Guide to EUROCK 2025 Pre-Congress tour

By Roger Olsson and Bjørn Nilsen

We will travel approximately 525 km by bus from Gardermoen Airport to Trondheim. Driving this distance in one stretch takes a little over 7 hours, but we will spend about 1.5 days as we will make several stops along the way. In the program, you can see the various stops and the times we need to try to stick to.

Program

Saturday 14. June

11:30-13:00 Bus from Oslo airport Gardermoen to Gjøvik

13:30-15:00 Presentation and guided tour in the Gjøvik Underground sports hall

15:00-16:00 Bus from Gjøvik to Hunderfossen

16:00-17:00 Guided tour in the Norwegian Rock Blasting Museum, Hunderfossen

17:00-18:00 Bus to Peer Gynt Thon Hotel (Vinstra)

19:00 Dinner at the hotel

Sunday 15. June

09:00-10:10 Bus from Peer Gynt to the viewpoint Solbergplassen

10:10-10:30 Short stop at Sohlbergplassen

10:30-11:30 Bus from Sohlbergplassen to Folldal

11:30-13:30 Visit to the Mining Museum in Folldal

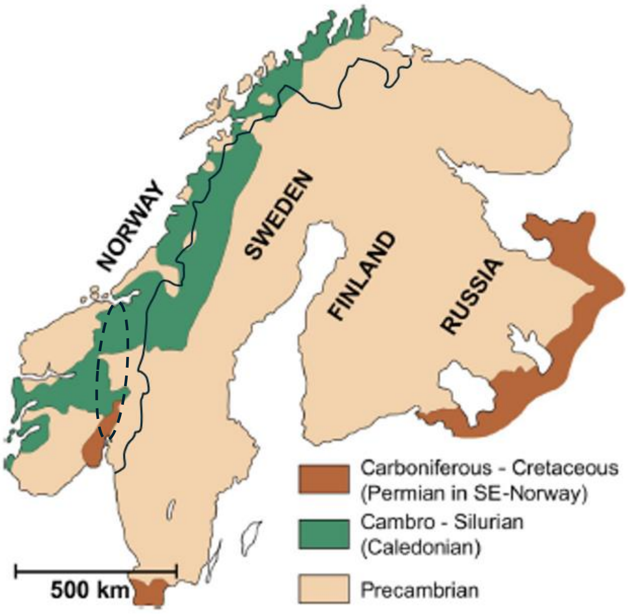
13:30-14:15 Lunch at "Gruvekroa", Folldal

14:15- 19:00 Bus from Folldal to Trondheim with short stops at Dovrefjell/former Hjerkinn underground mine, Brattset hydropower plant and Soknedal road tunnel.

Norwegian Geology

(from Høien, Nilsen and Olsson, 2019)

Geologically, Norway mainly consists of Precambrian and Cambro Silurian (Caledonian) bedrock, as shown in the figure below. The Precambrian rocks are mainly gneisses and intrusive granite and gabbro of various degrees of metamorphism. The Caledonian rocks are mainly metamorphosed sedimentary and volcanic rocks. Permian volcanic and igneous rocks can be found in Southeast Norway i.e. the Oslo region. In the Mesozoic, there was a weathering of bedrock that eroded during glacial landscape formation in the Pleistocene. The bedrock today therefore mainly consists of hard rock intersected by weakness zones of different extents and character originating from tectonic activity and in some cases, Mesozoic weathering.



Overview of regional geology. The dotted ellipse shows approximately the area we pass.

For more information and the opportunity to follow the geology along the way, please use the following on your mobile:

https://geo.ngu.no/kart/berggrunn_mobil/?lang=eng

Gjøvik Underground sports hall with 61 m span

(from Grøv and Olsson, 2017)

Introduction

Norway has a long tradition of building large rock caverns for different purposes. During the 1970s, a series of studies, including some *in situ* testing, were initiated to investigate the feasibility of underground siting of nuclear power plants. The focus, at that time, was on the need for a reactor containment cavern with a hemispherical domed arch of at least 50 m diameter [1].

The experience from excavation of the many large powerhouse caverns related to hydropower development, large caverns for storage of petroleum product, and large mine caverns (with Skorovatn, having a span of 65 m and practically no rock support in the roof), contributed considerably to the decision to build the underground ice hockey hall at Gjøvik.

In Seoul 1988, the IOC-president Juan Antonio Samaranch announced that Norway had been awarded the 17th Olympic Winter Games to be held in Lillehammer in 1994. Two ice hockey halls were needed for the games. Gjøvik already had an underground swimming pool that had been completed in 1974. The experience from the early investigations regarding large caverns in Liåsen and the presence of an underground swimming pool in the rock massive where the Gjøvik cavern could be located, gave the idea and the boldness to recommend that the world's largest underground cavern hosting an ice hockey arena be built. Thanks to the prefeasibility study at Liåsen, the Gjøvik cavern project could start directly with a detailed design. The first sketches were actually drawn on a napkin at a dinner in 1989 [3].

The Gjøvik rock cavern

The Gjøvik Olympic Mountain Hall was excavated between 1991 and 1993. With a span of 61 m, a length of 95 m, and a height of 25 m, it is the largest man-made rock cavern for public use in the world. The total excavated volume was 140 000 m^3. The width of the cavern is not the only exceptional feature of this project, equally interesting is the fact that the rock cover varied between only 25 m and 55 m, i.e. the overburden throughout the underground cavern is far less than its span.

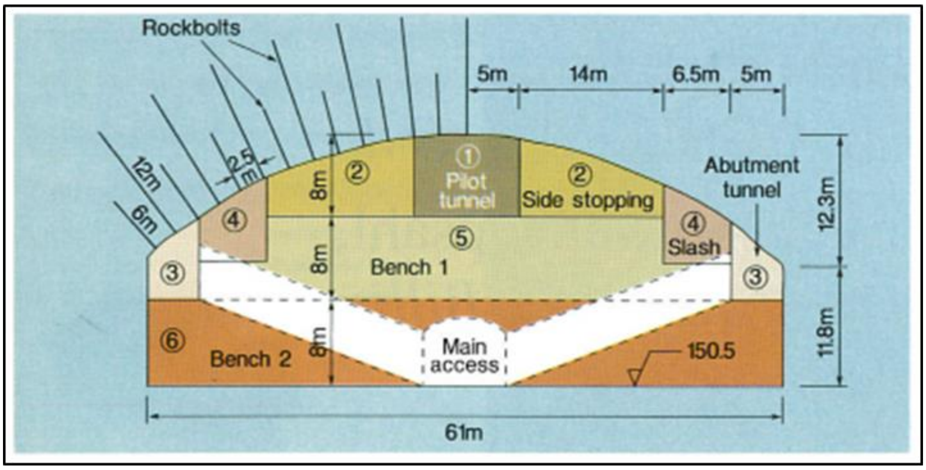


Figure 1. Cross section of the Gjøvik Mountain Hall [4]

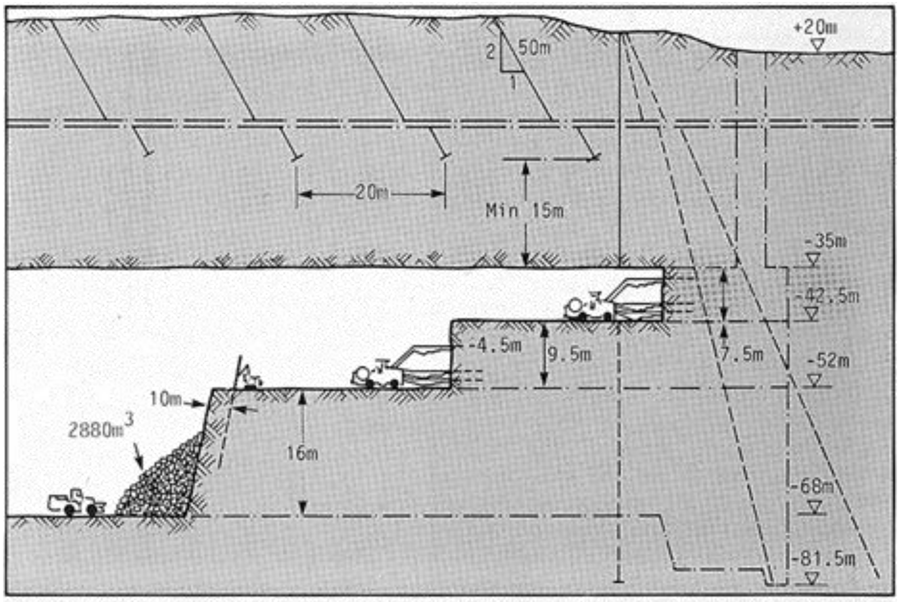


Figure 2. Excavation sequence Gjøvik Hall (Photo: NGI)

The rock at the site is a Precambrian gneiss. The rock has a network of tectonic micro-joints, which are often filled or coated with calcite or epidote, creating a well jointed rock mass with an average RQD of about 70. The rock joints are typically persistant, with moderate to marked roughness, and normally without clay filling, i.e. positive characteristics when considering large spans. The Q-value is typically 30 for the best and 1 for the poorest quality rock mass, with 12 as an average value.

Experience from large span mining chambers in Norway indicated that an important prerequisite to obtain stable large span caverns without heavy rock support was a sufficiently high horizontal rock stress. Therefore, at a very early stage of planning, insitu rock stress measurements were made from an existing tunnel. The results showed a major horizontal stress of the order of 3 - 5 MPa, with an E-W orientation. At a depth of 25 - 55 m the vertical stress due to gravity is less than 1 MPa, indicating that the horizontal stresses are generated by geological processes (tectonic stress). This was verified later by additional tests, conducted in several rounds, including both over-coring and hydraulic fracturing in vertical boreholes drilled from the surface above the hall. In this investigation the major horizontal stress direction was N-S. Based on these findings, it was decided to proceed with the investigations.

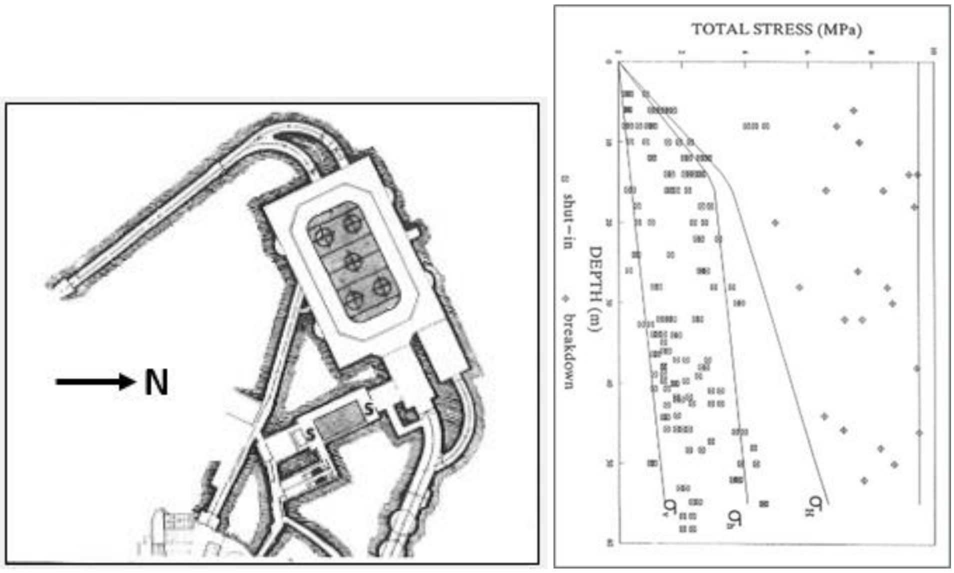


Figure 3. Left: Plan sketch of the cavern, right: Results of rock stress measurements using hydraulic fracturing and joint jacking [1].

With reliable in-situ stress values from the stress measurements, numerical modelling was carried out, using various BEM, FEM, UDEC and FLAC codes. The final conclusion was that a stable and virtually self-supporting 61 m span could be constructed under the given geological and rock mechanics conditions. The maximum roof displacement was expected to be in the range of 5 – 10 mm. A key element of this entire process was the results of the in-situ stress measurements. Adjacent to the location of the proposed main cavern hall area, an underground swimming pool had already been constructed in 1974, thus the geology of the area was well known, and later this facility was included in the new construction. In addition, there was an underground telecommunication centre in close vicinity to the proposed Gjøvik hall. To monitor roof deformations a number of multiple position borehole extensometers (MPBX) were installed. Figure 5 shows the cavern layout and the position of seven, 3-anchor (position) MPBXs placed in boreholes drilled from the surface (marked E1-E7), and three placed in boreholes drilled vertically upwards in the cavern roof (marked S1 – S3). In addition, surface precision levelling was carried out on top of the three centre-line extensometers.

Readings were taken regularly throughout the construction period. Figure 6 shows typical readings for the central extensometer E4, with A1 being the anchor close to the cavern roof. After the full span was excavated in about 100 days, the deformations show a decreasing trend until they stabilised completely after some 300 days. The maximum displacement was less than 4 mm. By adding the readings from surface and roof extensometer and the surface levelling, the maximum displacement was estimated to be about 7 mm. This is well within the predicted values from the different numerical models. To check the roof stresses, 2D in-situ rock stress measurements were carried out mid-span close to the S1, S2 and S3 extensometer locations. They all showed compressive roof stresses in the range of 2 - 5 MPa, which are good indicators of stable conditions in the immediate vicinity of the roof.

The investigations clearly indicate that the roof “globally” is a self-supporting structure. The roof is, however, systematically supported by 6 m fully grouted 25 mm rebar bolts in a 2.5 m x 2.5 m grid, where every fourth bolt is substituted by a 12 m cable anchor. The rock surface is also supported by a 100 mm thickness of fibre reinforced shotcrete.

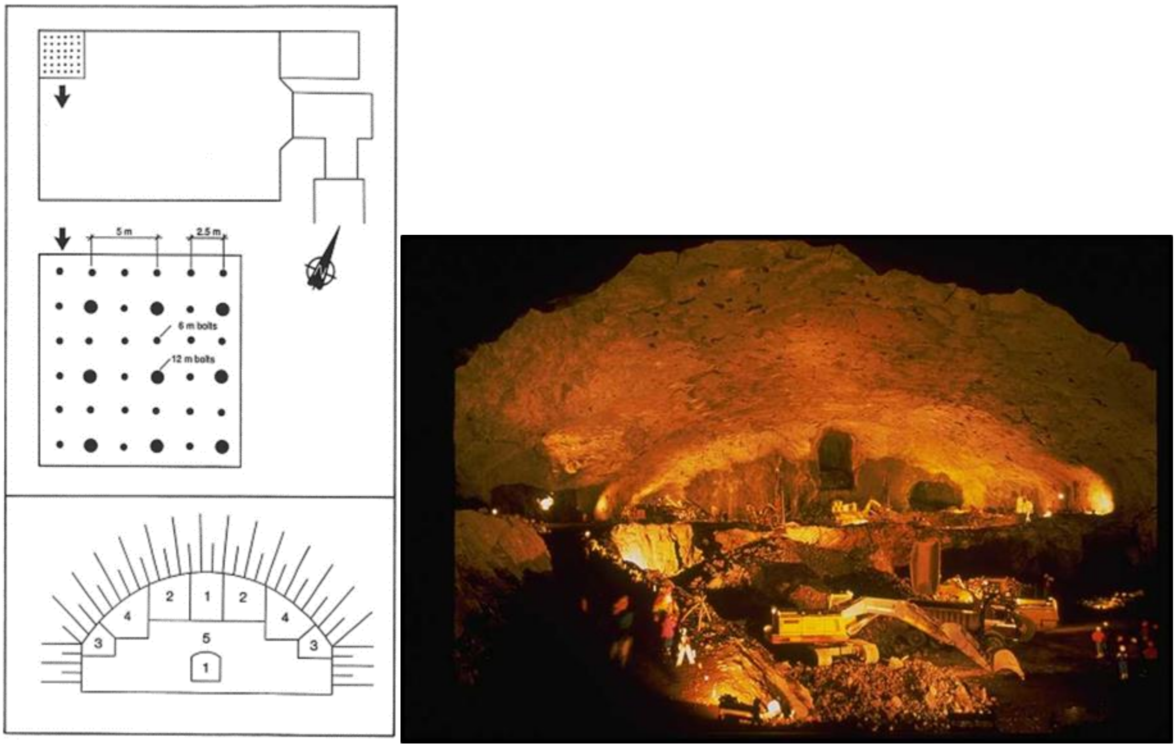


Figure 4. Left: Rock support pattern [1], right: Construction of cavern [5].

Eight rebar bolts were instrumented by strain gauges, and the load change was monitored as the span was increased from 10 m, through 37 m to the final span of 61 m. Only three bolts showed any indication of being loaded. This happened close to the roof surface, with very moderate load in two cases (10 kN and 15 kN), while the third one showed 87 kN, which is about 40% of the yield load.

To check the performance of the fibre reinforced shotcrete, strain gauge rosettes specially made for concrete were installed at four locations. The readings indicated only very low tensile stresses, which are probably due to shrinkage of the shotcrete. The strength of the bond of the shotcrete to the rock was tested by a direct pull test on drill cores containing the intersection. The average tensile strength of the bond was 0.85 MPa, which was regarded as satisfactory. The main purpose of the shotcrete seems to be to bond the rock surface together, preventing smaller rock volumes from loosning and falling.

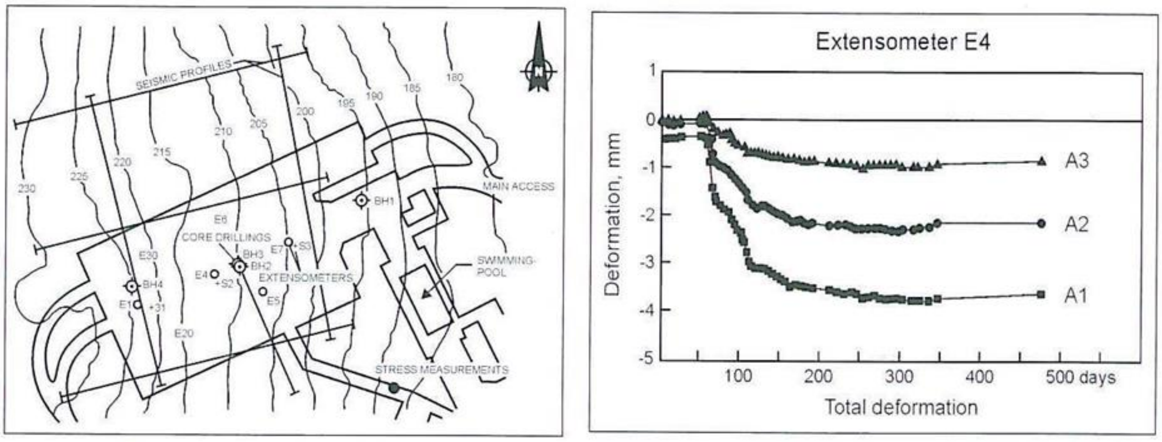


Fig. 5. Left: Cavern lay-out and borehole extensometer locations, Right: Typical readings of surface extensometer [6]

Based on this, it may be concluded that the need for the systematic pattern of 6 m and 12 m bolts and cables is questionable [7].

A systematic 2.5 m x 2.5 m pattern with 3 – 4 m fully grouted rock bolts, combined with 75 mm to 100 mm shotcrete will do the job even for a 50 m to 60 m span. However, horizontal stresses of sufficient magnitude are necessary to establish the global stability of the roof.

References

[1] Barton, N. et al., Prediction and Measured Performance of the 62 m Span Norwegian Olympic Ice Hockey Cavern in Gjøvik. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 31, No. 6, pp. 617-641, 1994.

[2] Oslo commune, Mountain resort in Liåsen, Søndre Nordstrand. Rock cavern with 60 m span used as ice halls, swimming pool, sports hall, and public shelter for Oslo municipality. May 1979.

[3] Book: Gjøvik Olympic Mountain Hall.

[4] Norwegian tunnelling methods. Presentations at the British Tunnelling Society. Reprinted from Tunnels & Tunnelling, June 1995.

[5] Aarvold, V. 1992, Gjøvik Colosseum, World Tunnelling and Subsurface Excavation, June 1992.

[6] Myrvang, A. 2004, Rock Stress Measurements and Deformation Monitoring, Norwegian Tunnelling Society NFF Publication No. 14.

[7] Grøv, E. 20??, Understanding and Utilizing *in-situ* rock stresses in designing and building large rock caverns.

Norwegian Rock Blasting Museum, Hunderfossen

The Norwegian Rock Blasting Museum is an underground museum located near the Olympic City Lillehammer in Norway. The museum was established by the main stakeholders in the Norwegian tunnelling industry 25 years ago on 31 August 1992. The museum is operated by the Norwegian Public Roads Administration.

The 240-meter-long museum tunnel was internationally recognized as the “most innovative use of underground space” at the ITA industry conference in China in 2018.

Inside the tunnel’s darkness, you can experience equipment, techniques, and stories from centuries of mining and tunnel construction. Adjacent to the tunnel is the spectacular event venue Berghallen – with capacity for 150 people. It is available for rent for various events – read more here.

Outside the tunnel, you’ll find construction locomotives and several impressively large machines, including the O&K front loader, which at 218 tons is considered Norway’s heaviest land-based museum object.

The large barracks building at the rock blasting museum houses an exciting exhibition featuring objects, authentic rooms, and tableaux. On the second floor, there is a dedicated play and activity area for the youngest rock blasters.

www.vegmuseum.no

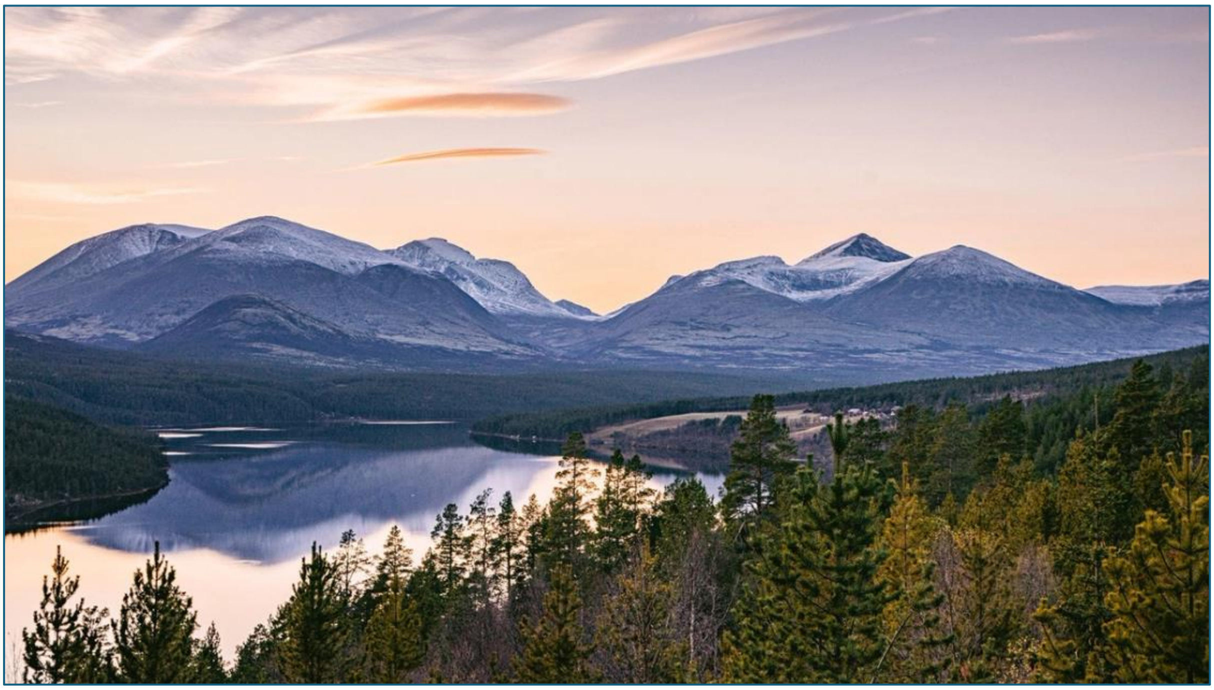
Foto: Morten Reiten/Norsk vegmuseum

National Tourist Route - Rondane

After about 30 minutes of driving from the hotel, we enter one of the 18 designated scenic routes, Rondane that is 75 km long. It was the Storting (Norwegian Parliament) and the Government that gave the Norwegian Public Roads Administration the responsibility for developing and maintaining the **National Tourist Routes** as an attraction.

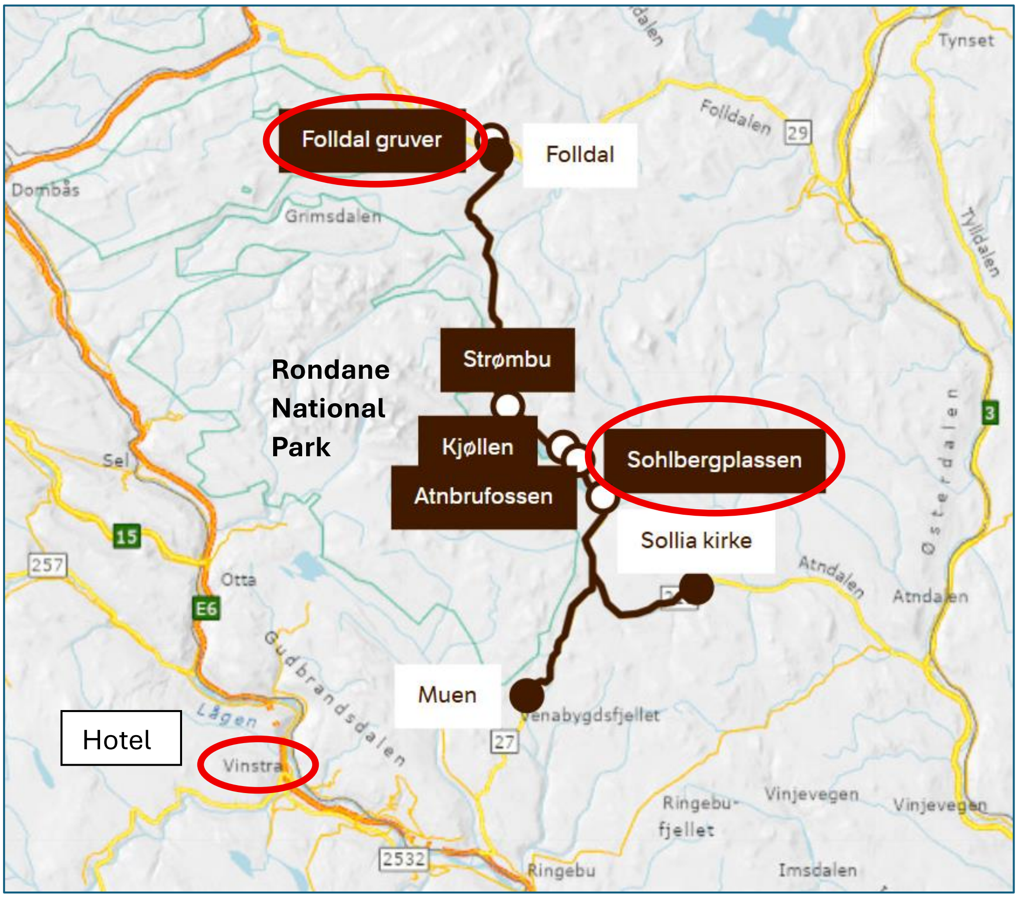
A drive in close contact with Norwegian nature, in an easily accessible borderland between high mountains and ancient cultural landscapes. Like ancient giants, the mountains rest along the road that takes you past **Rondane National Park**. The experience of the slow-paced landscape with towering peaks is truly unique.

There are 48 national parks in Norway, where 7 of the are at Svalbard, and the rest at the mainland Norway. Rondane was the first national park in Norway and was established in 1962.



www.intersport.no

Mountain peaks rising over 2,000 meters in a distinctive landscape covered in chalk-white snow, the sun hanging low in the sky making the snow sparkle, the blue light. The peace and quiet. Perhaps this is exactly what has inspired so many artists and writers over the years – and maybe it's the reason people keep returning to Rondane, generation after generation.

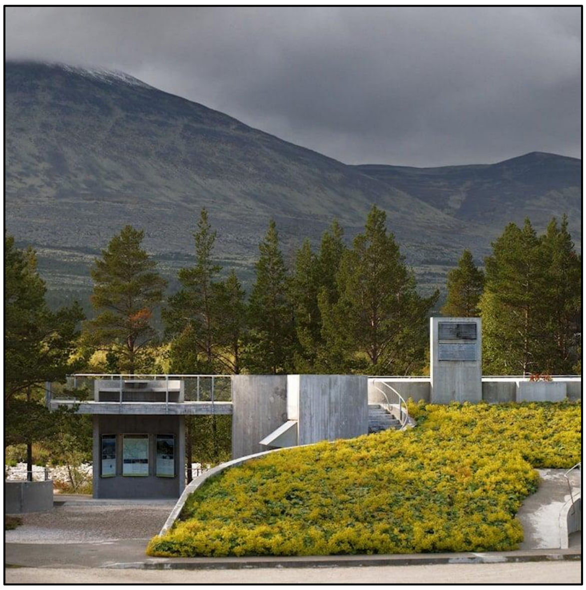


https://www.nasjonaleturistveger.no/no/turistvegene/rondane/

By Atnsjøen is the **Sohlbergplassen viewing platform**, which winds between slender pine trees. The platform frames the view of Atnsjøen and the round mountains of Rondane almost as it appears in Harald Sohlberg's painting "Winter Night in the Mountains".

www.nasjonaleturistveger.no/no/turistvegene/rondan

After the Sohlbergplassen viewing platform (rest area) with its fantastic view, come the rest areas Kjøllen and Strømbu. Unfortunately, we do not have room to stop at these. Kjøllen is famous for its stone mosaic "Skyldner" based on a charcoal drawing of a wooden head from the 12th century, most likely a head of Christ. The stone used is light and dark granite. Strømbu is one of the main gateways to Rondane from the east and a good starting point for hiking.



The picture on the left shows the stone mosaic at Kjøllen and the picture on the right shows Strømbu. www.nasjonaleturistveger.no/no/turistvegene/rondan.

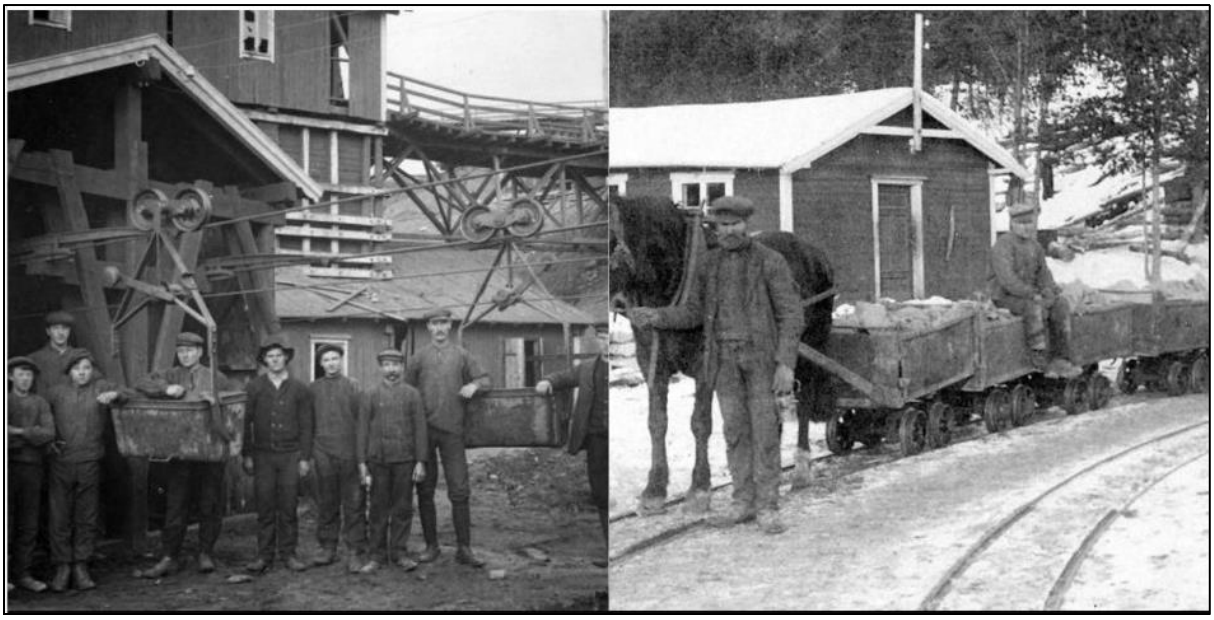
Mining Museum in Folldal

(from https://folldalgruver.no)

Folldal Gruver – a historical mining community in the mountainous heart of Norway

Folldal Mines is one of 15 works included in the Directorate for Cultural Heritage's national programme for industrial heritage. It consists of 70 buildings, slag heaps and tips. Today, it is a vibrant museum with exhibitions, way-marked trails, café, accommodation and the main attraction - the mine.

It all started in 1745 when the farmer Ole Husum discovered ore. A license to mine was granted in 1748, and the operation in Folldal had begun. At the time, the company was called Fredrik Gaves Verk. The first mining period lasted until 1878, when low prices of the mine's products and high transportation costs brought operations to a halt. The site lay dormant until 1906. A young engineer called Worm H. Lund was not content with this situation and had new maps of the mines drawn up. Backed by funding from the British, he established The Foldal Copper & Sulphur Co. Ltd where he himself became the Managing Director. The company embarked on a period of vast expansion and development. A power station, ropeways, workshops and production facilities were built, but also cottages for the workers, a villa for the director, a bakery, laundries and baths for the workforce. Not only a company, but a community, was built.

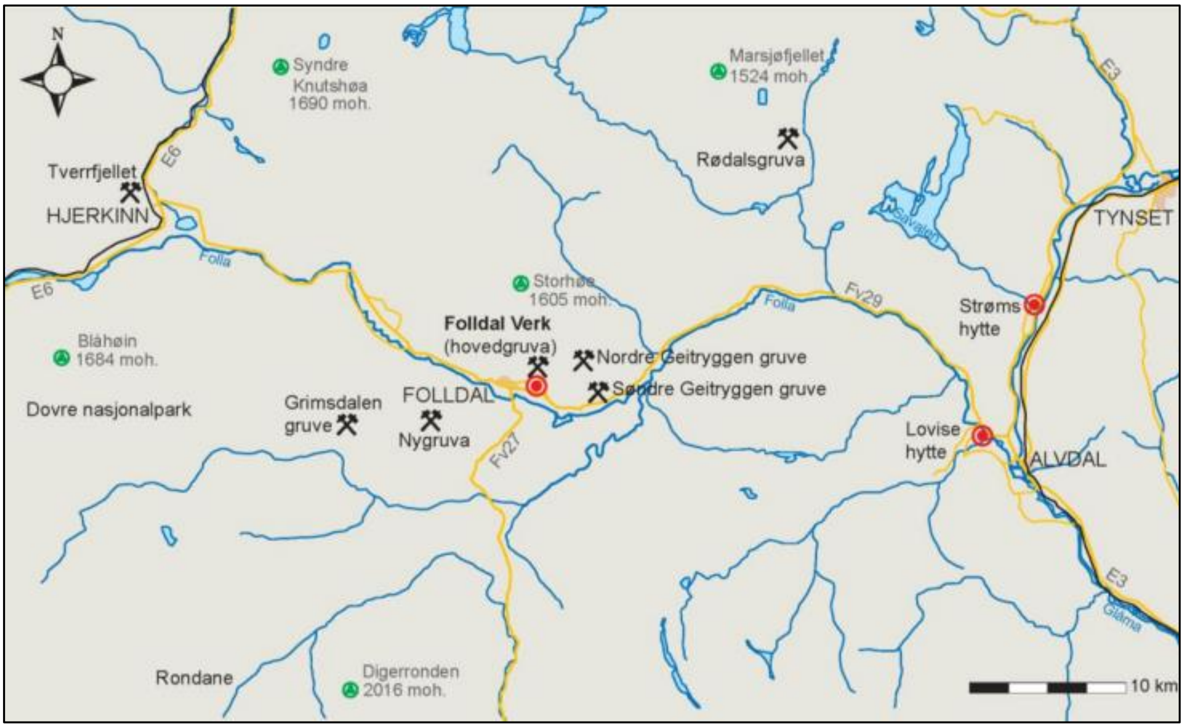


https://folldalgruver.no/historien.

Mr. Lund was a skilled engineer, but an uncompromising and wilful leader. The mining workers organized from 1906 on, and the following years were marked by a long series of strikes and other conflicts. In 1929, a major strike broke out, ending only in 1931. Worm Lund had to leave, after one of the longest lasting conflicts in Norway's industrial history.

In 1938, The Folldal Copper & Sulphur Co. Ltd went bankrupt. Operations were carried on by the Social Department until the new company Folldal Verk with Norwegian owners was established soon after. In 1941, the main mine was empty, but operations continued based on ore from the satellite mines in the area, which was brought to the enrichment facilities by the main mine on ropeways. When the minerals had been separated, they were sent by another ropeway to Alvdal station for onward transport by rail. In 1968, mining activities were moved to Tverrfjellet, a promising site near Hjerkinn, and the production process followed gradually. A modern and large-scale mine was developed. Mining operations ended in 1993, as extractable resources had been taken out. 245 years of mining activity had come to an end.

In 2018, the Australia-based company Koppar Resources was investigating the old mines of Folldal Verk, with the prospects of possible mining in the future.



Map showing the location of Folldal Verk (the main mine) and other mines that were established under Folldal Verk. From the book "Bergverk i Norge – Kulturminner og Historie", Fagbokforlaget, 2016.

Main Mine:
1748 - 1878 and 1906 - 1941.
14 levels, approx. 700 metres deep
Ore extraction: 1.5 million tons

Søndre Geitryggen Mine:
From the 1760s to 1963, operation in periods
Ore extraction: approx. 330.000 tons

Grev Moltke Mine or Nygruva:
1783 - 1952, operation in periods.
Ore extraction: approx. 220.000 tons

Grimsdalsgruva:
From 1780 to the 1950s, operation in periods
Ore extraction: Uncertain, but 230 tons were extracted annually during the period 1907 - 1919. The volume indicates a combination of production and trial operation.

Nordre Geitryggen Mine:
1935 - 1970. Ore extraction: approx. 1.95 million tons

Tverrfjellet:
1968 - 1993. Ore extraction: approx. 15 million tons, with an annual production of over 690,000 tons

Dovrefjell National Park and former Hjerkinn Mine

Information about the park copied from
https://dovrefjell-sunndalsfjella.no/en/about-the-national-park/:

Dovrefjell-Sunndalsfjella National Park was established in 2002,and expanded in 2018. Together with the surrounding protected areas, nine protected landscapes and four nature reserves, the national park constitutes a large mountainous area that stretches from Isfjorden in the west to Kvikne in the east – a distance of over 100 kilometers as the crow flies. The most famous hiking destinations are the two mountains called Snøhetta and Romsdalseggen ridge.

Dovrefjell used to be the name of the mountain pass where the old thoroughfares ran between Dovre at the top of Gudbrandsdalen valley and Oppdal in Trøndelag. Today, the name is used for a large and extensive area on both sides of the E6 highway and The Dovre Line (railway line).

The area as a whole can't be characterized as having one type of landscape, but instead is made up of several different types. In the westernmost parts and around the Snøhetta mountain massif, the landscape is dominated by sharp ridges that stoop into sheltered, forested valleys. Further east, the landscape is more rounded and hospitable, but the differences in height can also be large here. If we look at the national park in isolation, it is almost entirely located above the treeline in the mountains.

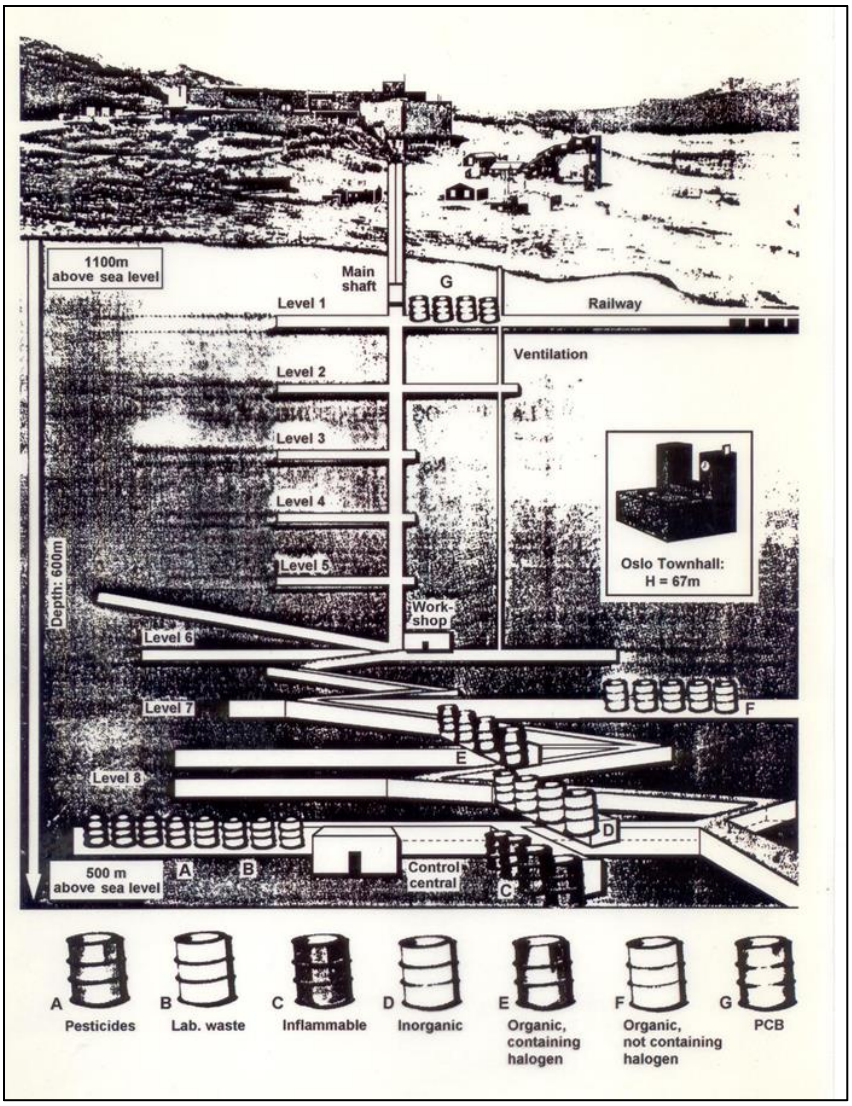
A mountain ecosystem that is the country's most intact, and the fact that the area is home to the most genetically original mountain reindeer, is evidence that Dovrefjell-Sunndalsfjella has been equipped with exceptionally rich nature. This places great responsibility on the shoulders of those of us who use the mountains, and visitors should leave no traces behind. There are many hiking opportunities, from easy day trips for both children and adults, to several days of mountain hiking.

Tens of thousands of years ago, musk oxen lived side by side with the woolly mammoth in the mountains and valleys of what is now Norway. Today you can still experience this primeval animal alive and well in the Dovrefjell mountain range.

In Norway, national parks are large natural areas that are protected in order to preserve important natural values and cultural heritage sites. The parks safeguard these values and sites against development, pollution and other activity that could harm natural and cultural values. At the same time, national parks ensure undisturbed experiences of nature.

Parts of Dovrefjell have large ore deposits, and mining has been carried out in Folldal since 1748. In 1969, modern mining operations were started at Hjerkinn. Tverrfjellet mines were opened by the then Crown Prince Harald and were in operation for 25 years. Every day, one to two freight trains traveled from Hjerkinn to Borregaard's factory in Sarpsborg. Most of what was mined consisted of iron pyrite, copper and zinc. In addition, 99 tons of silver and almost one ton of gold were mined! At its peak, 450 people worked at Tverrfjellet mines, so it was an important workplace for the region.

By 1993, the available mineral resources had been extracted and mining operations were discontinued. Proposals were then put forward to use the mines for storing hazardous waste, such as nuclear waste. This was met with great resistance both locally and nationally, and the plans were eventually scrapped. Below the ground in the area between the parking lot at viewpoint SNØHETTA and the vantage point, there are large halls that are currently filled with water. The largest of these is so huge that it would be able to room both Nidaros Cathedral and Folldal Church.

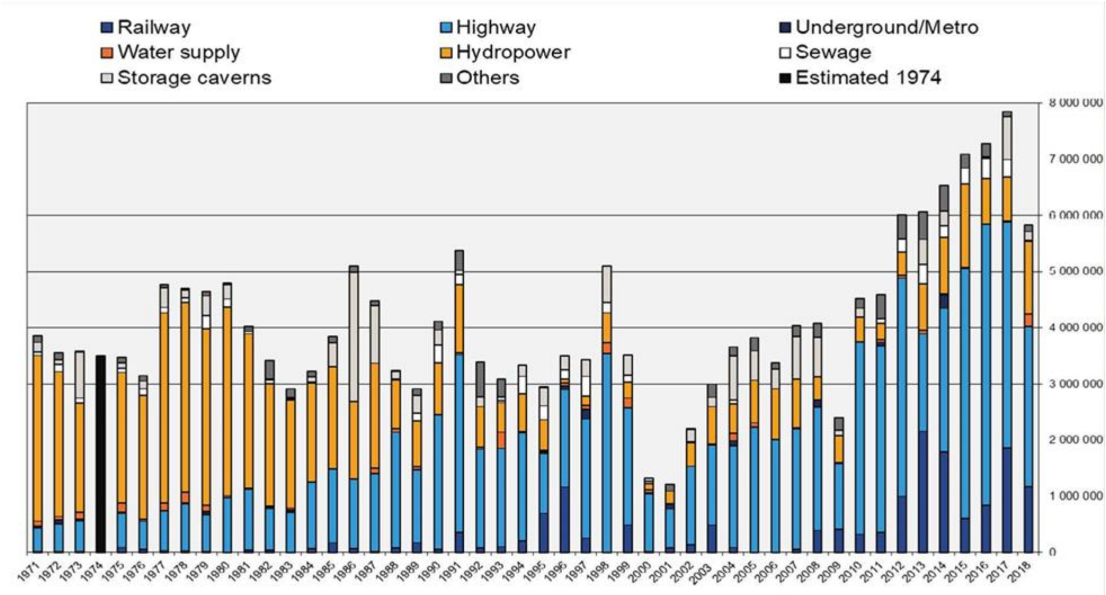


Brattset hydropower plant

This part of the tour guide is based mainly on the following paper in Journal of Rock Mechanics and Geotechnical Engineering: Nilsen B (2020): Norwegan oil and gas storage in rock caverns – Technology based on experience from hydropower development. https://www.sciencedirect.com/science/article/pii/S1674775521000019?via%3Dihub

Norway has long traditions for utilizing the underground for a variety of important purposes such as communication (road, railway and metro tunnels), hydropower development, water supply, storage of various products, sport utility caverns, sewage treatment and much more.

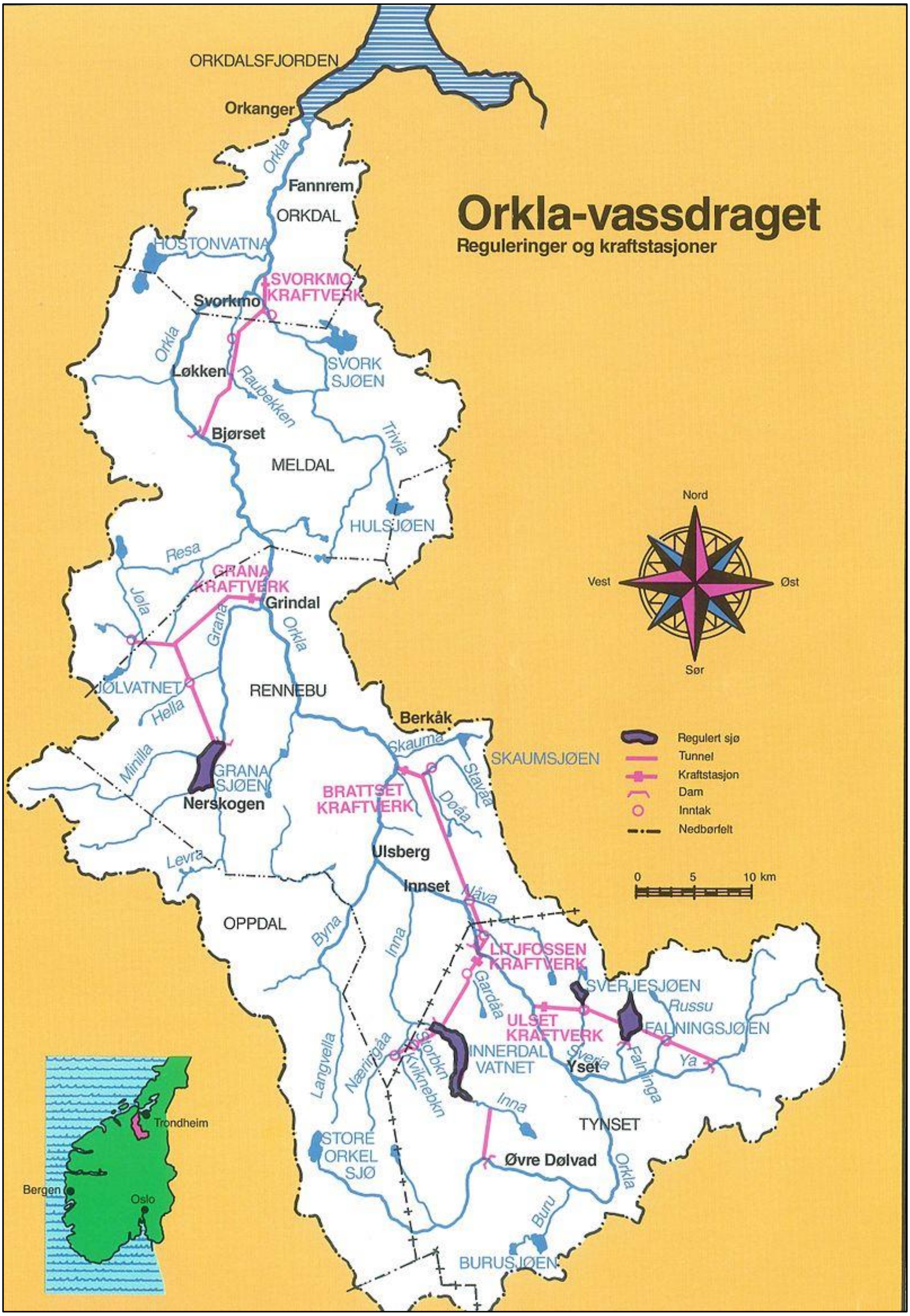
The high activity regarding underground projects is reflected by statistics published by the Norwegian Tunnelling Society (NFF). As can be seen from the diagram below, tunnel production has been going up and down during the almost 50 years covered by the statistics, reflecting variations in market demands, but on average the annual excavated volume (in solid m^3) has been as high as around 4,000,000 m^3. Most recently, production has been highest in road and railway tunneling, although there has also been considerable production related to hydropower tunneling, which used to be the main activity before the 1980s.



Underground excavation for civil purposes (mining for minerals not included) in Norway 1971-2018 (from NFF, 2019).

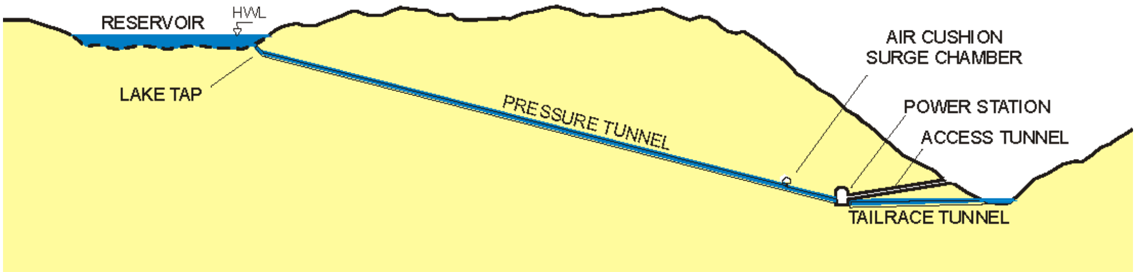
A hydropower project, including tunnels, shafts, large caverns, intake structures etc., is far more complex than a road or railway tunnel (and most other underground projects). Rock excavation related to underground hydropower development in Norway include around 4,500 km of tunnels and shafts, around 200 powerhouse caverns, unlined tunnels and shafts with up to 1,000 m hydrostatic water pressure and10 air cushion chambers with air pressure of up to 7.7 MPa and volume up to 110,000 m^3.

A major hydropower development near Trondheim, which took place along the Orkla watercourse in 1978-1985, includes 100 km of tunnels and 5 power plants with Brattset as of these, see map below. The total installed effect of the 5 power stations is 320 MW and the annual production capacity 1250 GWh. Brattset power plant has a stic water head of 273 m, installed capacity 80 MW and an annual production capacity of 400 GWh (highest of the 5 plants.



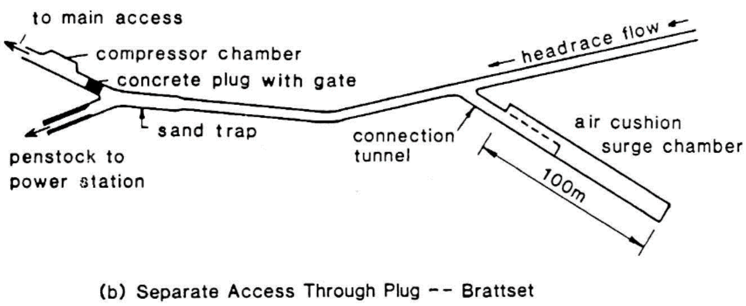
Tunnels and power plants are included in the Orkla hydropower development.

Most of the Norwegian hydropower projects have a surge shaft from the headrace tunnel which mitigates the hydraulic pressure ("water-hammer effect") in case of sudden stop of power production, but some have air cushions for this purpose. The latter is of most interest in this connection. Typical layout of a Norwegian hydropower project with air cushion chamber is illustrated in the figure below.



Principle sketch of hydropower project with air cushion chamber (from Palmstrøm, 2008).

The experience from the hydropower projects has played a key role in the development of technology for many other types of underground projects in Norway, including underground storage of oil and gas. The air cushion chambers are large gas (i.e. air) storage caverns with considerable pressure, representing a very valuable base of experience for planning and operation of gas storage facilities. The large caverns related to hydropower projects represent a valuable base of experience regarding excavation and support also of caverns for oil and gas storage. And finally, the technology related to design and sealing of concrete plugs; particularly the plug between the dry access tunnel and the water filled headrace tunnel as illustrated in Fig. 3, is highly relevant also for plugs related to oil and gas storage caverns.



Typical layout of hydropower project (Brattset) with air cushion chamber and access to the headrace tunnel through concrete plug with gate (from Goodall et al., 1989).

The two fundamental requirements for design of the concrete plug are static capacity which can withstand the water pressure, and satisfactory sealing effect to prevent leakage. The length of the plug is normally 10-40 m, depending upon the static head and the geological condition (in most cases around 4 % of the head). Extensive grouting is in most cases required for sealing of the surrounding rock, as well as the spaces between concrete and rock and between steel pipe and concrete.

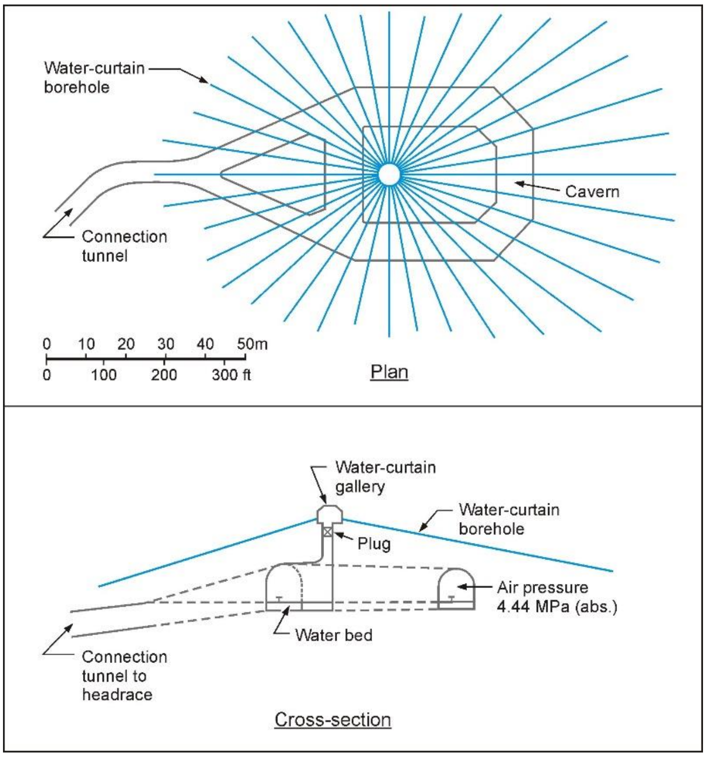
The air cushion concept has been used at 10 Norwegian hydropower projects. Several air cushion chambers have also been built in China (Hu et al., 2007), South Korea and Japan. Contrary to the Norwegian unlined air cushion chambers, to this author's knowledge, most of these (if not all) are however lined. The Norwegian air cushions are all built before 1990. This is due to the fact that many of the more recent projects represent refurbishment/ upgrading of existing plants and because for newer projects, the topographic conditions have not been in favor of air cushion instead of surge shaft.

Key figures of the 10 Norwegian air cushion chambers are shown in Table 1. As can be seen, 8 of the projects are built in gneissic rocks, while 2 are built in metasediments (phyllite and meta-siltstone). Most of the chambers have rock cover of hundreds of meters, and only two have rock covers less than 200 m. The volumes of the air cushion chambers vary greatly, from 1,900 m^3 for the smallest (Tafjord) to 110,000 m^3 for the largest (Kvilldal). The highest operating pressure at the air cushion has been 7.7 MPa (Tafjord).

Key data for the Norwegian air cushion chambers (based mainly on data from Kjørholt (1991) and Broch & Nilsen (1992)).

Project	Year built	Main rock type	Rock cover, m	Total volume, m^3	Air volume, m^3	Pressure, MPa	Operational experience
Driva	1973	Banded gneiss	1,100	7,350	2,600-3,600	4.0-4.2	No leakage
Jukla	1974	Granitic gneiss	340	6,050	1,500-5,300	0.6-2.4	No leakage
Oksla	1980	Granitic gneiss	645	18,000	11,700-12,500	3.5-4.4	<5 Nm^3/h
Sima	1980	Granitic gneiss	425	9,500	4,700-6,600	3.4-4.8	<2 Nm^3/h
Osa	1981	Granitic gneiss	142	12,500	10,000	1.8-1.9	Extensive grouting
Kvilldal	1981	Migmatite	522	110,000	70,000-80,000	3.7-4.1	Water curtain
Tafjord	1982	Banded gneiss	658	1,950	1,200	6.5-7.7	Water curtain
Brattset	1982	Phyllite	150	8,900	5,000-7,000	2.3-2.5	11 Nm^3/h
Ulset	1985	Mica-gneiss	264	4,900	3,200-3,700	2.3-2.8	No leakage
Torpa	1989	Meta-siltstone	225	17,400	11,000-13,000	3.8-4.4	Water curtain

To illustrate the general design concept of Norwegian air cushion chambers, plan view and cross section of Torpa air cushion chamber is shown below. As can be seen from the Table above, Torpa represents an approximate average regarding volume, air pressure and rock cover, and is also the newest of the Norwegian air cushion chambers. In addition, it is one of air cushions equipped with water curtains, which is a common concept also for underground oil and gas storage.

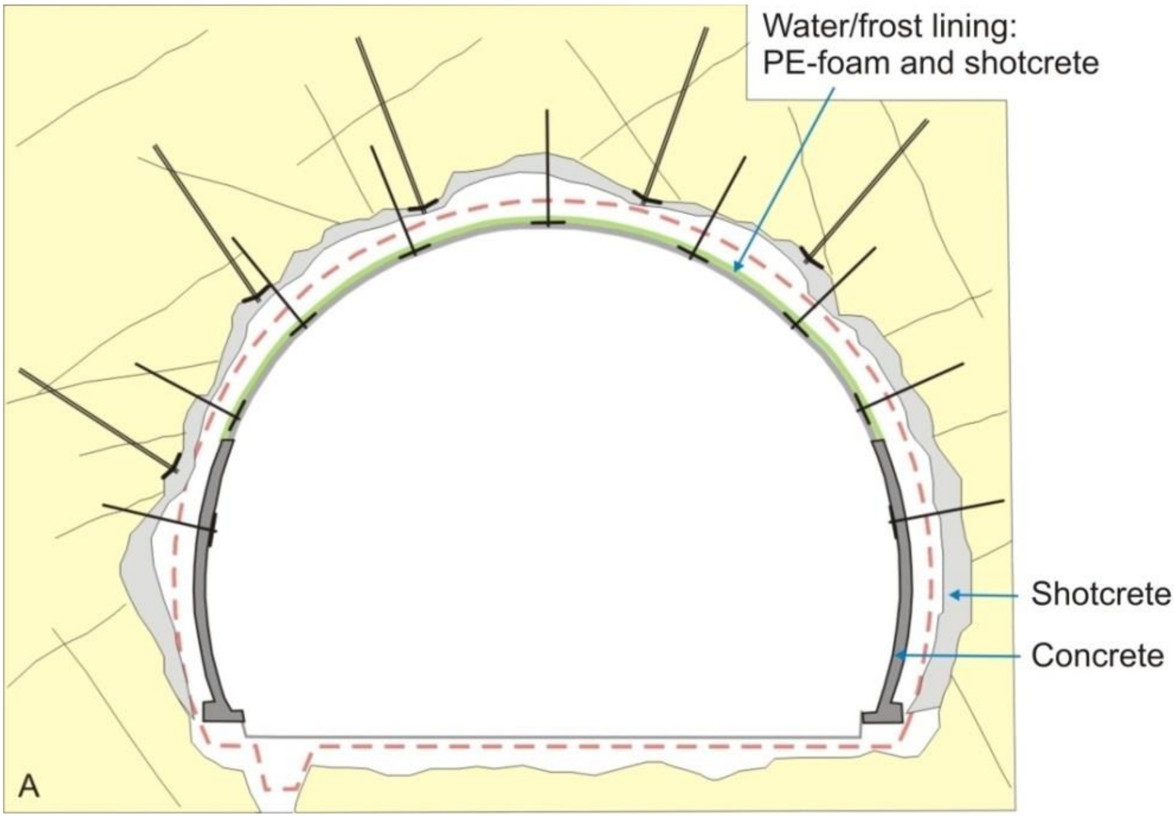


Soknedal road tunnel

Due to the rough topography of the country, stricter regulations regardiing curvature and many other good reasons, a considerable number of new roads are today placed in rock tunnels. During the last few decades, a considerable increase of the already large total length of around 2,000 km therefore has taken place.

The Eurock pre-congress tour will take us through a considerable number of road tunnels of various lengths and standards. One of the newest of these tunnels is the Soknedal-tunnel, which was opened for traffic in July 2020. Metasediments (metasandstone, schists etc) of Cambrian-Silurian age are the predominant rock types at the site. The tunnel is 3.6 km long, and for the time being has only one tube. A second tube has been prepared for at the entrance areas. If time and traffic permits, a shhoty stop will be done to observe this tunnel from distance. Alternatively, comments will be given in the bus while driving through.

The great majority of Norwegian road tunnels are drained, with a certain amount of water allowed to leak into the tunnel and then being drained down to behind the water shielding behind trenches ar the invert. Typical design of rock support and water shielding is shown in the figure below.



Common concept for rock support and water/frost lining of Norwegian road tunnels: drained tunnel, minor controlled inflow behind lining is accepted-