Guides

GEOLOGICAL AND HYDROGEOLOGICAL WALKOVER SURVEYS FOR TUNNELLING PROJECTS

Objectives, specifications, contractual organisation

December 2021

Centre d'Études des Tunnels (Centre for Tunnel Studies)

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INTRODUCTION

Guidelines and standards of practice on geotechnical studies place great importance on site inspections: French standard NF P94-500 and recommendation GT43R1F1 from AFTES stress the need for such inspections, in particular during the initial study phases of a tunnel project. Several inspection levels are possible, from a general overview of the site to check accessibility and the suitability of the site for the projected works, through to an in-depth geological and hydrogeological survey. Such an in-depth investigation comprises walkover field surveys. They provide information only accessible on site to an expert eye and help to set up, establish and substantiate the geological and hydrogeological models.

During the initial study phases of a tunnelling project, the development of these models is decisive in determining construction feasibility, the choice of possible tunnel routes and the construction methods envisaged. These models start out as preliminary conceptual models based on existing bibliographic elements and then become interpretative models based on the information collected in the field such as the geomorphology of the site, outcrops, anomaly indicators or the presence of water. Walkover surveys are part of initial site investigations and are easy to conduct as they do not require a particular installation or organization.

There are, however, prescriptive shortfalls with professional standards and recommendations describing these preliminary geological studies as indispensable on the one hand, but without clearly explaining the content of such studies, and academic publications on the other listing field observations, but without precisely defining how they are to be recorded and used.

It is these shortfalls that the current guide aims to fill. Primarily intended for project owners, it formally sets out the content of geological and hydrogeological walkover surveys. Most often conducted in the initial stages of a study, the main objectives of geological and hydrogeological walkover surveys are to:

- collect all information which can only be obtained out in the field (geomorphology, presence of outcrops or water, anomaly indicators), and record and process this information;
- develop or consolidate interpretative geological and hydrogeological models for the project. Linked to these main objectives are two corollary objectives that can be added. The first is the identification of the major uncertainties that could be a source of risk in light of the work planned. The second is the elaboration of the site exploration programme (other than walkover surveys) using geophysical means, probes, etc.

Field surveys are said to be “initial” when they are carried out from the first study phases (preliminary geotechnical studies G1 ES[1] “Site study” then G1 PGC “general principles of construction” to define geotechnical risks). They are said to be “complementary” when they are carried out in a subsequent phase to supplement existing knowledge (preliminary geotechnical study G1 or design study G2[1]).

There are three phases in the organization of these field surveys:

1. **A preparatory phase.** This phase is when the geological and hydrogeological context is determined in order to initiate the conceptualization of the site that is the subject of the surveys. Of course, this preparation phase firstly includes a desk study to look for and summarise existing knowledge and can be widened to include a photo interpretation study.

2. **An implementation and recording phase.** It is during this phase that the site is covered in the most exhaustive manner. The report on this phase includes all observations.

3. **A processing, interpretation and summarization phase.** Interpretations are proposed based on the data obtained in the preparatory phase and the data collected, processed and recorded in the field. These data are primarily used to draw up the geological and hydrogeological summary which transcribes the interpretative geological and hydrogeological models. Thus, the assignment report includes all the data collected and the summaries produced. Nowadays, digital technologies are clearly an essential part of this process: observations are summarised in data tables and mapping elements are drawn up using a geographic information system (GIS). The aim is to capitalize on the information and facilitate its use in subsequent phases.

This guide thus addresses the following points:

- preparations for walkover surveys involving bibliographical studies and photo interpretation studies;
- the implementation of geological and hydrogeological walkover surveys, and the recording and processing of data;
- the contractual organization of these walkover surveys in order to ensure they are run smoothly and efficiently.

1. *Within the meaning of NF P94-500.*

2

PREPARATION OF WALKOVER SURVEYS

A preparatory phase is required to achieve comprehensive and relevant walkover surveys. This phase enables the available elements to be assimilated, the large geological units and their relationships to be located, the main accidents and the geological history to be determined (how the site was formed, tectonics, geomorphology) and a view of the site to be obtained via aerial image data.

2.1 DEFINITION OF THE GEOLOGICAL AND HYDROGEOLOGICAL STUDY AREA

The geological and hydrogeological study area (Fig. 1) is the area from which the information is collected for use in developing geological and hydrogeological models. This study area is of necessity larger than the geotechnical influence area in order to be able to justify the latter, and depends on the geological and hydrogeological structures (hydrogeological watersheds) that may be of interest to the project.

At the end of the survey preparation phase, when there is sufficient knowledge of the geological structures, based on available documents, the service provider defines the perimeter of the study area. This perimeter is also confirmed at the end of the walkover surveys. If necessary, when drafting the contract, in addition to the geometric elements of the project and any variations thereto, the project owner may define a study area from the outset which can then be adjusted by the service provider upon completion of the preparation phase.

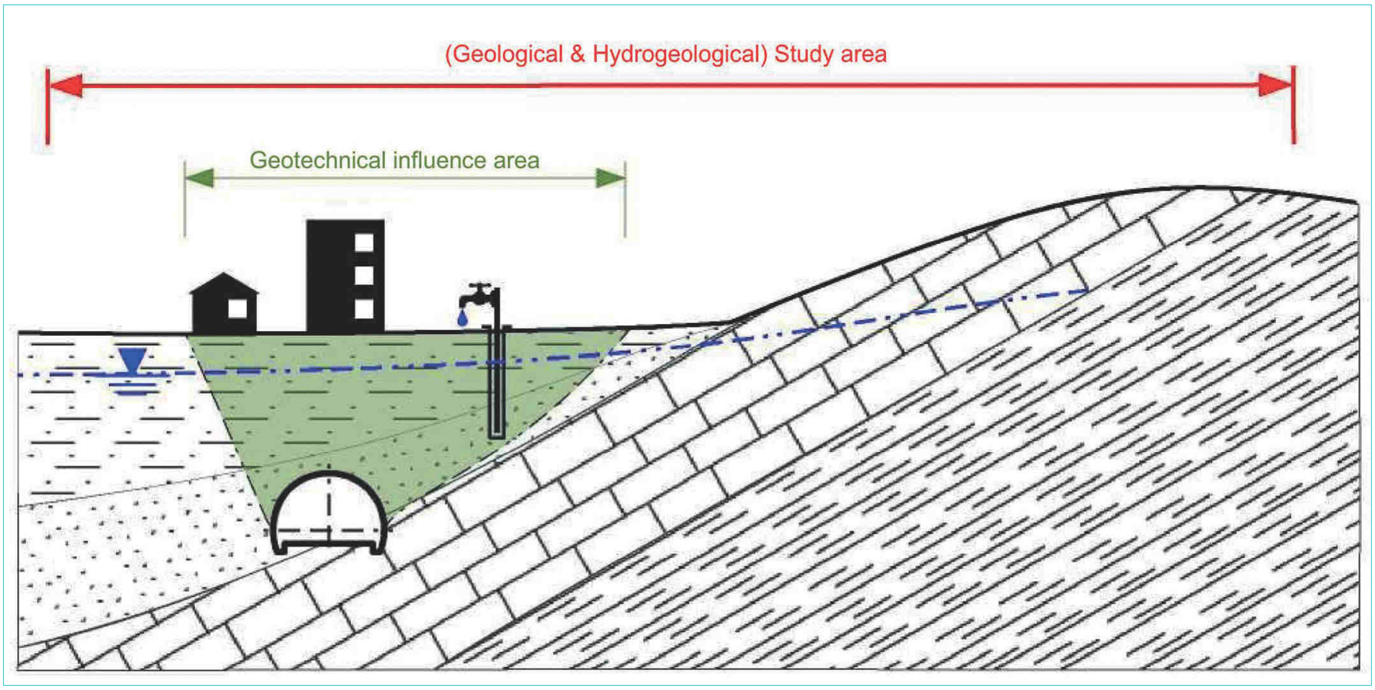


Figure 1: Definition of the geological and hydrogeological study area in relation to the geotechnical influence area.

The study area includes all geological and hydrogeological structures that may be of interest to the project. This expanded exploration area helps define the boundaries of the geotechnical influence area.

2.2 ADDITIONAL PREPARATORY STEPS

Within the scope of desk studies and prior to any visit to the site, the contractor must have at least a summary of existing knowledge and a photo interpretation study. These desk studies form the preparatory phase and can either form part of the overall “walkover survey assignment” or be ordered separately in advance as specific missions.

Research, knowledge gathering and assessment

This assessment is based on existing topographic, geological and hydrogeological maps, previous studies, articles, theses, etc. When summarised, these data enable a description and the general organization of the terrain encountered to be established (toponymy, morphology, stratigraphy, structural context, hydrogeological organization). The deliverable (knowledge report) includes the following chapters:

- **Data:** entry data not only in the form of a list of references consulted but also a digital directory comprising the associated documents;
- **Geology:** a chapter describing the structural context, the lithological log* and the characteristics of the terrain likely to be encountered;
- **Hydrogeology:** a chapter describing the presence of aquifers, flows and connections, seasonal regimes, the presence of springs and available permeability values.

Photo interpretation study*

The preferred data for the photo interpretation study are satellite, aerial or drone images. They are used directly and/or in stereoscopic vision (richer in information). When available, it is recommended to have images at different scales and taken on different dates. Having at least two different scales offers a contextual summary view (small scale of around 1/30,000 or more) and a detailed view (large scale of around 1/10,000). Images taken on significantly different dates enable the site evolution over time to be determined. IGN aerial archive images are freely available at remonterletemps.ign.fr.

In addition to aerial images, shaded topography images from digital terrain models (DTM*, LiDAR* or photogrammetric campaigns) can be used or the level lines from a very accurate DTM. However, special attention must be paid to ensuring that conclusions from their interpretation is not automatic.

The study of these data enables the geomorphology of the terrain to be analysed (delimitations of lithological and structural units by photo-geomorphology*, faults, folds), the lineaments* and the hydrographic network to be described, recent or active geodynamic evolutions to be identified (neotectonics, landslides observable by slope failures) and all observable anomalies to be detected (due to subsidence, karsts, old quarries, changes in vegetation type, moisture, variations in slopes, etc.).

In addition to the delivery of a data table and a map (development of a GIS*, Fig. 2) categorising all observations made, a photo interpretation note is to be provided in paper and electronic format, comprising:

- **the input data** with the references of the photographs, their paper prints;
- **the observation notes** of photographs and DTM* with key and indexed comments;
- **a summary** describing the lithological and structural units of the hydrographic network, lineaments and anomalies observed. The directions of the lineaments are summarised on a stereogram with weighting of their lengths to determine the main families.

Whether in the context of initial or subsequent walkover surveys, this preparatory phase leads to the production of a summary report. This report indicates the knowledge obtained through research and the photo interpretation study. This summary confirms the perimeter of the study area. Initial conceptual versions of geological and hydrogeological models are presented forming the first stage in the development of interpretative geological and hydrogeological models. Finally, the critical areas to be surveyed first are listed to confirm, supplement or on the contrary modify the most delicate points of the models drafted.

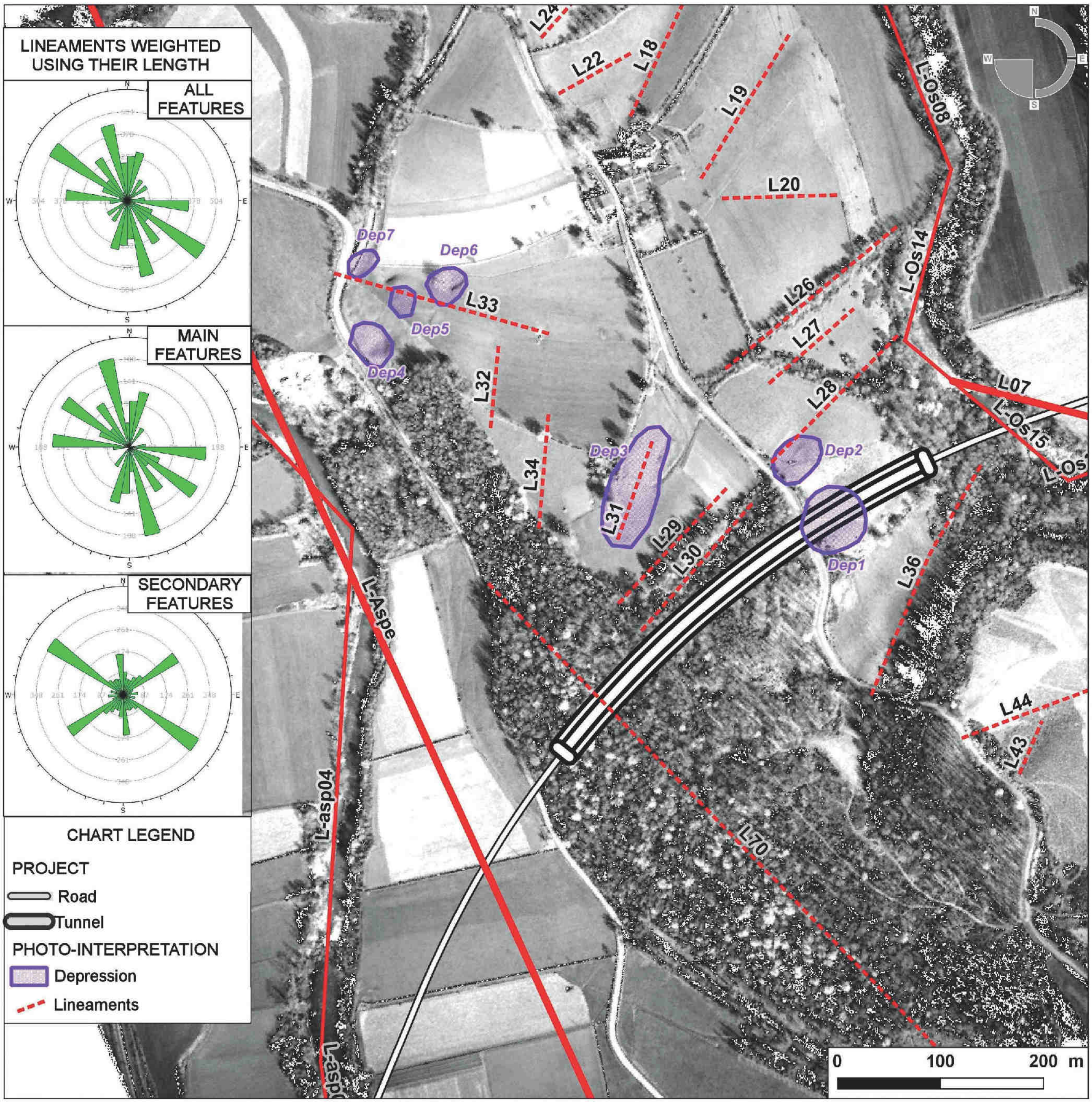


Figure 2: Example of a GIS deliverable of the photo interpretation study.

The lineaments (categorized according to their importance) and the anomalies each form vector layers integrated into a GIS*. The directions of the lineaments thus categorised are used for statistical purposes (in the example present on a study area wider than the area close to the tunnel depicted here).

3

CONDUCTING AND RECORDING WALKOVER SURVEYS

The walkover survey comprises surface explorations based on large-scale mapping (typically from 1/10 000 to 1/250, and up to 1/100 for land entries). The first stage of the walkover survey enables a comparison between bibliographic descriptions and in situ observations to be made. The subsequent steps are intended to collect and record the totality of information available only in the field. A map developed for a tunnel project differs from general geological maps since it is developed directly for engineering use: the characteristics of the terrain are considered in addition to their lithology and structure such as their degree of weathering or geotechnical differentiation within a given geological formation.

Particular attention should be paid to the condition of surface formations. The characterization of these terrains (including weathering) is often poorly or irregularly documented but is of particular interest in the case of tunnels in areas of shallow cover and at the level of entrances on the site.

3.1 ELEMENTS INCLUDED IN THE SURVEY ROUTE

The walkover survey route must be as comprehensive as possible and guided by the preparatory work. The first stage in understanding the site is to draw up one or more general sections in order to identify the different terrains and check, correct and complete the geological perimeters established during the preparatory phase.

From a geological point of view, the route should at least include an examination of all the indicators derived from the knowledge review and summary, along with the photo interpretation study to confirm/refute their existence. Additional observation points may be included along this route depending on the requirements and complexity of the site. The walkover survey is a key exercise where the geologist is able to build an overview of the geology of the terrain and its structure, and compare mapped elements with elements observed in situ, notably*:

- interpretations of panoramas, enabling the link between the landscape and the map analysis;
- outcrop (survey) analyses.

As regards hydrogeology, the walkover survey route should at least include an inspection of all the springs and watercourses identified during the preparatory phase.

As for other structures, the geologist uses the survey route to draw up an inventory and photograph them (even distant ones).

The information collected on outcrops is used to draw up a detailed description of the lithological log*, the structural elements (discontinuities) and any singularities: karst cavities, large blocks in a formation of fine soils, fault and crushed areas, weathering pockets in healthy rock, point water ingress, wet zones, etc.

3.1.1 Panoramas

Panoramas are an integral part of walkover surveys. These overviews of all or part of the survey area are interpreted depending on the structural units, major discontinuities, etc. They provide important information when the geology is visible and in part interpretable, particularly in difficult-to-access areas.

3.1.2 Outcrop mapping

The mapping of the observation points consists in identifying all the outcrops, recording their extent and noting the location of the viewpoints analysed. This mapping is used to immediately report the facts on which the interpretation is based (outcrops and panoramas). Inaccessible areas will thus naturally be highlighted, as will complex areas, thanks to the multiplication of observation points near to one other.

The survey of the outcrop begins with its contextual description, which includes photographs and an interpretative diagram of the outcrop or panorama to help decipher and record the observation. The survey then focuses on the description of rocky ground, loose formations and hydrogeological conditions observed:

- As regards rocky ground, the description includes the characteristics of the rock mass, its matrix and discontinuities according to the terms of the “Dictionnaire de Geologie” (Foucault et al., 2014), the AFTES GT1 recommendation and the ISO 14 689 standard.

The mass is described in its entirety, along with its weathering. Description of the rocky matrix includes its petrography and mineralogy from the geological map or in situ interpretation. Representative facies are sampled for further analysis and testing. Discontinuities are characterised by identifying the different families, estimating the lengths and fracturing frequencies, with measurements of dip vectors, by globally observing the apertures (possible fillings or evidence of crushing) and the presence of water. More detailed descriptions based on establishing measurement lines to compile statistics on spacings, extent, roughness, openings, and fillings, are obtained by conducting additional surveys;

- loose formations are described according to ISO 14 688 standards. The minimum description must provide the mineralogical and grain size characteristics of the hard elements on the site (including the maximum diameter);
- for hydrogeological conditions, the description includes the location of springs, losses, size of wetlands and an estimation of flow rates and associated water levels. Monitoring water levels, temperatures and conductivity is a specific task.

At the end of these observations, the outcrop is attached to a lithological log entity*.

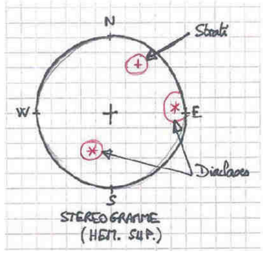
3.2 RECORDING COLLECTED INFORMATION

All the information collected on each observation point is noted on a survey data sheet (Fig. 3). This sheet includes the number of the observation point, its XYZ position, its attachment to the lithological log, photographs of outcrops, panoramas or nearby structures present, an interpretative diagram, description of the terrains and hydrogeological conditions. A stereogram can be included to supplement the description of the discontinuities. A data table of the observation points is established.

In addition to being integrated into the GIS, all graphic and photographic elements are also supplied separately in digital format with an explicit naming system.

The survey route (Fig. 4) is recorded in a data table (GIS) and a map is produced representing the route followed, the observation points and the extent of the observed outcrops, along with the main measures (stratification, schistosity, major faults).

<table>
<tr><td>Type and reference</td><td colspan="2"></td><td>OUTCROP</td><td colspan="2">C05</td></tr>
<tr><td>Date</td><td colspan="2">26/02/2017</td><td>X Y Z (L93-RGF93)</td><td colspan="2">308259 5237265 239</td></tr>
<tr><td>Geographic location</td><td colspan="5">Left bank of the river</td></tr>
<tr><td>Descriptions, comments, measures</td><td colspan="4">Alternation between limestones and marls (c4, Coniacien) with domination of limestones. Subjacent layer made of marl with a 2 m thickness almost clayey localy (bottom left of the picture

Stratigraphic measures : N20 42°, N19 37°, N19 43°
Measures of other discontinuities :
- N87 82°, N83 80°, N85 87°, N78 75°, N90 78°
- N192 46°, N194 48°</td><td>


</td></tr>
<tr><td>Photograph(s)

Top right: alternation between large limstones layers and thin layers of marls (c4, Coniacien).
Bottom left: 2m thick clayey layer.</td><td colspan="5">

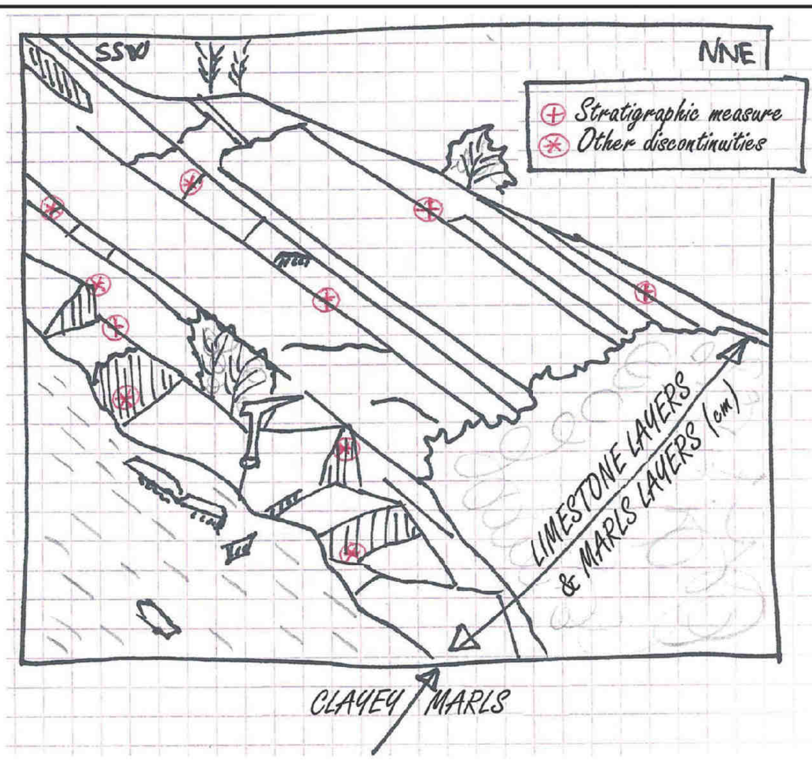
</td></tr>
<tr><td>Schema</td><td colspan="5">


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Figure 3: Example of a survey record.

Each observation point has its own survey sheet, which contains locations, descriptions, photographs and interpretations.

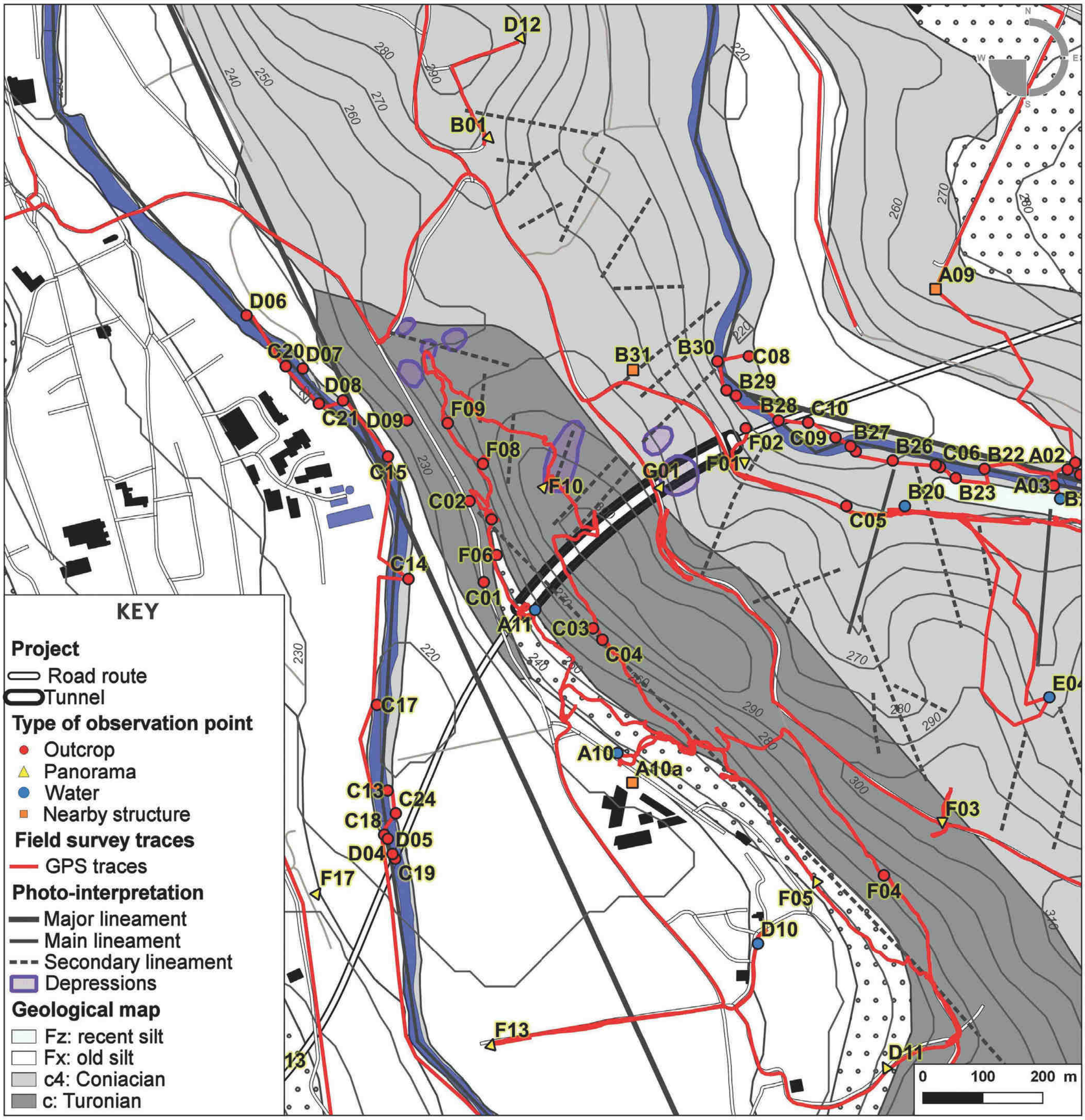

Figure 4: Example of an outcrop map on the geological map of the project being studied.

The observation points and the survey routes are indicated on the geological map, thereby highlighting the areas where information is lacking: the reliability of the geological map is thus apparent.

4

PROCESSING AND SUMMARIZING WALKOVER SURVEY DATA

Walkover surveys are designed to be an integral part of site investigations. They are the first tasks carried out and determine the need for subsequent geophysical surveys, probing and other investigations. Their integration is guaranteed thanks to the very first interpretative models produced at this stage of the site reconnaissance. These models will be supplemented, confirmed or refuted by the results of subsequent explorations.

The interpretative geological and hydrogeological models are established by confronting the rough conceptual models developed in the preparatory phase (existing geological map, geophysical data, probing and photo interpretation study) with data from the walkover surveys. These interpretative models are three dimensional with maps and cross sections to illustrate the understanding of how the geological structures are organized. These models must clearly highlight any specific features and uncertainties, as recommended by AFTES GT32R2F1.

Graphic media include interpretative geological and hydrogeological maps (with observation points) associated with one or more cross sections highlighting the organization and structure of the rock mass (interpretative geological cross section, showing the links between the lithological, stratigraphic and structural data) and the estimated level of the aquifers (interpretative hydrogeological cross section).

The report indicates the survey missions and conditions under which they were carried out (including outcrop surveys). It contains all the data recorded during walkover survey missions, geological and hydrogeological summaries and the description of the models through interpretative maps and cross sections. Uncertainties about the modelling are clearly identified. The report is structured with the following chapters:

1. the preparatory studies featuring the knowledge research and report, along with the photo interpretation study;
2. recording of observations;
3. the correction of photo interpretation data based on walkover survey observations;
4. the descriptions of the terrains encountered, the structural context and the conceptual model:
    - **terrains encountered:** the lithological log* is described exhaustively. The descriptions from the walkover surveys are linked to bibliographic descriptions. The characteristics of the terrains are illustrated by photographs of outcrops to depict the conditions of the rock mass and the morphology of loose formations, photographs of samples to illustrate the conditions of the matrix (rock mass) and the characteristics of loose formations, photographs of discontinuities to illustrate the categories of the wall (rock mass),
    - **geological structure :** a reminder is given of the major geological units, their relationships, the main accidents and their tectonic history. In the case of the rock masses, the structural context of the area under study is described by the representation and identification of families of discontinuities (Wulf or Schmidt stereograms, upper hemisphere). This interpretation links the walkover survey measurements of discontinuities with the lineament rose diagrams obtained from the photo interpretation study,
    - **interpretative model:** the maps and the interpretative geological cross section(s) (Fig. 5 & 6) are presented with an explanatory construction note. The uncertainties are represented on the model according to the AFTES GT32R2F1 recommendation (and Appendix 3). The uncertainties are described literally in the notice;
5. the hydrogeological description of the aquifers and the conceptual model:
    - **hydrogeological context:** a reminder is given of the bibliographic knowledge of the aquifers, the seasonal regimes observed where appropriate with a map of the springs and an estimate of the associated flow rates,
    - **interpretative model:** the maps and the interpretative hydrogeological section(s) (Fig. 7) are presented with a explanatory construction note. Similarly to the geological conceptual model, the uncertainties appear in the model and are described in the notice.

A debrief meeting is organised at the end of the mission to present all the work, the results and the description of the conceptual models proposed by the service provider.

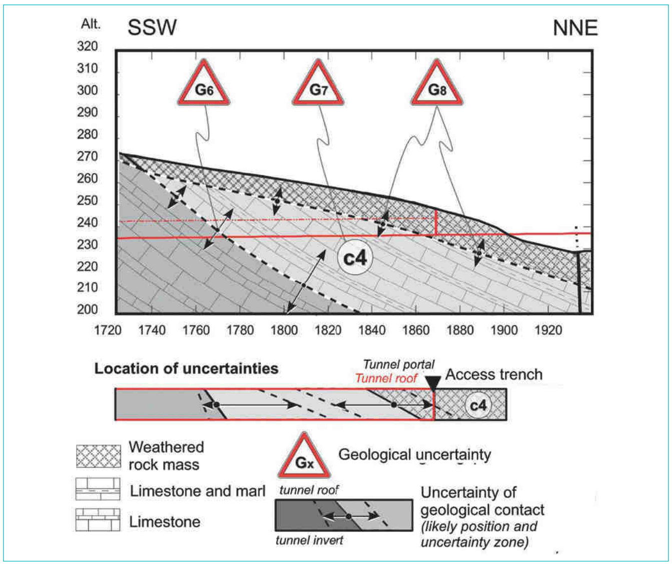

Figure 5: Extract from a longitudinal geological cross section (see Fig. 6 attached for full section).

Proof of the reliability of the geological model is given: the uncertainties and their extent are clearly highlighted.

5

CONTRACTUAL ORGANIZATION

High-quality walkover surveys necessarily take time, to prepare, conduct, record, use and summarize. When the order is placed, an initial estimate of the time required is made. It is advised to update this estimation when finalising details of the walkover survey to be conducted. This enables the owner's desire for quality work to be reconciled with the realities of the time needed to carry out the surveys. The following examples highlight cases where it may be necessary to readjust previous time estimations:

- the case of a specific knowledge search: the number of bibliographic documents is larger than originally anticipated. It takes more time to sufficiently understand and summarize these documents;
- the case of a specific photo interpretation study where the study area is extended or the number of good quality photographs of different types (infra-red or black and white) is larger than expected: the time required to study them is proportional to their number;
- the geological context is complex, requiring extensive interpretation with several intermittent walkover survey and data processing phases. This notion of complexity is important: the time spent on walkover surveys and high- quality data processing is directly correlated with the geological complexity.

The contract agreement must enable these adjustments to be integrated so that quality has precedence over contract management alone. The general objective is to define the geological and hydrogeological contexts. This objective can be achieved at the walkover survey stage, if the preparation, implementation and processing phases are correctly conducted, all three resulting in precisely defined deliverables. Bidders are invited to provide a technical brief explaining the means they intend to employ to achieve the objectives. Special care should be taken in drafting the contract to provide a flexible framework to allow for overruns where necessary.

The amount of preparation required for walkover surveys depends on existing data:

- existing knowledge will simply need to be reviewed and assimilated if all necessary documents are given to the service provider. However, if nothing is available, the provider must search for documents and other information. This specific mission will result in an intermediate deliverable (knowledge report) including bibliographic references and digital versions of all referenced documents (see §2);
- if photographs from a previous study are forwarded to the service provider, then the photo interpretation study consists in reviewing and assimilating the said photos. However, where such a study does not exist, it is the subject of a specific mission (see §2) involving the acquisition and study of images and the establishment of a possible DTM* over the study area. The observation notes and associated comments are intermediate deliverables.

Concerning payment, a distinction is made between desk studies and field missions (both of which may be paid for based on the time spent) and the related deliverables, which may be paid for on a lump-sum or unit basis. Table 1 summarises the details of the walkover survey services and the types of payment associated with them.

If the walkover surveys are part of a public procurement contract, the services fall under the General Administrative Provisions applicable to public procurement contracts for intellectual services (CCAG-PI), which must be set down in a contract. The most suitable type of contract is a framework agreement, as it enables flexibility with respect to the geological complexity of the project. This framework agreement is for one single contract awardee in its simplest version with purchase orders or with several awardees with subsequent contracts if specific missions become necessary in the course of performing the service.

	WALKOVER SURVEYS	PRICE
Preparation		
11	Mission – Knowledge gathering and assessment and/or photo interpretation study	j
12	Deliverable: assimilation note and identification of any specific needs	F
13	Intermediate meeting to present the preparatory phase (and adjust the study area if necessary)	U
Specific preparatory missions		
14	Specific Mission – Knowledge gathering and assessment (including document searches)	j
15	Literature study deliverable –input Data file (list and pdf documents)	F
16	Aerial photography (small scale mission + large scale mission covering the study area), aerial images, DEM*	U
17	Specific mission – conduct the photo interpretation study	j
18	Photo interpretation deliverables: input data, observation notes, GIS, geological and hydrogeological photo interpretation notes	F
Performance and recording		
21	Travel expenses	J + expenses
22	Mission - Walkover surveys carried out by a geologist	j
23	Deliverable (hardcopy and GIS formats) - Outcrop map, route followed and outcrop data sheets	F
24	Outcrop data sheets deliverable	U
25	Deliverable (hardcopy and GIS formats) – amended photo interpretation map	F
26	Deliverable (hardcopy and GIS formats) – Spring map, showing estimated flow rates	F
Survey exploitation		
31	Deliverable (hardcopy and GIS formats) – interpretative geological map	F
32	Deliverable (hardcopy and GIS formats) – geological cross-sections	U
33	Deliverable (hardcopy and GIS formats) – interpretative hydrogeological map	F
34	Deliverable (hardcopy and GIS formats) – hydrogeological cross-sections	U
Summary report and debrief		
41	Report including bibliographic and photo interpretation notes as well as geological and hydrogeological summaries	F
42	Feedback meeting	U

Table 1: Walkover survey services and type of remuneration (d for days, F for all-in package, U for unit).

6

GLOSSARY

Outcrop: part of a terrain visible on the surface for which a descriptive naturalistic observation is carried out, excluding organic soils.

Anomalies (indicators): significant geomorphological, structural and lithological variation due to the presence of geological heterogeneities, significant variation in humidity due to hydrogeological heterogeneities. These variations are detected by photo interpretation studies and confirmed by the walkover survey.

Geological map: representation on a topographic background of geological formations that are visible at the surface of the site, carried out specifically for the underground construction project.

BRGM Geological Map: geological map at a scale of 1:50,000 published by BRGM and covering the entire French mainland territory showing visible geological formations under organic soil according to a colour code based on their age and nature. Superficial formations (regoliths and quaternary deposits) are partly and irregularly figured.

Geomorphology: descriptive and explanatory study of relief forms.

LiDAR (Light Detection And Ranging): a topographical acquisition system enabling rapid acquisition of millions of points on the ground for modelling purposes.

Lineaments: alignment (decametric to kilometric in scale) having a structural (fault, stratum), geomorphological (talweg, cliff, slope break), hydrologic (hydrographic network) or unknown origin. They are demonstrated by photo interpretation or by an analysis of the fine topography (based on a LiDAR survey, for example).

Lithological log: graphic column representing the formations present in the geological and hydrogeological study area. It presents the oldest land at the bottom and the most recent above, with an indication of the level of erosion observed. The age and nature of each terrain are specified as well as the relationships between the formations (normal or discordant stratigraphic contact, overlapping fault contact, etc.).

DTM (Digital Terrain Model): representation of the topography of an area by a grid network of elevation points.

Observation point: location for which a naturalistic observation is made from a panorama or outcrop.

Photo interpretation (study): an analysis that results from the observation of aerial photographs, satellites and the use of a DTM. Most often the photographs are observed in the stereoscope by pair. From the resulting relief view, assumptions about geology and hydrogeology can be drawn using morphological arguments.

GIS (Geographic Information System): an information system designed to collect, store, process, analyse, manage and present all types of spatial and geographic data.

GZI (Geotechnical Zone of Influence): volume of land within which there is interaction between the structure (construction and exploitation) and the environment (soils and nearby structures). Its shape and extension are specific to each site and each construction.

Study area (geological and hydrogeological study area): area of the territory around the underground construction project used to collect information useful to establish geological and hydrogeological models.

7

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APPENDICES

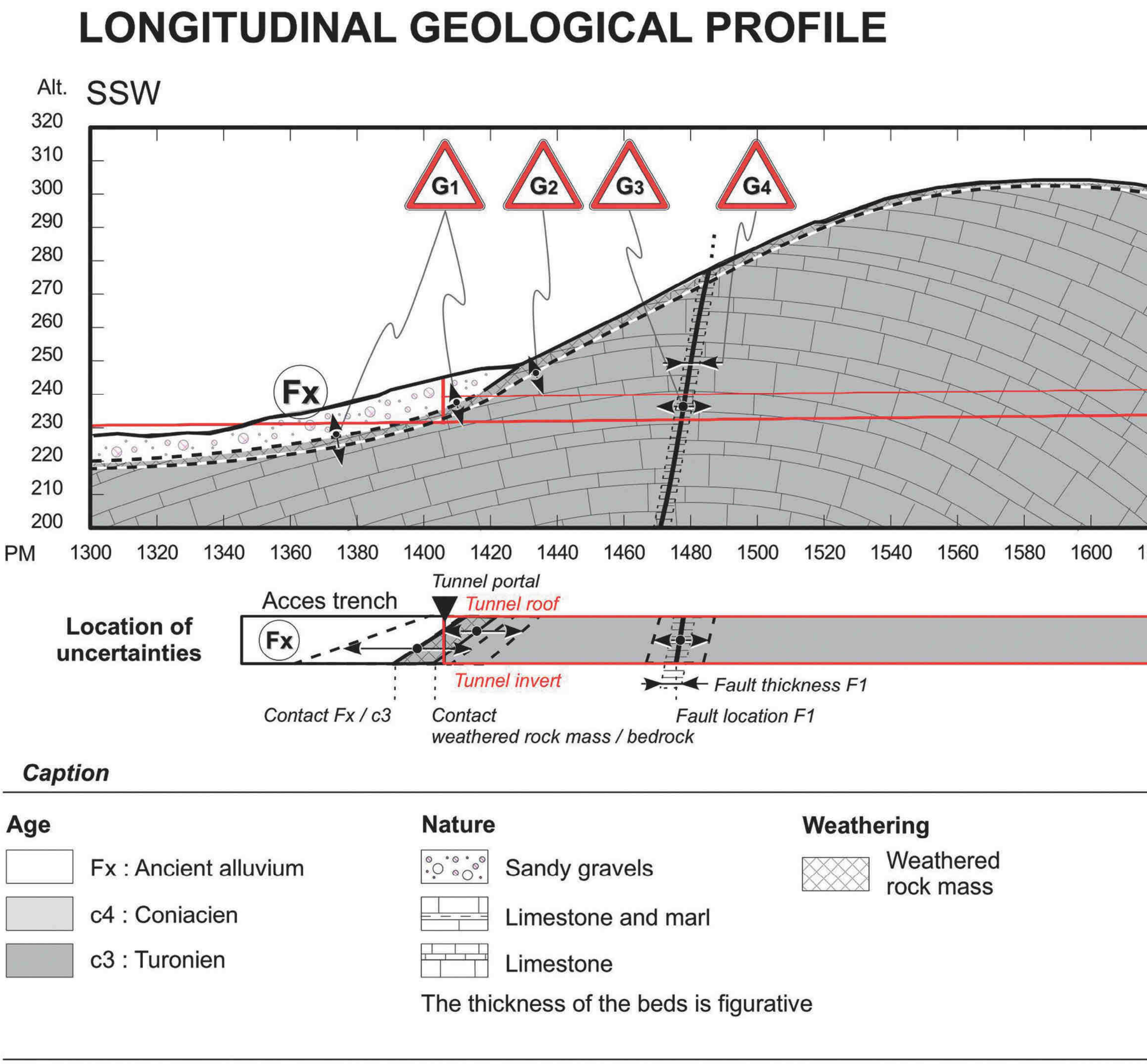
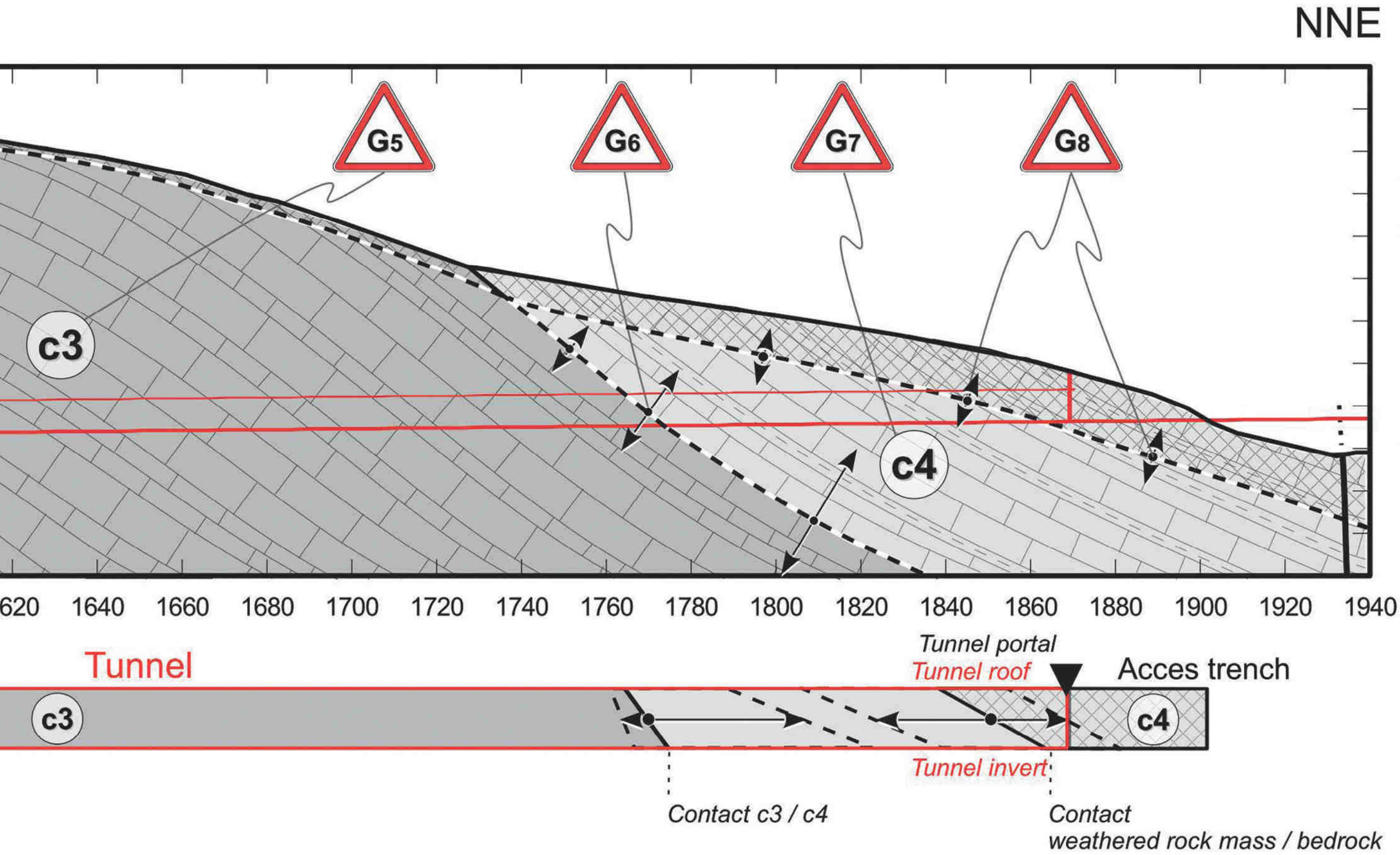
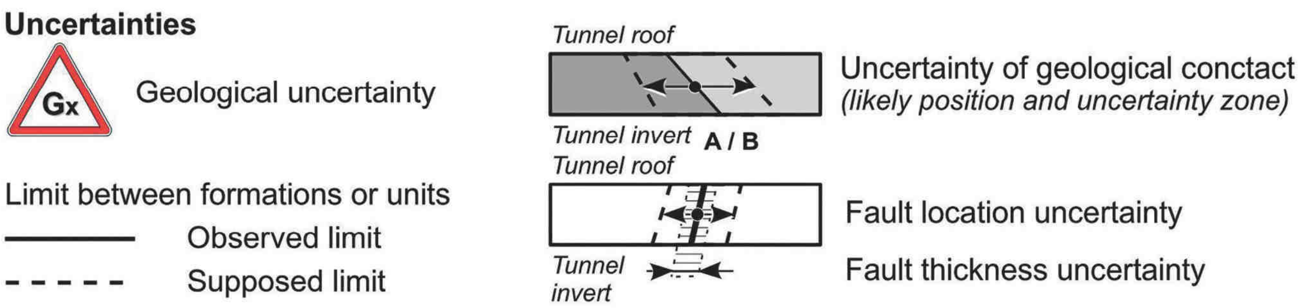


Figure 6: Example of a geological model from a field survey campaign.

The model is represented as a longitudinal section and highlights the different uncertainties (distinction between observed and supposed limits). Their extensions are explicitly quantified and represented.
The link is made by a specific sign (here "warning" signs) between the uncertainties indexed in the report and their spatial location on the model.
The geological model includes the weathering model and the superficial formations on the emerging elements in particular.
The location of uncertainties on a longitudinal section specifies the contacts, faults and singularities encountered when boring the tunnel.


NNE
320
310
300
290
280
270
260
250
240
230
220
210
200
G5
G6
G7
G8
c3
c4
620
1640
1660
1680
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
Tunnel
Tunnel portal
Tunnel roof
Acces trench
c3
c4
Tunnel invert
Contact c3 / c4
Contact
weathered rock mass / bedrock


Uncertainties
Gx
Geological uncertainty
Limit between formations or units
Observed limit
Supposed limit
Tunnel roof
Tunnel invert
A / B
Uncertainty of geological conctact
(likely position and uncertainty zone)
Tunnel roof
Tunnel
invert
Fault location uncertainty
Fault thickness uncertainty

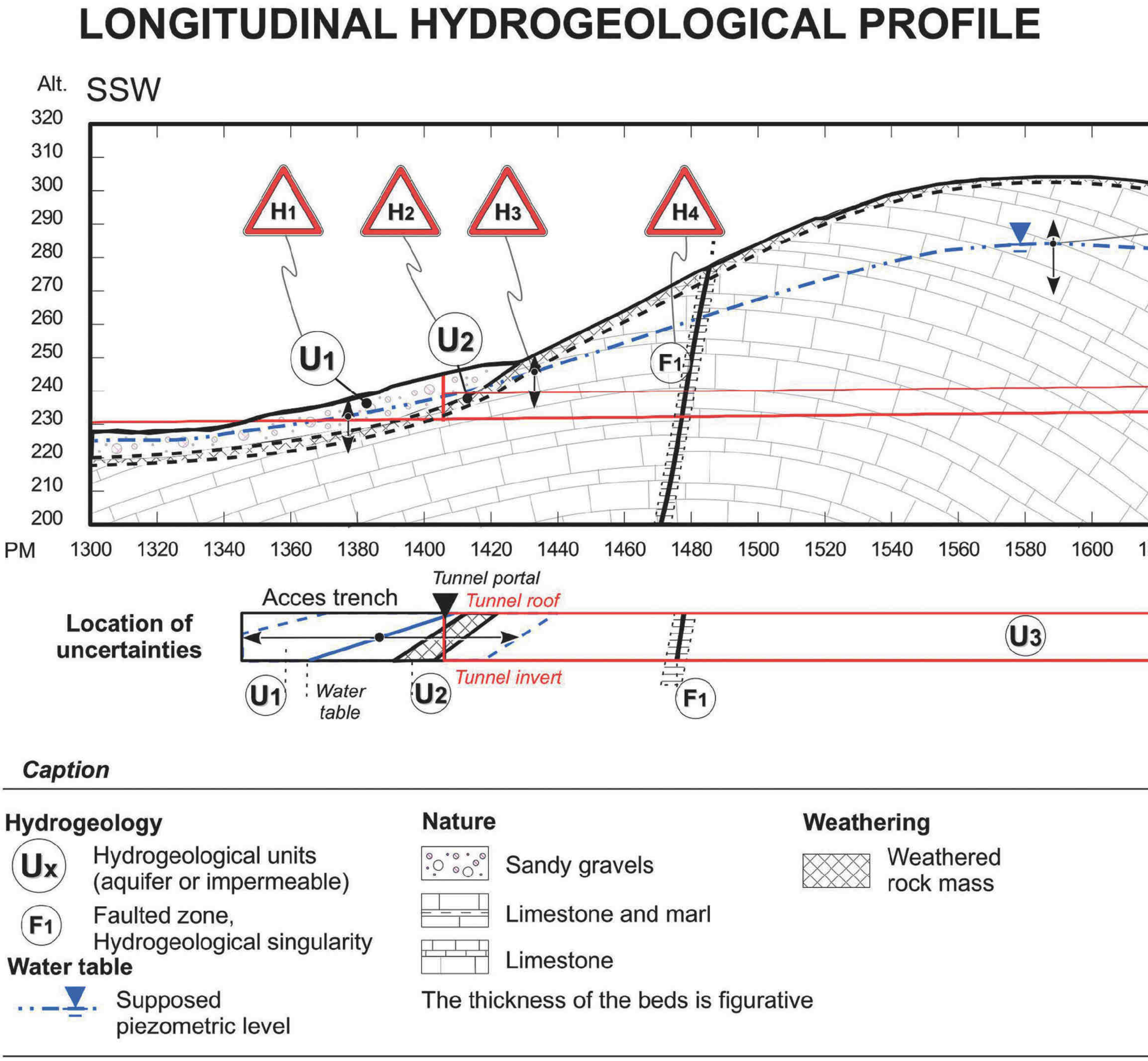
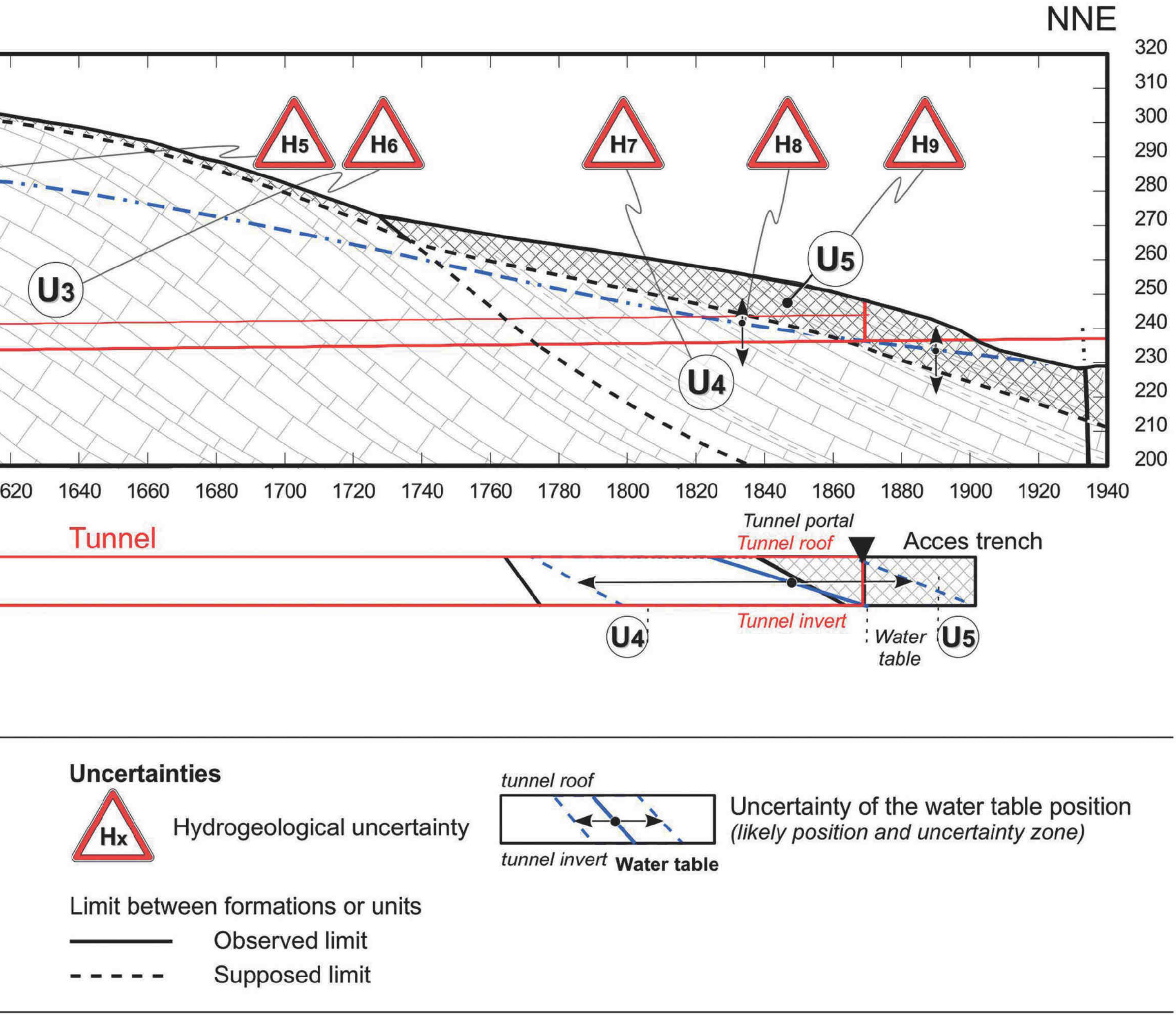


Figure 7: Example of a hydrogeological model from a field survey campaign.

The hydrogeological model is based on the geological model from which some of the geological uncertainties have been removed to focus on just the hydrogeological uncertainties.
The model includes at least the groundwater heights and the identification of the different hydrogeological units and singularities. As with the geological model, the link is made between the uncertainties indexed in the report and their spatial location on the model (here by "warning" symbols).


NNE
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H5
H6
H7
H8
H9
U3
U4
U5
620
1640
1660
1680
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
Tunnel
Tunnel portal
Tunnel roof
Acces trench
Tunnel invert
U4
Water table
U5
Uncertainties
Hx
Hydrogeological uncertainty
tunnel roof
tunnel invert
Water table
Uncertainty of the water table position
(likely position and uncertainty zone)
Limit between formations or units
Observed limit
Supposed limit

NOTES

CONTRIBUTORS

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