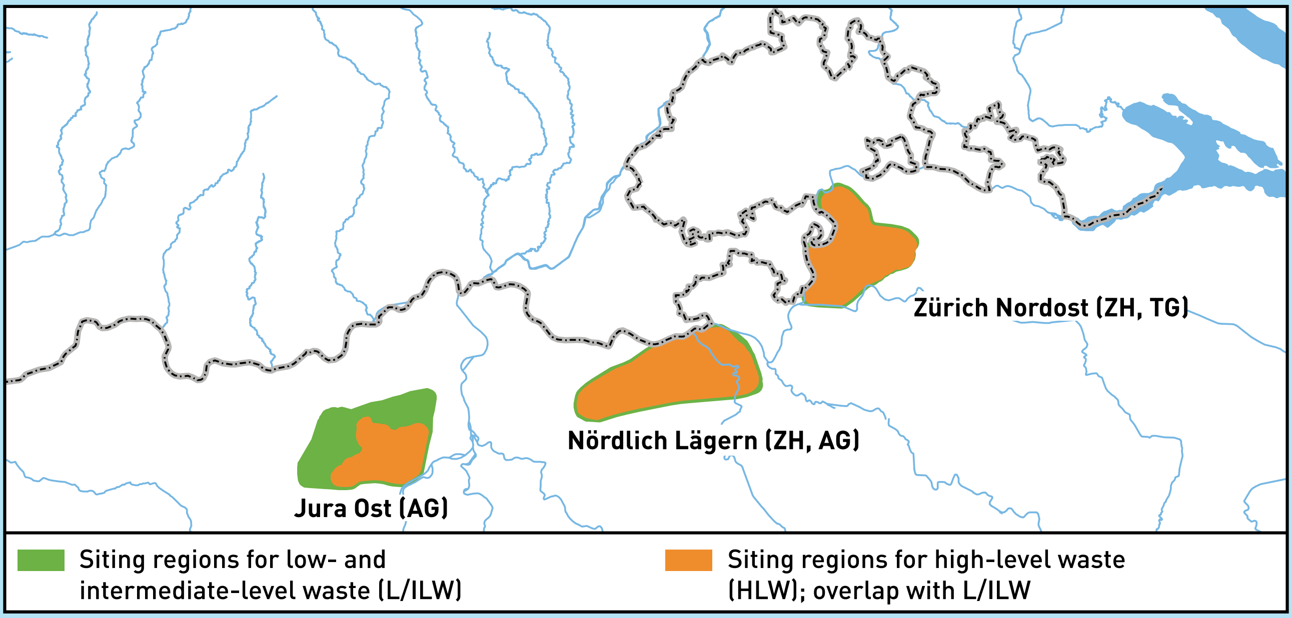
deep boreholes

for geoscientific investigations

nagra we care

Imprint

About this brochure



Nagra is planning a series of exploratory boreholes (specifically: deep boreholes) in the three potential siting regions Jura Ost, Nördlich Lägern and Zürich Nordost. Drilling of the first boreholes is scheduled to start in early 2019.

This brochure describes the purpose of the boreholes and the different phases of the drilling activities. It also includes an introduction to different geoscientific investigation methods and explains how the results provide input for the safety-based comparison of the siting regions to be carried out by Nagra in the third and final stage of the site selection process for deep geological repositories.

A selection of the terminology used in this brochure can be found in the Glossary starting on page 24.

Deep boreholes for geoscientific investigations
Nagra publishes special brochures on nuclear waste disposal at
irregular intervals
February 2019

Cover picture: Julia Buschbeck - scientific illustrations

Step by step towards the

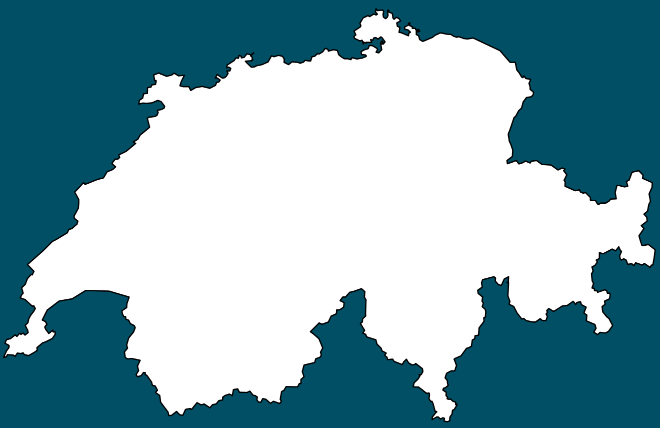
In the Sectoral Plan for Deep Geological Repositories, the Federal Government specifies how to proceed with the search for repository sites in Switzerland.

The Swiss Federal Office of Energy (**SFOE**) has the lead in the site selection process. The Swiss Federal Nuclear Safety Inspectorate (**ENSI**) monitors **Nagra's** site investigations, and the Expert Group on Nuclear Waste Disposal (**EGT**) supports ENSI. The Federal Nuclear Safety Commission (**NSC**) advises the Federal Council, the Federal Department of the Environment, Transport, Energy and Communications (**DETEC**) and ENSI on questions of nuclear safety. Other involved parties include: Cantons, communities located in the siting regions, neighbouring countries and the public.

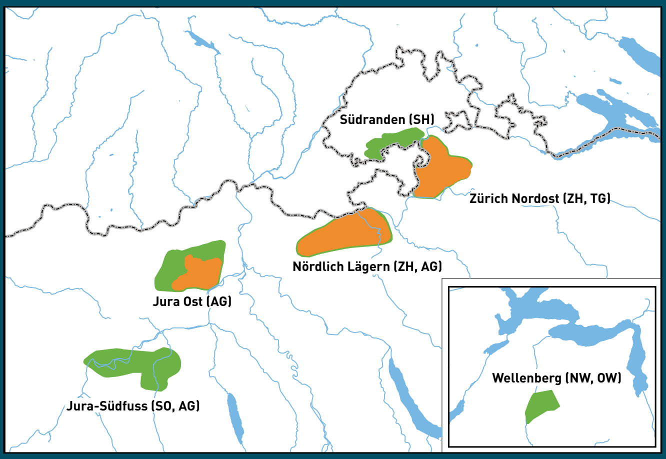
In **Stage 1** of the Sectoral Plan – and beginning with a blank map of Switzerland – Nagra identified suitable large geological areas and potential host rocks. In **2008**, Nagra proposed the following siting regions: Jura Ost, Nördlich Lägern and Zürich Nordost for a HLW and a L/ILW repository and, in addition, Jura-Südfuss, Südranden and Wellenberg for a L/ILW repository. After a broad consultation process on the results of Stage 1, the Federal Council decided at the end of November **2011** to consider all six, or three, potential siting regions for further investigation.

Following a safety-based comparison in **Stage 2**, Nagra recommended keeping two of the siting regions, Jura Ost and Zürich Nordost, for further geoscientific investigation in Stage 3. In **2016**, the Cantons and ENSI also recommended further investigation of the Nördlich Lägern siting region in Stage 3. On 21st November **2018**, the Federal Council decided that all three siting regions should undergo further investigation in Stage 3.

Starting point: Blank map of Switzerland / selection criteria: safety and engineering



Decision of the Federal Council on Stage 1



goal

In the **third and final stage** of the site selection process, the remaining three regions will be investigated in depth. This is necessary to allow a comprehensive safety-based comparison between the siting regions.

The investigation programme includes the previously conducted seismic surveys as well as Quaternary investigations and deep boreholes. The purpose of the boreholes is to complete the overall geological picture of the siting regions.

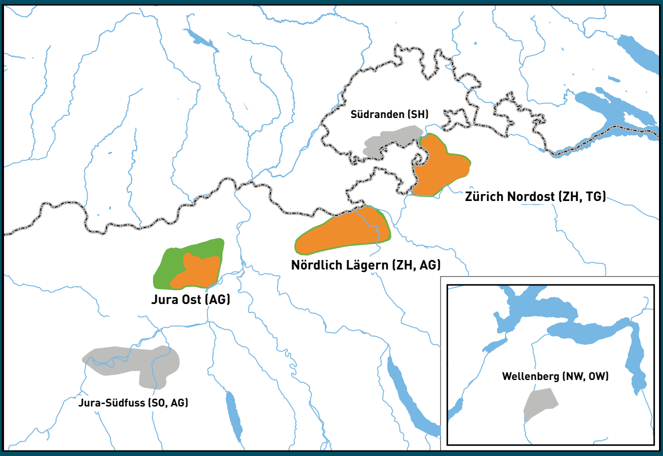
The focus of the geoscientific investigations in the deep boreholes is to determine the depth, thickness, permeability and composition of the Opalinus Clay selected as the host rock for the deep geological repository. The properties of the confining geological units located directly above and below the Opalinus Clay are also of great interest.

The additional knowledge gained from the deep borehole investigations will help Nagra to select the siting regions for which it will prepare general licence applications* (see Glossary). These applications are expected to be submitted in 2024. After a detailed review by ENSI, the Federal Council (around 2029) and then Parliament will decide on the general licence applications. The decision of Parliament is subject to an optional national referendum.

* L/ILW, HLW repository or combined repository

feasibility

Nagra's proposals and ENSI's safety-based assessment for Stage 2



General licence applications for a L/ILW and a HLW repository or for a combined repository

?

Investigations for the sa

To compare the siting regions, Nagra must conduct geological investigations to find the answers to important questions about the geological underground, such as:

Is there sufficient space for a deep geological repository?

Seismic measurements provide a detailed image of the geological underground. 3D seismics, for example, can determine the stratification of the rock layers over a large area. This helps to evaluate how much space is available for a planned repository and whether any features such as faults might limit this space.

How thick are the host rock and the confining geological units?

A deep borehole investigates the geological barrier, or the so-called "containment-providing rock zone", of a site. This includes the Opalinus Clay host rock and the adjacent layers of impermeable rock (confining geological units) that retain the radioactive substances, the so-called radionuclides (see Glossary). Deep boreholes provide accurate data about the thickness of the penetrated layers.

How are the rocks structured?

Samples of the penetrated rocks can also be recovered from deep boreholes. By analysing these samples and conducting different measurements in the borehole, it is possible to obtain information on, for example, hydraulic conductivity and the chemical composition of the rocks.

How deep should the repository be constructed?

Seismic surveys and deep borehole investigations in the siting regions do not provide all the answers. To evaluate the long-term safety of a deep geological repository, Quaternary investigations are also needed to examine the most recent history of the Earth. This includes erosion processes such as those of glaciers once located in the siting regions, which helps to assess at what depth a deep geological repository has to be located to be sufficiently protected from future erosion.

Table
Various investigations provide data for the safety-based comparison of the siting regions.

Figure 1
From top left to bottom right: Experiments in rock laboratories, Quaternary boreholes, field studies and seismic measurements (photos: © Comet Photoshopping, Dieter Enz; Nagra; Ernst Müller; Beat Müller)

fety-based comparison

The Sectoral Plan specifies 13 criteria divided into four main groups for the safety-based comparison of the siting regions.

Criteria	**Investigations**	Deep boreholes	3D seismic measurements	Quaternary investigations	Experiments in rock laboratories	Laboratory experiments, natural analogues
Properties of the host rock (or of the containment-providing rock zone)	Spatial extent	🟢	🟢	🔵		
	Hydraulic barrier effect	🟢			🟢	🟠
	Geochemical conditions	🟢			🟢	🟢
	Release pathways (see Glossary)	🟢	🟠		🟢	
Long-term stability	Stability of the site and rock properties	🔵	🟢	🟢		
	Erosion	🔵		🟢		🔵
	Repository-induced effects (see Glossary)	🟢			🟢	🟠
	Conflicts of use (see Glossary)	🟠	🟢			
Reliability of geological findings	Ease of characterisation of the rocks	🟢			🟢	
	Explorability of spatial conditions	🔵	🟢			
	Predictability of long-term changes			🟢		
Engineering suitability	Rock-mechanical properties and conditions	🟢			🟢	🟢
	Underground access and drainage	🟠	🟠			

🟢 Key information

🟠 Important additional information

🔵 Supporting information

What is investigated with

The investigations focus on the Opalinus Clay host rock and the confining geological units lying directly above and below it. The properties investigated include thickness, depth, composition and permeability.

How thick are the rock formations and at what depth are they located?

A geologist processes and examines the drill cores (see Figure 2) as well as fragments of rock, so-called drill cuttings (see page 18), extracted from the deep boreholes. He keeps a record of the drilling procedure and creates a drilling profile that is as complete as possible.

The rock types are identified directly at the drill site. In this way, it is possible to continuously measure the thickness of each penetrated rock layer and determine at what depth it is located.

It is important to accurately measure the thickness and depth of the Opalinus Clay host rock in which the repository will be constructed. Based on pres-

a deep borehole?

ent-day understanding, the Opalinus Clay layer is around 100 metres thick in all three potential siting regions. Depth is an important factor in providing protection from future erosion.

What is the composition of the rock layers?

During the drilling phase, the composition of the rocks will be determined through measurements in the borehole and in the laboratory. Analyses include the rock type, the proportion of different minerals, the clay content, etc.

Natural gamma radiation: an indicator of hydraulic conductivity and clay content
Measuring the natural gamma radiation in rock is an important borehole investigation (see Figure 3). Every rock contains natural radioactive isotopes (see Glossary) that emit gamma radiation upon decay. When the rock type changes, e.g. from a calcareous rock to an argillaceous rock, the natural radioactivity changes along with it. This allows the interfaces between the different rock types to

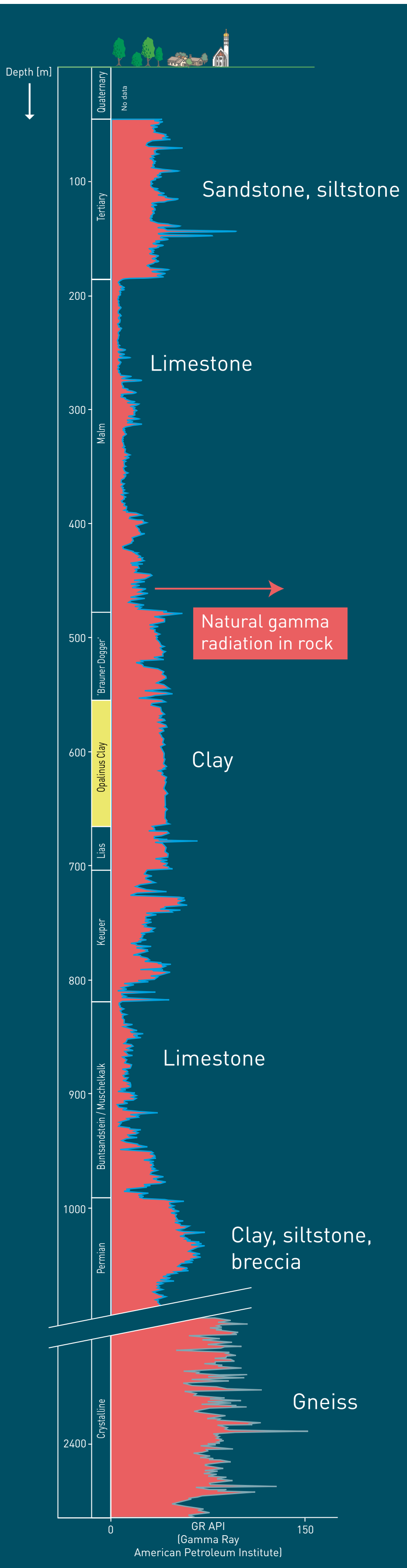


Figure 3
Measuring the natural gamma radiation allows the interfaces between different rock types to be determined in boreholes, as can be seen for the example of the deep borehole in Weiach (Zürich lowlands). The Opalinus Clay, the host rock for a deep geological repository, is highlighted in yellow.

Figure 2
Page 8, left: Drill cores are cleaned and photographed. The drill core shown here was extracted from the borehole in Benken from a depth of approximately 945 metres (photo: Nagra).
Page 8, right: A geologist measures and documents the extracted drill cores (photo: © Comet Photoshopping, Dieter Enz).

be identified. Measuring the gamma radiation allows conclusions to be drawn on the clay content of the rocks because clay minerals contain potassium, which has a high proportion of radioactive isotopes. The clay content of a rock determines its degree of permeability. Clay minerals are also important for the retention of radionuclides from radioactive waste.

Thin sections: Examining rock under a microscope
Thin sections are prepared from rock samples sawn out of the drill core. They are around thirty micrometres thick, which is equivalent to half the diameter of a human hair. Special microscopes are used to examine the thin sections, making it possible to determine, for example, the distribution of the different minerals in the rock as well as their orientation. Conclusions can then be drawn regarding the rock type and, by looking at the fossils, it is possible to determine its age and even potential migration paths for radionuclides.

How permeable are the rock formations?

The permeability of the host rock should be as low as possible. This is one of the most important properties of the Opalinus Clay and the confining geological units. It prevents radionuclides from being transported with water. One method for determining permeability is so-called "packer testing".

Packers (see Figure 4) are an essential tool for deep borehole investigations that allow selected sections (so-called test intervals, see Figure 5, right) to be isolated in a borehole. The isolated test interval can be accessed by cables, for example for measuring probes.

Figure 4
The dark section of the packer between the blue metal parts is made of rubber and is used to seal the borehole (photo: Nagra).

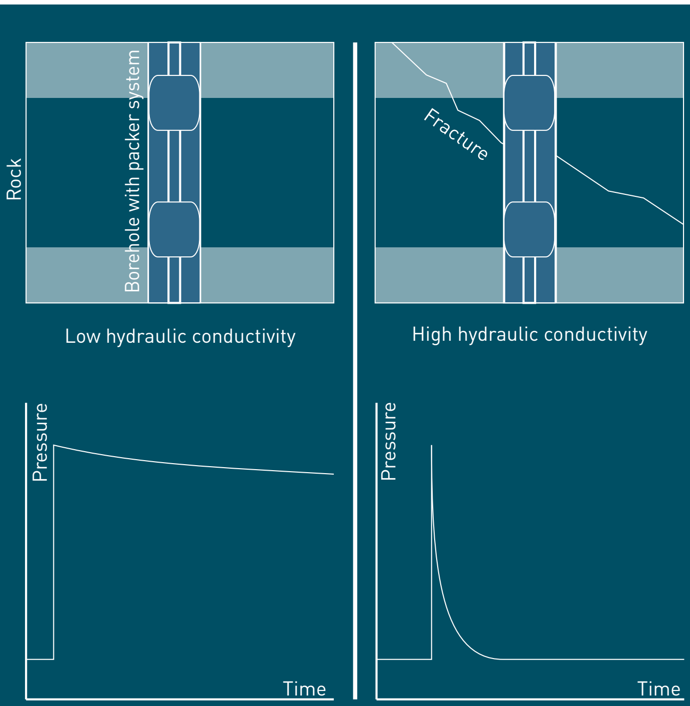
Figure 5
Page 11, right: Schematic diagram of a double packer system. In the isolated test interval, it is possible to determine the hydraulic conductivity of the rock or to take water samples in permeable rock.
Page 11, left: Principle of a measurement to determine the hydraulic conductivity of two different rocks.

Hydraulic conductivity: The ability of water to move through rock

To determine hydraulic conductivity, the pressure is increased in the test interval. In rock that has a low conductivity, the pressure in the test interval remains constant or decreases only slowly. By contrast, the pressure decreases rapidly when the rock is highly permeable (see Figure below).

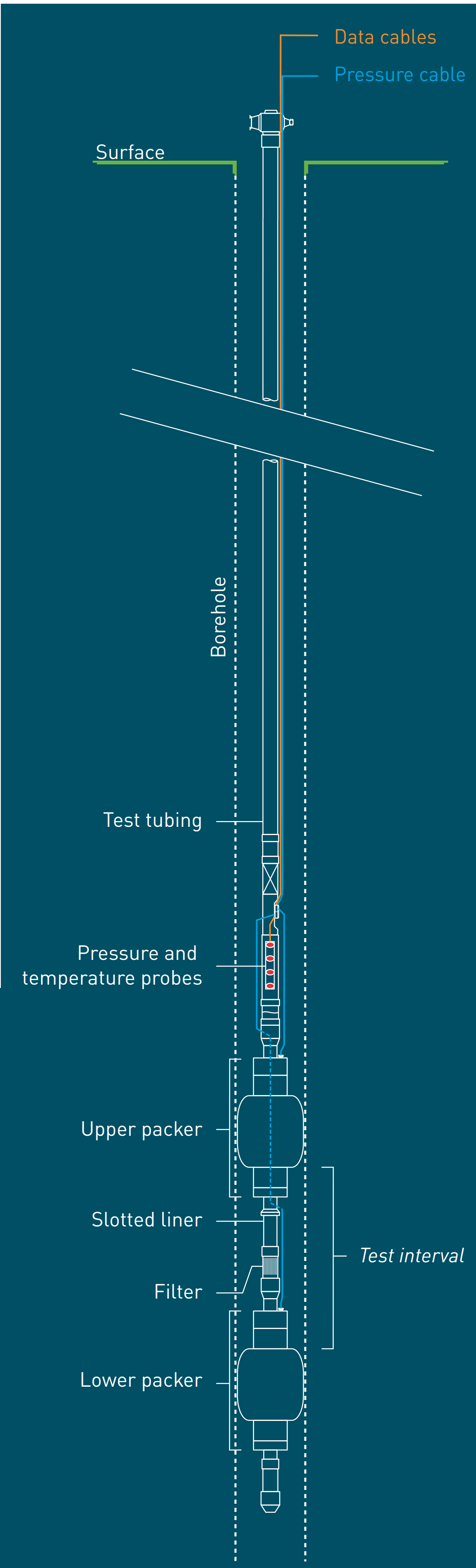
Hydrochemistry: Chemical analysis of water samples

Samples of the groundwaters present can be collected in permeable rocks. These water samples undergo hydrochemical analysis, meaning the analysis of dissolved substances and gases. It is thus possible to determine factors such as age and the residence time of the waters.



Low hydraulic conductivity

High hydraulic conductivity



In impermeable rocks such as Opalinus Clay, extracting a sample to examine the water contained in the pores is a complex procedure (see Figure 6). The substances contained in the porewater provide an important insight into the age of the waters. Examining the porewaters also provides information on how dissolved substances can migrate through rock formations by diffusion. Based on this, the retention properties can be assessed more accurately.

Age of porewaters provides information relevant for long-term safety

Opalinus Clay is a good example. The approximately 173 million-year-old rock still contains 10 to 20 grams of dissolved salt water per litre of porewater. This salt comes from the ancient sea in which the Opalinus Clay was originally deposited. The fact that seawater was confined in the rock over many millions of years demonstrates how well Opalinus Clay can confine substances.

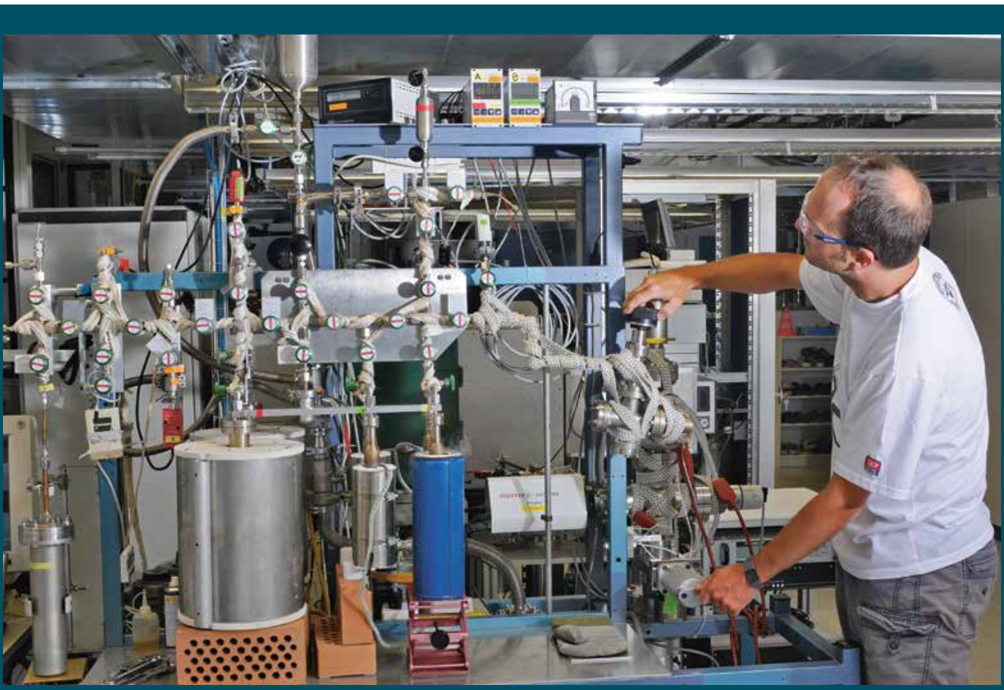


Figure 6
Extracting porewater from rock to analyse its components can be a complex procedure (photo: © Comet Photoshopping, Dieter Enz).

Seismic and borehole investigations: Complementary data

3D seismic measurements provide images of the underground geometry, depicting the boundaries of the rock layers (see Figure below left).This method does not, however, define the properties of the rocks in detail. Only boreholes can allow direct investigation of rock properties (see Figure below right). By combining the two methods, an accurate image of the underground geology emerges.

The rocks encountered in the borehole (drilling profile) are examined and their physical properties are determined. Based on this, a synthetic seismogram can be calculated. Borehole seismics are conducted in the borehole and a vertical seismic profile (VSP) is generated. The results of these investigations can be used to calibrate the results of the 3D seismics.

It is thus possible to gain deeper knowledge of the rock layers as well as of the spatial and tectonic conditions.

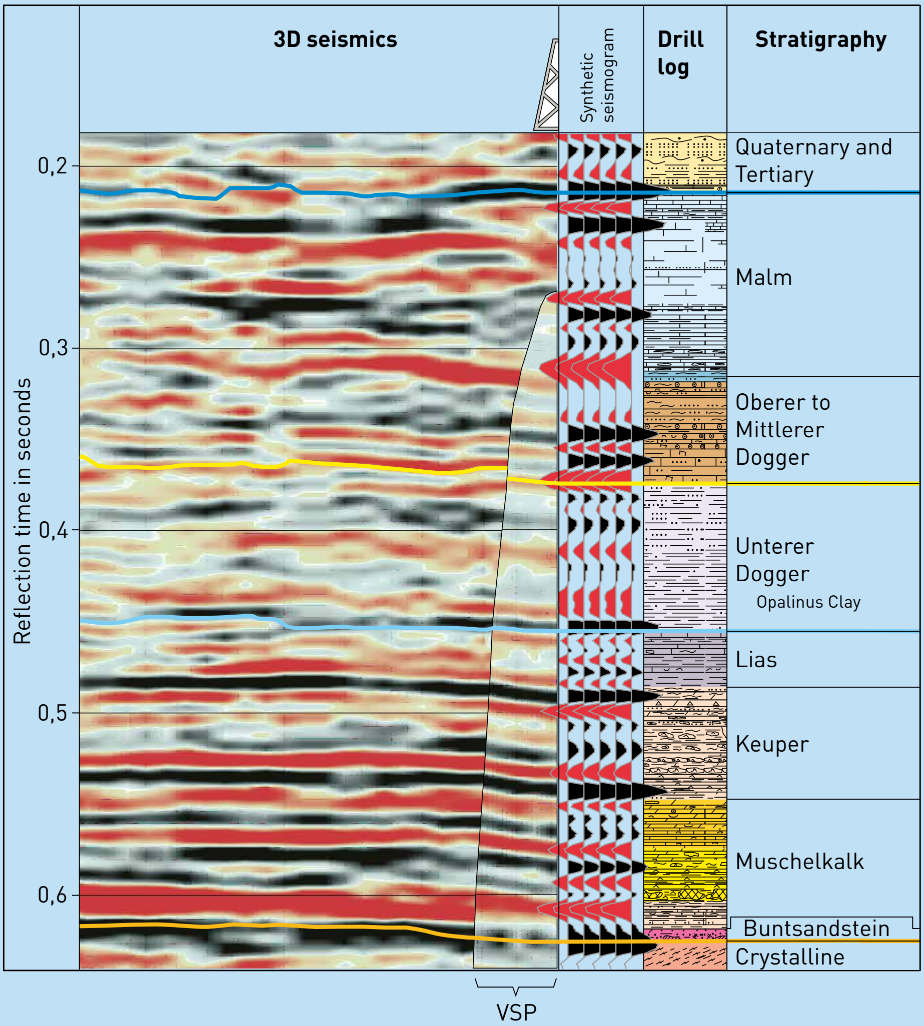


Figure 7
Example of various data sets obtained from the Benken borehole along with 3D seismics conducted in the Zürich Nordost siting region (source NTB 02-03, simplified).

Further measurements

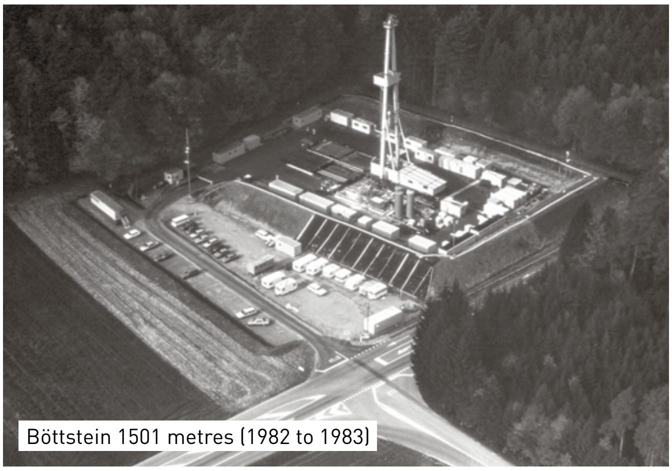
A number of further measurements will be conducted either directly in the borehole, at the drill site or later in an external laboratory.

These include:
- Measuring the density and porosity of rocks in the borehole
- Surveying the borehole and determining the condition of the casing and the cementation (see pages 20 and 21)
- Measuring the geomechanical properties of rock samples in the laboratory

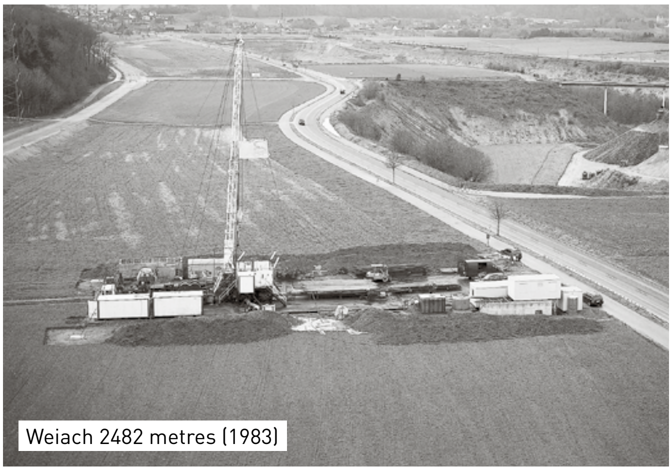
No fracking

The drilling and testing work does not include any stimulation. When extracting oil and natural gas or when exploiting geothermal energy, the goal is to use so-called fracking to increase the permeability of the rock. This is not the case with the tests Nagra is conducting. Earthquakes are thus not to be expected from the drilling of these boreholes.

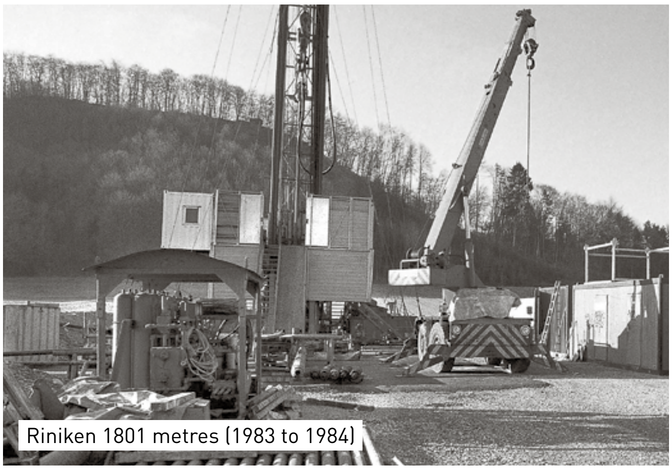
Figure 8
Extensive experience: To date, Nagra has drilled eight boreholes between approximately 1 000 and 2 500 metres deep in Northern Switzerland (all photos: © Comet Photoshopping, Dieter Enz; except: second row, right: Nagra).



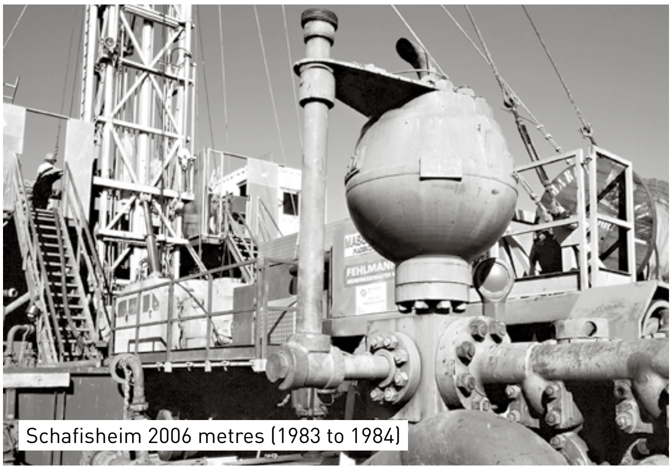
Böttstein 1501 metres (1982 to 1983)



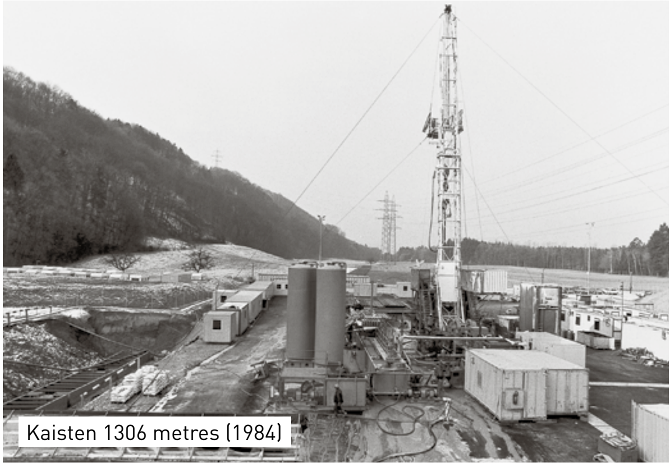
Weiach 2482 metres (1983)



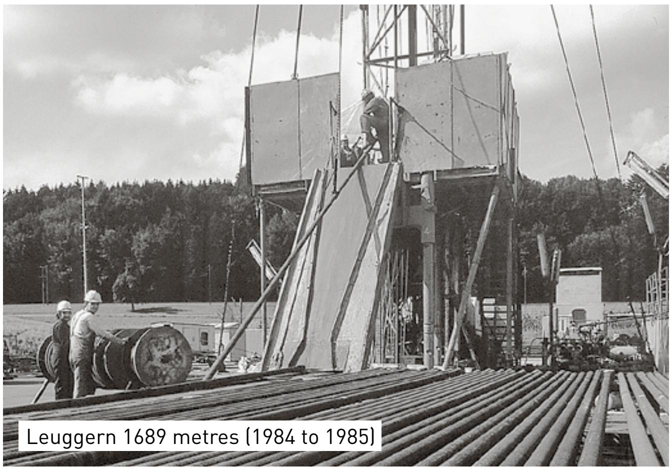
Riniken 1801 metres (1983 to 1984)



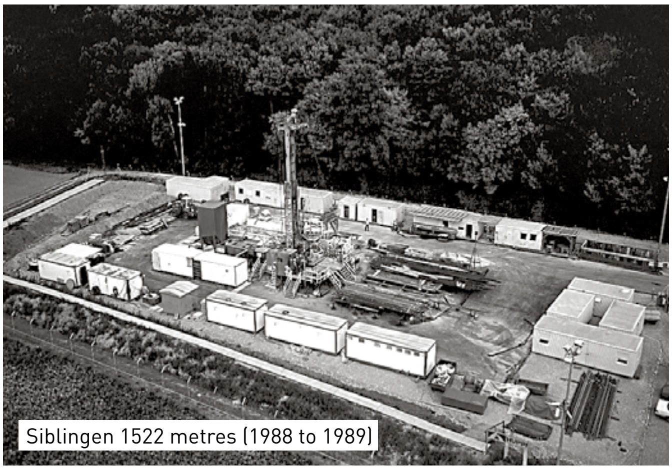
Schafisheim 2006 metres (1983 to 1984)



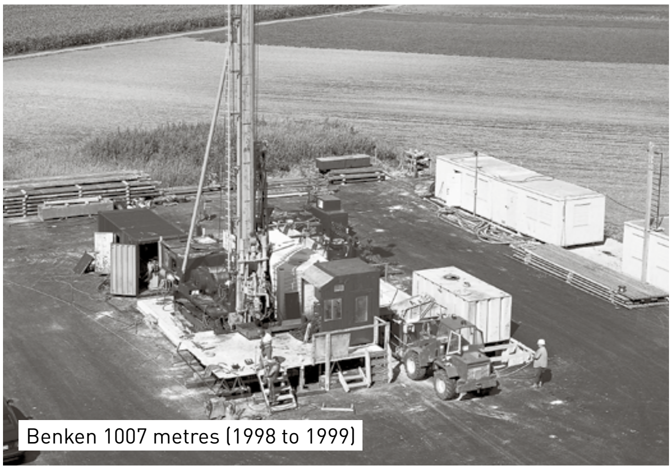
Kaisten 1306 metres (1984)



Leuggern 1689 metres (1984 to 1985)



Siblingen 1522 metres (1988 to 1989)



Benken 1007 metres (1998 to 1999)

An overview of the differ

A deep borehole is a complex project that is divided into several phases.

The investigation goals determine the drill site

The first step is to define the goals of the investigations: They include determining the barrier properties of the Opalinus Clay or the underground conditions for constructing a deep geological repository within the disposal perimeter. The goals define where the deep borehole must be located. To locate a suitable drill site within this area, interests are weighed against each other. Considerations include the minimum distances to residential buildings and site accessibility. Environmental protection and construction guidelines also play a role. Once a suitable drill site has been found, Nagra must submit a permit application to DETEC.

Selecting a site and granting a permit can take up to two and a half years.

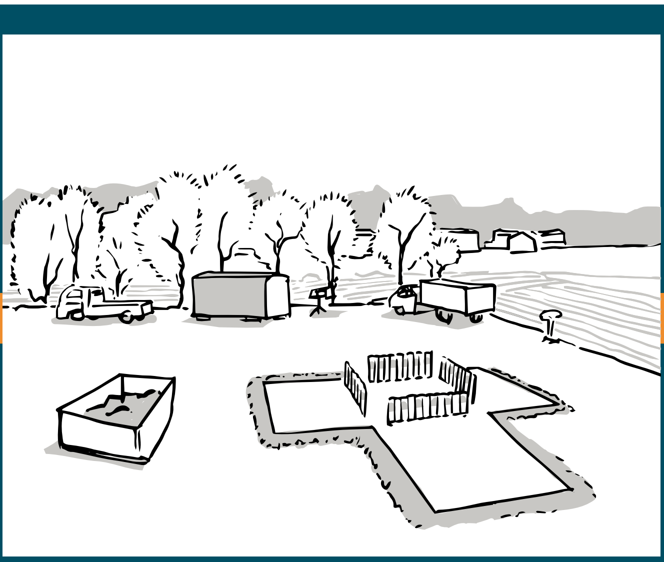
Constructing and setting up the drill site

Once the permit for a deep borehole has been granted, the drill site can be constructed. The ground is strengthened in the working area and sealed so that no potentially leaking fluids can contaminate the ground or the groundwater. Some of the excavated materials will be stored in depots located at the edge of the drill site and can later be used for recultivating the site. Wherever possible, the depot for excavated material should also function as a noise barrier.

The so-called rig cellar is constructed at the centre of the site. It forms part of the foundation and is made of concrete. The foundation must be able to carry the weight of the drilling rig with the drill pipe. In the remaining strengthened area, the drilling contractor will set up different machinery and containers. The drilling rig will be erected above the rig cellar.

It takes about three months to erect a drill site.

Project phase 1 (application)
Selection of a suitable drill site and permit from DETEC



Project phase 2 (construction)
Construction and setting up of the drill site

ent stages of a borehole

Drilling operations

The drilling operations include numerous tasks such as drilling the borehole, recovering and processing the drill cores (see page 18) and conducting measurements in the borehole.

To keep the borehole stable, it must operate around the clock. The work is geared towards minimising the noise disturbances in the immediate neighbourhood and complying with legal requirements. When illuminating the drill site, the light sources should be aimed accurately so that only the workspace is lit up and scattered light is avoided. A visitor information container is set up on-site, where the public can obtain information about the progress of the ongoing work.

The drilling phase can last between six and nine months.

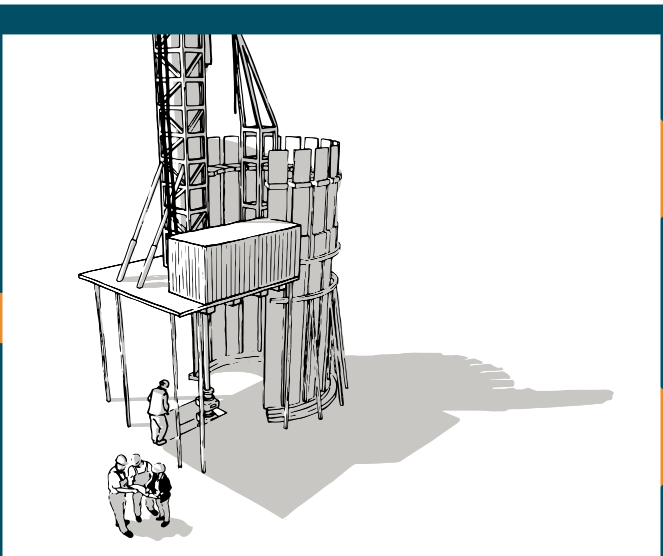
After the borehole investigations

After the borehole has been completed, there are two possible ways to proceed with the drill site:

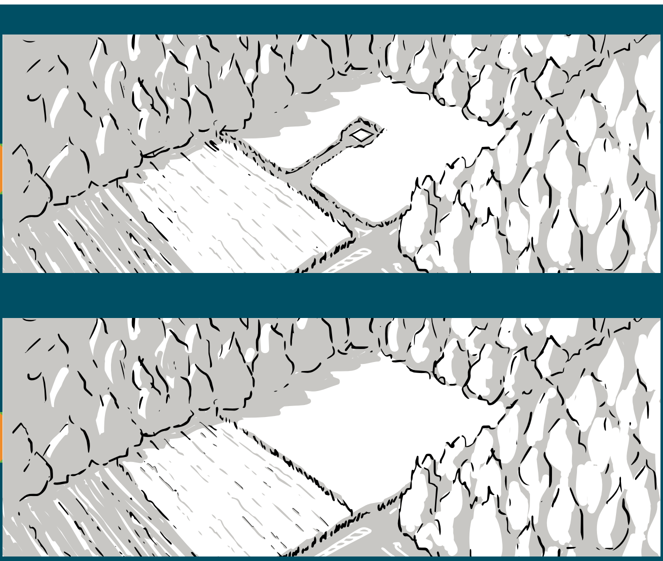
If no long-term monitoring is planned, the borehole is backfilled and the site is completely recultivated.

Otherwise, systems are installed for the long-term monitoring of temperature and hydraulic pressure of the groundwater in the borehole. For this, an access and a ground-level rig cellar are left behind. How long they will remain depends on the further course of the site selection process for a deep geological repository. After a legally valid construction and operating licence has been issued for the repositories, long-term monitoring will only be continued at the selected sites.

The rig cellar and its monitoring systems can remain in place for fifty years or longer.



Project phase 3 (drilling)
Drilling operations and investigation of the rock layers



Graphics: Julia Buschbeck - scientific illustrations

Project phase 4 (monitoring and recultivating)
The decision on whether to conduct a long-term monitoring programme is made as part of the site selection.

How is a deep borehole

Drilling begins once the drill site has been constructed and the drilling rig has been erected.

First, the so-called conductor casing is inserted past the unconsolidated rock and into the solid rock (see Figure 12, page 21). The conductor casing protects the groundwater from the drilling process. Drilling is then carried out using either drill bits or core bits. They are screwed onto the bottom of a drill pipe. An electrical drive in the drilling rig causes the drill pipe to rotate. The rotation and weight of the drill pipe cause the drill bit to crush the rock in the borehole. As the borehole becomes deeper, the drill pipe is extended piece by piece. Each time, the drilling process comes to a brief stop.

Drilling with a drill bit or a core bit

Nagra uses two common drilling techniques: A drill bit crushes the rock at the bottom of the borehole. The drilling fluid (see the following section) carries rock fragments, the so-called drill cuttings, up to the ground surface. Coring is a more complex technique where core bits only cut along the sidewall of the borehole, while the rock located in the centre, the drill core sample, remains intact (see Figure below). The resulting rock flour is flushed out along with the drilling fluid. Nagra uses coring for the rock layers that it wants to examine in greater detail. The collected drill core samples are examined on-site or later in a laboratory.

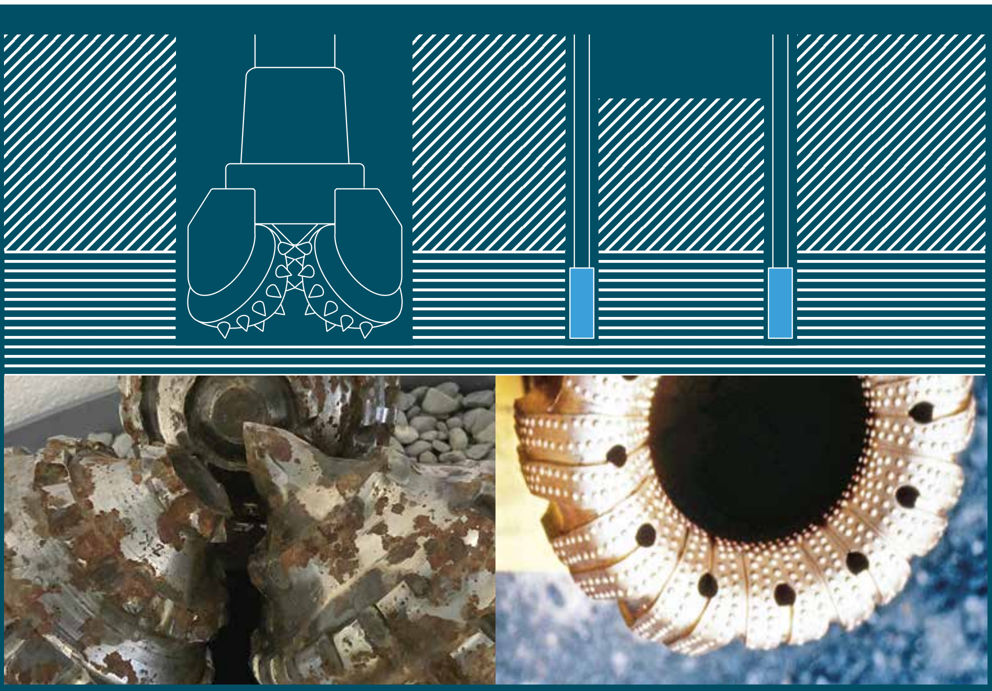


Figure 9
Left: Drill bit (photo: Nagra)
Right: Core bit (photo: © Comet Photoshopping, Dieter Enz)

drilled?

Drilling fluid has several functions

Deep boreholes operate with drilling fluid which is pumped down through the drill pipe and circulated back to the surface again outside the pipe. Drilling fluid has several functions such as transporting the drill cuttings to the surface or keeping the borehole stable. It also cools and lubricates the core bit. Drilling fluid usually consists of water and bentonite (natural clay minerals).

At the surface, the fluid is filtered in a mud tank and conditioned before being pumped back into the borehole (see Figure below).

Precautions in case gas is encountered

When drilling through rock layers, gases can occasionally infiltrate into the borehole. Low concentrations of gas are not critical because they mix with the ambient air as soon as they reach ground surface. Should larger amounts of gas occur, the borehole can be sealed with a shut-off device called a “blowout preventer”. The gas can then be evacuated in a controlled manner or burned off. Finding exploitable gas deposits in the boreholes is unlikely.

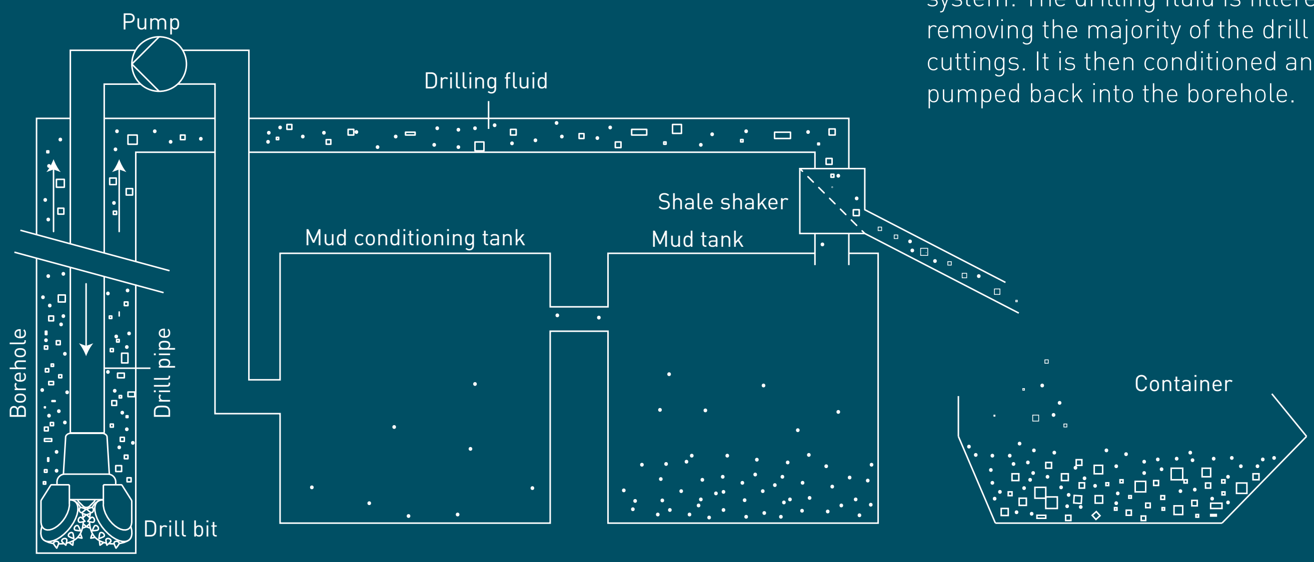


Figure 10
Schematic drilling fluid circulation system: The drilling fluid is filtered, removing the majority of the drill cuttings. It is then conditioned and pumped back into the borehole.

How is the core sample brought to the surface?

To recover a drill core, Nagra uses the so-called wireline coring technique (see Figure below).

The drill pipe contains an inner core barrel. During the drilling process, the new drill core "grows" into this barrel. When the core reaches the required length, the drilling process comes to a halt. Springs located inside the core barrel retain the core. Using a cable and a core catcher, the inner barrel is "captured" and pulled to the surface, causing the drill core to snap off at the bottom. On the surface, it is removed, and the inner barrel is placed back into the drill pipe and lowered down the borehole again. The drilling process is then resumed until the next core sample has reached the required length.

Securing the borehole

To secure a borehole, different casings are inserted during the drilling process (see Figure right). A long steel pipe is inserted into the borehole with a smaller diameter than the borehole or than an already existing casing. Afterwards, the space between the wall of the borehole and the pipe is backfilled with cement. This keeps the borehole stable.

Other drill site activities

Aside from the actual drilling operations, a number of further jobs are performed at the drill site every day. An on-site geologist identifies the penetrated rock formations with the help of drill cuttings and the drill cores. The drill cores are measured, and the rocks are described in detail. Various samples are extracted from the cores for laboratory analysis.

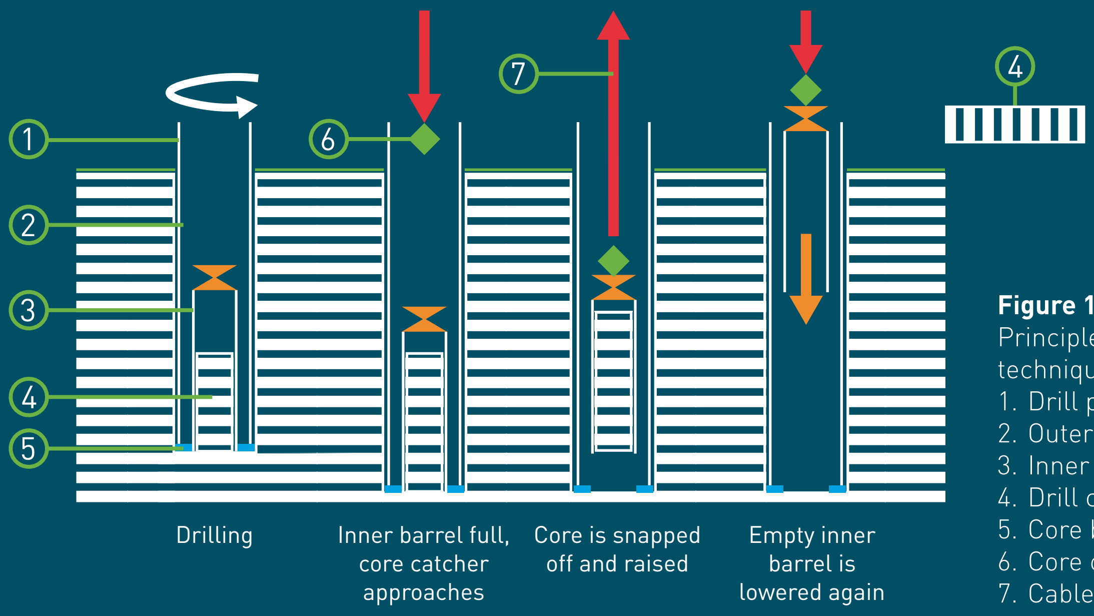


Figure 11
Principle of the wireline coring technique

1. Drill pipe
2. Outer barrel
3. Inner barrel
4. Drill core
5. Core bit
6. Core catcher
7. Cable

In addition, data on the drilling fluid, gas deposits and drilling technology are continuously monitored and recorded for safety-related and scientific investigations.

During the drilling phase, measurements will repeatedly be conducted in the borehole. In most cases, this will happen when the drilling process has come to a stop and the drill pipe has been pulled out of the borehole.

Groundwater protection

Any potential threat to the groundwater is minimised or eliminated well in advance. The drill site is sealed and individually adapted to the site's features. In the borehole, the conductor casing (see Figure to the right) protects the groundwater. Cementation effectively separates the different groundwater aquifers (see Glossary).

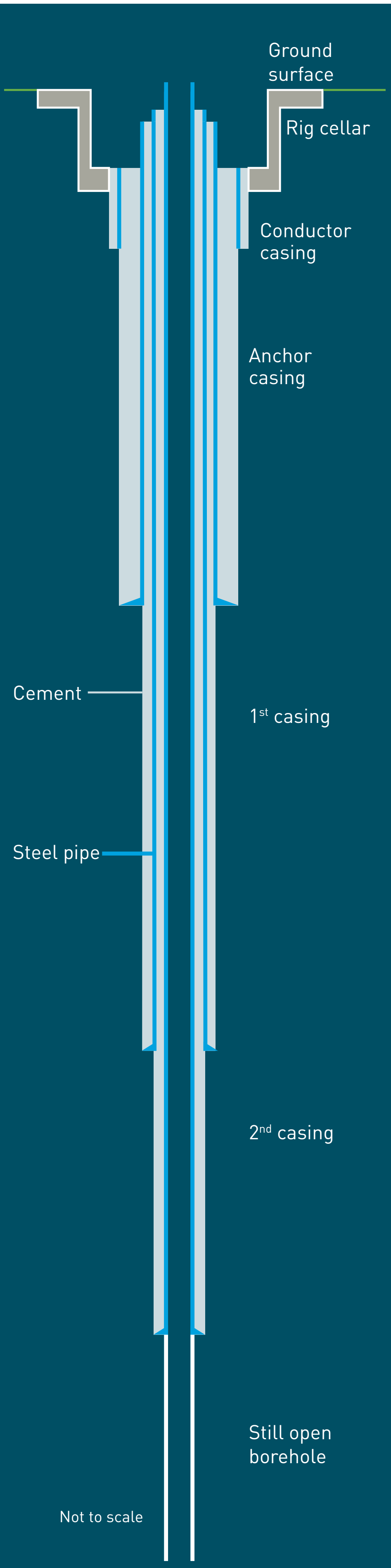
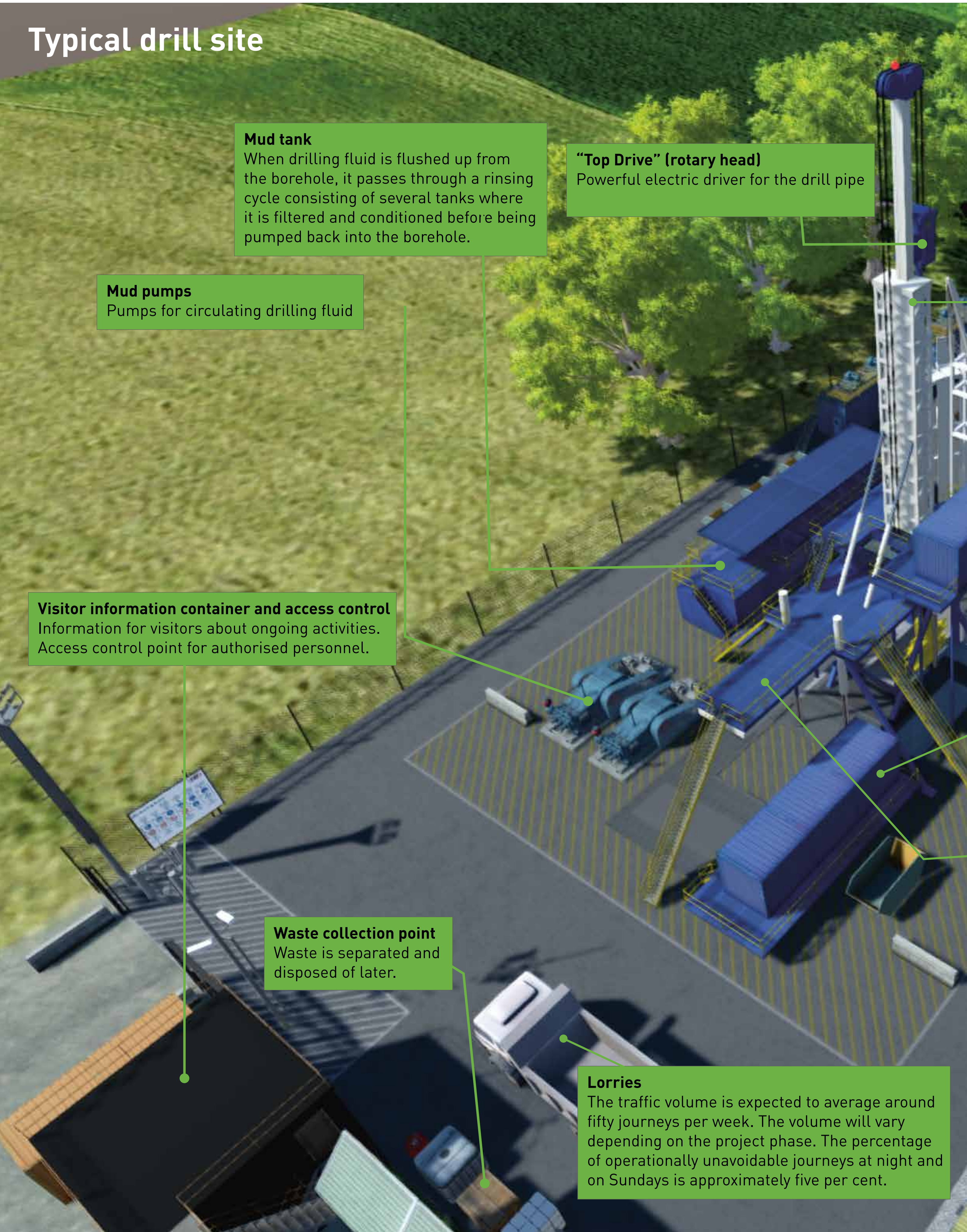


Figure 12
Schematic diagram of a borehole with installed casing

Typical drill site



Mud tank
When drilling fluid is flushed up from the borehole, it passes through a rinsing cycle consisting of several tanks where it is filtered and conditioned before being pumped back into the borehole.

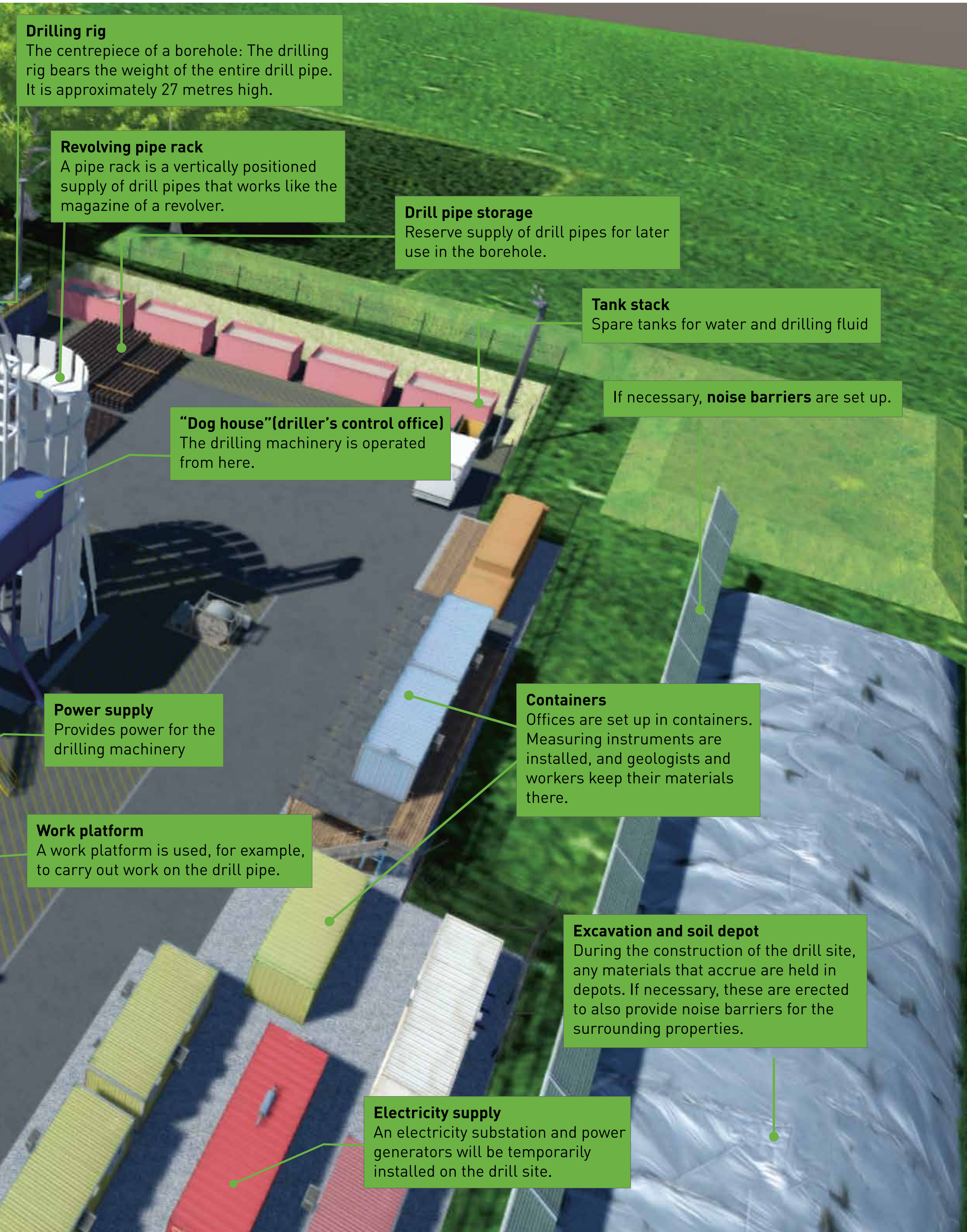
“Top Drive” (rotary head)
Powerful electric driver for the drill pipe

Mud pumps
Pumps for circulating drilling fluid

Visitor information container and access control
Information for visitors about ongoing activities. Access control point for authorised personnel.

Waste collection point
Waste is separated and disposed of later.

Lorries
The traffic volume is expected to average around fifty journeys per week. The volume will vary depending on the project phase. The percentage of operationally unavoidable journeys at night and on Sundays is approximately five per cent.



Drilling rig
The centrepiece of a borehole: The drilling rig bears the weight of the entire drill pipe. It is approximately 27 metres high.

Revolving pipe rack
A pipe rack is a vertically positioned supply of drill pipes that works like the magazine of a revolver.

Drill pipe storage
Reserve supply of drill pipes for later use in the borehole.

Tank stack
Spare tanks for water and drilling fluid

If necessary, **noise barriers** are set up.

"Dog house"(driller's control office)
The drilling machinery is operated from here.

Containers
Offices are set up in containers. Measuring instruments are installed, and geologists and workers keep their materials there.

Power supply
Provides power for the drilling machinery

Work platform
A work platform is used, for example, to carry out work on the drill pipe.

Excavation and soil depot
During the construction of the drill site, any materials that accrue are held in depots. If necessary, these are erected to also provide noise barriers for the surrounding properties.

Electricity supply
An electricity substation and power generators will be temporarily installed on the drill site.

Glossary

Application for exploration permit
Application for permission to construct a deep borehole. It documents issues such as the balancing of interests for concrete site selection and the expected development of the drill site.

Conflicts of use
The Nuclear Energy Act calls for the protection of a deep geological repository from any intrusions, which could entail restrictions for other exploitation projects. However, a deep geological repository may not unnecessarily restrict the predictable future exploitation of natural resources.

Deep geological repository
A deep geological repository is an installation built in stable and impermeable rock layers in which radioactive waste can be safely disposed of.

Depth
The depth of a deep geological repository ensures the spatial separation of waste from the human environment. The repository must be sufficiently deep to protect it from the consequences of erosion processes but, due to construction feasibility concerns, it may not be located too deep.

What is a general licence application?

Deep geological repositories require a general licence from the Federal Council. The general licence application submitted by Nagra includes a description of the main features of the facilities in the proposed siting regions. The general licence specifies the location, size and the approximate layout of the most important buildings. More detailed descriptions of the installations, procedures and technologies will be required later for the construction licence and operating licence applications.

Disposal perimeter
The disposal perimeter comprises the area of host rock in the underground of a geological siting region that, in terms of safety, is best suited for hosting a deep geological repository.

GR API
This unit is used when measuring the natural radioactivity in rocks and allows the interfaces between the different rock types to be identified.

Groundwater aquifers and aquicludes
A groundwater aquifer is a body of rock containing voids (pores, fractures) that allow the migration of groundwater. As opposed to this, so-called aquicludes act as barriers to groundwater flow.

Host rock, confining geological units, containment-providing rock zone
The host rock accommodates the emplacement rooms of a deep geological repository and plays a decisive role in the retention of radionuclides. Low-permeability confining geological units may lie directly above and below the host rock. The host rock and the confining geological units are termed the "containment-providing rock zone".

Hydrogeology
Area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the earth's crust.

Isotope
Isotopes are atoms of the same chemical element but with a different number of neutrons in their nucleus.

Long-term geological evolution
The long-term evolution of the earth's surface due to processes such as erosion.

Long-term safety
Site selection and the layout of a deep geological repository ensure long-term safety so that any threats can be ruled out even over a very long time period.

Natural analogues
As opposed to laboratory experiments, it is possible to observe relevant natural processes, some of which have occurred over many millions of years.

Quaternary
The Quaternary is a geological period that began approximately 2.5 million years ago.

Radionuclide
Unstable atomic nucleus that transforms while emitting ionising radiation. There are naturally occurring and synthetically produced radionuclides.

Release pathways
These include connected pore spaces, fractures or fault zones that allow radionuclides to migrate through the host rock or the confining geological units and into the biosphere.

Repository-induced effects
A deep geological repository can affect the host rock (e.g. through heat production or chemical interactions).

Repository type
A distinction is made between the repository for low- and intermediate-level waste (L/ILW) and that for high-level waste (HLW). A third possibility is a combined repository for both waste types.

Seismics
Seismic measuring techniques are used to spatially depict the geological underground by means of artificially stimulated vibrations.

Water management
Management of water encountered underground.

Further reading

Nagra (2016):
Konzepte der Standortuntersuchungen für SGT Etappe 3 – Nördlich Lägern; NAB 16-28 (in German)

Nagra (2014):
Konzepte der Standortuntersuchungen für SGT Etappe 3; NAB 14-83 (in German)

Nagra (2002):
Projekt Opalinuston – Synthese der geowissenschaftlichen Untersuchungsergebnisse – Entsorgungsnachweis für abgebrannte Brennelemente, verglaste hochaktive Abfälle sowie langlebige mittelaktive Abfälle; NTB 02-03 (in German)

Brochures and special issues (in English and German)

“Erosion – long-term geological evolution and deep geological repositories”, December 2017

“Bohrungen für Quartäruntersuchungen”, February 2018 (in German)

“Radioactive waste – where from, how much, where to?”, March 2017

“Long-term safety – the main goal of deep geological disposal of radioactive waste”

These can be downloaded or ordered at www.nagra.ch, “Publications”.

Where have applications boreholes?

By January 2019, a total of 23 applications for exploration permits had been submitted for deep boreholes in three siting regions. A Not all the boreholes will be drilled. During the investigations, new knowledge is gained on a continual basis. For this reason, Nagra submits more applications for boreholes than it plans to implement in order to have flexibility in deciding which further boreholes are most suited for clarification.

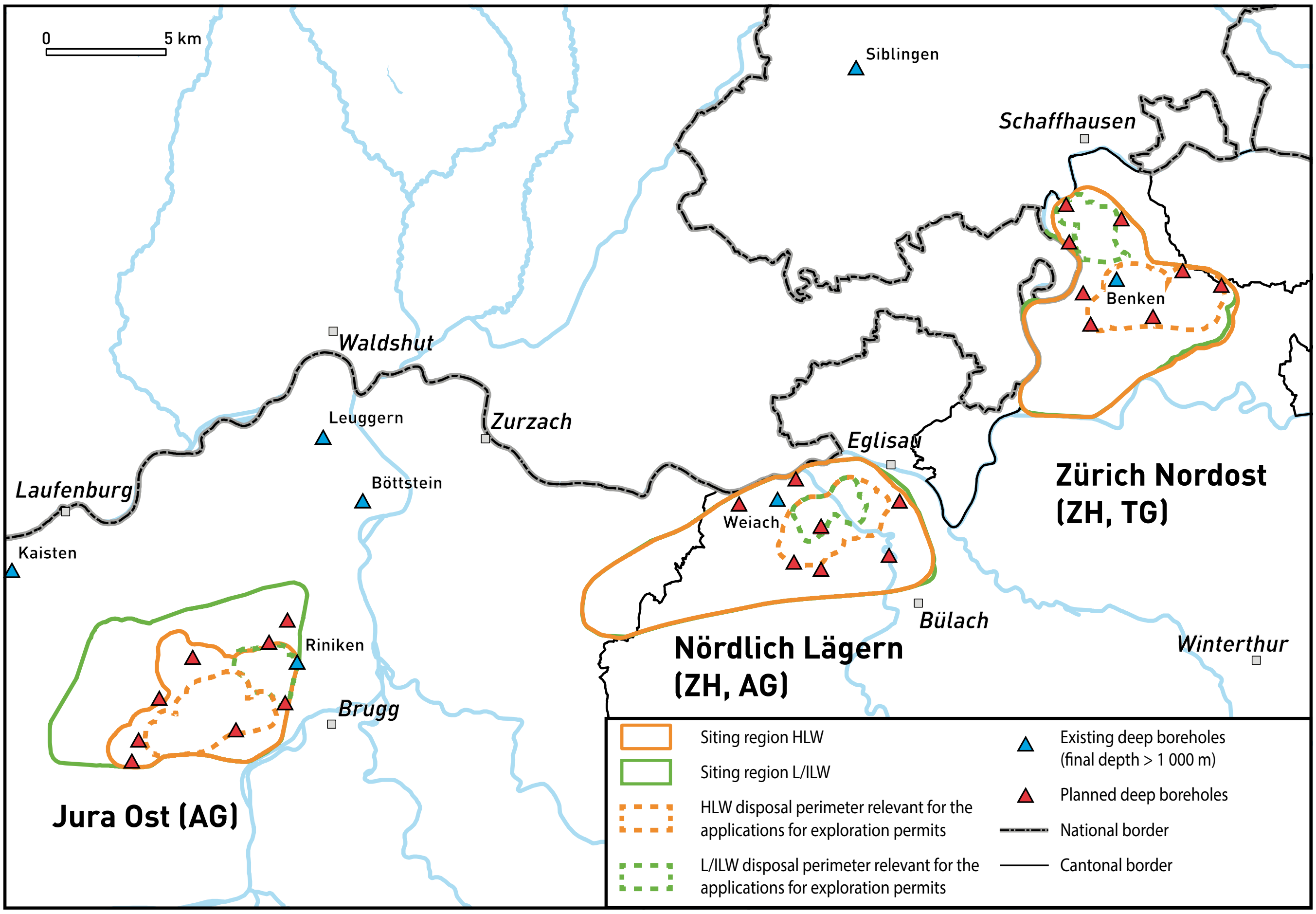


Figure 13
The drill sites are arranged around the disposal perimeter. While the goal is to characterise the Opalinus Clay host rock as accurately as possible, boreholes drilled directly into the perimeter would damage the rock.

been submitted for deep

Factsheets – deep boreholes

Description of the drill site and the goal of the exploratory borehole investigations.

Jura Ost

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All factsheets can be downloaded under www.nagra.ch → publications/downloads → special topics

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