borehole (ID: BSS001QCJR) harmonisation from the InfoTerre open data source into the U_SOLSTISS framework. This figure illustrates the harmonisation phase within the overall workflow for integrating BRGM data

into U_SOLSTISS in Fig. 3.7 (Meftah & Moscariello, 2025).

3.3. Data transfer

The data transfer is the process of securely moving information from one system to another. In our case study, data were transferred from the U_SOLSTISS database to a software enabling 3D subsurface modelling, such as Petrel (SLB, 2024), used in this project. The required raw geological data from U_SOLSTISS were thus transferred into usable information with the selected software, which allowed data visualisation, analysis and modelling. This transferred dataset included the harmonised boreholes from the BRGM database alongside the existing boreholes from SOLSTISS. All boreholes were assigned the same "ID_Sondage" number from U_SOLSTISS, which is the identifier in modelling software to facilitate the verification of raw data from the borehole report. The selection of the boreholes to be exported from the U_SOLSTISS into the modelling software was based on: (i) the data quality of the logs /reports, for boreholes inherited from the SOLSTISS database, was checked prior to their integration into the modelling software, (ii) the presence of the Top Molasse and (iii) their distribution in the study area. The data transfer procedures allow a second opportunity to control the accuracy and reliability of data during the integration of geological data, such as borehole location and geological unit description, and therefore avoid a possible negative impact on the geological model. Thus, many boreholes have been revised for stratigraphic inconsistency with the neighbouring ones to ensure alignment between borehole data. These may help to identify unnoticed errors during the database input of the U_SOLSTISS. The transferred dataset included location (X, Y), elevation depth (Z) calibrated with the DEM, facies and geological units and borehole total depth (TD) (see Fig. 3.11).

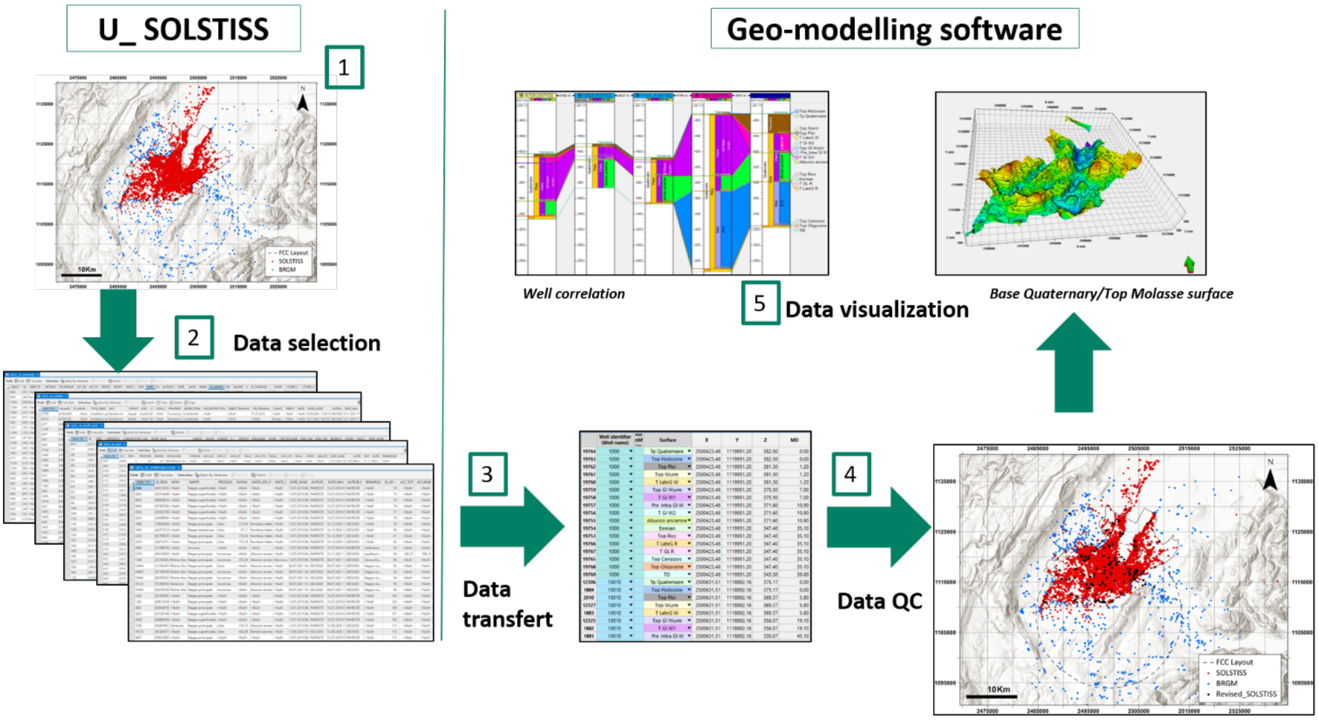


Fig. 3.11. Data transfer from database to modelling software (SLB), visualisation and valorisation (Borehole correlation and surface generation) (Meftah & Moscariello, 2025).

3.4. Database QC

Data quality control determines whether or not the data is reliable. Consequently, it is imperative to verify the quality and suitability of data before utilisation and effective decision-making. Thus, the quality check during the data collection from BRGM was needed to improve the 3D geological model. Therefore, for each data collection phase the following tasks were carried out: i) check and add –unavailable coordinate system and Elevation depth, ii) check the quality of existing information to identify data completeness and consistency, iii) evaluate the report before filling-in information of the geological units (Top Molasse, Top Cretaceous); (iv) ensure stratigraphic accuracy by comparing borehole data from neighbouring ones.

Most of the examples where inconsistent data were encountered in both SOLSTISS and BRGM databases were caused by misinterpreted stratigraphic units, data entry errors and incorrect borehole location (geographical coordinates and altitude of boreholes that did not match with the elevation model of the region). For example, when boreholes are poorly reported, with missing files, or unclear, corrupted, or erroneous reports from the BRGM database, a correction is carried out prior to importing into the U_SOLSTISS database. During the geoprocessing step, some boreholes were revealed to have incorrect X and Y coordinate projections or were located in the same location but with different ID. If the stratigraphic description was identical in both boreholes, one of them was digitised in the U_SOLSTISS database. In most of cases, the elevation values of borehole top surfaces did not match the DEM of the region.

Therefore, the borehole elevation values were modified and aligned with the DEM elevation values. These issues might potentially contribute to incomplete data and gaps within the database. In case of great uncertainty about a borehole, the latter was not integrated into the database.

The data harmonisation can be very challenging when considering the genetic and stratigraphic interpretation of a certain lithology. In the Canton of Geneva, stratigraphic nomenclature, i.e., Würm, Riss, Interglacial, etc, has been based on the lithology, generating much ambiguity about the stratigraphic unit and chronostratigraphic position. Within the BRGM database, most boreholes have only the lithological description, leaving the chronostratigraphic interpretation unresolved. Therefore, the data examined were often inconsistent and presented incompatible information, leading to uncertainties and unreliable stratigraphic subdivisions, for example, the "Riss or Würm withdraw" and "Alluvion ancienne" present the same lithology descriptions (Fig. 3.5, i.e. sand and gravel) but have completely different geotechnical characteristics such as the compactness, colour, and density of the sediments.

Conclusion and recommendations

The harmonization of geological data improves the quality and accessibility of subsurface information. This part describes the steps and methodology involved in database harmonization for cross-border projects. The database of U_SOLSTISS is one of the key deliverables for FCC CERN to carry out further studies in the area. Following this work, CERN is planning to drill more boreholes all along the future FCC trajectory to improve the knowledge of the subsurface in critical areas and thus update the geological model of the FCC. The ultimate goal is to use these borehole data to develop an accurate subsurface 3D geological model. As far as the database infill is concerned, vigilance and data control are required during data input in the database, integration and data transfer.

During the drilling and interpretation of well logs, contractors should include an examination of at least 2 to 4 wells in a 50-100 m buffer zone around the newly drilled borehole in order to ensure reliable data interpretation. Based on the observations from this study, it is recommended to adopt standardized litho- and chronostratigraphic charts, such as the SOLSTISS framework, to ensure consistent description of geological sections in all boreholes, whether cored or drilled destructively. In addition, the results highlight the need to reconsider the historical classification of Penck and Brückner (1909) in the Geneva Basin. Future work should aim to refine the stratigraphic interpretation through targeted dating to establish a revised, locally adapted stratigraphic column for the region.

4. Database management

In parallel to the harmonization work provided in E. Meftah, Ph.D, UniGe was tasked with the management and organization of the database for the CERN. In this context, two guidelines documents have been redacted by UniGe to set the best practice in the context of data acquisition during the feasibility stage.

4.1. Data management plan

In the context of the FCC project, the UniGe was in charge of managing data by generating, managing, and supporting a database (DB).

These tasks were regrouped into the Database Management Plan (DMP), which entails collecting data that will be acquired or produced during research; how the data will be managed, described, and stored; what standards will be used; and how data will be handled and protected during and after the completion of the project. Third parties contracted by CERN generated new data and interpretations of already existing data. In this context, these entities were required to provide CERN and then UniGe with any data generated to be collected, harmonized, and implemented in the U-SOLSTISS DB.

UniGe was tasked to ensure the collection, organization, assessment, and implementation of all data received from CERN in the U-SOLSTISS database (Figure 1, red box). After a quality assessment (QA) and quality check (QC), it was intended that U-SOLSTISS would be provided to GESDEC to be implemented in the SOLSTISS database. To this date, the U-SOLSTISS DB has not been merged with GESDEC's SOLSTISS database and remains the most up-to-date database. The merge will happen upon GESDEC's request.

4.2. Data specification requirements

The U-SOLSTISS database contains both spatial and non-spatial data sets. To ensure these data sets are discoverable and usable by data consumers, they must conform to specific standards and product specifications. In this context, UniGe has provided CERN with a guideline document (Data Specification Requirements) recommending general standards for data collection and submission. Further specifications might be requested in the future. The specification presented in the DSR is suggested to change over time as the FCC project progresses.

The DSR specifies the following procedures to ensure data sustainability and easy data management:

- Processes of data delivery
- Requirement for a descriptive document associated with data distribution
- File naming and directory structure conventions
- Coordinate systems to be used for consistency
- Spatial and non-spatial data formats are acceptable
- Example of metadata table

To achieve this, UniGe has participated in meetings with CERN's contractors responsible for data acquisition. These meetings aimed to explain the DSR and ensure a common understanding of best practices.

4.3. Data preparation and transfers

On top of data management, UniGe has also supported specific requests for data transfer to CERN. Most of these transfers occurred in 2024 and concern work provided by UniGe in the context of the modelling task or specific data manipulation requests for CERN's purposes. The following table provides an excerpt of these transfers:

Table 4.1. Data transfer

Type	Object	Date
Dataset	Transmission to CERN of the 3D geological models	19.03.24
Dataset	Transmission to CERN of fault map	10.05.24
Dataset	Transmission to CERN of a first fault grid to test the implementation	10.05.24
Dataset	Transmission to CERN of the 3D geological model reliability maps	17.05.24
Dataset	Transmission to CERN of a contour map of the molasse and the limestone	17.05.24
Dataset	Transmission to CERN of all the fault in the chosen format	31.05.24
Database	Transmission to CERN of all the boreholes in a buffer zone around the FCC trace	31.05.24
Dataset	Transmission to CERN of the 3D geological models	31.07.24
Dataset	Transmission to CERN of fault map	01.11.24
Dataset	Transmission to CERN of the 3D geological models	31.01.25
Database	Transmission to CERN of the U-SOLSTISS DB	13.03.25

The U-SOLSTISS DB was provided to CERN in March 2025. This database contained all of the collected, compiled and harmonized data at the moment of transfer.

The data acquired during the drilling and seismic acquisition campaign from GEOTEC and SGS3 were received in June 2025. These data are currently being treated using the workflow designed in the DMP for later integration in a new iteration of U-SOLSTISS.

5. Borehole data analysis

In April 2025, UniGe partially analyzed and sampled the MAND_02 core. The focus was on the Molasse/Cretaceous transition, with 49 samples collected for further analysis (**Error! Reference source not found.**). A first draft was created to identify the potential unit and member, helping to constrain the stratigraphy encountered by the borehole.

Fig. 5.1A – Photograph of the core barrel immediately after recovery at the surface of borehole MAND_02, showing a portion of the Lower Cretaceous limestone (“Urgonian” Facies).

The borehole sections MAND_02 and MAND_03 have been collected in January and February 2025 by a multidisciplinary team of the Department of Earth Sciences, Geneva University. As part of this study, a microfacial analysis of the Mesozoic (Cretaceous) to Tertiary samples have been carried out by a team from the laboratories of ´Sedimentology, Biostratigraphy, and Micropalaeontology´ and ´Geo-Energy of Sedimentary basins´. The aim of this study is to assess the sedimentology, and well as the bio- and lithostratigraphy of the recorded sedimentary sequence.

At first, this study is dedicated to the analysis of microfacies, observed in thin sections. It is focused on examining sedimentary processes, structures and grain to determine the formation and evolution of the depositional environment. Later, a study of microfossils observed in thin sections has been carried out. The encountered microfossils are of different origins (reef builders, corals, algae, foraminifers, ostracods, among others) and can be used for their biostratigraphical and palaeoecological values. Indeed, due to their small size and high abundance, microfossils provide good markers to determine the age of rock sequences. Certain fossils indicate specific depositional environments of past climate conditions, which can be used to propose palaeoecological and palaeobiogeographical reconstructions.

The current analysis is based on a total of 57 samples, which range from the Cretaceous to the Tertiary sequence of the Geneva Basin. The 28th of January 2025, 10 samples have been collected in the MAND_03 borehole. The 05th February 2025, 47 more samples have been collected in the MAND_02 borehole. Among these 57 samples, 22 have been processed as thin sections for microscopical investigation.

The following is a lithological and microfacial description of the recorded Hauterive and Pierre Jaune de Neuchâtel members (Grand Essert Formation), the Gorges de l'Orbe and Rocher des Hirondelles formations (Urgonian facies) and the Molassic sequence.

GRAND ESSERT FORMATION

In term of lithology, the MAND_02 borehole encompasses almost the entire Grand Essert Formation (approximately 85 metres thick). The Grand Essert Formation starts with the Lower Hauterive Member. Only the top 17 metres of this unit have been recorded in this study. It is followed by the Middle and Upper Hauterive Members (9 and 22 metres, respectively). The Pierre Jaune de Neuchâtel Member is divided into a lower and upper units (13 and 2.75 metres, respectively), divided by 4.5 metres of Uttins Marls. This Formation extends from the Upper Valanginian to the Lower Hauterivian (Fig. 5.1).

In term of biostratigraphy, only a few recorded species are currently significant to constrain the stratigraphic range of the Cretaceous to Tertiary sequence. In the Hauterive Member, the occurrence of the species Dorothia kummi and Meandrospira favrei indicate the sequence cannot be older than Late Valanginian in age. Indeed, Dorothia kummi is known from the late Valanginian to the Aptian (Moullade, 1966); while Meandrospira favrei is usually considered as a marker of the Late Valanginian to Early Hauterivian (Charollais et al., 1966).

HAUTERIVE MEMBER

The "Marnes d'Hauterive", firstly defined in de Montmollin (1833) constitutes the lower Member of the Grand Essert Formation. In its type section, it consists in 52 meters of predominantly marly facies, and is divided into three units (Fig. 5.1).

Lower Unit

The lower unit of the Hauterive Member has been visually identified at the base of the MAND_02 borehole, at a depth of 265 to 248 metres (i.e. approximatively 17 metres thick). The unit begins with approximatively 8 metres of calcareous marly limestones containing rare interlayers of marl and a few cemented fractures. This is followed by 9 metres of mudstone containing rare bivalves and other undetermined fossils.

Two samples were prepared for thin section analysis in this interval (Fig. 5.2A).

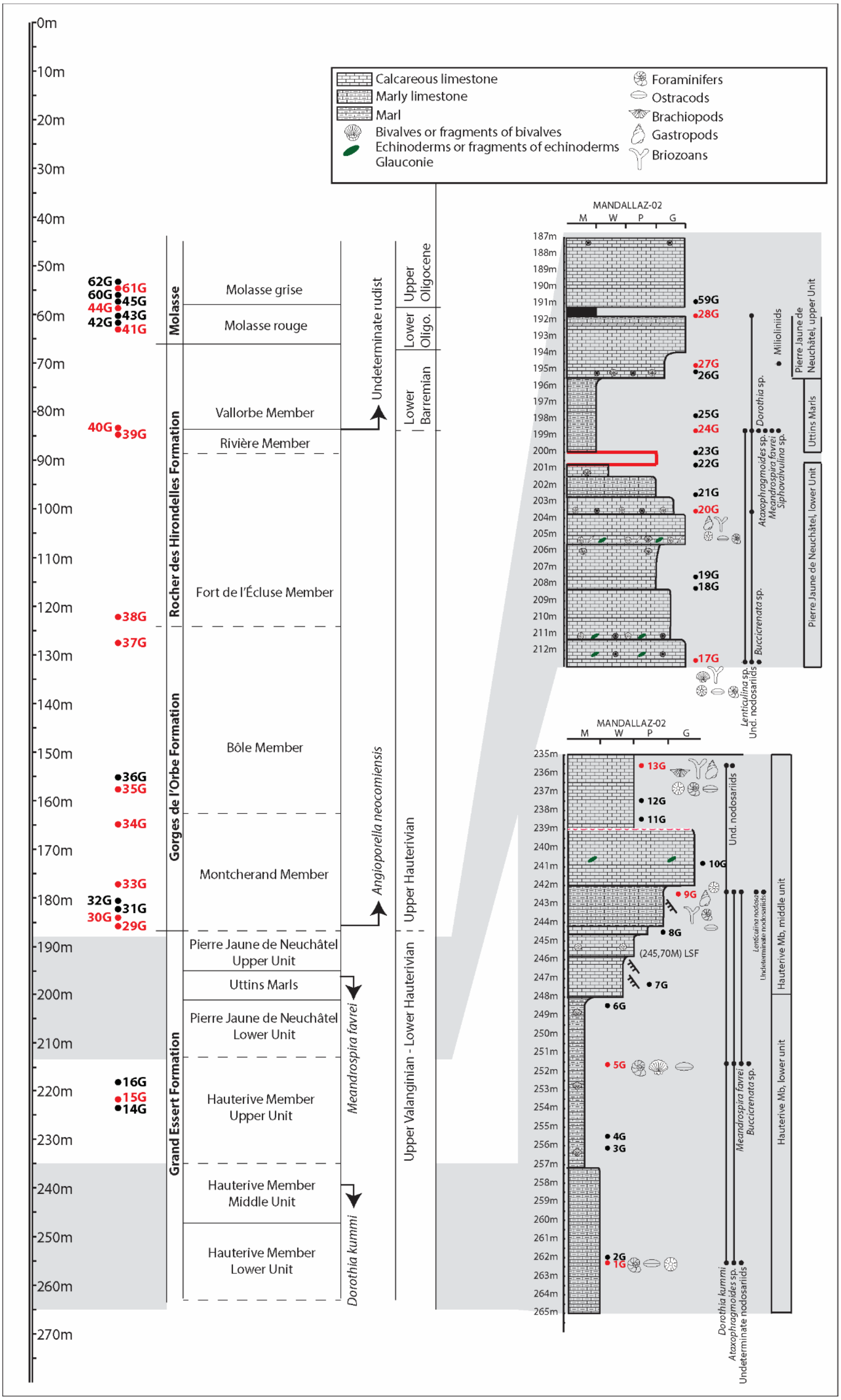


Figure 5.1B. Lithostratigraphy and Biostratigraphy of the Valanginian to Oligocene MAND_02 borehole.

Sample 1G (262.2-262.3 metres depth). It consists in a micritic facies with glauconite, rare benthic foraminifers, ostracods, and echinoderms. The foraminiferal assemblage is represented by abundant specimens of Dorothia kummi and a few specimens of Ataxophragmoides sp. and of undeterminate nodosariids (Fig. 5.2B).

Sample 5G (251.55-251.6 metres depth). It consists in a micritic facies with rare bivalves, benthic foraminifers, and ostracods. The foraminiferal assemblage is represented by abundant specimens of Dorothia kummi, together with Ataxophragmoides sp., Meandrospira favrei, and Buccicrenata sp.

Middle Unit

The middle Hauterive Member has been visually identified in the MAND_02 borehole, at a depth of 248 to 239 metres (i.e. approximatively 9 metres thick). The unit is characterized by massive calcareous limestones rich in fossils (e.g. biocalcarenite) and ripple marks (Fig. 5.1).

Two samples were prepared for thin section analysis in this interval.

Sample 9G (242.55-242.6 metres depth). It consists in a biomicritic facies with abundant echinoderms, gastropods, ostracods, briozoans, and benthic foraminifers (Fig. 5.2C). The foraminiferal assemblage is characterized by the occurrence of Dorothia kummi, Meandrospira favrei (Fig. 5.2D), Lenticulina nodosa, as well as Ataxophragmoides sp., and undeterminate nodosariids.

Sample 13G (235.5-235.6 metres depth). It consists in a biomicritic facies rich in echinoderms, gastropods, brachiopods, ostracods, briozoans, and benthic foraminifers. The foraminiferal assemblage is characterized by the occurrence of Dorothia kummi and undeterminate nodosariids.

Upper Unit

The upper Hauterive Member has currently been identified in one sample of the MAND_02 borehole. Although its thickness is at the moment unknown, it is worth notice that 22 metres have been recorded between the top of the Middle Hauterive and the basis of the Pierre Jaune de Neuchâtel Members. It was visually associated with marls, associated with the decrease in abundance of microfossils (Fig. 5.1).

Sample 15G (223.1-223.15 metres depth). It consists in a micritic facies very similar to the one recorded in the lower Hauterive Member, but characterized by the almost complete absence of microfossils (Fig. 5.2E). Only one specimen of benthic foraminifers has been recorded here and corresponds to an undeterminate specimens of nodosariid.

PIERRE JAUNE DE NEUCHATEL MEMBER

The upper part of the Grand Essert Formation, which mainly consists in limestone, has been defined as the “Neuchâtel Yellow Stone Member” by Strasser et al. (2016). In the Grand Essert type section, this member is 60.5 metres thick and is subdivided into two parts, separated by the Uttins Marl interval (Fig. 5.1).

Lower Unit

The lower Pierre Jaune de Neuchâtel Member has been visually identified in the MAND_02 borehole at a depth of 213 to 200 metres (i.e. approximatively 13 metres thick). The unit is a typical oolithic grainstone with a sparitic cement and abundant bioclastic fragments. The limestone is occasional characterized by fractures, stylolithes and some lenses of oil (Fig. 5.1).

Two samples were prepared for thin section analyses in this interval.

Sample 17G (212.6-212.7 metres depth). It consists in an oolithic grainstone (Fig. 5.1F) with sparitic cement, glauconite, pyrite, and abundant microfossils of bivalves, echinoderms, briozoans, ostracods, and benthic foraminifers. The foraminiferal assemblage is characterized by low abundance and diversity and is represented by specimens of Lenticulina sp., Buccicrenata sp. (Fig. 2H), and undeterminate specimens of nodosariids.

Sample 20G (203.65-203.75 metres depth). It consists in a typical oosparite with bioclastic fragments, including echinoderms, gastropods, briozoans, ostracods, and benthic foraminifers. The foraminiferal assemblage is characterized by very low abundance and diversity with a few specimens of undeterminate nodosariids.

Uttins Marls

The Uttins Marls have been visually identified in the MAND_02 borehole at a depth of 200 to 195.5 metres (i.e. approximatively 4.5 metres thick). It is represented by a calcareous yellowish bed rich in microfossils (Fig. 5.1).

One sample was prepared for thin section analyses in this interval.

Sample 24G (198.25-198.36 metres depth). It consists in a bioclastic micritic mudstone rich in benthic foraminifers, ostracods, echinoderms, and dasycladales algae (Fig. 5.2G). The foraminiferal assemblage is characterized by high abundance dans diversity. It includes specimens of Dorothia sp., Ataxophragmoides sp., Meandospira favrei, Siphovalvulina sp., Lenticulina sp., and undeterminate nodosariids.

Upper Unit

The upper Pierre Jaune de Neuchâtel has been visually identified in the MAND_02 borehole at a depth of

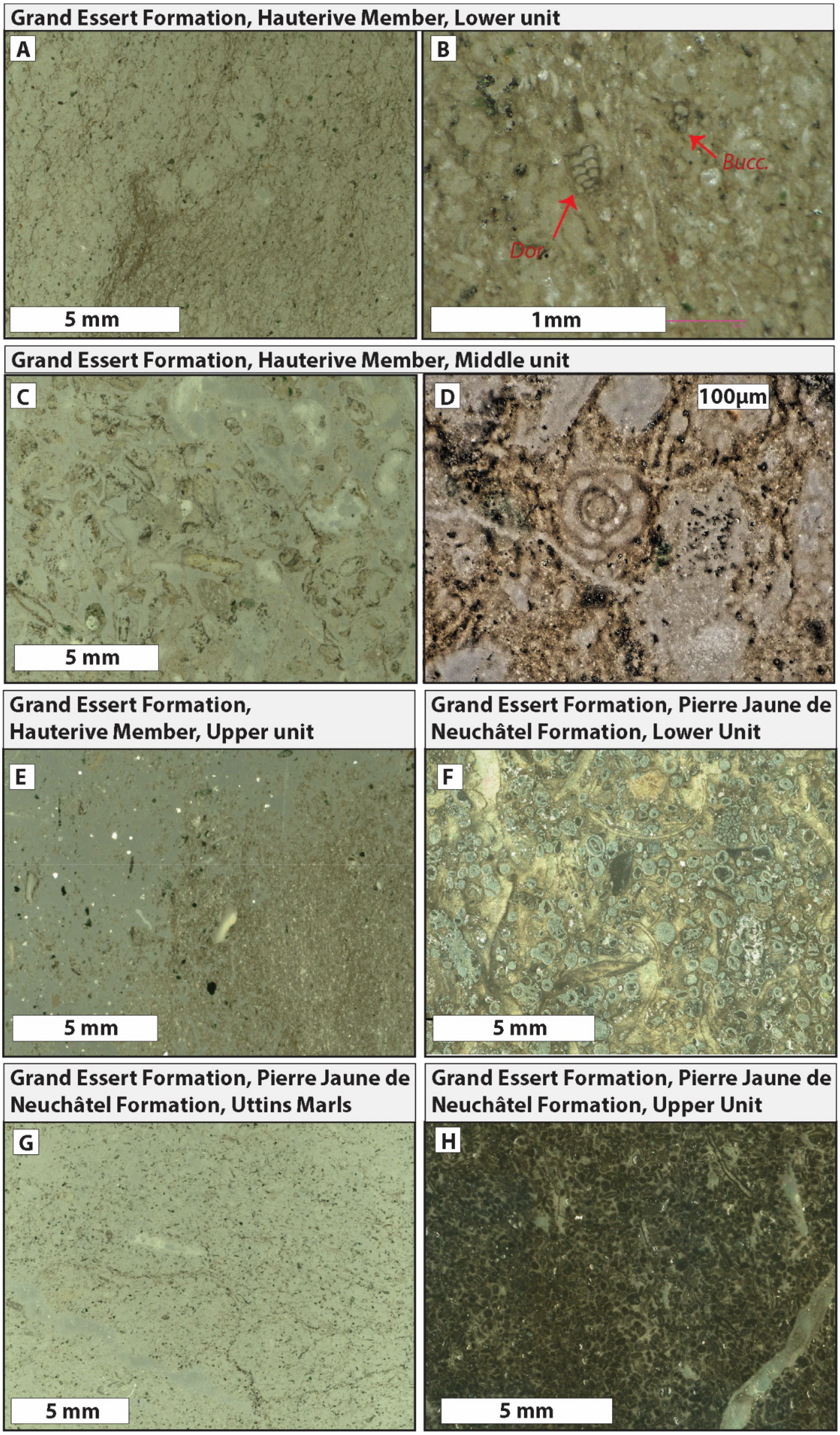
195.5 to 191.75 metres (i.e. approximatively 2.75 metres thick). The unit is characterized by oolithic calcareous limestone with marly interlayers. Rich peloids facies can be observed in some intervals (Fig. 4.1).

Two samples were prepared for thin section analysis in this interval.

Sample 27G (194.9-194.95 metres depth). It consists in bioclastic grainstone rich in ooliths and peloids (Fig 5.2H). Ostracods, benthic foraminifers and echinoids spicules have been recorded here. The foraminiferal assemblage in this interval is characterized by low abundance and diversity and is represented by the first occurrence of undetermined specimens of milioliniids.

Sample 28G (191.95-192.05 metres depth). It consists in an oolithic grainstone rich in peloids. Bioclastic fragments are rare in this sample. The benthic foraminiferal assemblage is represented by the occurrence of very rare specimens of undeterminate nodosariids.

Figure 5.2 (next page): Grand Essert Formation, Microfacies. ***A and B.*** *Hauterive Member, lower Unit (sample 17G).* ***C and D.*** *Hauterive Member, middle Unit (sample 9G).* ***E.*** *Hauterive Member, Upper Unit (sample 15G).* ***F.*** *Pierre Jaune de Neuchâtel, Lower Unit (sample 17G).* ***G.*** *Pierre Jaune de Neuchâtel, Uttins Marls (sample 24G).* ***H.*** *Pierre Jaune de Neuchâtel, Upper Unit (sample 27G).*


Grand Essert Formation, Hauterive Member, Lower unit
A
5 mm
B
Bucc.
Dor.
1 mm
Grand Essert Formation, Hauterive Member, Middle unit
C
5 mm
D
100µm
Grand Essert Formation, Hauterive Member, Upper unit
E
5 mm
Grand Essert Formation, Pierre Jaune de Neuchâtel Formation, Lower Unit
F
5 mm
Grand Essert Formation, Pierre Jaune de Neuchâtel Formation, Uttins Marls
G
5 mm
Grand Essert Formation, Pierre Jaune de Neuchâtel Formation, Upper Unit
H
5 mm

GORGES DE L'ORBE FORMATION

The Gorges de l'Orbe Formation was proposed by Strasser et al. (2016) to replace facies-based terms such as "Urgonien Jaune", "Urgonien Inférieur" or "Russilien". In the MAND_02 borehole, it is recorded directly above the Grand Essert Formation and is about 60 metres thick. The Gorges de l'Orbe Formation is divided into the Montcherand and the Bôle Member which are respectively 25 and 35 metres thick (Fig. 5.1).

This interval is biostratigraphically marked by the first occurrence of the dasycladal species *Angioporella neocomiensis,* which is a typical marker of the Upper Hauterivian (Clavel et al., 2014).

MONTCHERAND MEMBER

This member corresponds to the "Urgonien Jaune" of Remane (1989), a marl and limestone series close to the Pierre Jaune de Neuchâtel Member.

In the MAND_02 borehole, it is currently observed in four samples which range from 185.05 to 164.6 metres depth (approximatively 20.45 metres thick). It consists in slightly argillaceous, nodular limestone, separated by thin marly interbeds. The texture is bioclastic, showing partly oolitic grainstones or packstones (Fig. 5.1).

Sample 29G (185.05-184.95 metres depth); *Sample 30G* (182.3-182.05 metres depth); *Sample 33G* (177.55-177.45 metres depth); *Sample 34G* (164.6-164.55 metres depth). The samples are quite similar in term of microfacies and consist in bioclastic grainstones to packstones rich in oncoids, briozoans, bivalves, brachiopods, benthic foraminifers, ostracods (Fig. 5.3A), and dasycladals. The cement is sparitic with debris flow deposits. The dasycladal fauna is represented by the *Angioporella neocomiensis* (Fig. 5.3B). The foraminiferal assemblage is characterized by rare undeterminated miliolids, trocholiniids, and orbitolinids (Fig. 5.3B).

BÔLE MEMBER

The Bôle Member is defined by an alternation of extremely fossiliferous yellow marls and cream-coloured limestone units (Fig. 5.1).

Sample 35G (158.85-158.75 metres depth). It consists in an undifferentiated abiotic mudstone. Although it might correspond to one of the marly layers of the Bôle Member, it is important to notice the absence of any bioclastic components. Indeed, marly levels of the Bôle Member are traditionally described as rich in faunal associations, including bivlaves, brachiopods, and echinoids.

Sample 37G (126.4-126.3 metres depth). It consists in a biomicrite rich in briozoans, large size bivalves and brachiopods, as well as rare foraminifers (Fig. 5.3C).

ROCHER DES HIRONDELLES FORMATION

The Rocher des Hirondelles Formation has been for the first time introduced by Pictet et al. (2021) in order to resolve the restricted sedimentary facies of the previously proposed Vallorbe Formation. Indeed, the white Urgonian facies seems to be arranged in successive lenses in forced progradation and encompasses three different members: the Fort de l'Ecluse Member, la Rivière Member, and Vallorbe Member. In the currently studied MAND_02 borehole, it measures around 60 metres thick (Fig. 5.1).

Upward in the section, the occurrence of very abundant large-size oribitoliniids together with rudist remains is typical of the Barremian sequence. The occurrence of *Orbitolinopsis* ?*debelmasi* in sample 40G, associated to the Vallorbe Member suggests an Early Barremian age for this part of the section.

FORT DE L'ECLUSE MEMBER

The Fort de l'Ecluse Member is proposed by Pictet et al. (2021) as the first photozoan carbonate platform unit of the Rocher des Hirondelles Formation. The lithology consists in massive beds of light yellowish to white limestone rich in bioclastic components. In the Mand_02 borehole, it is recorded in sample 38G only (Fig. 5.1).

Sample 38G. (121.9-122 metres depth). It consists in a biosparite with abundant benthic foraminifers and rudist remains (Fig. 5.3D and E). Brachiopods, bivalves, dasycladals and gastropods have also been recorded. This interval is characterized by the first occurrence of orbitoliniids such as *Orbitolinopsis* sp.

RIVIERE MEMBER

The Rivière Member is defined by an alternation of grey marls or fine-grained limestone rich in rudist remains (Fig. 5.1).

Sample 39G. (85-84.9 metres depth). It consists in a biomicrite rich in benthic foraminifers and rudists. This sample contains abundant open-sea taxa, such as rich specimens of Orbitolinids (Fig. 5.3F).

VALLORBE MEMBER

The Vallorbe Member is characterized by white, massive limestone, containing typical lagoonal fauna (Fig. 5.1).

Sample 40G. (84.2-84.3 metres depth) and *Sample 41G* (62-61.9 m). It consists in a biosparite with abundant large benthic foraminifers (Orbitoliniids type) and rudist remains. Brachiopods, bivalves, dasycladals and gastropods (Fig. 5.3G) have also been recorded in this interval. The foraminiferal assemblage in this interval is diversified and abundant (Fig. 2P). A few specimens of what seems to be *Orbitolinopsis ?debelmasi* (Figs. 5.3I-J) are recorded in this sample.

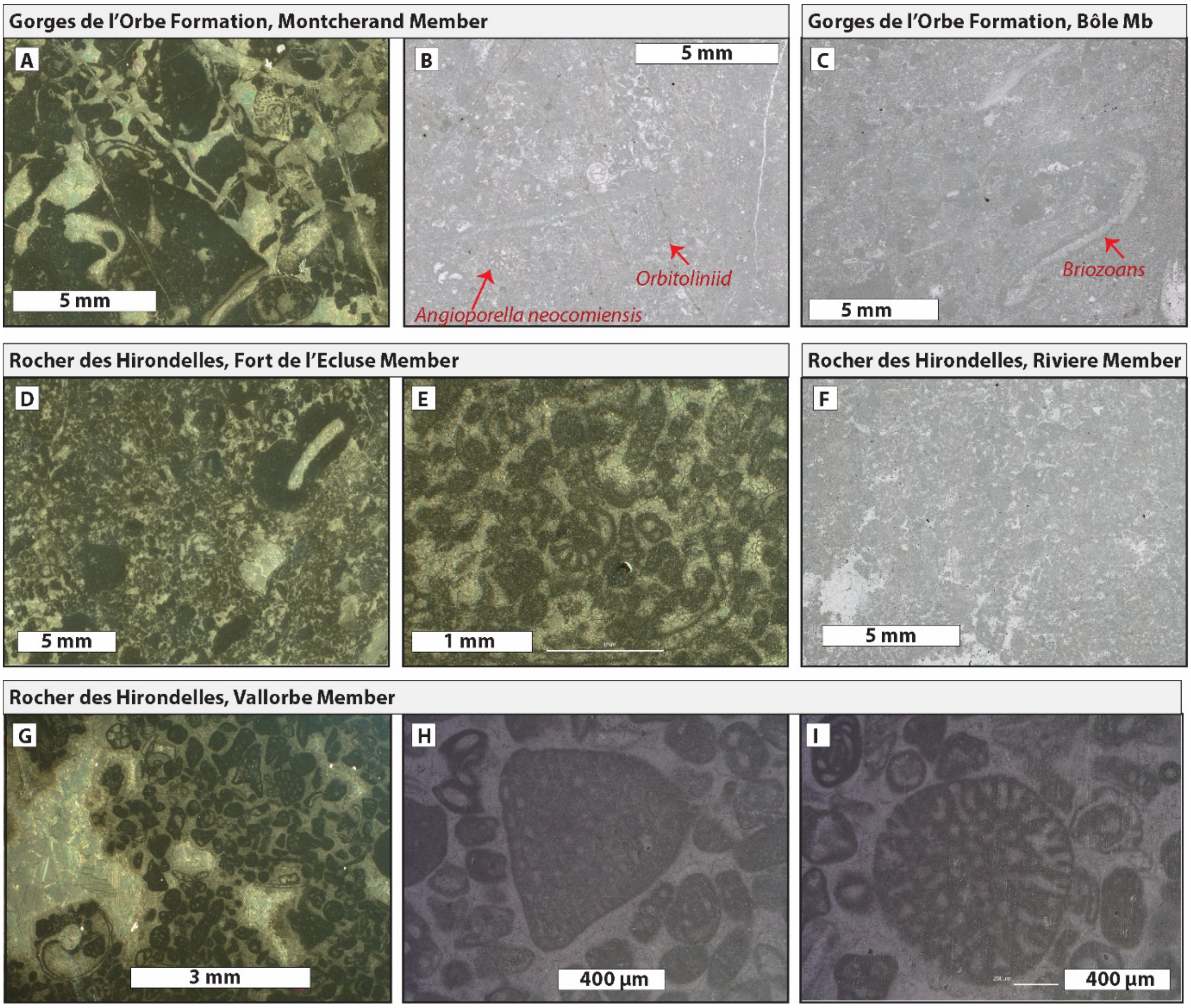


Figure 5.3. Urgonian, Microfacies. ***A and B.*** *Gorges de l'Orbe Formation, Montcherand Member (sample 33G and 33G.* ***C.*** *Gorges de l'Orbe Formation, Bôle Member (sample 37G).* ***D and E.*** *Rocher des Hirondelles Formation, Fort de l'Ecluse Member (sample 38G).* ***F.*** *Rocher des Hirondelles Formtion, Rivière Member (sample 39G).* ***G, H, and I.*** *Rocher des Hirondelles Formation, Vallorbe Member (samples 40G).*

MOLASSE

MOLASSE ROUGE

The Molasse Rouge is often divided into two units. The lower succession is dominated by clayey to partly silty limestone while the upper succession is comprised predominantly of sandstone with intercalations of marlstone. The basis of the Molasse Rouge has been visually attributed to about 60 metres depth. It allows to estimate the thickness of the Urgonian facies to about 125 metres (± 30 metres).

The lower unit of the Molasse Rouge has currently been recorded in sample 44G. (59.2-59.3 metres depth). It consists in reddish, abiotic, and continental clays.

MOLASSE GRISE

The Molasse grise is characterized by the increased amount of anhydrite/gypsum, intercalated in sandstone and marlstone of various grain sizes. The Molasse grise has currently been recorded in sample 61G (56-56.1 metres depth).

Figure 5.4. Mandallaz 2 core displaying the 97-millions years gap unconformity between the lower Cretaceous limestones and the Oligocene Molasse). The carbonates consist of the "Urgonian" micritic white limestones while the Molasse consists of clastic deposits associated with continental depositional environment.

5. Conclusions

5.1 Summary of Achievements

Between 2022 and 2025, the Geo-Energy Group (GE-RGBA) of the University of Geneva conducted a series of geological and geospatial studies in collaboration with CERN in support of the *Future Circular Collider (FCC)* project. The work presented in this report outlines the development, implementation, and outcomes of these activities.

The main achievements can be summarized as follows:

- Development of a **3D geological model** integrating seismic reflection, borehole, and geological mapping datasets, providing improved characterization of the Molasse, Cretaceous, and Quaternary units along the FCC trace.
- Establishment of the **U-SOLSTISS** cross-border subsurface database, integrating and harmonizing data from the Swiss SOLSTISS and French BRGM InfoTerre systems.
- Preparation and implementation of a **Data Management Plan (DMP)** and **Data Specification Requirements (DSR)** to standardize data acquisition, storage, and delivery.
- Execution of detailed **borehole data analysis**, including the sampling and interpretation of the MAND_02 core to refine the stratigraphy of the Molasse–Cretaceous transition.

Collectively, these deliverables provide a coherent and quality-controlled foundation for the geological interpretation and engineering design of the FCC subsurface infrastructure.

The harmonization of Swiss and French geological datasets under the U-SOLSTISS framework represents a significant achievement in cross-border data integration. This initiative enhances the reliability of subsurface information used for modelling and promotes consistent geological interpretation across administrative boundaries. The methodology developed, linking database management, data quality control, and 3D modelling, serves as a reference workflow for future geoscientific projects involving complex and heterogeneous datasets. The work has also contributed to improving communication and interoperability between institutional partners (UniGe, GESDEC, BRGM, and CERN).

The results obtained from 2022 to 2025 have considerably advanced the geological understanding of the Geneva Basin. The strong collaboration between the University of Geneva and CERN demonstrates the value of integrating academic expertise with applied geoscience to address complex engineering challenges. The methodologies, databases, and models developed through this partnership will remain essential tools for ongoing and future studies related to the FCC and other regional subsurface projects.

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APPENDIX 1: List of collected samples on the MAND02 core.

WELL No.	Sample No	Depth		First obs.	Unit	Member
MAND_02	62G	53,9	54	Molasse grise?		undefined
MAND_02	61G	56	56.1	Molasse grise		GRISE
MAND 02	60G	56.7	56.9	Molasse rouge		
MAND 02	44G	59.2	59.3	Molasse rouge		
MAND 02	44G	59.2	59.3	Molasse rouge	MOLASSE	ROUGE
MAND_02	43G	60.35	60.4	Molasse rouge		
MAND 02	42G	60.8	60.9	Molasse rouge		
MAND_02	41G	61.9	62	Molasse rouge	undefined	undefined
MAND 02	40G	84.2	84.3	Cretaceous		
MAND_02	39G	84.9	85	Cretaceous		BLANC
MAND_02	38G	121.9	122	Cretaceous		
MAND_02	37G	126.3	126.4	Cretaceous		
MAND_02	36G	155.5	155.55	Cretaceous		
MAND_02	35G	158.75	158.85	Cretaceous		undefined
MAND_02	34G	164.55	164.6	Cretaceous	URGONIEN	
MAND_02	33G	177.45	177.55	Cretaceous		
MAND_02	32G	180.75	180.85	Cretaceous		
MAND 02	31G	181.5	181.6	Cretaceous		
MAND 02	30G	182.05	182.3	Cretaceous		
MAND 02	29G	185.05	184.95	Cretaceous		JAUNE
MAND 03	59G	190.85	190.95	Cretaceous		
MAND 02	28G	191.95	192.05	Cretaceous		
MAND 02	27G	194.9	194.9	Cretaceous		
MAND 02	26G	195.05	195.15	Cretaceous		UPPER UNIT
MAND_02	25G	197.75	197.85	Cretaceous		
MAND_02	24G	198.25	198.35	Cretaceous		
MAND_02	23G	200.45	10.5	Cretaceous		
MAND_02	22G	200.75	201	Cretaceous	PIERRE JAUNE DE NEUCHATEL	UTTINS MARLS
MAND_02	21G	203.75	203.9	Cretaceous		
MAND_02	20G	203.65	203.75	Cretaceous		
MAND_02	19G	207.8	208.25	Cretaceous		
MAND 02	18G	208.35	208.55	Cretaceous		LOWER UNIT
MAND 02	17G	212.6	212.7	Cretaceous		
MAND 02	16G	219.15	219.25	Cretaceous		
MAND 02	15G	223.1	223.15	Cretaceous		
MAND 02	14G	224.9	225	Cretaceous		UPPER UNIT
MAND 02	13G	235.5	235.6	Cretaceous		
MAND 02	12G	237.55	237.6	Cretaceous		
MAND_02	11G	238.5	238.6	Cretaceous		
MAND_02	10G	240.95	241.05	Cretaceous		MIDDLE UNIT
MAND_02	9G	242.55	242.6	Cretaceous		
MAND_02	8G	244.6	244.6	Cretaceous	HAUTERIVE MEMBER	
MAND_02	7G	247.5	247.5	Cretaceous		
MAND_02	6G	248.55	248.6	Cretaceous		
MAND_02	5G	251.55	251.6	Cretaceous		
MAND 02	4G	255.95	256.1	Cretaceous		
MAND 02	3G	256.1	256.2	Cretaceous		LOWER UNIT
MAND 02	2G	262	262.05	Cretaceous		
MAND_02	1G	262.2	262.3	Cretaceous		