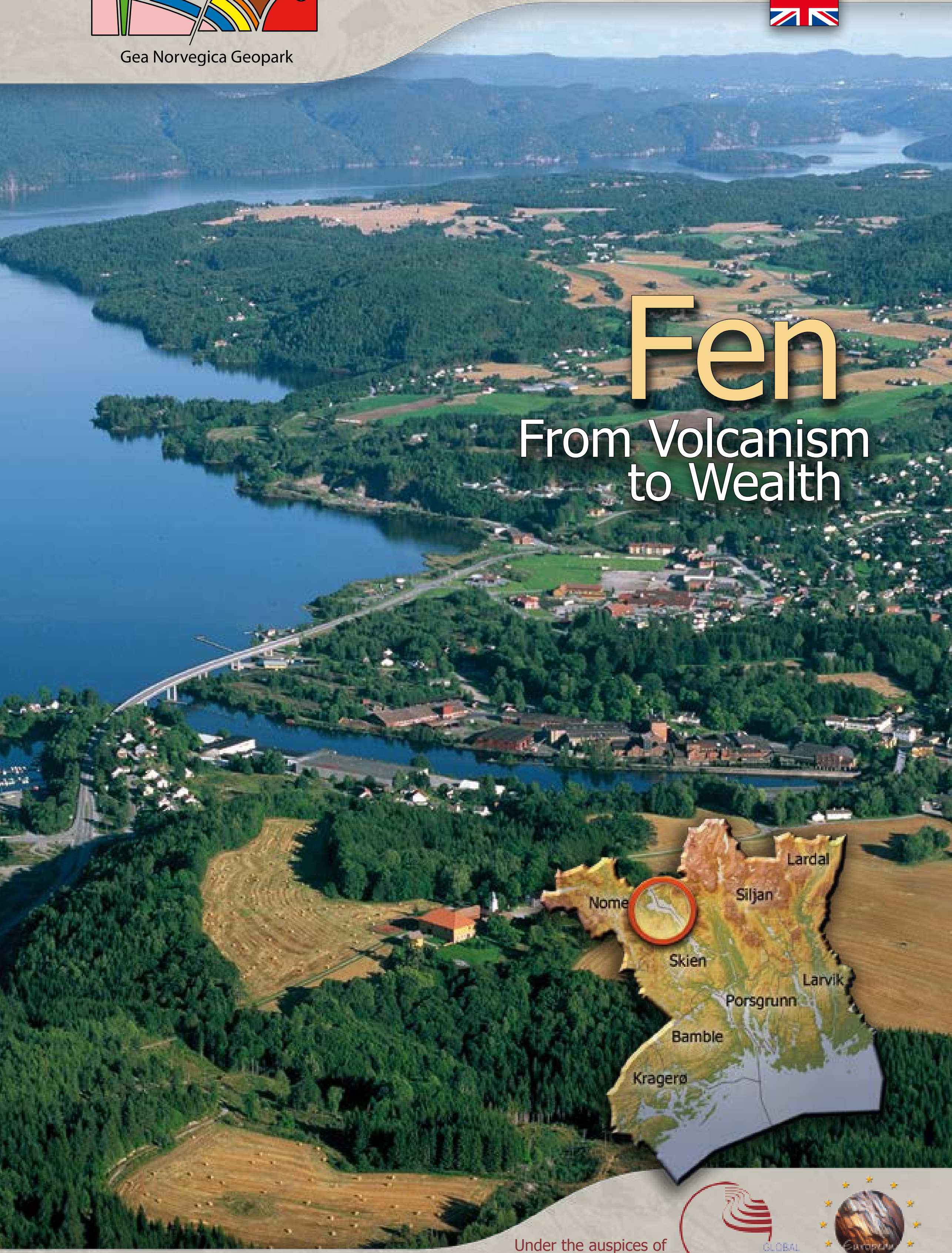
Gea Norvegica Geopark

In English

Fen

From Volcanism to Wealth

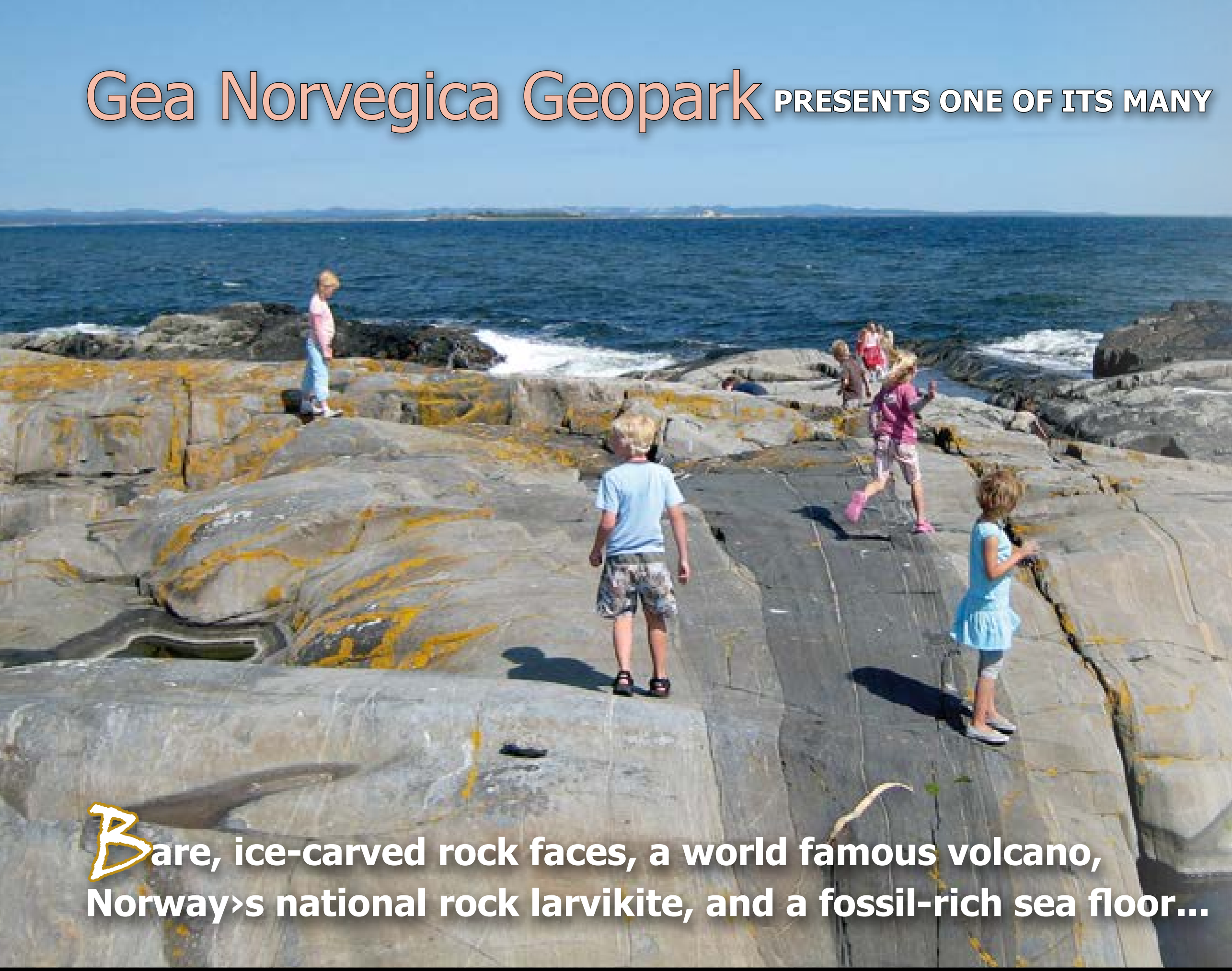


Under the auspices of UNESCO

GLOBAL GEOPARKS NETWORK

European Geoparks

Gea Norvegica Geopark PRESENTS ONE OF ITS MANY



Bare, ice-carved rock faces, a world famous volcano, Norway›s national rock larvikite, and a fossil-rich sea floor...

Gea Norvegica Geopark aims to increase interest in and knowledge about our geological heritage, and show how geological processes shape our environment and our lives – from the past to the present.

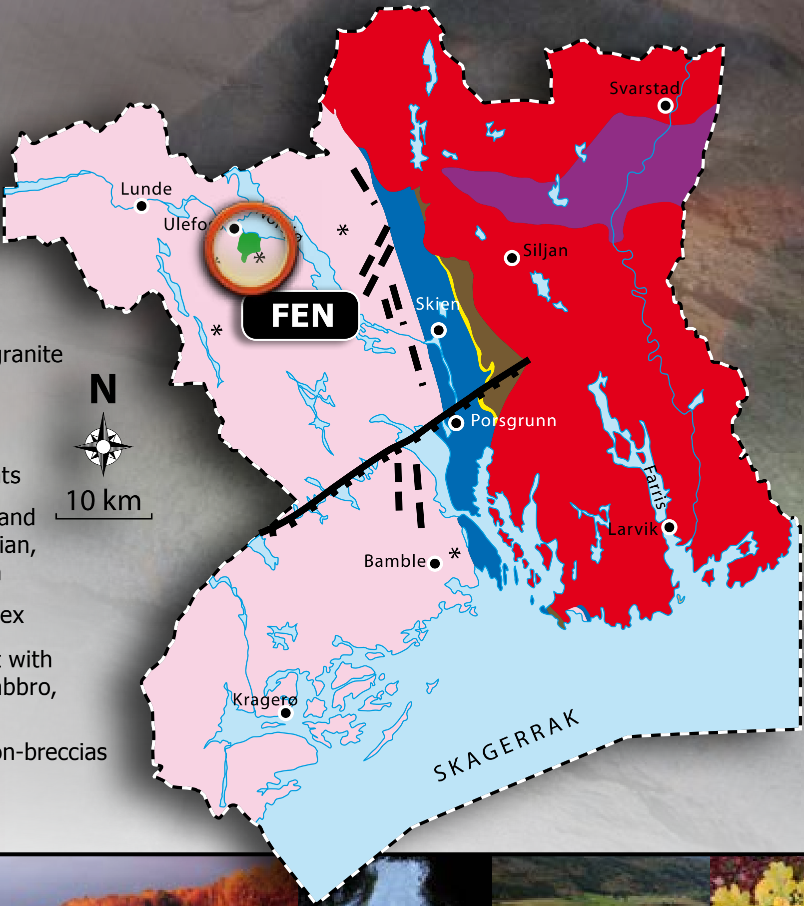
This landscape, which stretches across Telemark and Vestfold counties, has so much exciting geology and natural history that in 2006 it was awarded the status of a new European Geopark. In order to become a member of the UNESCO-supported European Geoparks Network (EGN) and Global Geoparks Network (GGN), a number of criteria must be met: The area must show geological localities of unique value, having scientific importance, it must exhibit rare aesthetic qualities and be able to provide a suitable arena for education.

In addition, it is required that Geopark localities be of interest also archaeologically, ecologically, historically and culturally – and have a high capacity for communicating these virtues! Few places have as varied geology as that which can be experienced in Scandinavia's first Geopark.

This geological diversity is clearly reflected in our landscape's unique forms and features. Perhaps less obvious, but no less important, is the role this geology plays in shaping the existing conditions for the region's biological diversity, its settlement, agriculture and industry.

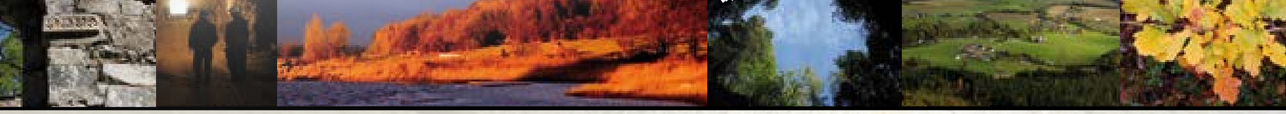
A Geopark's role is to help the ancient history come alive and show its bonds to human life, culture and history.

ATTRACTIONS. THIS TIME THE DESTINATION IS FEN.



BEDROCK MAP
GEA NORVEGICA GEOPARK

🟥 Larvikite, syenite and granite
🟪 Rhomb porphyries
🟫 Basaltic lavas
🟨 Carboniferous sediments
🟦 Limestone, sandstone and shales from the Cambrian, Ordovician and Silurian
🟩 Fen Carbonatite-complex
⬜ Precambrian basement with gneiss, amphibolite, gabbro, granite, quartzite, etc.
* Volcanic pipes, explosion-breccias
▬ Main faults



Gea Norvegica Geopark therefore sees its role as:

- **Communicating the importance of geological processes for society**
- **Spreading knowledge of sustainable use of our natural inheritance**
- **Making the region's geological attractions accessible**
- **Exhibiting the region's geological, historical, cultural and ecological qualities**
- **Using the area’s cultural and natural heritage to strengthen regional pride and identity**

Gea Norvegica Geopark

The Geopark’s logo gets its inspiration from the unique assemblage of rock types in the park. A schematic, and of course somewhat simplified cross-section of this assemblage, coloured according to bedrock type, shows the dynamic forms that inspire the logo’s unique pictogram.

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Photo: Sverre S. Aksnes

FEN
AND THE FEN VOLCANIC AREA

FROM VOLCANISM TO WEALTH

The history of Fen in Nome is the story of a very special volcano, of an intense academic debate from the 1920s until today, and of a series of unusual rock types and minerals.

Another part of this story is a church from the Middle Ages, with ornaments carved in pliant limestone, an iron factory based on iron originating from this volcano, and the emergence of a community.

The rock types at Fen have captured the interest of geologists far outside of Norway's borders. The same rock types, and the conditions that formed them, have also formed the basis for the settlement of Ulefoss and its fascinating history.

Large photo: View of the Fen area in Nome, in Telemark county

Geology

Geologists refer to it as the Fen Volcanic Complex, and here one finds what is undoubtedly some of the most extraordinary geology in the whole Geopark. In the area around Ulefoss in the Nome municipality, there was unique volcanic activity about 580 million years ago.

The volcano is called the Fen Volcano, but it is not easy to see it today. However, it is lucky that we can compare it to a volcano that is very visible today: Ol Doynio Lengai, in the so-called African Rift. In Tanzania, this volcano towers majestically over the landscape and regularly has eruptions of lava that resemble the rock types at Fen.

The volcanic area at Fen, however, has been eroded down by ice ages, wind and weather. That which makes up today's surface is in fact a cross-section through what once was the supply pipe for this mighty, ancient volcano. Around the supply pipe, the earth's crust is fractured, and in the faults we can find different rock types that were magma flowing out from the volcano.

Such rock types that are formed from volcanic magma are commonly referred to as *igneous* rock types. Lava is an igneous rock type that once flowed out of volcanoes and solidified at the earth's surface, while the intrusive rock types at Fen solidified for the most part beneath the earth's crust.

Controversy and debate

The geology of the Fen area is complicated, and contains many unusual rock types. When the famous Norwegian geologist Waldemar C. Brøgger described the rock types in 1921, many of them were new to the scientific community. Brøgger reflected a great deal about these unique rock types. It was not difficult to understand that some of them were limestones, but there was much speculation about their origin.

Brøgger understood that these limestones must have been associated with volcanic activity, that is, they must be so-called igneous minerals (formed from magma), even though it was well known that carbonate rocks were otherwise of sedimentary origin (mainly formed from loose sediment deposits).

In order to describe the rock types at Fen as something other than common carbonates, Brøgger gave them the name *carbonatites*. He named the different rock types at Fen after farms and localities in the area, so they have names like *soevite*, after the Søve Farm, and *hollaite*,

Ol Doinyo Lengai

In East-Africa there is a geologically-speaking very active area: The African Rift. Both earthquakes and volcanoes occur there, because the earth's crust is on the verge of breaking up.

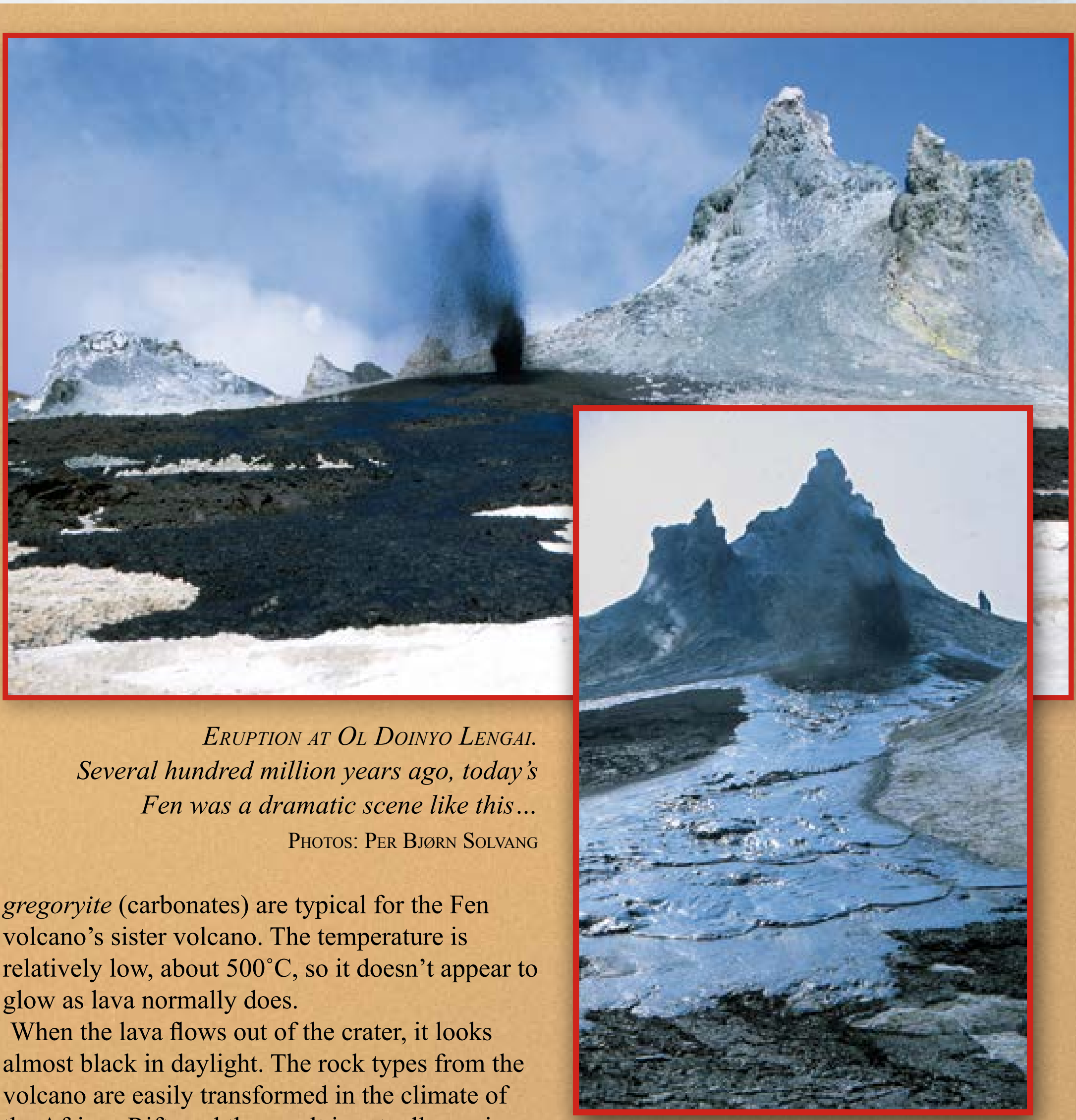
The fracturing occurs slowly, but the active volcanoes lying all in a row tell us that something is about to happen.

One of the mighty volcanoes is Ol Doynio Lengai, in north Tanzania, and it rises up from the flatlands to a height of nearly 2,900 metres. "God's Mountain", its name translated from Masai, is the only active volcano in the world with carbonate-rich lava flowing out of it. When these lava flows cool, they form carbonatites, like those we find at Fen.

The carbonatites contain *sodium- and potassium-rich* minerals, and the minerals *nyerereite* and after Holla. Other names of rock types with similar origins are *vipetoite, meltegite, rauhaugite, damtjernite, kåsenite, ringite* and, not least, *fenite*. Some of these names are only used in Norway, but others have become international "names" after being described first at the Fen area.

Most of Brøgger's colleagues disagreed with the old scholar. Even though some understood that the carbonates were not of the usual kind, they did not believe that a carbonate-rich magma could flow out from a volcano. They instead embraced an explanation whereby hot fluids containing dissolved carbonate circulated far down beneath the earth's crust.

Some of the rock types at Fen may well have had such an origin, but when in the 1960s the active carbonate volcanism was discovered in Tanzania, it was at last realized that Brøgger's interpretation could be correct.



Eruption at Ol Doinyo Lengai.
Several hundred million years ago, today's Fen was a dramatic scene like this…
Photos: Per Bjørn Solvang

gregoryite (carbonates) are typical for the Fen volcano's sister volcano. The temperature is relatively low, about 500˚C, so it doesn't appear to glow as lava normally does.

When the lava flows out of the crater, it looks almost black in daylight. The rock types from the volcano are easily transformed in the climate of the African Rift, and the result is actually a mixture of baking soda and baking powder!

And at the foot of Ol Doinyo Lengai, we find Lake Natron, the red saltwater lake that is famous for its large flocks of pink flamingos.

One of Brøgger's contemporaries was the renowned Canadian-born geologist Norman L. Bowen (1887–1956). Bowen could not believe that Brøgger had found volcanic limestones, so he travelled to Norway himself in 1923 to collect samples and study the rock types in the field.

He did not stay for many days, nor did he take many samples, but enough to compile a publication in which he claimed that Brøgger was mistaken.

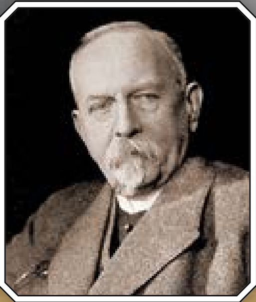
Bowen believed that the carbonate-rich fluids had their origin in the limestones of *the Oslo Rift*, east of Ulefoss. Bowen thought that even the volcanic activity at Fen was related to the volcanism in the Oslo Rift.

It was not possible for Bowen to date the rocks, as we do today. If he could have, he would have found that there could not be any connection between the volcano at Fen and the story which unfolded in the Oslo Rift further to the east. While the Fen Volcano is ca. 580 million years old, the oldest sedimentary carbonate rock types are "only" 450 million years old, and the volcanism in the Oslo Rift started ca. 300 million years ago.

Unfortunately, neither Brøgger nor Bowen were able to experience the discovery of the active carbonatite volcano in the African Rift. Today we know of many extinct volcanoes that have formed carbonatites, e.g. from Alnö in Sweden and from Germany, Brazil, Africa, the USA and Russia.

Fen will always be the classic area for these rock types, however, since it is the type locality where they were first described and named.

Was it really possible to find rock types like soevite at Fen, of volcanic origin?



Waldemar C. Brøgger

(1851–1940)

Waldemar Christopher Brøgger was born in Christiania (old name for Oslo) in 1851, as the son of book printer A.W. Brøgger. Since the printing office specialized in academic literature, young Brøgger was able to meet many of the day's foremost scholars, and this gave him great inspiration.

Brøgger passed his first and only exam at University in 1870, and plunged into the study of science, taught and inspired by the geologist Theodor Kjerulf.

Brøgger's research would come to span a wide scope, from the first investigations of molluscan fauna in the Oslo Fjord to most of the disciplines within the geological sciences. He published many works in palaeontology, mineralogy, petrology, the geology of the Oslo Rift, mineral resources, and Quaternary geology. He also described the geology and landscape in other parts of the country.

In addition, history has viewed Brøgger as a builder of universities and museums and as one of the country's important nation-builders in the years around 1905.

Brøgger was well known in the area that today comprises the Gea Norvegica Geopark. He published important works from the Kragerø area, the Langesund Fjord, about the rock types in Larvik and, not least, he was the first to describe the rock types at Fen and their connection with volcanism.

One of Brøgger's main works was a seven volume-piece: *Die Eruptivgesteine des Kristianiagebietes*, about the magmatic rock types of the Oslo Rift. The fourth edition of this very influential work was published in 1921 and is about the rock types of Fen.

Why was there volcanic activity at Fen?

The face of the Earth is constantly changing, even though we do not notice the changes on a daily basis. But, the earthquakes and volcanic eruptions we hear about in other parts of the world are signs that the major continental plates are moving. In our part of the world we are essentially spared this kind of natural disaster, since Norway lies in a geologically-speaking stable part of the world.

But, that has not always been the case! The continental plate that Norway is a part of is moving slowly north-eastwards, a plate motion that over the course of billions of years has brought us from southerly latitudes to where we are today. Our continental plate has been through periods of collision with other continental plates, forming large mountain chains and larger continents as a result. The mountain chains have been eroded down over time, and the land masses have been altered and broken into smaller pieces again.

Toward the end of the time we call *Precambrian*, "Norway" was a part of a continent called *Rodinia*. This ancient continent got broken into pieces and one result of this was that *Baltica* was formed – the piece of continent that Norway lies on today.

After the break-up of Rodinia, an area that probably had an especially high heat production got established right under where Ulefoss lies today, and this in turn led to the formation of the Fen Volcano.

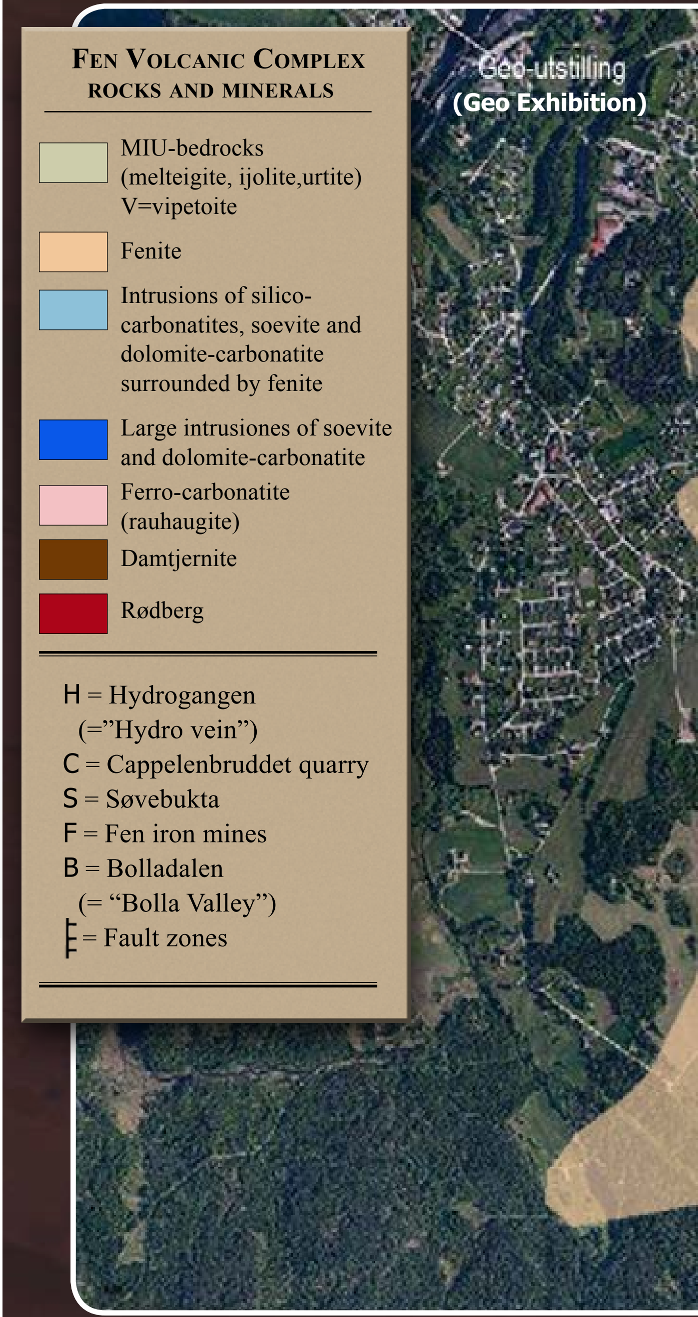
The rectangle shows Norway's location on the Baltica plate during the latter part of the Precambrian. Modified from Nystuen 2013

Extent of the Fen Area

The area geologists refer to as the Fen Volcanic Complex is not large, only about 4.5 square kilometres. But there are many different rock types found here, and not only carbonaceous lavas or other magmatic rock types, either.

Traces of the Fen volcano can also be found far outside the Fen area. We find rock types from Fen as far south as Skåtøy in Kragerø and north to Lifjell in Bø. At some places we can see narrow veins where Fen rock types have penetrated into older rock formations, and small explosion channels, where magma from the Fen Volcano has blasted its way in.

When the volcano was active, eruptions and earthquakes were surely felt over large distances – if there was anyone in the area to notice, of course. We do not find traces of the first human beings on Earth until 577 million years later, and even the dinosaurs had not set foot on the earth until 350 million years had passed.



Fen Volcanic Complex
rocks and minerals

🟩 MIU-bedrocks (melteigite, ijolite,urtite) V=vipetoite

🟧 Fenite

🟦 Intrusions of silico-carbonatites, soevite and dolomite-carbonatite surrounded by fenite

🟦 Large intrusiones of soevite and dolomite-carbonatite

▨ Ferro-carbonatite (rauhaugite)

🟫 Damtjernite

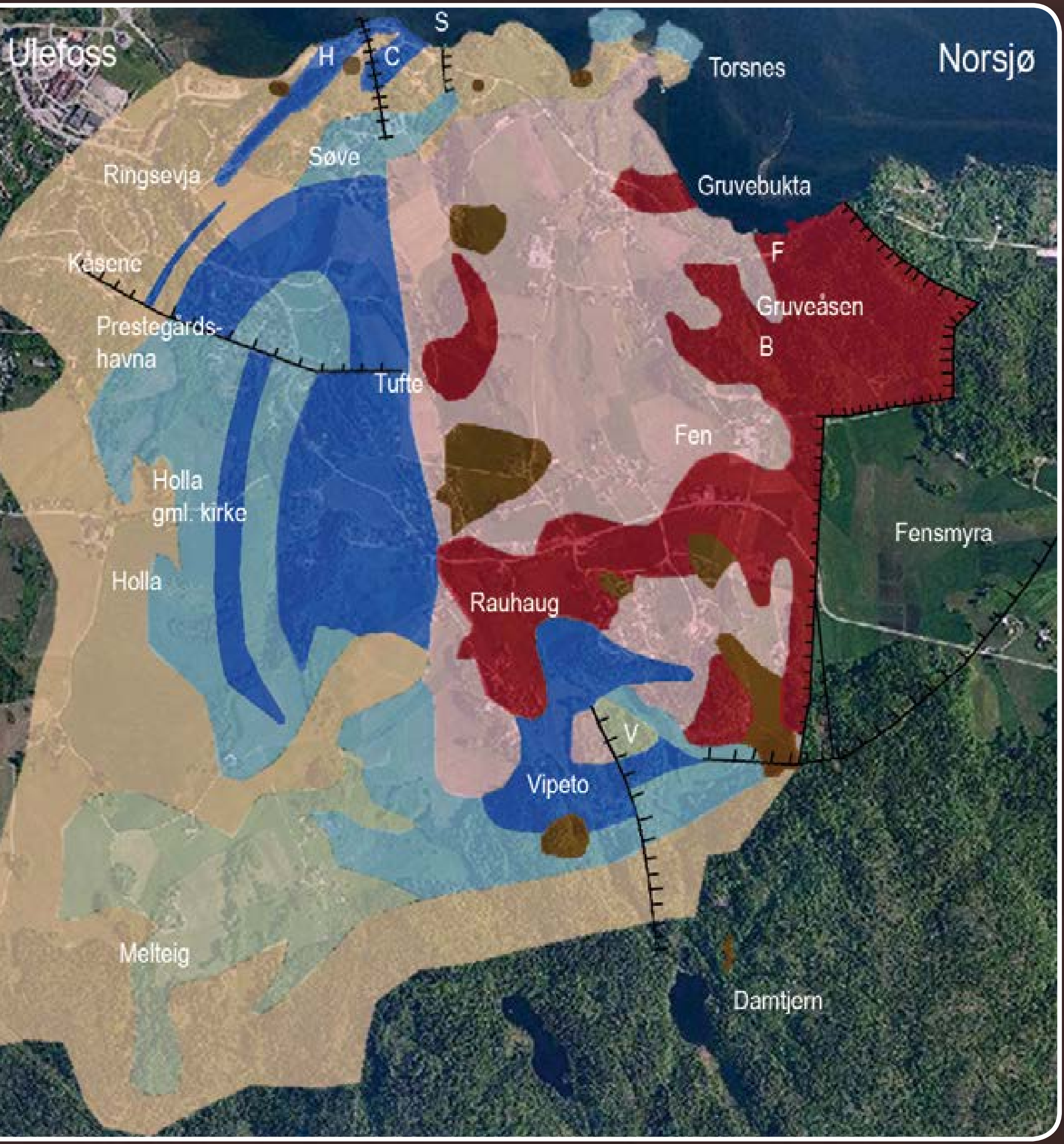
🟥 Rødberg

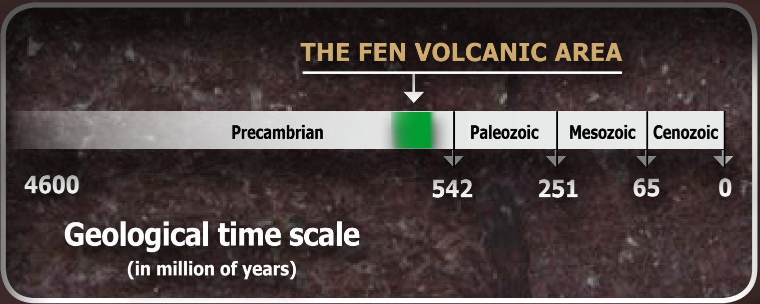
H = Hydrogangen
(=”Hydro vein”)
C = Cappelenbruddet quarry
S = Søvebukta
F = Fen iron mines
B = Bolladalen
(= “Bolla Valley”)
⊧ = Fault zones

Above: Geological map of the bedrock at the Fen area

The map was made by Sverre Aksnes in 2010 and was simplified from Egil Sæther (1957)

Left: Carbonate volcanoes spew out black magma, in contrast to the red glowing lava one usually associates with volcanic eruptions.
Photo: Per Bjørn Solvang





The period of volcanic activity at Fen shown on a geological time scale

Like cream on milk

When explaining the different rock types at Fen, one must try to imagine a model of a volcano and, not least, of what was occurring under the volcano. The vast majority of magmas that occur in connection with volcanoes in the world are rich in minerals that contain *silicates*. Some of the volcanic rock types at Fen quite clearly have come from silicate magmas, such as the rock types melteigite and *juvite*. But there are also other magmas that contained carbonates and formed rock types such as soevite and *ankerite*.

Regional geologist for the Buskerud, Telemark and Vestfold municipalities, Sven Dahlgren, has described the conditions in the magma chamber under the Fen Volcano as follows:

> ***«It can be imagined in the same way as when we let raw milk stand still, and the cream particles rise up to form a lighter cream layer (carbonate magma) on top of the milk (silicate magma). As we know, the cream layer takes up much less volume than the volume of the milk.»***

If we consider the rock types at Fen, however, there is much more of the carbonate-rich type than the silicate-rich rock types. Therefore, there is much to suggest that a lot of silicate-rich rock types remain underneath the ground at Fen, parallel to what we see in the example with the milk.

Transformation by heat

As mentioned above, not all of the rock types at Fen are magmatic. The large masses of magma were of course hot, and gas-rich solutions could have been released as the magma made its way upwards through the earth's crust. The hot fluids contained much dissolved CO_2 and elements such as for example *sodium*. The fluids seeped into cracks and crevices in the surrounding bedrock, the old Precambrian basement gneisses.

These were affected by the solutions, and the composition of minerals could have been altered completely. Such processes are called *metasomatic*, and the result at Fen was the rock type called fenite. The transformation from gneiss to fenite is commonly called *fenitization*. Geologists around the whole world now use this expression to describe this special process that occurs between bedrock and hot solutions. It was not only the old Precambrian basement rocks that were affected by the hot circulating fluids. Also carbonatites that already had solidified could be altered in this way.

The reddish-brown rock type we find e.g. in road-cuts near the Fen iron mines is called *rødberg* (="red rock"). This rock type was formed when other Fen rock types, probably the so-called ankerite-carbonatites, got altered by hot

Rauhaugite surrounded by rødberg
PHOTO BY SVERRE S. AKSNES

Regional geologist Sven Dahlgren (centre) gives interested participants a lively description of the dramatic geological processes that have taken place at the Fen area.

solutions. Rødberg contains much of the iron mineral *hematite*, which gives the rock its characteristic reddish colour.

In some zones the rødberg contains essentially only hematite, and it was from these iron-rich zones that iron ore was extracted. This natural resource laid the foundation for the iron works at Ulefoss, which are still in operation today, even if production is no longer based on iron from the Fen area.

Enriched rock

There are many reasons for the great interest in rock types from Fen. One of them is that they contain rare earth elements. In recent years, there has been a lot of focus on *thorium*, which is a radioactive element. This element might be used to produce atomic power in the future. Thorium is primarily found finely distributed in rødberg and in ankerite carbonatites and is not easy to remove from the bedrock.

There has also been commercial mining of *niobium*, which is another relatively rare element. (Read more about this in the chapter on Søve mines).

The world's need for such elements is increasing, and efforts are currently being made to map the occurrences of these so-called rare earth elements (REE) on a global basis. The rock types at Fen are of major interest to this mapping effort.

The most common rock types in the Fen Area

CARBONATITES

Carbonatites is a collective term for magmatic rock types that contain more than 50% carbonate minerals. They are often calcium-rich.

Soevite contains mostly calcite, but also a little apatite, a different calcium mineral that contains phosphate. The sovites have a varying amount of phlogopite, magnetite, amphibole, pyrochlore, pyrite and zircon.

Rauhaugite is a name that was used by Waldemar C. Brøgger. After a time it became apparent that Brøgger had used the name for two different rock types. Today, rauhaugite is not in use internationally; instead we use *dolomite carbonatite*, a rock with dolomite as its main mineral, or ankerite carbonatite for the more iron rich variety.

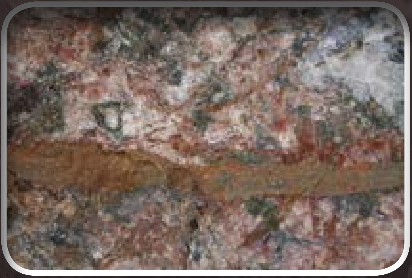
Ankerite carbonatites typically occur as thin veins, often rust-coloured. They contain the carbonate mineral ankerite with the addition of chlorite, quartz, albite and barite. They can also contain some rare earth elements, in addition to a little monazite, fluorite and allanite.

Silico-carbonatites have calcite as the only carbonate mineral, but in addition have a varying amount of silicate minerals (green clinopyroxene, biotite, apatite, titanite, potassium feldspar and nepheline/ muscovite.

Rødberg ("red rock") is, as the name suggests, a red-brown rock that contains calcite, hematite, pyrite and quartz. The rock type is formed as a result of the alteration of other rock types, especially ankerite carbonatites.

Sovite

Rauhaugite



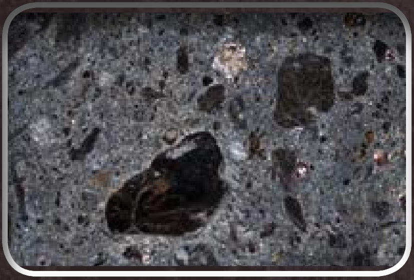
Ankerite in fenite (Søve)

Rødberg

Melteigite

Vipetoite

Fenite



Damtjernite

SILICATE ROCKS

Melteigite – ijolite – urtite. The series has pyroxene and/or nepheline as primary minerals, in addition to a little bit of apatite, calcite, titanite, titanium-rich granite and perovskite.

Meltegite consists for the most part of pyroxene, while ijolite has roughly equal amounts of pyroxene and nepheline. It can also have a little potassium feldspar. Nepheline has often been altered to scapolite, muscovite or cancrinite.

Juvite is not common, but was described by Brøgger in 1921. The rock type consists of potassium feldspar and nepheline (nepheline syenite).

Vipetoite is the local name for a silicate rock type that is only found around the Vipeto-area at Fen.

Fonolites are mainly found locally in veins around the Fen Area. They contain potassium feldspar, nepheline, aegirin and some biotite and titanite.

METASOMATIC ROCK TYPES

Fenite is altered granitic gneiss. The gneiss originally consisted of quartz, potassium feldspar, plagioclase, biotite and hornblende, but several of these minerals are dissolved or completely altered.

LAMPROPHYRES

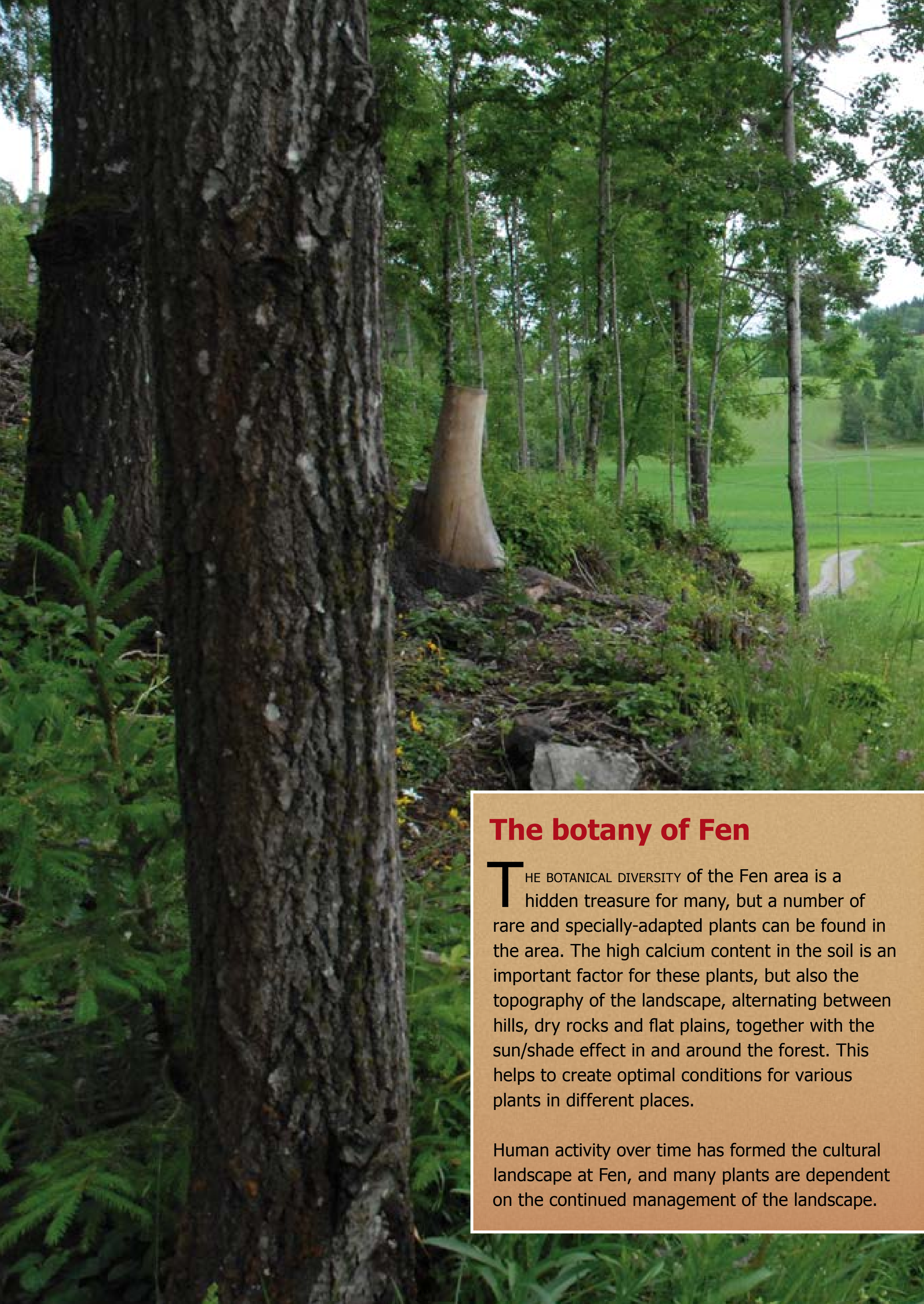
Damtjernite is a typical intrusive rock that can be found far beyond the Fen area. There are different types of damtjernite, with varying mineral content. The large variation in minerals suggests that this was a mixture of the two magma types in the volcano: silicate- and carbonate-magmas.

PHOTOS OF THE ROCK TYPES WERE TAKEN BY
SVERRE S. AKSNES

In order for the history of Fen to be told in the most interesting and vivid way, it is important to be able to show the rock types out in nature. Thus, Fen offers exciting opportunities, but it also confers a special responsibility. Several of the localities where the rock types lie visibly exposed are therefore carefully protected. Here, it is not permitted to hammer or damage the rock in any way.

In order to preserve the exciting geology at Fen for coming generations, it is important that the rule of careful trespass is adhered to everywhere. Use your cameras often, instead!

PHOTO: SVERRE S. AKSNES



The botany of Fen

THE BOTANICAL DIVERSITY of the Fen area is a hidden treasure for many, but a number of rare and specially-adapted plants can be found in the area. The high calcium content in the soil is an important factor for these plants, but also the topography of the landscape, alternating between hills, dry rocks and flat plains, together with the sun/shade effect in and around the forest. This helps to create optimal conditions for various plants in different places.

Human activity over time has formed the cultural landscape at Fen, and many plants are dependent on the continued management of the landscape.

Farming activity, maintenance of roads and forest, and livestock grazing help to keep the area open and varied.

If the landscape grows in, the species composition changes, and this can threaten the existence of a number of rare species. This in turn influences the total experience of the landscape, a landscape that at Fen stands out as both varied and beautiful.

The "Gruvehytta" at Fen – in the cultural landscape

Knowledge of the plants' utilitarian value and special characteristics is valuable, since many plants have great potential for being utilized, e.g. in medicine, as food or as dyes. But it is worth remembering that in nature's fight for survival, many plants are equipped both with poison and "claws". One should therefore never pick plants one does not know. They may be poisonous, or threatened with extinction, and should therefore be left in peace, as a beautiful sight for the eye – in their right element.

Plants you might see at Fen

Do not be fooled by the poisonous *celandine*; with its yellow flowers and thin lobed leaves it can seem both mundane and harmless – a beautiful colour contribution to roadside. The milky orange juice in its stems is poisonous, however, so the celandine should be enjoyed where it stands.

Hairy St. John's wort (Hypericum hirsutum)

Celandine (Chelidonium majus)

The species of the *Hypericum (St. John's wort)* genus are known for their beneficial health effects. Whether the species known as *hairy St. John's wort* has such qualities is unknown, but it has its main distribution in Eastern Norway and along the coast of Nordland county.

Even if it is not quite rare, one should nonetheless stop and take note of this species for its distribution. This sleek plant with the soft hair on its stem grows especially on slightly dry, nutrient-rich hills in the mining area.

The sight of stately strawberry plants in the grass is a curiosity. The *hautbois strawberry* is one of several strawberry species in the area, all of which require highly nutritious soil.

It is possible that the species has become wild since the time the mining area was in operation and the settlement (mine building) was intact; they compete nonetheless for a place in steadily more overgrown areas and are a beautiful element of the cultural landscape.

Carpets of *lily of the valley (Convallaria majalis)* decorate the forest floor in the mining areas in spring. The plant requires much light and is found naturally where the soil is nutrient-rich.

Lily of the valley has a characteristic angular stem and hanging white "porcelain bells", but remember that it is also poisonous.

Hautbois strawberry* *(Fragaria moschata)

PHOTO: TORBJØRN NILSSEN

The Fen mines and iron works at Ulefoss

It all started in troubled times. Ambitions of great power and bitter neighbourly relations between the Scandinavian countries created a threatening backdrop for the industrial adventure that was soon to unfold at Ulefoss.

There would therefore be many military castings from the ore at Fen, to arm the Danish-Norwegian troops in the 1600-1700s. It was claimed, and probably with good reason, that without the cannon production by Norwegian iron works, the King of Denmark would have had no chance of waging war.

Cannon balls, helmets and armaments were also commissioned from the iron works at Ulefoss. Fortunately, some of the production was intended for more peaceful objectives, a production that would come to play an ever increasing role and eventually result in the famous woodstoves that were produced by the Ulefoss Iron Works.

Picture to left: Daylight shines down into the upper part of the Bolla mine at Gruveåsen.

Under: Workers at the rinsing station, where the ore-bearing gravel got washed before being transported further. (Picture taken ca.1920).

Pioneer time

The iron ore in Gruveåsen at Fen was probably discovered as early as the 1540s. It is said that two German mining engineers laid their claim on the deposits at around this time, that is, they got the proprietary rights to explore and eventually mine whatever they found. The iron deposits at Fen may therefore represent the first mining in Norway in "modern" time.

However, it is said that these earliest claims never amounted to anything, at least not in the form of mining. The proprietary documents were nonetheless archived for posterity, in accordance with good business practice.

More than a hundred years later, around 1650, a nail-maker named Hans Siegel was inspecting the rolling landscape of Nome, down by the shores of Lake Norsjø. Probably, he was out

exploring for ore, with his trained eye for noting signs in the rocks, red traces that could indicate iron ore in the bedrock.

It is possible that he was sent out by his employer, the Fossum Iron Works, that was continuously searching for this so-called red iron stone, since one of Norway's biggest weapon manufacturers could never get enough iron ore. And perhaps there were two old prospecting records that had come to light and were leading these ore-hunters along the trail…?

This view from the Holla Church ruins probably looks much the same as it did for Siegel 350 years ago…

The illustration to the left shows the technique of "fire-setting", loosening rock by heating it, as pictured in Georgius Agricola's classical work on operating the mines.

To right: A cannon ball produced at Ulefoss

PHOTO: SVERRE S. AKSNES

After further investigation, which only confirmed Siegel's discovery, mining equipment and manpower was sent up from Fossum. There was enough ore exposed, ore that therefore could be mined from so-called open pit quarries through the use of fire-setting. This method consisted of first heating up the bedrock by lighting a fire, with so-called "fire-starting wood", and thereafter cooling it off. This fractured the rock, making it easier to dig out the ore-rich bedrock. The ore was then shipped across Lake Norsjø and on to the Fossum Iron Works' smelting plant. With time, it was realized that the deposits at Fen were so rich that it would be most rational to build a smelting plant right there.

The conditions for mining were also good, with abundant access to iron ore a short distance from the new smelting plant at Ulefoss.

The river could give the necessary energy, and large forests nearby gave the promise of charcoal for the blast furnaces. And Lake Norsjø was well suited for transporting the iron ore and cast iron produced at the iron works.

After some years of operation, in 1657, the Ulefoss Iron Works was created, under the name *Det holdensognske jernverk*, after the name of the parish – Holden, – and became, like its mother company Fossum Iron Works, a large producer of cast iron and rod iron.

Eventually, the Holden Iron Works became an important weapon producer for King Fredrik III, who had military ambitions against Sweden and therefore had a great need for cannons, helmets and other military equipment.

Above: From Fredrik III's ill- fated war against Sweden. Extract from J.P. Lemkes painting depicting the Swedes' march over the ice to Zealand in 1658

Early iron production

Blast furnace building at Bærums Verk around 1800. Extract of a painting by C.A. Lorentzen

Before the large blast furnaces were common, iron ore was often melted down in a so-called "smeltery". One of these was also built at Ulefoss, when the owners realized how rich the ore formations at Fen really were.

The usual method consisted of warming up the iron ore in an open oven, so that the liquid slag floated off, leaving fresh clumps of iron. The heating was accomplished with the help of charcoal that was fed with an abundant supply of oxygen from several bellows. The oven, built of brick and of modest size, with a height of about one metre, goes by the German-sounding name «rennherd». The Rennherd-technique did not give a high enough temperature for cast iron quality. With a temperature under the melting point of iron, the iron remained in a semi-hardened state.

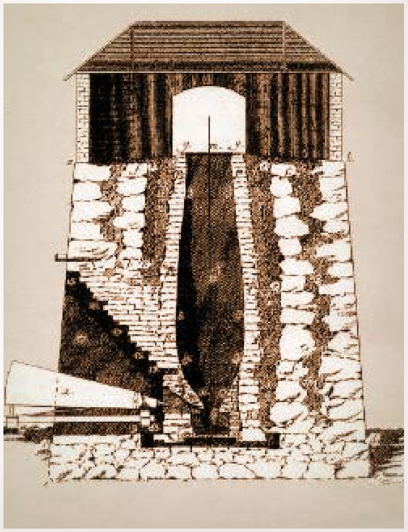
After the fresh clumps of iron were kneaded together into a larger clump, a smelt, more slag was removed by powerful banging with heavy clubs. First then, the smelt could be divided up into suitable pieces, heated again and forged.

Blast Furnace

A fair way into the 1600s the blast furnace came into use in Norway. The blast furnace was the heart of the iron works, a continuously glowing chamber where the iron ore and charcoal were put together to be transformed into raw iron. But first, the charcoal and ore had to be transported several metres up to the opening at the top, and in a precise way be fed layer by layer into the oven.

The blast furnace in the 1600s was usually about 7–8 metres high with a wall of several layers of stone, sand and clay that surrounded the cylinder-shaped chimney. One or two huge, waterwheel-driven bellows kept the temperatures up to the required thousand-and-a-half degrees. The molten raw iron could then be tapped out of the bottom of the oven, and separated from the lighter slag layer which was lying on top. Under the supervision of the furnace master, the raw iron could then be used directly in the production of cast iron, or be further treated for use as wrought iron.

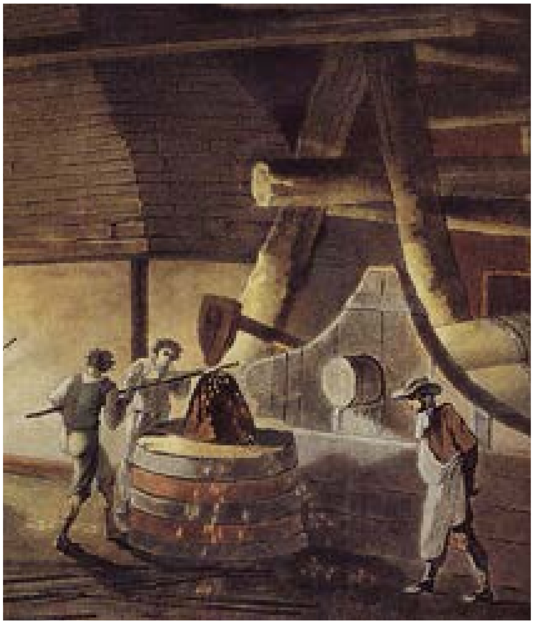
First after two or three years of uninterrupted operation, the oven had to be shut down for maintenance. This involved e.g. replacing the innermost bricks in the oven.



Cross-section of a blast furnace. Illustr. from "Bergwerks lexicon" (1789)

The Hammer

In the hammer building, at an open furnace, the raw iron that was to be further worked into wrought iron was heated using charcoal



Bar iron hammer in action. Extract from C.A. Lorentzens' painting from 1792

and a strong current of air. This method was practised until the end of the 1700s. It removed much of the carbon, along with other impurities. Then, the iron could be further worked with a large hammer, which was used with great force to transform the iron's structure, so it could be used as wrought iron or iron rods, which in turn could be used to make a variety of tools.

The hammer building could contain several types of hammers, from one huge «first-hammer» or "bar iron hammer", to the smaller nail hammers.

Regardless, one is talking about large structures, made of massive wood and iron, weighing up to a tonne and ingeniously driven by a water wheel. The water wheel was coupled to the hammer such that it struck at the desired tempo, depending on the size and use.

The noise from the hammer building could be colossal; it is said that deafness tended to be widespread among the experienced workers.

Charcoal oven

The availability of fuel for the blast furnaces was essential to the production of iron ore. The farmers within a circumference area from twenty to forty kilometres around the iron works, were obliged to deliver charcoal to the iron works – for payment.

After the trees were cut, they had to be transformed into charcoal in order to give high enough temperatures during burning in the blast oven. The transformation took place in the so-called charcoal ovens out in the terrain, preferably near where the timber was cut.

The wood, cut to lengths of two to three metres, had to be stored in a specific way, usually on its end and thereafter covered in pine needles, peat and soil. The size of the charcoal ovens varied from a diameter of under ten metres, to nearly twice as large.

The burning started from the bottom, in the centre of the oven, and was carefully directed and controlled by the addition of air through air channels. This normally took about two weeks, but could take even longer in the largest charcoal ovens.

Charcoal oven prior to being covered by peat etc. From Schwarzwald in Germany around 1900

Charcoal burning is not safe work; burns and smoke injuries were common. Sometimes an oven worker fell asleep, never to awaken again, after cozying up to the warm coal oven on a cold night, unaware as many were of the dangers of carbon monoxide poisoning.

When all of the wood had been transformed into charcoal, and sufficiently cooled, the oven was emptied and the charcoal was transported to the iron works. The demands were great; to produce one tonne of iron, 1–2 tonnes of charcoal were needed – for wrought iron a lot more!

New owner at Ulefoss

Halvor Borse from Skien managed the Ulefoss Iron Works for several years and, realizing what great potential it had, bought it in 1676. Borse was both enterprising and knowledgeable, and he had a proprietary interest in a number of mines and iron works. He created a wide-ranging network where iron ore and iron products were transported over great distances, with Lake Norsjø as the connecting transit channel.

The iron works were given special rights by the highest authorities in society, giving them the power to demand certain goods and services from the farmers, albeit for payment. This applied especially to supplies of charcoal for operating the iron works.

Charcoal, which was used for heating the blast furnaces, was scarce for most iron works throughout history. This was the source of many conflicts, both between the iron works and in their relations to the farmers.

The iron works needed to secure best possible access to wood for charcoal production, which made it desirable for them to control large areas of forest. Because of this, several of the iron works at the time also became large owners of forest, a connection that has continued to the present day.

The iron works represent in many ways a new time, and the new industrialist economy and organization, with its resulting social class divisions for all who were involved in the operations, centrally or peripherally. Not least, the iron works' enormous requirements for fuel had a great impact on the local environment, both its landscape and its people. The intense forestry and charcoal production often involved large adjustments, but also carried with it new opportunities for the local population.

As in most periods of great upheaval, it was a time of many disagreements and conflicts. Halvor Borse got shot from behind one autumn evening in 1701 as he rode over Geiteryggen ridge. His murderer was never found.

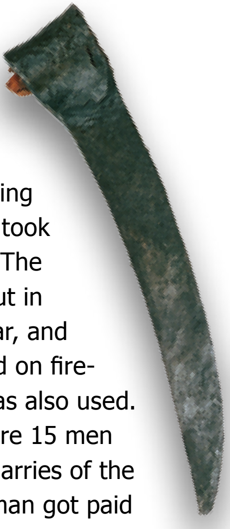
Herman Leopoldus Løvenskiold (1701-1759)

Borse's son-in-law, Herman Leopoldus, who later was given the noble name Løvenskiold, took over the iron works in 1722 after a long-standing legal dispute, and it remained in his family's ownership for over a hundred years.

Lowermost photo on opposite side:
From a contemporary mine: Head of a pickaxe
Photo: Norwegian Mining Museum, B.I. Berg

Photo: Sverre S. Aksnes

Part of the Ruslagangen, a branch of Adlergangen mine



Adlergangen and *Old Åse* mines had the richest iron ore and were the first mines to be put into operation. Until the beginning of the 1800s, most mining took place in open pit quarries. The quarry work was carried out in the summer half of the year, and in the beginning was based on fire-setting. Later, dynamite was also used.

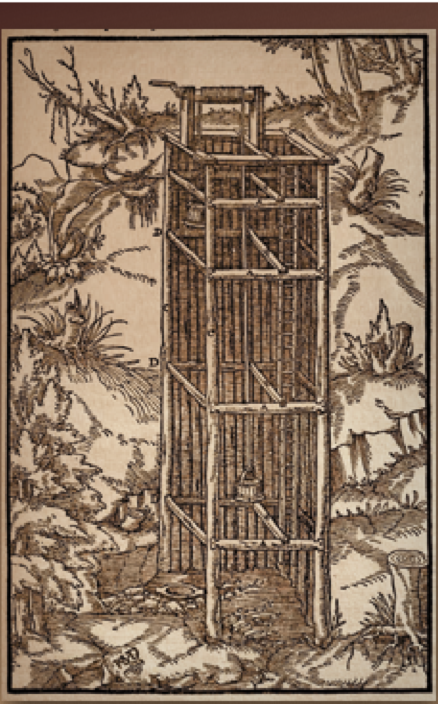
During this time there were 15 men working regularly in the quarries of the Ulefoss Iron Works. Each man got paid according to the amount of ore he quarried, and the ore got weighed at Gruvehaugen.

Depression

The period after the Napoleonic wars and 1814 were characterized by economic depression. Norway lost its privileged position in the Danish market when the Danes imposed high duties on iron. In addition, the Norwegian iron works were affected by high export duties.

In 1833, Holden Iron Works was taken over by the Norwegian government as its biggest creditor, and got sold at an auction two years later to timber merchant and landowner Diderik Cappelen from Skien.

The business has remained in the Cappelen family’s ownership ever since, and the iron works became Norway’s leading producer of cast iron.

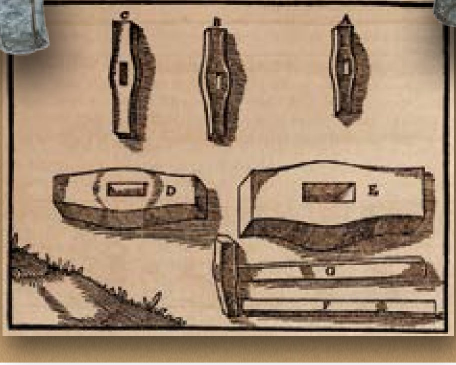


In Georgius Agricola's work from the 1550s there is a detailed description of how the mine shafts should be built and equipped…

…and what kind of tools should be used to extract the ore…

It is interesting to see how strong Agricola's influence seems to have been: compare for example the lump hammers and stone chisel (lowermost) found in mines from the same time, with Agricola's illustration.

Photos: Norwegian Mining Museum, B.I. Berg



At the same time, the decision was made to cease the production of wrought iron. The company changed its name, also, to Ulefoss Iron Works.

Ovens of high quality were produced under this name, ovens that because of their great popularity have contributed to making Ulefoss

Iron Works famous around the world.

Newer, more effective methods of production came into use in Europe, and it became steadily more difficult for the Norwegian iron works to compete with cheap and good quality imported iron, produced by coke-fired plants. Increasing problems with finding charcoal for the blast furnaces made the situation even more difficult.

In Diderik Mine. Long ladders were the workers' entryway down into the Fen mines. Considering that the depth of the mineshaft could be as much as 200 metres, and climbing up and down the ladders took place under sparse lighting and probably often with heavy equipment, it was a time-consuming and dangerous path to and from work.

During the 1860s and 1870s, nearly all of the old Norwegian iron works were closed down. Only Ulefoss, Fossum and Bærum iron works remained open – as foundries (factories producing metal castings). At Ulefoss, the blasting furnaces were closed down in 1877.

Ulefoss Iron Work survived during these years by exporting iron ore and producing cast iron made of imported iron. Toward the end of the 1870s, the price of iron ore sank dramatically on the world market. Unsold stores of iron ore piled up at Gruveåsen, and in 1880, the owner, Severin Diderik Cappelen, decided to stop the mining operations.

The last big blast furnace, based on charcoal, came into operation in 1861. Already in 1877 it was extinguished for good.

Note the symbol under the pitch of the roof; the ancient symbol for Mars is also the symbol for iron – and the male gender.

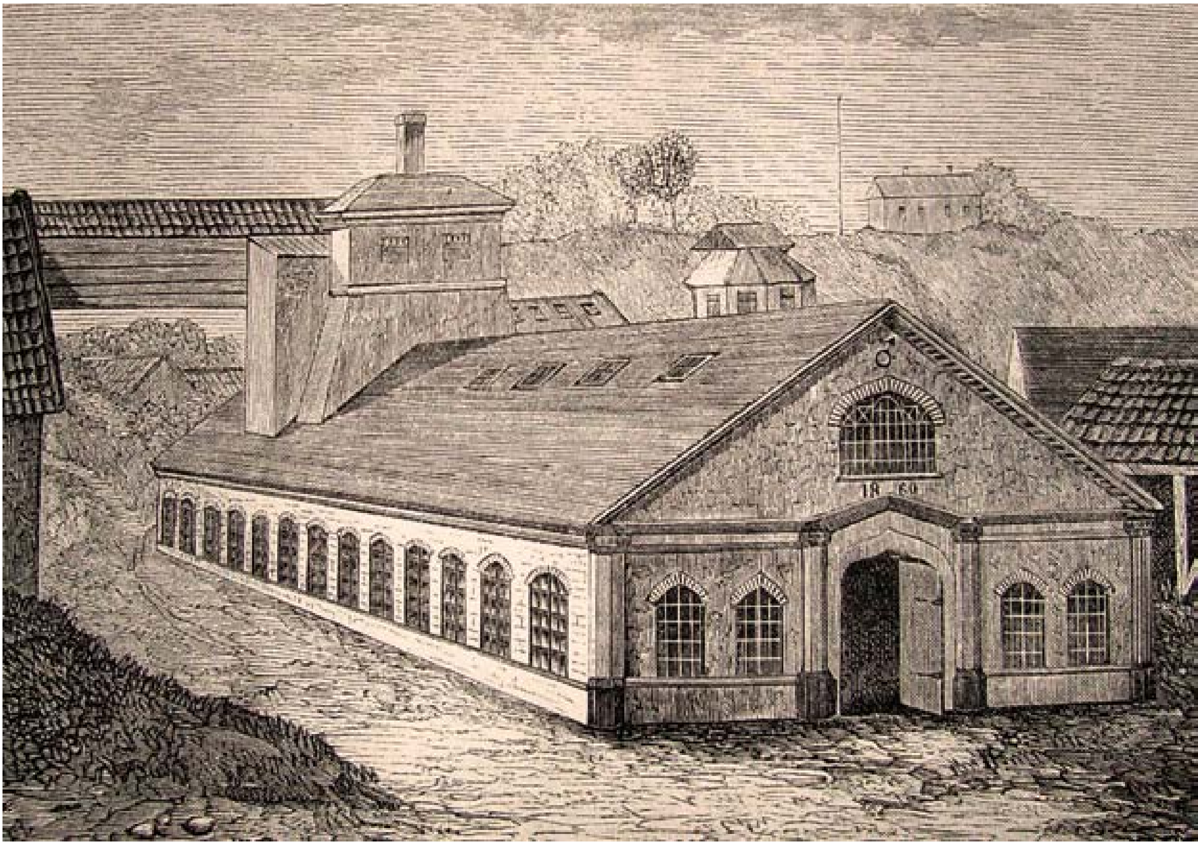
New optimism

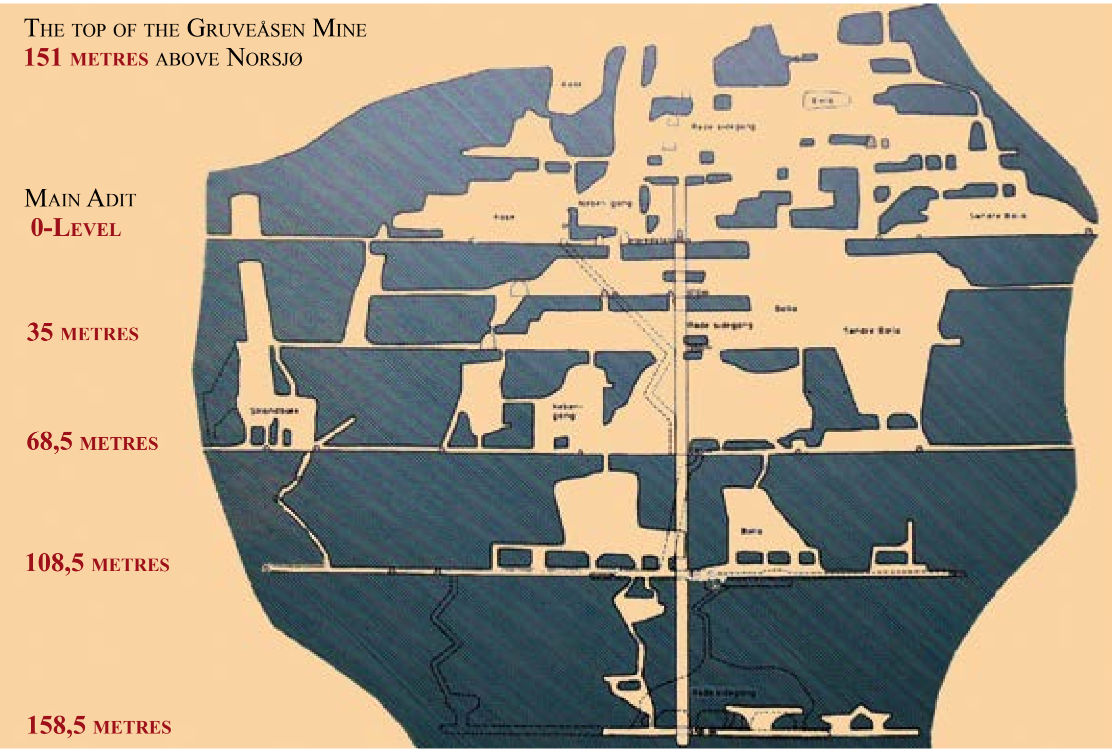
The mines were not opened again for 20 years. Operations resumed around 1899–1900, now aimed at export. With increasing demand, and electrification of the mining process, production increased greatly. At the most there were ca. 300 men down in the mines at this time.

Diderik Cappelen, who was educated as a mineralogist and mining engineer, now realized that the largest deposits of the iron-bearing mineral hematite lay deeper. As a result, the mines at Fen developed into a comprehensive mining complex, five stories high, down to 158 metres under the surface of Lake Norsjø.

Removal of iron ore was substantial, and the Fen mines were about the only place in Norway where iron ore was being mined during this period. From 1836–1917, ca. 700,000 tonnes of iron ore were taken out, with greatest annual production in the years after 1900.

In 1913, experimental operations were under-





A vertical profile of the Gruveåsen Mine in the early 1900s*

taken using an electrical blast furnace. That was the last time that iron from Fen was used in the production of raw iron. The attempt was short-lived. The First World War and the crisis years of the 1920s, with the fall in prices and decline in demand, led to the closure of the blast furnace in 1926. The year after, the mines finally closed forever.

*The word "Gruveåsen" literally means "The Mining Hill"

Diderik Cappelen
(1856–1935)

To right:
Rinsing station in
early 1900s

Søve Mines and Norsk Bergverk Ltd. 1951–65

THE TEMPORARILY LAST chapter in the mining history of Fen also has its background in war time, in Europe's last major war, which reached Norway in 1940.

Because of the war the production of raw materials for fertilizer was stopped, and the search for possible replacements started at Søve. For a long time there was hope that phosphorus and potassium could be extracted from limestone to give a basis for new production.

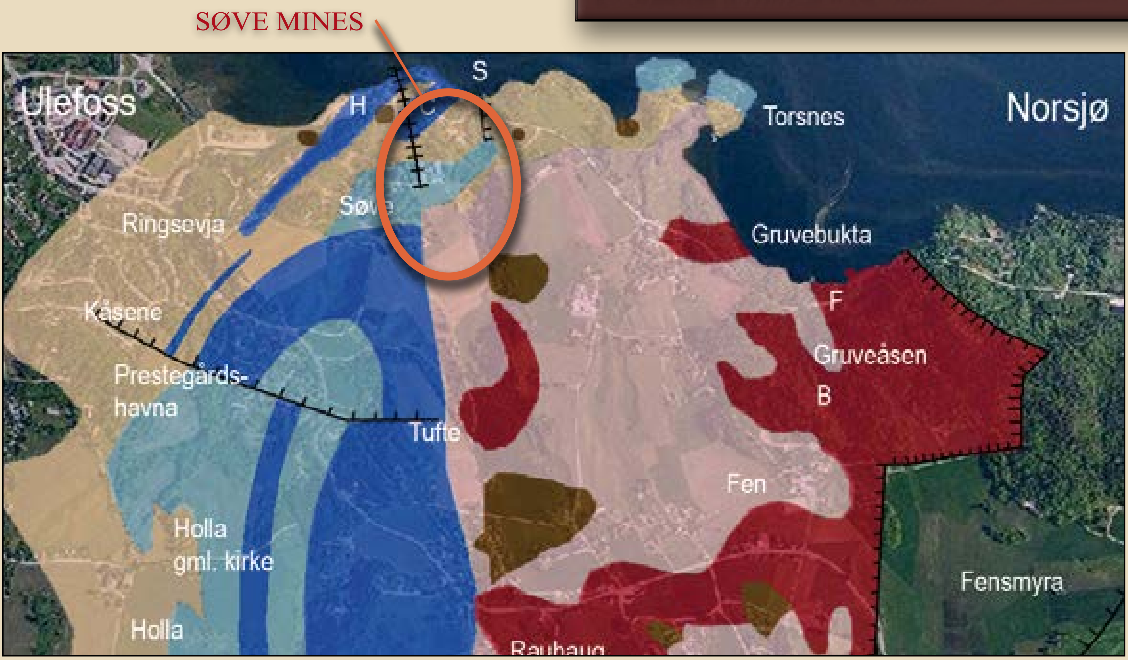
For the Germans, it was the occurrence of an element referred to as *niobium* that was most interesting. Niobium was to be used in the production of the newest, most highly technological weapons the world had hitherto seen, weapons that could have potentially reversed the losing trend of the war. But, it was first during the Cold War, and at the start of the space race, that the mining of niobium really began, with USA as the main driving force.

Limestone has been mined from Søve (sovite) as far back as the 1100s. The uses have been quite varied, from the decoration of churches, e.g. the Middle Ages Church at Holla and Romnes Church, to additives used in iron production at the Ulefoss Iron Works. Calcium carbonate binds the slag from the iron and makes it easier to remove. An additional bonus was that the slag in solid form could be used as building stone.

Early in the 1900s Norsk Hydro undertook an investigation into the potential for mining limestone, but this did not result in the start of operations.

The war and occupation in the 1940s created an entirely new situation, with respect to supply

Decorative elements carved in sovite, Holla Church Ruins



and demand for raw materials. During the Second World War plans were therefore made for operations at Hydrogangen, *(Hydro Vein)* and preparations were set in motion. While the Norwegian interests focused primarily on investigating whether the amount of apatite in sovite made it suitable for further production of e.g. phosphate, an important ingredient in fertilizer, the Germans were interested in securing niobium for the production of special steel.

The Germans' interest in niobium was motivated by their wish to develop jet- and rocket motors for the V1 and V2-rockets, Hitler's "secret weapons", that came into use in 1944. This type of motor reached such high temperatures that the steel in the motor could easily become deformed, which naturally enough would cause it to be both short-lived and unreliable. By adding the very heat resistant niobium to the alloy, it was hoped that this problem could be solved.

The Germans lacked access to niobium from other sources, and they viewed the possibility of extraction from the Søve mines with great interest. It was well known since the 1930s that the sovite veins contained niobium resources that could be mined.

Despite thorough investigations and extensive construction work, the Germans never managed to get started with extracting niobium from the shores of Lake Norsjø.

During the years after the war, the Americans had great expectations of niobium as an alloy for

The fact that sovite may contain minerals and metallic elements with special qualities, such as ferroniobium (over), captured in interest in Søve from several world superpowers.

FROM MIDDLE AGES TO SPACE AGE

Already in the Middle Ages a use was found for sovite from Søve. The soft limestone was easy to shape into decorations, as shown in the photo to the left of a cloister in Holla Middle Age Church…

… but did sovite also have qualities that could be used in advanced technology, e.g. in rocket engines?

V2-rocket hailed the start of the space age

Inside one of the mine shafts at Søve

use in the atomic- and defence industry and they pressured the Norwegian authorities about starting mining operations.

In 1951, the first installation was started in the name of the newly established nationally-run company A/S Norsk Bergverk. A very lucrative contract for delivering concentrated niobium to the USA was decisive for its inception.

Regular operations started in September 1953. During the first years, the raw ore was collected from the quarry at the exposed Cappelengangen *(Cappelen vein)*. The vein turned out to be cut off by a steep fault: diamond drilling revealed that it continued underground, and in 1955–56 a vertical shaft was erected in order to gain access to the deposit at depth. Over this shaft, a 38m high elevator tower was built out of cement. The mine's deepest part lay ca. 150 m below the surface of Lake Norsjø.

Twelve years of operation

Production of *ferro-niobium*, an alloy of iron and niobium, began in 1957. The manufacturing process was developed in cooperation with NTH (Norwegian Technical College) and the University of Oslo. As an additional component in the high quality steel, this product had to be completely free of sulphur and phosphorus, and a special process was invented in order to eliminate any last remains of undesirable elements.

In 1953, there were 50 employees working at the Søve Mine, and in 1956, this number had increased to 120. At most, 147 men worked in the mines. During the twelve years that the

Norsk Bergverk Ltd. mining facility at Norsjø

Broad stripes of sovite light up in the mountainside.

mines were in operation, ca. 1.15 million tonnes of raw ore were mined, and the total production was ca. 3000 tonnes of concentrated niobium (washed and unwashed) and ca. 350 tonnes ferro-niobium. As by-products, significant quantities of the iron-containing minerals magnetite, together with pyrite and apatite were extracted.

The Søve Mine was the only niobium producer in Europe. Nevertheless, operations were closed in 1965 because it became unprofitable. The high price in the middle 1950s, and the discovery of new, rich occurrences elsewhere in the world had led to an overproduction of niobium on the world market, leading to a fall in price toward the end of the decade.

Atomic power

In recent years, it is perhaps the deposits of thorium that have received most attention, and which have been the cause of appreciable controversy and discussion.

Could thorium become a possible future source of profit at Søve? This radioactive element has been viewed as a possible fuel for producing energy, similarly as uranium, in an atomic reactor.

The Fen Volcanic Area has large quantities of thorium, but it is not certain that they could be mined in a responsible manner, economically or environmentally. To the contrary, the reaction from the academic community has squelched even the most optimistic proponents, who had believed that thorium could make an important contribution to solving the energy crisis.

There is little to suggest that Fen will become a core area for mining of thorium in the near future. Thorium, like uranium, is always a potential risk to mine or use, and already today Ulefoss has a controversial waste problem relating back to its mining operations in the 1950s and 1960s. A much discussed slag heap with a high content of radioactive material still lay unprotected in the landscape at Søve in 2013, and is considered by many to pose a substantial environmental risk. The Government has now accepted responsibility for cleaning it up and storing it in a responsible way.

Regardless of which view one has on the potential for thorium, it is to be found in the magma at Fen, rocks and minerals that could potentially be quite valuable, if new technological conditions arose as a result of changing needs for raw materials.

The Fen Volcanic Area, with its rich content of unique bedrock, has a very special geological status, not just nationally, but also in the context of international research. For that reason, plans were made to preserve it, including the designation of a total of 13 geological deposits, as natural monuments.

Being given conservation status can be decisive for ensuring that this unique area will be protected for future teaching and research – and give everyone the possibility of experiencing exciting discoveries in our own natural history.

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The chapter "Geology" was written by Gea Norvegica Geopark by geologist Kristin Rangnes.

The chapter "The botany of Fen" was written by Gea Norvegica Geopark by botanist Anne Aasmundsen.

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PHOTOGRAPHS:

Cover photo: Åsmund Tynning

In addition to named photos, Sverre S. Aksnes has taken the photos of the rocks shown on the following pages: Page 5, page 8 and page 35

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GEA NORVEGICA GEOPARK 2014

Gea Norvegica Geopark IKS is owned by the eight municipalities

Bamble, Kragerø, Lardal, Larvik, Nome, Porsgrunn, Siljan and Skien

and

Telemark and Vestfold County Councils

Together these municipalities define the
Geopark's geographical boundaries

Gea Norvegica Geopark

Gea Norvegica Geopark

The aim of the Gea Norvegica Geopark is to spread knowledge about our geological heritage and what this has meant for human settlement, industry and culture. This involves showing the complex interrelatedness of nature, including the small and large interconnections that have formed and which continue to shape our varied district – from mountain to coast.

Through comprehensive information and via guided tours to chosen localities, the Geopark seeks to increase awareness and understanding of the natural heritage we all share, and which surrounds us daily.

We hope that this will also contribute to making everyone's enjoyment of nature even greater!

Gea Norvegica Geopark is the first Geopark in Scandinavia to be a member of the "European Geoparks Network" and the "Global Geoparks Network". These networks are supported by UNESCO and include 100 Geoparks (Febr. 2014), spread throughout the world.

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