Geological Advisor
Buskerud Telemark Vestfold County Councils

REE mineralization in the Fen Carbonatite Complex, Telemark, Norway - A world-class exploration target for the Hi-Tech and "Green-shift" Industry?

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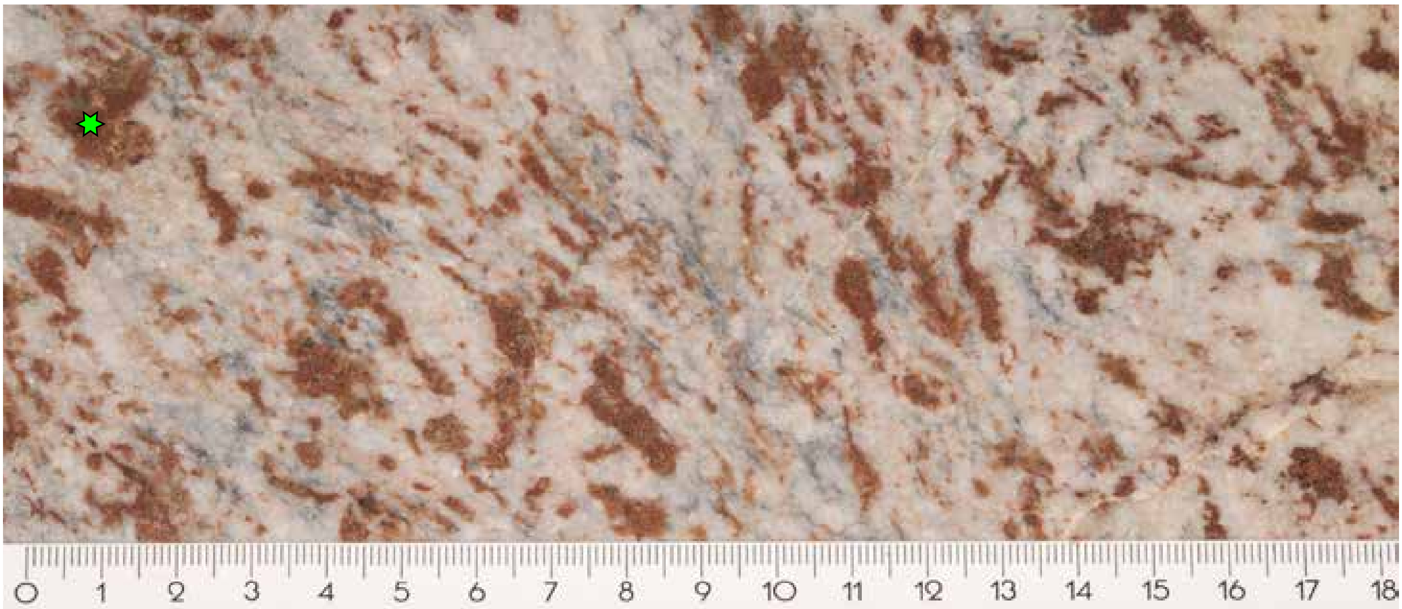
Exploration target
New geological map
Field studies
Petrography / SEM-EDS
Whole-rock analyses

Front cover photo, and below:
Is this an image of the basic raw material for an Industrial future within green-shift technologies?
This image shows a polished slab of REE mineralized Fe-Dolomite carbonatite from the old Tuftestollen Adit, Fen Complex. A detail of the same photo as on the front, including a scale in cm, is shown below. Red areas are fine-grained aggregates rich in REE minerals. The remaining minerals of the rock are mainly an iron-rich carbonate (Fe-Dolomite), and minor barite, quartz, magnetite and pyrite. An analysis with hand-held XRF of the cluster shown with a green star gives 4.0% La, 4.8% Ce, 1.1% Nd and 0.35% Pr (weight % metal). This gives a total of 10.25 % of the four most common REE's in this cluster.



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2019 November

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This report is published with the objective of giving a basic geological background for the potential of the discovery of industrially exploitable REE deposits in the Fen Complex, Norway. However, The Geological Advisor as well as the Buskerud, Telemark and Vestfold County Councils, and our collaboration partners, are not responsible in any legal, technical, political, economic or other respect regarding the contents of this work.

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Forord

Denne rapporten er skrevet av en geolog og er for geologer. Dette fordi den gir en geologisk informasjon som er grunnleggende viktig for det videre arbeidet som må gjøres på Fensfeltet.

Det geologiske kartleggingsprosjektet "Geologiske ressurser og Næringsutvikling i Fensfeltet", i regi av Regiongeologen, Buskerud Telemark Vestfold fylkeskommuner, er et regionalt utviklingsprosjekt i programmet *"Tilskuddsordning for å skape arbeidsplasser basert på utnyttelse av naturressurser"*. Det har hatt finansiering med 1,6 mill kr fra "*Hovudutval for Næringsutvikling*", Telemark Fylkes-kommune (TFK), og 0,8 mill kr fra Nome kommune / Midt-Telemark Næringsutvikling (MTNU) fordelt over perioden 2015-2018, samt fra Regiongeologens årlige budsjetter. De grunne boringene, samt ulike geofysiske undersøkelser (som blir rapportert seinere) ble finansiert i samarbeid med NGU.

Regiongeologen har tidligere levert flere rapporter og holdt flere foredrag om arbeidet med dette prosjektet underveis. Enkelte av disse er listet opp i referanselista bak i rapporten.

Den geologiske kartleggingen på Fensfeltet utviklet seg etterhvert til å bli 2 hovedprosjekter:

1. Geologisk ny-kartlegging av Fensfeltet og avgrensning av arealer med potensielle mineralressurser.
2. Boring av to lange bergartskjerner.

Prosjekt 1 fikk bevilgning i mars 2015, og skulle strekke seg over 4 år. Regiongeologen og politikere fra Telemark (fra Fylkesting, Storting og Nome kommune) gjorde i tillegg i 2016 til 2017 en større innsats for å få Regjeringen til å finansiere to langhullskjerneboringer på Fensfeltet, og boringene ble finansiert med en bevilgning fra Nærings- og Fiskeridepartementet i revidert statsbudsjett våren 2017. Bevilgningene gikk til Norges geologiske undersøkelse som prosjektansvarlig (prosjekt 2), men Regiongeologen ble svært involvert i planlegging, oppfølging av geologien under boringene og rapportering av disse boringene i et drøyt år. Rapport fra langhulls-kjerneboringene ble offentliggjort 28. februar 2019 (kan lastes ned fra www.ngu.no). Som en konsekvens så har derfor prosjekt 1, som er grunnlaget for denne rapporten, hatt knappe 3,5 år for gjennomføringen, mot planlagt 4 år.

Fensfeltet er et geologisk meget komplekst felt. Mineralforekomstene i feltet ble dannet som følge av mange komplekse prosesser. Skal vi ha noen mulighet til å utnytte de mulige ressursene må vi ha en inngående kunnskap om prosessene som laget dem, hvor ressursene er, hva de består av og hvordan vi kan nyttiggjøre oss av dem. Dit er det fremdeles en lang vei å gå. Målet om ressursutnyttelse på Fensfeltet kan bare nås gjennom omfattende geologiske undersøkelser og et nært samarbeid mellom industri, akademia, offentlig administrasjon og politikere på alle nivåer.

Denne rapporten er et grunnlag for forvaltning av mineralressurser i Fensfeltet i Nome kommunes kommuneplan. Videre geologiske undersøkelser av REE-forekomstene må utføres av industriselskaper, og det er å håpe at denne rapporten er med på å legge et godt grunnlag for videre undersøkelser. Regiongeologen vil i tiden som kommer arbeide med andre forhold i Fensfeltet.

En foreløpig versjon av denne rapporten ble presentert for TFK, Nome kommune og MTNU, samt rettighetshaverne på Fensfeltet, på Ulefoss den 29. august 2019. Seinere samme dag ble det redegjort for resultatene i denne rapporten i åpent møte på Ulefoss.

Til deg som synes denne rapporten går i stor detalj: I et industriprosjekt med mål om å utvinne REE så sitter djevelen i detaljene. Denne rapporten er kun å regne som et lite pirk i overflaten av utfordringene.

Jeg vil takke alle, både lokalt, regionalt, nasjonalt og internasjonalt som har bidratt til å gjøre de geologiske undersøkelsene på Fensfeltet i dette prosjektet mulig.

Tønsberg 15. November 2019
Sven Dahlgren
Regiongeolog
Buskerud Telemark Vestfold fylkeskommuner

Preface

This report is written by a geologist for an audience of exploration geologists. The objective is to present the basic geological information important for further work that must be performed during exploration in the Fen complex.

The geological mapping-project "Geological resources and development in the Fen complex", performed by the Geological Advisor, Buskerud Telemark Vestfold county councils is a regional development project in the program "Tilskuddsordning for å skape arbeidsplasser basert på utnyttelse av naturressurser". This project was financially supported with 1.4 MNOK from "Hovudutval for Næringsutvikling", Telemark county council, and 0.8 MNOK from Nome Municipality / Central-Telemark Business Development for the period 2015-2018, and additionally from the annual budgets for the Geological Advisor. The shallow core-drilling, and various geophysical studies (to be reported later) was co-financed with the Norwegian Geological Survey.

The Geological Advisor has previously released reports and given presentations concerning the preliminary results of this project. Some of these are listed in the reference list in this report.

The geological mapping of the Fen complex evolved into two major projects during the project period:

1. Production of a new geological map of the Fen complex, and delineation of areas containing potential mineral resources.
2. Drilling of two long rock-cores.

Project 1 gained financial support in 2015, with a project period of 4 years. The Geological Advisor and politicians from Telemark (Telemark County Council, the Norwegian Parliament and Nome Municipality) joined forces during 2016-2017 to convince the Norwegian Government to finance the drilling of two long cores within the Fen Complex. The drilling of these cores was financed by the Ministry of Commerce and Fisheries in the revised state budget of 2017. The financing for Project 2 was granted to the Norwegian Geological Survey, but the Geological Advisor was for a period of one year heavily involved in the planning, the on-site geological logging during the drilling and reporting of these drill-cores. The geological report from these drill-cores was released on 2019 February 28th (and can be downloaded from www.ngu.no). As a consequence, Project 1, which is the topic of this report, was performed during 3.5 years compared to the planned 4 years.

The geology of the Fen Complex is very complicated. The mineral deposits in the Fen Complex formed as a consequence of many different geological processes. If the Fen Complex is to be realised as an exploitable mineral resource, the geological processes that formed it, , where the resources are located, their composition and how we can develop them must all be understood.
A long journey still remains to reach these objectives. The goal of mineral exploitation in the Fen Complex can only be reached through extensive exploration and a close cooperation between industry, academia, public administration and politicians at all levels.
This report represents a basis for resource management of the mineral deposits in the Fen Complex in the area master plan of the Nome Municipality. Further investigations of the REE-deposits must be performed by exploration companies, and it is my hope that this report will be a useful basis for future studies. The Geological Advisor will in the future continue to work on other mineral deposits within the Fen complex.

A preliminary version of this report was presented to representatives of the Telemark County Council, Nome Municipality, MTNU, and the stakeholders in the area, at Ulefoss on 2019 August 29th. The main results of this report were presented to the inhabitants during the following evening.
For those who think this report is overly detailed: This document will show that, as in any industrial project aiming to exploit an REE deposit, the devil is in the details. This report only scratches the surface of the complex challenges with the Fen deposit.
I would like to thank everyone, both locally, regionally, nationally and internationally, who has contributed to make the geological investigations reported here possible.

Tønsberg, 2019 November 15th
Sven Dahlgren
Geological Advisor
Buskerud Telemark Vestfold County Councils

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Norsk sammendrag

Sjeldne jordartsmetaller (Rare Earth Elements, REE) er metaller som er svært viktige for framstilling av høyteknologiske / miljøteknologiske produkter. EU har i en årrekke klassifisert REE som kritisk viktige råstoffer. Metallene er viktige for Europeisk høyteknologiindustri, og det er høy forsyningsrisiko i det globale markedet. Nær all utvinning av REE foregår i Kina, og det globale markedet er nesten fullstendig avhengig av salg av REE-produkter fra Kina.

EU har foretatt en gjennomgang av alle geologiske forekomster av REE i Europa (www.eurare.no). To store REE-mineraliseringer finnes på Grønland, og en forholdsvis stor i Sverige. Fensfeltet ble også pekt på som en mulig viktig REE-forekomst.

Gjennom dette prosjektet er det gjort sannsynlig at det i Fensfeltet finnes store forekomster av REE. Sannsynligvis har vi med Europas største forekomster av REE bundet i fosfat (monazitt) og fluorokarbonater (bastnäsitt, parisitt/synchysitt) å gjøre. Dette er de mineralene REE tradisjonelt har blitt utvunnet fra REE-forekomster andre steder i verden.

Telemark fylkeskommune, v/ Regiongeologen, har gjennomført et geologisk kartleggingsprosjekt slik at arealet der de REE-førende bergartene forekommer nå er mye bedre avgrenset enn tidligere. Dette arbeidet må karakteriseres som geologisk kartlegging og ikke det som forstås med "exploration" i internasjonal industriell sammenheng. Målgruppa for denne rapporten er geologer / industriselskaper som vil vurdere å sette i gang et exploration-program etter REE i Fensfeltet. Rapporten er derfor skrevet av en geolog og er for geologer.

Feltundersøkelsene (på overflaten og i gamle gruver) og undersøkelsene av borekjerner er utført av Regiongeologen med hjelp av korttidsengasjerte geologistudenter / geologer som feltassistenter. Programmet for de grunne boringene ble ledet av Regiongeologen. Boringene ble foretatt med Norges geologiske undersøkelses' (NGU) litho-borebil. Boringene ble foretatt av en borer fra NGU i samarbeid med 1-3 personer fra Regiongeologen. Registreringene i felt og alt etterarbeid med kjernene er utført av Regiongeologen.

Denne rapporten omfatter geologisk, mineralogisk og kjemisk undersøkelse av bergartsgruppen "rauhaugitt", eller Fe-dolomitt-karbonatitt (FDC), som denne bergartsgruppen blir kalt i denne rapporten. Denne bergartstypen finnes i Norge bare på Fensfeltet, og er forøvrig høyst uvanlig andre steder på Jorda.

Det er laget et nytt og bedre geologisk kart som viser utbredelsen av FDC på eller nær Fensfeltets overflate mer nøyaktig enn tidligere. Kartlegging er blitt foretatt:

- der bergarter er funnet eksponert på overflaten
- under overflaten i gamle gruveanlegg
- ved kjerneboringer gjennom tykke løsmasser og oppak av korte kjerner fra underliggende berggrunn.

Grensene for Fe-dolomitt-karbonatittkomplekset er nå kjent med ulik nøyaktighet avhengig av eksponeringsgrad, forekomsten av gamle gruveanlegg i undergrunnen og tettheten av grunne boringer i de forskjellige delene av komplekset. Fe-dolomitt-karbonatittkomplekset har en utbredelse på ca 1,35 - 1,45 km^2 på Fensfeltets overflate. FDC-komplekset gjennomsettes av flere yngre damtjernittintrusjoner som gjør at det egentlige FDC-arealet er mindre. Utbredelsen av damtjernittene er imidlertid foreløpig for dårlig kjent til å kunne fastslå det egentlige FDC-arealet.

Fe-dolomitt-karbonatittene viser en enorm variasjon i tekstur og modal sammensetning. Teksturene varierer fra breksjer til folierte / laminerte bergarter, samt granulære varianter. Samlet så fremstår "rauhaugittene" eller Fe-Dolomittkarbonatittene som ekstremt inhomogene.
Vanligvis er Fe-dolomitt (tidligere ofte, men feilaktig omtalt som ankeritt) det dominerende mineralet i de fleste variantene, men i enkelte varianter kan andre mineraler, særlig kloritt, forekomme i betydelige kvanta. REE-mineraler, barytt, kvarts, kalsitt, pyritt, Fe-oksider og fluoritt er hyppig forekommende mineraler, men de utgjør vanligvis under 5% modalt. Sphaleritt og thoritt, samt noen få andre mineraler, forekommer aksessorisk.

REE forekommer i mineralene: REE-fluorokarbonater (bastnäsitt og parisitt/synchysitt), samt i monazitt. Lokalt forekommer mindre mengder allanitt.

Alle bergartene og mineralene i FDC-komplekset er anriket i de lette sjeldne jordartsmetallene (LREE), noe som er typisk for REE-forekomster tilknyttet karbonatitter alle andre steder i verden.

REE-mineraliseringene i FDC-komplekset forekommer stedvis i mineraliserte årer / ganger, mens andre steder kan mineraliseringen være disseminert. REE-mineralene forekommer av og til i aggregater på opptil flere dm i diameter, men normalt som cm-store aggregater tilsynelatende ujevnt fordelt rundt i bergartsvolumet.

Like etter oppstarten av prosjektet i 2015 oppdaget Regiongeologen tidligere ukjente, rike REE-mineraliseringer i Tuftestollen. Dette var på steder der tidligere industriforetak også hadde utført undersøkelser etter REE, men ikke funnet noe av betydning. Seinere fant også Regiongeologen tilsvarende REE-mineraliseringer i flere gamle gruveganger drevet etter jern i de vestre delene av Fen jerngruver ca 70 meter under overflaten.

Basert på nye data fra disse gruvene, fra grunne boringer, fra observasjoner på overflaten og fra boringer utført av selskapet "REE Minerals" sydøst i Fensfeltet er inntrykket at REE-mineraliseringer forekommer hyppigst innenfor en kurvet sone innenfor FDC-komplekset. Denne sonen kalles for "Boomerangsonen". Den er på ca 0,6-0,7 km^2 i utstrekning på overflaten, og strekker seg i et belte fra Fen Søndre, via Fen gamle skole, til Ødegård og sydøst for Søve og Søvedalen. Det er imidlertid også fra dette området der vi foreløpig har mest data for FDC-komplekset. "Boomerangsonen" kan vise seg å ikke eksistere, men det kan være mulig at hele FDC-komplekset er mineralisert. Det vil vise seg når en får mer data fra framtidige kjerneboringer.

Regiongeologen har på basis av de kjemiske analysene av prøver samlet i gamle gruver (Tuftestollen og de vestre delene av Fen jerngruver), på overflaten, og fra data fra de lange kjerneboringene, gjort noen høyst foreløpige kalkuleringer av hvor mye REE som finnes i FDC-komplekset i Fensfeltet.
Analyserte REE-mineraliseringer i Fe-Dolomittkarbonatittkomplekset (FDC) på Fensfeltet viser REE-gehalter mellom 2,5 og 4,5% TREO. Totalt kan FDC-enheten inneholde opptil 52,8 Mt TREO. Et konservativt estimat for mulig utvinnbare REE ressurser er 4,9 Mt TREO.
De foreløpige beregningene tyder på at vi har med en REE-forekomst som er stor i global sammenheng. Vi kan med rimelig sikkerhet konkludere med at Fensfeltet er den største REE-forekomsten av REE-fluoro-karbonater / monazitt i Europa. Forekomstene av REE-mineralene på Fensfeltet er nå kjent godt nok til at de kan klassifiseres som "exploration target", d.v.s. at de er et definert mål for omfattende geologiske undersøkelser m.h.t mulig industriell utnyttelse. Det foreligger ikke noen estimater, hverken fra Regiongeologen eller andre, over REE-ressursene i Fensfeltet som tilfredsstiller internasjonale standarder for ressursklassifisering (d.v.s. JORC eller andre klassifiseringssystemer).

Det vil høyst sannsynlig bli en del utfordringer med å få REE ut ved mineralseparasjon i industriell skala. REE-mineraler finnes ikke bare i aggregater, men også som mengder med ørsmå inneslutninger i dolomitt, kvarts, barytt, magnetitt og pyritt. Mye REE kan derfor gå tapt i mineralprosesseringen og REE analyser av totalbergarter gir langt fra den hele sannheten.

REE-mineraliseringene inneholder thorium og uran. Thorium forekommer i høyere konsentrasjoner enn i de granittiske gneisene i Telemark, men i langt mindre konsentrasjoner enn i rødberget på Gruveåsen på Fen. Uraninnholdet er sammenliknbart med uraninnholdet i normale granitter i Telemark. REE-mineraliseringene inneholder svært lite tungmetaller. De som finnes vil trolig lett kunne fjernes fra avgangen ved separasjon av sulfider.

Regiongeologen gir i denne rapporten noen anbefalinger til industriforetak som ønsker å utføre grundige undersøkelser av REE-forekomstene. Dette vil i felt dreie seg om et svært omfattende kjernboringsprogram, samt geofysiske undersøkelser. Kjernematerialet må grundig analyseres kjemisk, og mineralogien må utredes i stor detalj.

Undersøkelser av REE-mineraliseringene og potensielt utnyttelse av ressursene på Fensfeltet er kun på et innledende stadium.

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English summary

Rare Earth Elements (REE) are metals of great importance for the manufacturing of Hi-Tech and environmental-Tech products. The EU has already classified REE's as critical for a number of years. The REE metals are important for European Hi-Tech industry, and it is a high supply-risk in the global market. Nearly all REE exploitation occurs in China, and the global market is nearly totally dependent on the sale of REE-products from China.

The EU has conducted a screening survey of all geological deposits of REE in Europe (www.eurare.no). Two large REE-mineralizations occur in Greenland, and one relatively large deposit is located in Sweden. The Fen Complex has been pointed out as a potentially important REE-deposit.

Throughout this project it is emphasized that the Fen Complex contains large REE deposits. The Fen Complex is likely the biggest deposit of REE in phosphates (monazite) and fluoro-carbonates (bastnäsite, parisite/synchysite) in Europe. These are the minerals from which REE's have traditionally been extracted from REE deposits elsewhere in the world.

The Geological Advisor, Telemark County Council, has made a new, updated geological map which more precisely limits the area of the REE-bearing rocks. This work must be characterized as "geological mapping", and not "exploration" in industrial terms. The audience for this report is geologists / industry companies who evaluates an exploration program for REE in the Fen complex. This report is therefore written by a geologist and is for geologists.

Geological mapping (on the surface and within the old mines), and the investigations of the drill-cores, has been performed by the Geological Advisor with geology students engaged as assistants on a short-term basis. The shallow drill-core program was conducted by the Geological Advisor, and the shallow drill-cores were drilled using the NGU litho-drill-truck. The drilling operations were performed by one driller from the NGU in cooperation with 1-3 persons engaged by the Geological Advisor. The geological observations of the drill-cores in the field, and all after-work with the cores has been performed by the Geological Advisor.

This report includes geological, mineralogical and chemical studies of the rock group "rauhaugite", termed "Fe-dolomite carbonatite" (FDC) in this report. In Norway this rock-type only occurs in the Fen complex, and it is also a highly unusual rock-type elsewhere on the Earth.

A new and better geological map has been produced. This map shows the extent of the FDC on or near the surface of the Fen complex more precisely than before. The mapping has been performed:

- Of rocks exposed on the surface
- Subsurface in old mine workings
- By drilling of shallow cores through the clay blanket and a few meters down into the underlying bedrocks.

The boundaries of the FDC complex in different parts of the area is now known with a variable degree of confidence depending on: degree of surface exposure, the presence of old subsurface mine workings and the density of shallow drill-cores. The FDC complex has an extent of 1.35-1.45 km² at the surface of the Fen complex. The FDC complex has been intruded by several younger damtjernite intrusions, making the actual FDC area smaller. The extent of the damtjernites is presently too poorly known to determine the actual FDC area.

The Fe-dolomite carbonatites shows an extensive variation in textural and modal composition. The textures vary from breccias to foliated / laminated rocks, as well as some granular types. Generally, the "rauhaugites" or the FDC's appear to be extremely inhomogeneous.
Typically, Fe-dolomite (erroneously described as ankerite previously) is the dominant mineral in most varieties, but in certain members other minerals, especially chlorite, may be very abundant. REE-minerals, barite, quartz, calcite, pyrite, Fe-oxides and fluorite are also common minerals, but typically they constitute less than 5% modally. Sphalerite and thorite, and a few other minerals occur as accessories.

The REE occurs in the minerals, REE-fluorocarbonates (bastnäsite og parisite/synchysite), and monazite. Locally small amounts of allanite may occur.

All rocks and minerals in the FDC complex are enriched in the light Rare Earth Elements (LREE), which is typical for REE-deposits associated with carbonatites in all other parts of the world.

The REE mineralization in the FDC complex occurs both as veins / dikes, and as disseminations. In some instances, the REE minerals occur as aggregates up to several decimetres in diameter, but typically as cm-sized aggregates unevenly distributed within the rock volume.

Shortly after the launch of the present project in 2015 the Geological Advisor discovered formerly unknown, rich REE mineralization in the Tuftestollen adit. This was in places where previous exploration had taken place, but at the time no significant REE mineralization had been found. Later the Geological Advisor also discovered similar REE mineralization in several mine workings, about 70m below the surface, in the western parts of the old Fen Iron Mines.

Based on new data from these old mines, from shallow cores, from observations made on the surface, and from drill-cores performed by the company "REE Minerals" in the south-eastern part of the complex, the impression is that the REE mineralization most frequently occurs within a curved zone. This is termed here as the "Boomerang Zone", within the FDC complex. This zone occupies 0.6-0.7 km² on the surface. Its extent is from the Fen søndre farms, via the Fen old school, to Ødegård, and southeast of Søve and Søvedalen. This is, however, also the area where most of the data is presently available. The "Boomerang Zone" may not actually exist, but rather the entire FDC complex may be mineralized. This can be evaluated by future core-drilling.

The Geological Advisor has, based on chemical analyses of samples from old mines (Tuftestollen and Fen Iron Mines), from surface exposures, and from the long drill-cores, made some highly preliminary REE resource calculations of the FDC complex. Assays of REE mineralization from different places within the FDC complex shows a TREO varying between 2,5 and 4,5%. Within the FDC complex the contained TREO may be up to 52.8 Mt. A conservative estimate of potential exploitable REE resources is 4.9 Mt TREO.

These preliminary estimates indicate that the REE deposits of the Fen FDC is large in an international context. We can with reasonable confidence conclude that the Fen FDC complex hosts the biggest deposit of REE-fluoro-carbonates / monazite in Europe. The REE mineralization of the Fen FDC complex is now known well enough to be classified as an exploration target. So far no resource estimates, neither from the Geological Advisor nor from anybody else, complying with international resource classification (JORC or similar) exists.

Many challenges are likely to emerge during beneficiation on an industrial scale of the Fen REE mineralization. The REE minerals occur in aggregates, as well as numerous tiny inclusions within dolomite, quartz, barite, magnetite and pyrite. Much REE may be lost during mineral processing, and analyses of REE in whole-rocks paints an incomplete picture.

The REE mineralized FDC-rocks contain thorium and uranium. Thorium is present in higher concentrations in the FDC-rocks than in ordinary granitic gneisses of the Telemark area which surrounds the Fen complex. The thorium content of the FDC-rocks is far lower than in the "red-rocks" of the Gruveåsen area within the Fen complex. The uranium content of the FDC-rocks is low and similar to the uranium content of the surrounding granitic gneisses in the Telemark area.

In this report the Geological Advisor gives some recommendations to industrial companies aiming for extensive exploration of the REE deposits. In the field this will include an extensive core-drilling program, and some geophysical investigations. The drill-cores must be properly analyzed chemically, and the mineralogy must be studied in great detail.

The investigation of the REE mineralization, and the potential REE-exploitation from the Fen complex is presently only at a reconnaissance level.

1. Introduction
1.1 International objectives

The Rare Earth Elements (REE) are special metals essential to modern technological industries. The REE metals are essential for the production of most technologies important for “the Green Shift”, and the world demand is growing. See table 1 for REE applications.

The REE metals share many chemical, and geochemical characteristics. This is why all these elements are found within a single mineral or within a REE-mineral deposit. The relative abundances of the different REE’s vary strongly from one mineral type to another, and also between rocks from different geological environments. Carbonatites and alkaline rocks are known to host the world’s largest REE deposits. The world’s biggest production comes from Bayan Obo, China, whereas the Mountain Pass deposit, California, was the main producer in recent times. The global REE resources have recently been reviewed in a number of papers, and the reader is referred to: Verplanck et al. 2014, and 2016, Smith et al 2016, Goodenough et al 2016, and Machacek and Kalvig 2017.

Today more than 90% of the world production originates from China. In 2010 China cut most of its export of REE’s. This prompted many countries, including the EU, to make a list of critical raw materials, mainly metals and minerals, important for the European industry. All commodities have subsequently been regularly weighted in a supply-risk and economic importance perspective. The most recent list of critical raw-materials was published in 2017 (www.etrma.org/uploads/Modules/Documentsmanager/20170913---2017-list-of-critical-raw-materials-for-the-eu.pdf), and the plot of the criticality of various raw minerals is shown in figure 1.1.

A EU REE-project, “Eurare”, was completed in 2017 (www.eurare.eu) with an objective to search through all geological environments to identify possibly exploitable REE deposits in Europe. The Fen complex was suspected as being one of these deposits, but too little was known about the REE-potential in the complex for further evaluation by the “Eurare”.

1.2 National, regional and local objectives

The Fen complex has long been suspected to potentially host mineral resources of REE and other minerals of industrial importance. The Telemark County council and the Nome Municipality started in 2015 a project to re-map the geology of the Fen complex. This project has been planned and performed by the Geological advisor of the Buskerud, Telemark and Vestfold county councils, and supported by the Norwegian Geological Survey.

The main objectives of the project were to:

- Map the area with “rauhaugite” (now called the Fe-Dolomite carbonatites) which could host a significant deposit of REE minerals.
- Use this information in the local / regional land-use plan
- Inspire the industry to start an exploration program with the aim of making a future industry and to create jobs.

The original mapping project was planned to take place from March 2015 to March 2019. However, a new project, the drilling of two long cores, was established during the mapping project (see section 7.2). The Geological Advisor was very involved in the application, planning, drilling and reporting of the data from the two long cores. That work took about a year, over the period from 2017 to 2018. Thus the effective time available so far for the Geological Advisor to perform the original mapping-project, i.e. the project reported here, has been less than 3,5 years and not 4 years as planned.

The original mapping-project has been performed by the Geological Advisor, Buskerud Telemark, Vestfold County Councils, with financial support from *“Tilskuddsordning for å skape arbeidsplasser basert på utnyttelse av naturressurser”*. The support was:

- 1.6 mill. NOK, Telemark County Council, “Hovudutval for Næringsutvikling”.
- 0.8 mill. NOK, Nome kommune / Midt-Telemark Næringsutvikling (MTNU).

The finances awarded were for the period 2015-2018.
Additionally, the drilling of the short drill-cores and geophysical surveys, has been co-financed by the Geological Survey of Norway (NGU).

References to previous project-reports by the Geological Advisor, and the references to scientific papers and conference abstracts being a part of this project are listed in chapter 14.

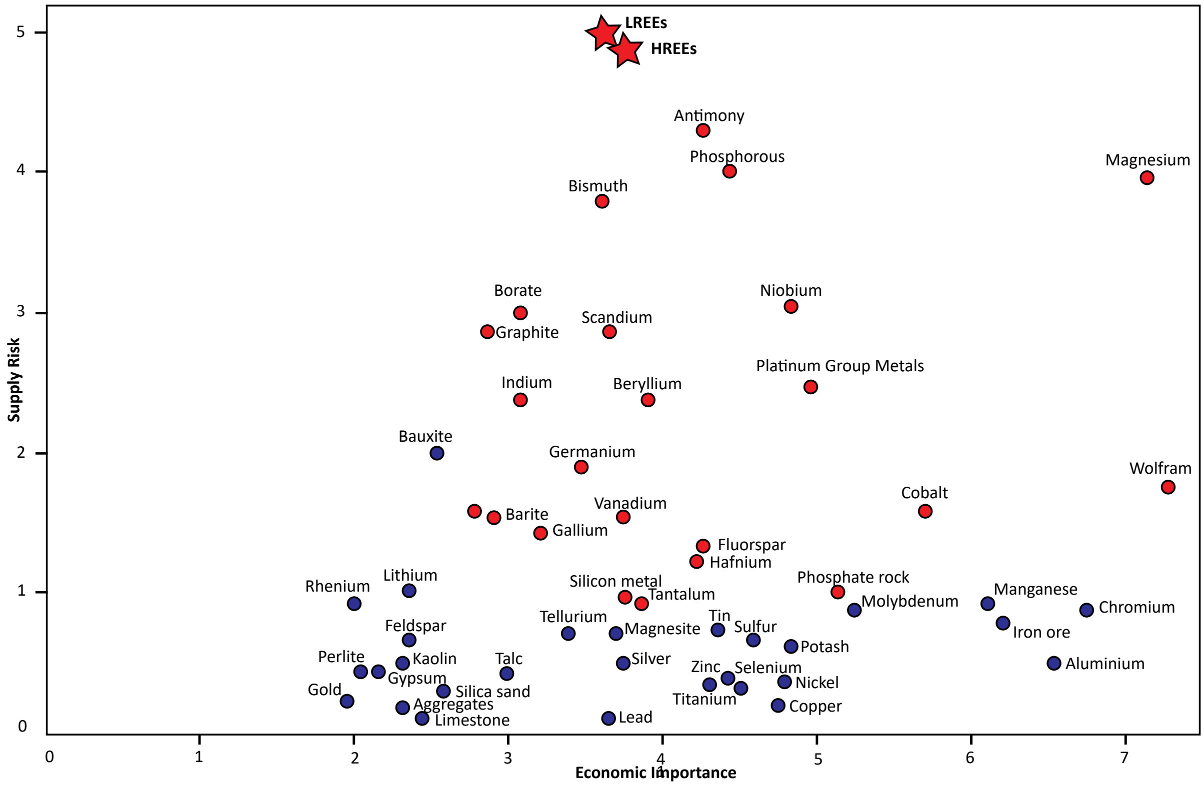


Figure 1.1
EU 2017 Critical raw materials (www.etrma.org/uploads/Modules/Documentsmanager/20170913---2017-list-of-critical-raw-materials-for-the-eu.pdf). The REE’s and other commodities shown in a supply risk and economic perspective. Red = critical raw materials in the EU. The REE’s plot in the top centre of the diagram as the most sensitive supply-risk of all raw materials. Both the LREE’s and the HREE’s (see explanation on the next page) have a very high supply risk.

Techology	Elements	Products
Magnetics	Nd, Sm, Tb, Dy, Pr	Electrical vehicles Microphones and speakers Mobile phones Computer disk drives Anti-lock brakes Automotive parts Frictionless bearings Magnetic refrigeration Microwave power tubes Power generation (wind-mills) Communication systems
Medical	Gd Nd, Sm	Medical imaging Magnetic resonance imaging
Phosphors	Nd, Eu, Tb, Y, Er, Gd, Ce. Pr	Displays, LCD Fluorescent lighting Lasers Fibre optics
Glass and polishing	Nd, Gd, Er, Ho, La, Ce, Pr	Polishing compounds Pigments and coatings UV resistant glass Photo-optical glass X-ray imaging
Metal alloys	Nd, Y, La, Ce, Pr	NimH batteries Fuel cells Steel Super alloys Aluminium / magnesium alloys
Catalysts	Nd, La, Ce, Pr	Petroleum refining Catalytic converters Fuel additives Chemical processing Air pollution control
Ceramics	Nd, Y, Eu, Gd, Lu, Dy, La, Ce, Pr	Capacitors Sensors Coolants Scintillators Refractories
Defense	Nd, Eu, Tb, Dy, Y, Lu, Sm, Pr, La	Satellite communications Guidance systems Aircraft structures Smart missiles Stealth technology

Figure 1.2 and table 1
Examples of applications of the REE metals. Compiled from various sources.

1.3 Rare Earth Elements (REE) - Definitions applied

The REE-terminology used in this report largely follows the definitions of the Rare Earth Elements (=REE) as was applied by the Eurare project (Machacek and Kalvig 2017):

The naturally occurring REE elements includes 14 metals of the lanthanide group:
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy Ho, Er, Tm, Yb and Lu. Also the two metals Y and Sc are included among the REE.
See figure 1.3

The REE are for various reasons subdivided into the Light REE (LREE) and the Heavy REE (HREE):

- **LREE: La, Ce, Pr, Nd, Sm**
- **HREE: Eu, Gd, Tb, Dy Ho, Er, Tm, Yb, Lu, Y**

Less conveniently, but still relevant for discussion of the REE in the Fen complex are the Medium REE:
MREE: Sm, Eu, Gd, Tb, Dy

The concentrations of the REE's are reported as either ppm element, i.e. gram element pr ton rock, or as oxide weight percentages of the elements. The REE oxides are calculated as trivalent oxides, i.e. RE_2O_3. The notation TREO is used for the total weight of all the REE oxides in a given rock volume, and includes Y, but not Sc. In this report both ppm element and TREO will be applied, but in each case it will clearly be stated what is used.

"Grade" is reported as either ppm or wt% TREO in the ore / mineralization.

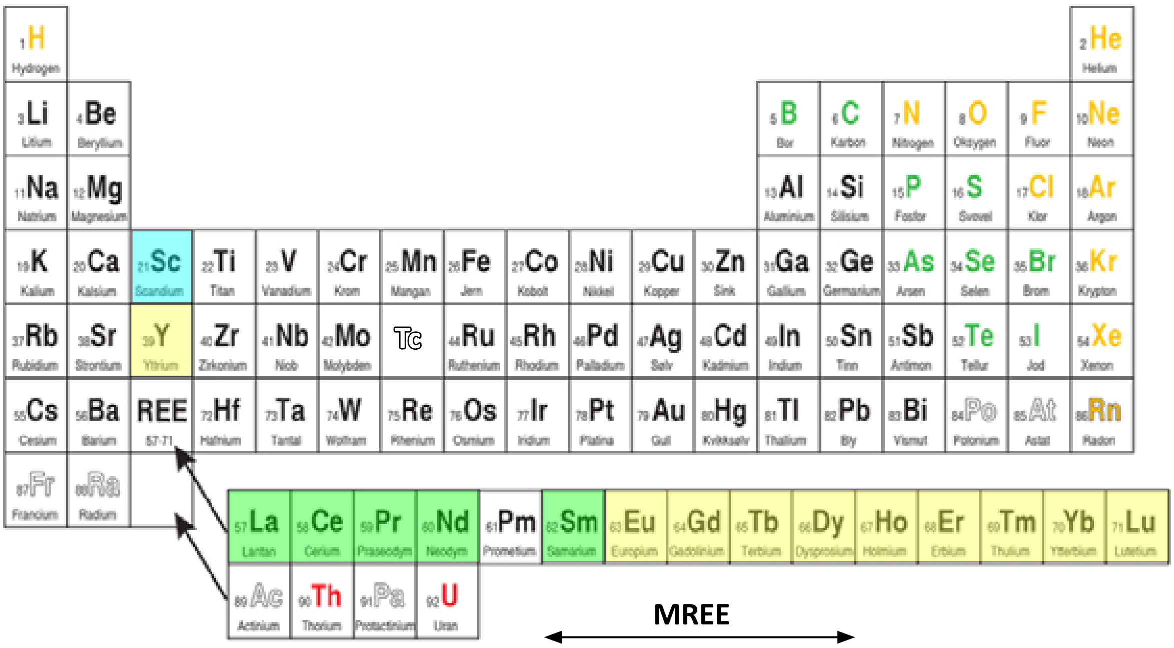


Figure 1.3
The periodic table of the elements with the Rare Earth Elements (REE) emphasized:

- *LREE (Light REE) = green*
- *HREE (Heavy REE) = yellow*
- *MREE = Medium REE (double-arrow)*
- *Scandium = blue*

In nature the element Pm (promethium) only forms in extremely small amounts during radioactive breakdown of naturally occurring uranium. Thus Promethium has no interest for the discussion of REE resources.

Field studies

The Fen project, 2015 to 2019, has involved many activities in addition to ordinary geological mapping. Also, the field mapping at Fen is different from most "normal" geological mapping projects. The geological complexity is unusually large, and the geological relationships frequently changes greatly over short distances. This complexity combined with few exposures due to extensive cover of clay deposits, and the deep weathering of most of those exposures that actually exists, makes the geological mapping a challenge. In the summer-time dense vegetation hide a large percentage of the exposures. Early spring is consequently the best period of the year in for mapping. Late fall is also useful to recognize exposures, but the daylight gets quite dim, which may affect the quality of observations substantially.

The maps of the Fen complex made by Brøgger (1921) and Sæther (1957) were already detailed (scales 1:15.000 and 1:10.000 respectively) compared to the standard geological maps in Norway. The goal of this project, of course, is to make a new and better map. Both Brøgger and Sæther had a couple advantages in the field during their mapping compared to the situation today. Grazing animals kept the vegetation low or absent, and they had exposures in some ravines that now are covered due to widespread ground-leveling of farm-land that took place in the 1950-60s. Additionally, a lot less of the complex had been "covered" by roads, houses and gardens. However, the advantages during the present mapping project by far outpace theirs: New road-cuts have emerged, blasted outcrops nearby houses can be inspected, and we even have access to an old 1km long mine adit that was produced after their mapping. Additionally, we have some old drill-core remains after "Norsk Bergverk" from the Søve and Tufte areas, drill-cores from Tuftehavna and Gruveåsen drilled by "Fenco" in the 1980s, the "REE Minerals'" cores from 2012 and 2014 in the south-eastern part of the complex, our shallow cores (2015-2018) drilled systematically to map the different units within the complex, and finally the two long drill-cores LHKB-1 and LHKB-2 drilled in 2017-2018. Especially the work under-ground in the old mines has been important. The importance of the Tuftestollen adit (abandoned in 1965) cannot be over-emphasized. The Fen Iron Mines are also very important. These mines were closed down in 1927, and Brøgger could conceivably have had the opportunity to work inside them, even at the deeper levels which now are water-filled. However, according to their field-notes, neither Brøgger nor Sæther made subsurface observations within the Fen Iron mines.

Brøgger engaged a retired military officer to produce a topographical map of the Fen area to make his geological mapping possible. Maps in the scale of 1:1000 were available to Sæther at Søve and Tufte, but had to use the same topographic maps as Brøgger for the remaining part of the complex. When the present project started, we used digital topographic maps with 1m contour lines, and a CPOS-GPS that could record observations within a mm. However, it turned out to be difficult to use the CPOS-GPS in the parts of the complex with the densest vegetation and with the most rugged topography. This actually became a serious problem, and therefore a new, detailed lidar survey, 10 points pr square meter, was conducted over the Fen Complex and its surroundings in the late fall of 2017. A digital map with 0,2m contour-lines was produced, and permitted high-precision manual mapping in areas where the CPOS-GPS did not produce satisfactory results. This boosted the mapping-speed from 2018.
Sæthers mapping was aided by numerous trenches and drill-cores, in the Søve, Tufte and Vibeto areas, made during the exploration preceding the niobium mining in the period 1953-1965. In this work we occasionally had the luck that some telecom or fiber-net companies made trenches we could inspect. At a few key localities on the surface we made great effort to clean the exposures thoroughly to make the best observations possible. A really big effort was made to clean large parts of the old mine walls for observation. See figure 2.1 and 2.2. This implied a lot of work, but it has been VERY important!

Figure 2.1
The mine-walls normally gets covered by thick dust-layers during the mining. This prevents the geologists from making good observations. Cleaning of the mine walls make a stunning difference. See fig 2.2

Figure 2.2
Cleaned mine-wall from the Tuftestollen adit. Compare photo in figure 2.1 taken before cleaning. Suddenly possible to make good observations!

Figure 2.3
In most places we used a gasoline-powered high-pressure washer for exposure / mine cleaning. In the poorly ventilated old Fen Iron Mines this was not possible, and we had to use manual pumps similar to those used by the fire-guards in the old days.

Figure 2.4
Cleaning of key-localities at the surface has been very important for good observations and new interpretations. Note the rusty weathering-color of the Fe-dolomite carbonatite at this locality.

2. Work performed by the Geological Advisor within the Fen carbonatite complex

The present mapping project benefit from all previous maps and reports generated from Fen during a century. However, absolutely all information included in the maps presented in this report is based on new observations only. All recordings of every exposure have been performed by the Geological Advisor. This ensures a homogeneous observation and interpretation basis, but will, of course, be biased towards one person's understanding and interpretation. Several geology students and others, especially Björn Strömberg, have been engaged as assistants during the work. Without their eager effort to find and clean exposures this work would not have been possible.
Core logging has been performed at the Fen old school and at the Geological Advisor's core / sample storage facilities near Tønsberg.

Laboratory studies
All the rock samples collected have been studied using the Geological Advisors' in-house facilities, i.e. polarization microscope and a table-top Hitachi TM 4000 Plus SEM equipped with Bruker Quantax EDS analytical tools for element mapping and semiquantitative analysis. The rock samples have been prepared in-house and submitted to ALS Global for commercial geochemical analyses. Two master students, C. Dietzel and T. Kristandt, from Tübingen, Germany, worked, under the supervision in the field by Prof. G.Markl, and S.Dahlgren, on the hydrothermal alteration processes and provided several quantiative mineral analyses. This work was published in Ore Geology Reviews 2019.

Figure 2.5
All geological observations on the surface has been recorded digitally or manually on very detailed topographic maps and only by the Geological Advisor.

Figure 2.6
Logging of the drill-cores has been performed at the Fen school, and at the geological advisors' facilities at Barkåker. All observations have been recorded by the Geological Advisor only.

Figure 2.7
Surface samples, as little weathered as possible, has been collected using hand-drill, sledge-hammer, diamond chain-/circular saw or dynamite.

Figure 2.8
Extensive use of a hand-held XRF (records La, Ce. Pr, Nd), and a hand-held gamma-spectrometer (U, Th, K), has been very important during the mapping.

Figure 2.9
In a few cases the use of large excavators has been necessary to see rocks or get access to mine openings. This image is from the main entrance of the adit of the old Fen iron mines.

Figure 2.10
Work in the western part of the old Fen iron Mine system requires rock climbing about 55m vertically down, and up again. With equipment and rock samples.

3. The Fen carbonatite complex - A new geological map and new geological interpretation

The objective of this project is to present a modern geological map of the Fen Complex, and to present an updated view of the geological evolution of all the Fen-rocks and the processes through which they formed. ***This report is focused on the geology (map, description, petrography, geochemistry) of the Fe-dolomite carbonatite unit and its REE-mineralization regarded relevant for exploration resource assessment purposes.*** Petrology and petrogenesis is not a topic of this report.

Why produce a new geological map?
Any attempt to exploit a mineral resource relies on exact geological maps of the target. Such maps should be as precise as possible. The newest geological map of the Fen Complex was produced by Sæther in the late 1940s (figure 3.4), and published in 1957 (Sæther 1957), i.e. the geological map of the Fen complex is more than 70 years old.
In the Fen carbonatite complex, the Fe-Dolomite carbonatite unit, abbreviated FDC, represents the most obvious REE-target, and an a new geological map of this unit is presented in this report (see figure 5.1.5). This map so far only presents the geology of the FDC unit in 2D. Much more information from drill-cores is needed to understand the geology of the FDC unit and its REE-mineralizations in 3D. A 3D map is essential in any future resource evaluation.

Why work out the details of the geological history of the complex?
A mineral resource is usually a result of several different geological processes that have acted over a considerable time-span. These processes may be closely genetically related, or they may just be coincidental. When we wish to unravel the secrets behind the generation of a mineral deposit, it is of great importance to understand the relative sequence of the different geological processes involved. ***A wrong geological understanding of the sequence of events may lead to wrong exploration models and unsuccessful search for mineral resources.*** The probability of discovering an exploitable mineral deposit increase the better the deposit is mapped in 3D and the better the geological processes that formed it is understood.

Location of the Fen Carbonatite Complex
The Fen complex is situated at a horizontal distance of 108 km SW of Oslo City Centre; and its position given by the coordinates longitude N59°16.3’ and latitude E9°17.5’. The location of the Fen Complex is shown on the map in figure 3.1.

3.1 The Fen carbonatite complex - Classical studies

The Fen Carbonatite Complex is famous in the geological scientific world literature because this was the first complex of its kind described as an eroded “limestone volcano” (Brøgger 1921). Brøgger introduced the term “carbonatite” for such “magmatic limestones”, and he described the complex as the eroded remains of the former volcanic conduit. Brøgger also introduced a series of rock-names, named after local farms, and some of these are still used; e.g. søvite, rauhaugite, melteigite and others.

Internationally, most geologists immediately opposed Brøggers view that the carbonatites were of magmatic origin. For several tens of years a hydrothermal / metasomatic origin was advocated by influential petrologists. Now, few geologists doubt that carbonatites are of magmatic origin. However, the carbonatites are commonly altered and modified texturally, mineralogically and chemically by secondary hydrothermal/metasomatic processes to a variable degree.

Another rock name introduced by Brøgger (1921) was “fenite”, a rock produced by alkali metasomatism adjacent to alkaline rocks and some carbonatites at Fen. He termed the process of their formation “fenitization”. The first map of the Fen carbonatite Complex made by Brøgger and Goldschmidt (Brøgger 1921) is shown in figure 3.2.

After WW2 the Norwegian Ministry of Industry (“Industridepartementet”) performed exploration for niobium at Søve. In this connection Sæther (1957) made a new geological map of the Fen complex and discussed the origin of all rocks in the entire complex. He very importantly distinguished between two different types of dolomite carbonatites, both originally described as one rock-type, “rauhaugite”, by Brøgger. Sæther (1957) concluded that the rauhaugites were of two generations: “Type 1”, consisting of a Fe-poor dolomite, and “type 2” in which the dolomite contains substantially more Fe. This distinction is supported by the present work, which is important since the REE’s are linked to the “type 2” rauhaugite.

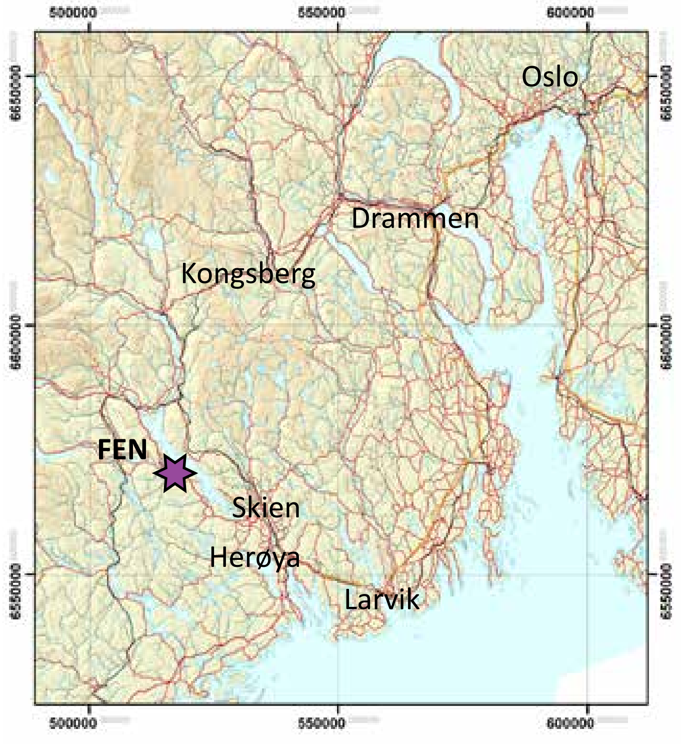


Figure 3.1
Key map showing the location of the Fen Complex (violet star), Telemark. Fen is located near the village Ulefoss, about 158 km and 2 h 25 min car-drive south-west-wards from Oslo via Kongsberg. The city of Skien is about 30 km and 30 min drive southeast of Fen.

Brøgger’s idea (1921) that the Fen complex represents a cross-section of an eroded vertical volcanic conduit was supported by gravity studies (Ramberg 1973). He modelled a downward cylindrical extension of the complex for at least 14 km. Furthermore his model indicated that the carbonatites most likely are confined to the uppermost 0.5-1 km of the complex, and that ultra-/mafic rocks constitute the rock volume deeper down. The age of the Fen complex is 580 Ma (Dahlgren 2006, and in prep.).

3.2 Carbonatite definition and classification

The definition and classification of carbonatites is a matter of debate. The main criteria for classifying a rock as a carbonatite was summarized by Mitchell (2005):

“Carbonatites are defined in the IUGS system of classification as igneous rocks composed of more than 50 modal per cent primary (i.e., magmatic) carbonate (sensu lato) and containing less than 20 wt.% SiO_2 (Le Maitre 2002). Varieties of carbonatite are named on the basis of the dominant carbonate mineral, e.g., calcite carbonatite, dolomite carbonatite, etc. (Woolley & Kempe 1989)”.

Mitchell (2005) argued that this definition is inadequate, an opinion shared by he present author. However, it is not the topic of this report to discuss nomenclature, and thus, for simplicity, the term “carbonatite” will be used for the carbonate-rich rocks within the Fen complex that possess evidence for at least some relic of a magmatic origin. See the terminology used in this report for the Fen Fe-Dolomite carbonatites in section 3.4.

3.3 Geological maps of the Fen carbonatite complex

The Fen complex has previously been mapped by Brøgger and Goldschmidt (Brøgger 1921; figure 3.2), and by Sæther (1957; figure 3.4). Both maps were impressively good for their time. The map by Sæther still serves as a reference map. Presently the Geological Advisor is preparing a completely new map of the Fen complex.

The ongoing work performed by the Geological Advisor attempts to provide a modern geological map of the entire Fen complex, and the goal is to present an updated model for the origin of the various rock groups within the complex as well as the complex as a whole. In this report the new map of the Fe-Dolomite carbonatite unit ("rauhaugite") is presented in figure 5.1.5.

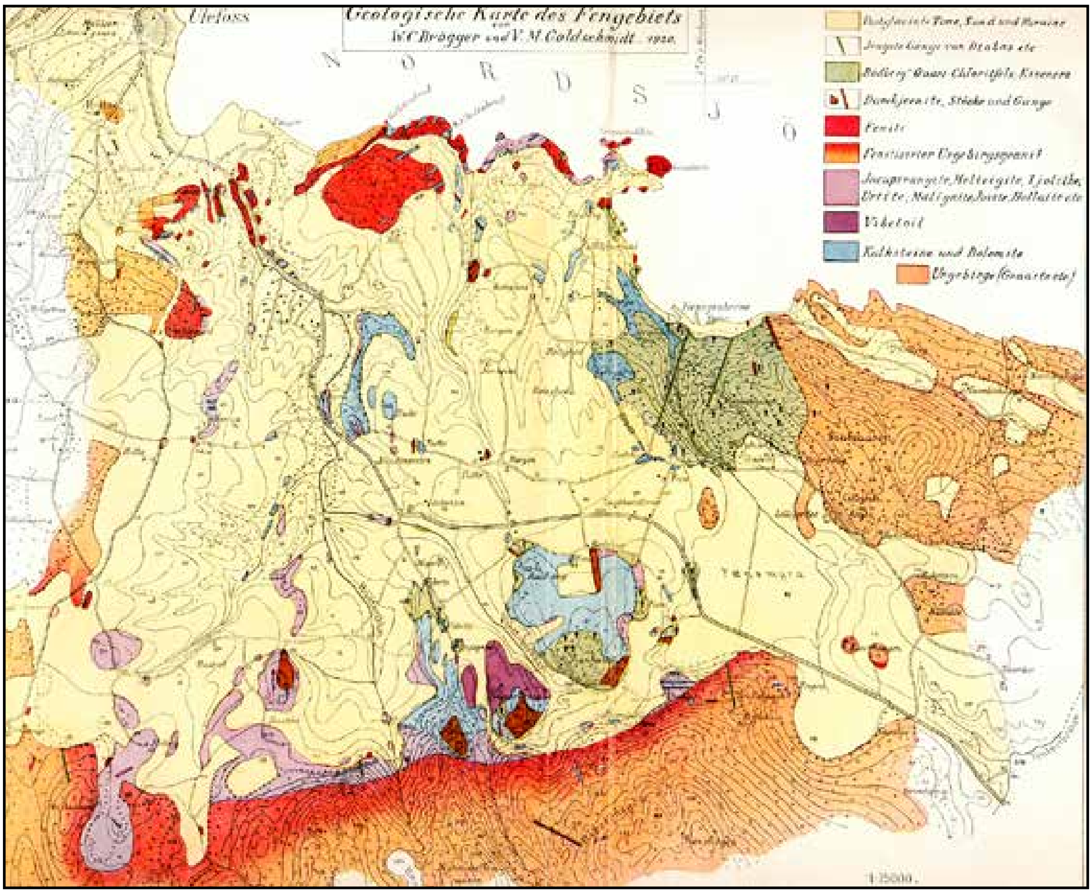


Figure 3.2
The first geological map of the Fen complex made by Brøgger and Goldschmidt (Brøgger 1921). No rocks are exposed on the surface within the large areas shown by light yellow color. The lack of exposures makes geological mapping and interpretation a challenge.

Figure 3.3
Most of the Fen Carbonatite Complex is extensively covered by post-glacial Holocene clay deposits. To be able to map the Fe-Dolomite Carbonatite unit the drilling of shallow cores from the rocks underlying the clay deposits has been essential. This photo was taken in the central part of the complex, view from Gamleveien west of Fen old school and looking northwards when we were drilling the Fen 2016 TEIG-2 core. The TEIG-2 core is presently the only shallow core that has been geochemiclly analyzed.

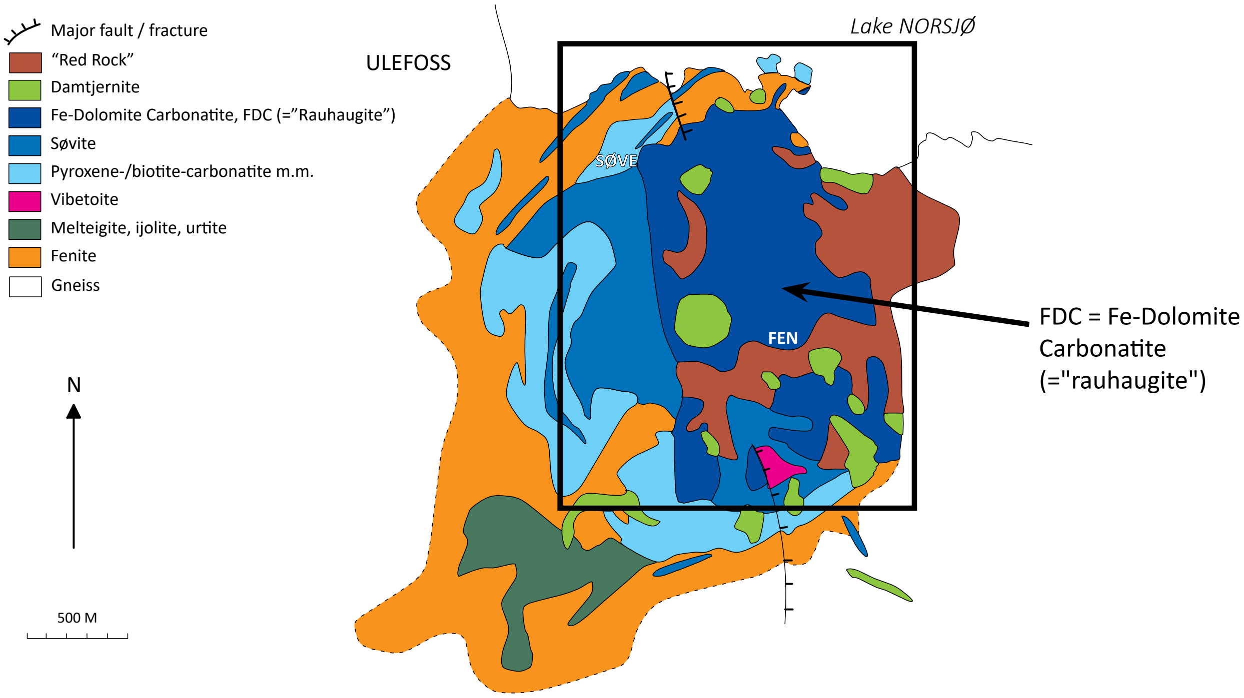


Figure 3.4
A modified version of Sæthers (1957) geological map (Dahlgren 2006). This map is highly interpretative as most of the rocks are unexposed. The Fe-dolomite carbonatites,"Rauhaugite" in the legend, is shown by the deep blue color on this map. A new geological map of the Fe-dolomite carbonatite complex, inside the rectangle above, is presented in figure 5.1.5.

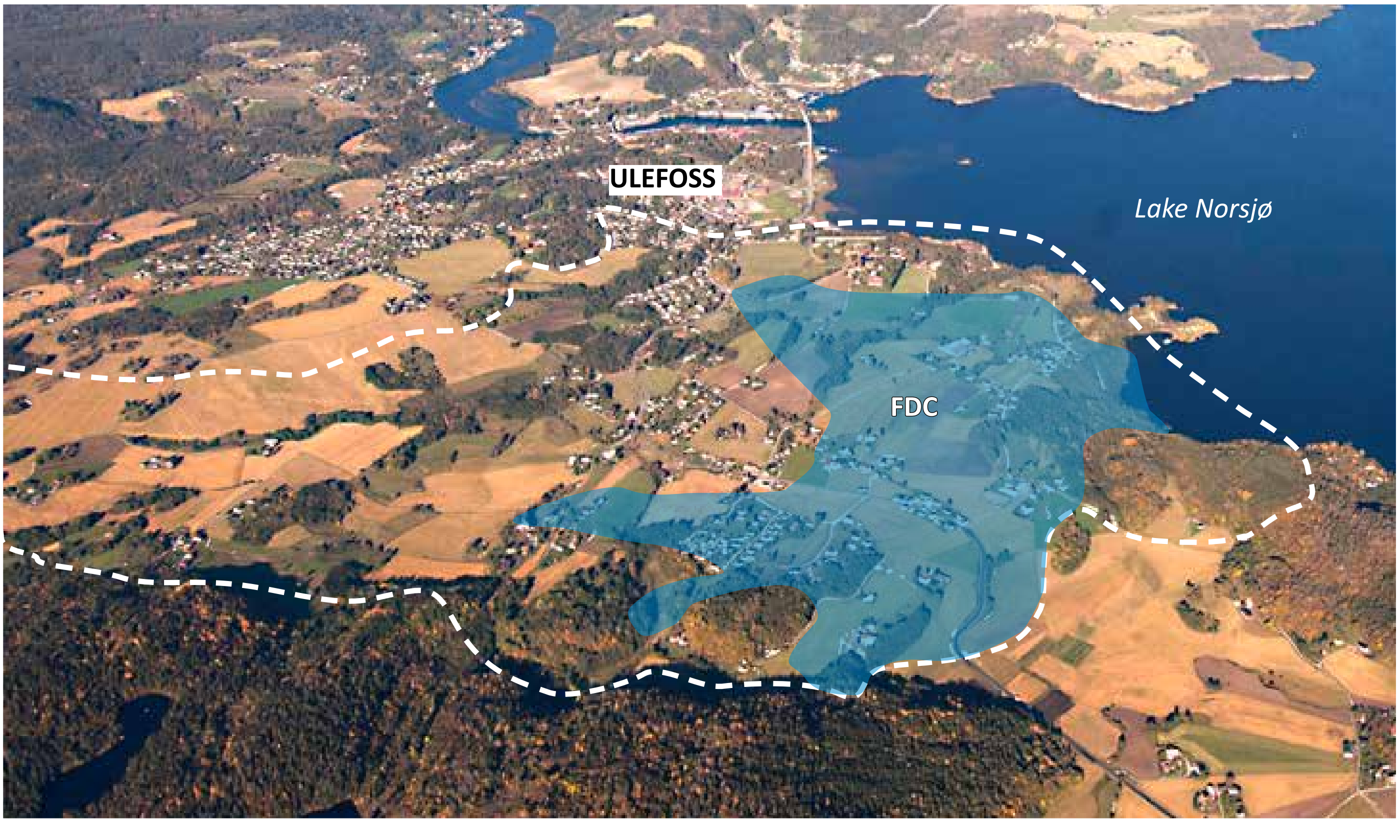


Figure 3.5
Oblique air photo of the Fen Complex seen from southeast. The approximate outline of the Fen Complex is shown with the white, dashed line. The blue-colored area (labelled FDC) shows the approximate area of the Fe-dolomite carbonatites. A few damtjernite intrusions and hematitized zones within the FDC complex have been omitted for reasons of clarity. See the new geological map, figure 5.1.5 for details, and map in appendix 2 for place-names.

3.4 New interpretation of the geological evolution of the Fen carbonatite complex

Sequence of the major geological events
A general sequence of main events of the evolution of the Fen complex can at present be summarized as follows (starting from the oldest events:

1. Emplacement of alkaline silicate rocks (i.e. nepheline-clinopyroxene rocks including melteigite, ijolite, urtite, nepheline syenites and clinopyroxene-Kfeldspar-nepheline rocks), vibetoite (a clinopyroxene-amphibole-mica rock), and carbonatites containing variable amounts of clinopyroxene, alkali amphibole, biotite, alkali feldspar etc. This event was associated with **strong fenitization.**

2. Intrusion of søvite dikes (calcite carbonatite), phlogopite-apatite-pyrochlore dikes and dolomite carbonatite dikes (the latter equals Brøggers type locality "rauhaugite"dikes and Særthers "rauhaugite type 1"). Also, rare phoscorite-like rocks (forsterite-magnetite-apatite-calcite rocks), belong to this event. Fenitization is associated with at least some of the søvites.

3. Emplacement of what will here be termed Fe-Dolomite carbonatites, FDC. This represents the rock termed "rauhaugite", i.e. dolomite carbonatites, by Brøgger (1921). Sæther (1957) demonstrated that the dolomite in these dolomite carbonatites, his "type 2", are more Fe-rich than the "type 1" dolomite carbonatites. This is the rock group being enriched in REE, and it is consequently the focus of this report. The FDC's have prevoiusly variably been termed "ankerite carbonatite" (e.g. Dahlgren 2016) or "ferrocarbonatite" (e.g. Andersen 1986). Both these terms are inadequate and will not be used in this report.

4. Intrusion of damtjernite in dikes and diatremes. Damtjernites are inequigranular ultramafic intrusions that were emplaced more or less directly from mantle depth.

5. Hydrothermal alteration and hematitization of pre-existing rocks. This rock group, traditionally called "rødberg" (="red-rock"), is most typically developed in the Gruveåsen area which historically (1657-1927) was mined for hematite ores (Vogt 1910). The hematitization is a late event and was studied in detail by Andersen (1983, 1984, 1986, 1987a). The hematitization affected pre-existing rocks to different degrees. In the present report it will be distinguished between hematitized FDC and hematitized damtjernite when the relic textures allow one to make this distinction. The term "red-rock" will be restricted only to those very fine grained, almost flint-like, rocks so intensely altered that no relics of pre-existing rocks can be observed

The sequence of events described above were not totally separated from each other, but some of them probably overlapped considerably. This particularly applies to the "stages" 3, 4 and 5. Apparently "red-rock" fragments occur within breccias of both FDC and damtjernite.

The evolutionary sequence presented above is a preliminary, unpublished version from the ongoing study by the Geological Advisor. It differs from the sequence of events proposed by Sæther (1957). He argued that the FDC's were younger than the damtjernites. The present study has revealed that at least the majority of the damtjernites are younger than the FDC complex. This difference in interpretation of evolution has very serious implications for the evaluation of the Fen REE resources.

"Ca-Fe-Mg-carbonatites" (CFM)
A certain group of carbonatites somewhat intermediate between søvite and FDC have recently been introduced during the mapping. These carbonatites have low Nb, REE , Th and P, and very variable Mg contents. In the field these rocks share some similarities with both søvite and FDC-rocks. In several areas these rocks have been extensively hematitized. The mapping of this unit requires the use of handheld XRF in the field. The very low REE content of this group make them uninteresting for REE exploration.

Post-Fen events
The Fen complex was also intruded by numerous diabase dikes and in places faulted and hydrothermally altered during the late Paleozoic (Dahlgren 1987). During the present project ample evidence has also been found for deep weathering, possibly during the Mesozoic.

Recent publications on some details of the geological evolution of the Fen complex where the Geological Advisor as a part of this project has contributed:

A review of fenites and fenitization at localities world-wide is given by Elliott et al (2017), and a contribution to that review was also made by the Geological Advisor as a part of the present project.

A discussion of the magmatic and hydrothermal processes in the Fen complex was published by Dietzel et al 2019. This publication was a part of the present project at Fen, and the Geological Advisor cooperated with Prof. Markl and Dr. M. Marks, University of Tübingen, Germany and co-supervised two master-students, C. Dietzel and T. Kristandt. It has been shown that all magmatic Fen-rocks have been subjected to post-magmatic hydrothermal alteration, but to a variable degree.

4. Previous work on the REE in the Fen complex

The distribution of REE in the various Fen carbonatites and related silicate rocks has over the years been studied for petrogenetic / petrological purposes, and for the purpose of exploration for exploitable REE resources. This section summarizes the different previous REE-projects at Fen.

4.1 REE exploration

4.1.1 Discovery of the REE deposits in the Fen complex

The discovery of the high REE contents of the rocks in the Fen complex dates back to 1955. In connection with the onset of mining for niobium in søvite at Søve, a gamma-ray reconnaissance survey of the entire Fen complex unravelled high thorium contents of the “red-rocks” and iron-ores (hematite-ores) in the Gruveåsen area of the old Fen Iron Mines (Bjørlykke 1955), and also near the old iron mines at Rauhaug (Svinndal 1967). Subsequently, in 1956, two drill-cores were drilled in the Bolladalen area (B.1 and B.2; both drilled with westerly azimuths from Bolladalen towards Foreningen mine), but these cores were not studied in detail until later, and then some parts of the cores were missing (Svinndal 1971). The initial focus was on the thorium, but Bjørlykke (1957; See Svinndal 1968 p10) reported that also REE’s occurred in unusual concentrations in the same area. By 1960 P.Sæbø had identified parisite-synchysite from the rocks of the Gruveåsen area (Braathen 1966).

4.1.2 Forskningsgruppe for sjeldne jordarter, (=”Research-group for REE”)

Systematic investigations of the Gruveåsen area with surroundings was started by the Norwegian geological survey (NGU) in 1967, and was from 1968 followed up with as research program “Forskningsgruppe for sjeldne jordarter, FSJ”. A number of institutions cooperated in this program and the results were reported by Svinndal (1967, 1968a, 1968b, 1971). This group performed geological observations, the drilling of 3 drill-cores (F1, F2, F3), sampling in the old mining area at Gruveåsen and at Rauhaug, sampling in the road-cut of the Fen Bay area, geochemical analyses of drill-cores and rock samples, also including analyses of some drill-cores from the Tufte area (drilled by Norsk Bergverk that had closed down in 1965), mineralogical studies, and mineral processing studies. Those involved in the mineral identifications were Sæbø (univ of Oslo) and Sverdrup (NGU), and Hazen Research (Bloodworth and Schmidt 1971). It is not always clear whether the reported minerals identified came from the “red-rock” or from the “rauhaugite type 2”. The FSJ-group obviously worked after the theory that the REE’s are concentrated along with Th.

The FSJ-drill-cores were drilled from the road-cut in the Fenbukta Bay area (F1 and F2) and from the northern Bolladalen area (F3) (see figure 5.1.5):

- **F1:** 251.1m, Az 208°, dip 11°; “rauhaugite type 2”, red-rock and damtjernite.
- **F2:** 195.45m, Az 200°, dip 10°; mainly “rauhaugite type 2”
- **F3:** 63.8m, Az 45°, dip 15°; mainly “red-rock”, some damtjernite and “rauhaugite type 2”

Some important mineralogical, geological, and geochemical conclusions from FSJ were (see the various reports by Svinndal and the sub-reports they contain):

- Three different types of REE-mineralizations:
    1. The rauhaugite type-2, from the road-cut in the Fenbukta Bay area. Contains on average 2.5% REE minerals, 12747 ppm TREE, 182 ppm Y and 965 ppm Th.
    2. “Red-rock”, of the Bolladalen area. 3% REE minerals, 13562 ppm TREE, 240 ppm Y and 1775 Th.
    3. Hematite iron ore, road-cut Fen Bay area. One sample containing 5% REE-minerals, 23781 ppm TREE, 220 Y and 3100 ppm Th.
- The REE minerals identified by XRD on mineral separates were parisite-synchysite, monazite, bastnäsite and allanite (“orthite”). Apatite did not contain significant REE.
- The rock types “red-rock” and the “rauhaugite type 2” occur intermixed in several zones in the boundary area (as observed from their drill-core logs, but not emphasized by them).
- Y was decoupled from the REE and was found by XRD to occur in the minerals kobeite, xenotime and possibly fergusonite
- Niobium was contained in kobeite and Nb-rutile. The average niobium content is 0.1% Nb_2O_5.
- Th and REE is correlated, and the Th content varies between 0,05 to 0.2%. This was used as a guide to ore.
- The REE minerals are very tiny and occur disseminated within the rocks. From initial studies mineral processing was considered by the FSJ to be very difficult.
- The REE in the drill-core F2 decreases towards the end of the core (Svinndal 1971, page 11
- The rocks of the Fen Iron Mine district and the Fenbukta Bay road-cut contains on average about 2% REE minerals. By the end of the FSJ project no clear advise was given whether further exploration should be performed, or what should be the preferred target for exploration (Svinndal 1971).
- The FSJ-group used different methods for analysis of the REE’s. Generally it was a problem to analyze the heaviest REE’s, but there was also a discussion of the quality of the Sm and Gd analyses.

The FSJ -group also analyzed REE in some old drill-cores, drilled by Norsk Bergverk, from Tufte. The cores T9, T11, T12, T13, T14, T18, and one from Tuftestollen, Ts7, all contained very little REE (a few hundred ppm). However, the T21 and a zone in T23, contained La up to 7400 ppm, whereas T16 showed some enrichment. This information is used for the discussion of the boundary of the FDC-unit in this report. See page 18.

4.1.3 The “KS AS Fenco” exploration, 1980 to 1985

Following an evaluation of the mineral potential of the Fen complex (Landreth 1979), a new exploration campaign was started in 1980 by a consortium of companies called “Fenco”. Some of the participating companies were also active in the previous FSJ group. “Fenco” worked all over the Fen complex, but they concentrated most of their work in Gruveåsen (Fen old iron mines), within the Tuftestollen adit, and especially in Tuftehavna (between the highway RV36 and Holla farm). They were exploring for Sc, REE and niobium.
The “Fenco” company also worked along the “FSJ-line” that the occurrence of Th and REE, and eventually Nb, were correlated. They focused their exploration for REE and Sc in the areas with high thorium in the “red-rocks” of Gruveåsen and Bolladalen (Hultin 1982, 1985, Mørk 1982, Braaten 1985).
10 short, vertical drill-cores (20-26 m long) and several large samples were collected near the old iron mines Storgruben and Breigangen. Additionally, a core, DDH2-81, was drilled from NE in Bolladalen and SW-wards for 304m, Az 270° and dip 45°. The Fenco exploration efforts at Gruveåsen did not bring very much new information on the REE’s compared to the previous FSJ work, but it was concluded that the geology in this area is much more complex than was formerly anticipated. Also the REE-contents seemed to be very variable and lower when compared to older analyses, and the Sc content of the rocks was also found to be fairly low (Braaten 1985, Hultin 1985).
“Fenco” also performed a sub-project in the Vibeto-Rullekoll- Brillekåshøgda area, i.e. in the southern and south-eastern part of the Fen complex (Wiik 1982). Wiik provided very good evidence of a strong REE-enrichment in the “rauhaugite type 2” in the extreme south-eastern part of the Fen complex, and suggested an intensified exploration of this area. He also questioned, on the basis of statistics of many chemical rock analyses from this area, the working hypothesis of a strong correlation between REE and Th widely used in the exploration program by “Fenco”. His proposal was not followed up in the “Fenco” exploration, and their entire program was terminated (Braaten 1985).

4.1.4 “Fen Minerals”

Cappelen, Ulefoss Iron Works, is the main partner in the consortium “Fen Minerals”. Their main effort has recently been mineral processing of “red-rock” (Davris et al. 2018) and søvite, and re-analysis of old drill-cores from Gruveåsen (C.D. Cappelen pers. comm).

4.1.5 “REE Minerals” 2011-...

In 2011 the company “REE Minerals” hired the exploration company “21st North” to perform exploration for REE in the “rauhaugite type 2” area in the south-eastern part of the Fen complex, i.e. in the area proposed for REE-exploration by Wiik (1982). The initial work was followed up with core-drilling in 2012 and 2014, and the results were very encouraging. These results will be summarized in section 7.1 of this report.

4.1.6 Old REE analyses

The chemical analyses reported by “FSJ” and “Fenco” were performed when analytical methods for REE’s was not fully developed to handle a large number of samples. It is obvious from several reports that there were analytical problems, especially for HREE, but also for element like Sm and Gd and others. These old data-sets should therefore be used with care. Moreover, only a few of the REE’s were analyzed, and thus TREE cannot be calculated from the old analyses.

4.1.7 Previous REE resource estimates

“REE Minerals” has presented resource estimates for their license are in the south-eastern part of the Fen complex (www.reeminerals.no). See section 7.1.
The Company “Fen Minerals” estimated a potential REE resource, mainly in the “red-rocks” of the Gruveåsen area, of about 0.36 Mt TREO (C.D. Cappelen pers. com. 2015). The precise background for this estimate is not known to the author.

4.2 Scientific studies of REE in the Fen complex

REE's are very useful as petrogenetic tracers, and several studies have been performed at Fen. Most of these studies are old, and the quality of the REE-analyses are in some cases questionable. Moreover, most studies did not analyze all the REE's due to analytical limitations at the time of study. TREE cannot be calculated for most of these old analyses, and below Ce-values are recorded for some comparison to be made (Ce is the easiest element to analyze). Most studies also included only a few samples, and the statistics is poor. The various data-sets are only to a certain extent comparable. Here a few main points will be made.

Mitchell and Brunfelt (1975) were the first to study t***he REE's of the entire rock suite from the Fen complex***. They analyzed 35 samples by radiochemical NAA for La, Ce, Sm, Eu, Tb, Yb and Lu. The characteristic LREE enrichment was noted. The red-rock (1 sample) contained 7548 ppm Ce, far more than any other of the rock units. The "rauhaugite type 2" (=FDC) they analyzed contained only 570-625 ppm Ce. These samples were all from Rauhaug. The FDC's in that area is now known to be relatively REE-poor.

Andersen (1987a) also studied the entire rock suite in the Fen complex, and high REE was recorded for both "red-rock" and FDC (his "ferrocarbonatite"). Andersen (1986) made partial REE analyses of the REE minerals bastnäsite, pariste-synchysite, monazite and allanite. Andersen (1984, 1987b) also studied the behaviour of the REE in the "FDC to "redrock" transition and found that the LREE was selectively leached, compared to the HREE, from the rocks during hematitization.

In a study of ***REE in søvitic carbonatites*** from localities world-wide, including Fen, Hornig-Kjarsgaard (1998) analysed whole-rocks, and mineral separates of carbonates and apatites from 3 søvite samples and 1 dolomite carbonatite ("rauhaugite type 1") from the Søve area. Similar and low total REE (1088-2131 ppm) was obtained for both the dolomite carbonatites and the søvites. All showed the LREE enrichment of carbonatites, but the La/Yb_n was low (28-53). Total REE was even lower in the carbonates (442-1110 ppm), with very low La/Yb_n in the søvites (19-32), but higher in dolomite from the dolomite carbonatite (86). As could be expected the REE was enriched in the apatites (3752 to 5220 ppm), and La/Yb_n 77-105.

The analyses by Schiling (2013) were, based on his petrographic information, performed on rock suites that were subjected to different sorts of alteration, and are thus less useful for further considerations.

Marien et al. 2018 and Dietzel *et al*.(2019) discussed the process of hematitization of the FDC, and especially the process of producing the HREE enrichment relative to the LREE in the "red-rocks".

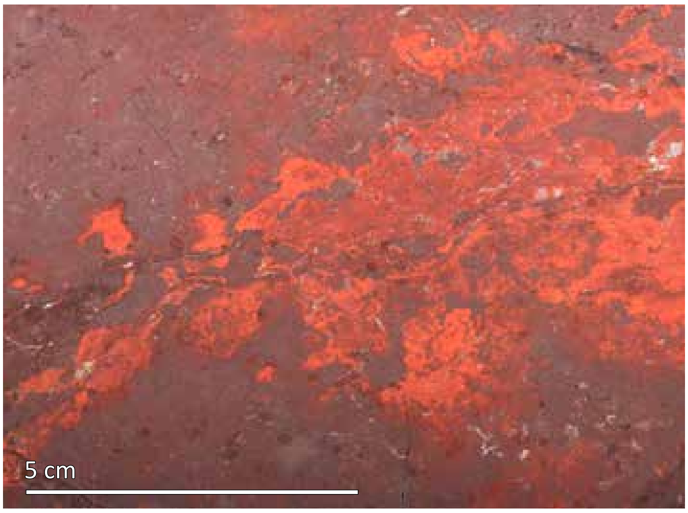


Figure 4.2.1
"Red-rock" from Fen iron Mines. The red color is due to finely dispersed hematite crystals within hosts of calcite, quartz and other minerals.

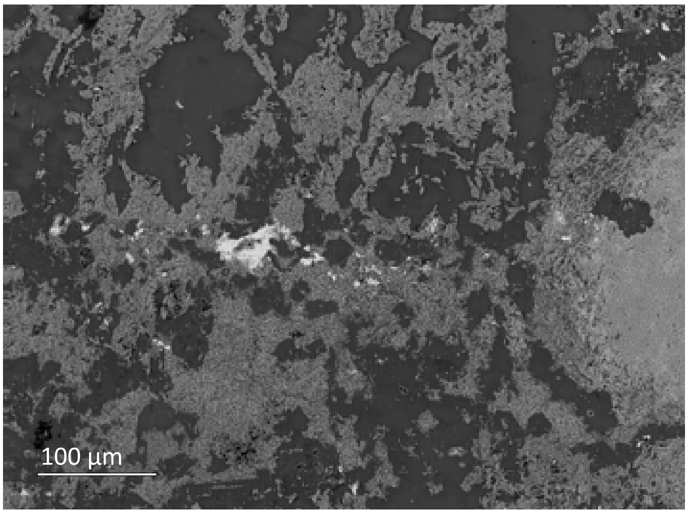


Figure 4.2.2
REE-minerals in the "red-rock" generally are very fine-grained, and occur much less in clusters than is the case for the FDC. The bright spots in this BSI of a"red-rock" sample are monazite and parisite/synchysite grains.

4.3 Which rock is the target rock for REE exploration at Fen?

The REE analyses summarized from the exploration reports (section 4.1) and the scientific literature (section 4.2) represents a clear guide for what should be the target for further REE-exploration in the Fen complex.

The whole-rock REE-analyses of damtjernite, fenite, melteigite-ijolite, and the clinopyroxene carbonatite rocks of the Fen area all generally have low REE contents. None of these rocks contain any interesting REE mineral phases either. Consequently, these rocks are ruled out as being of any interest for possible REE resources.

The rock groups eventually to be considered are the søvites/dolomite carbonatites, the "red-rocks" and the "Fe-dolomite carbonatites" (FDC):

Søvites and dolomite carbonatites (Fe-poor)
The søvite (calcite carbonatite) and dolomite-carbonatite ("type 1, sensu Sæther, 1957) generally have low total REE. The apatites from these carbonatites contain some REE. If apatite mining should be considered at Fen in the future, apatite could eventually be evaluated as a potential REE-source. The TREE of the apatites from these rocks are by this author considered too low to be the primary REE-target at Fen.

The "red-rocks"
The "Red-rocks" has been the rock group that gained attention in the early "FSJ"-work, and later by "Fenco". The "red-rocks" are indeed very REE enriched. The "red-rocks" are, however, very complex rocks, and are poorly explored geologically, mineralogically and geochemically in terms of modern exploration and analytical methods.
Some of the "red-rocks" show relative HREE enrichment compared to their LREE. This could be argued as favorable criteria for exploitation of REE from the "Red-rocks". However, from the poor data-base existing the HREE seem to be contained in minerals such as kobeite and possibly fergusonite (Bloodworth and Schmidt 1971), and samarskite, aeschynite and unknown Th-Nb phases (Dietzel et al, 2019). Little is known about processing of and extraction of REE's from such minerals. The thorium content of the "red-rocks" is also very high (Svinndal 1973, Dahlgren 2012) which, at present, is negative for REE exploitation.
Due to the very fine-grained nature of the REE-minerals in the "red-rocks" the research of mineral processing was terminated by the Fenco-group from this rock-type (Braaten 1985). However, recently a process has been developed by "Fen Minerals" and coworkers to separate REE from "Red-rock" using chemical leaching (Davris et al 2018). This has, however, only been demonstrated in the laboratory, and needs to be tested on an industrial scale. The small grain-size of the REE minerals, the different types of REE minerals, the high Th, and the difficulties of mineral separation are all challenges that may be solved in the future. The "red-rocks" could represent a substantial REE resource. This is, however, not likely to be a quick and easy path to success.

"Rauhaugite" = Fe-dolomite carbonatite = FDC
In this report it will be argued that the Fe-dolomite carbonatites in the Fen complex is the principal target for REE exploration. This was already proposed by Wiik (1982), and this has also been the guideline for the exploration by the company "REE Minerals" in the south-eastern part of the Fen complex.

5. Geology of the Fen Fe-Dolomite carbonatites (FDC) (=”Rauhaugite type 2” = “Ferro-carbonatite”)

5.1 Geology and a new geological map of the FDC complex

The FDC covers the largest area of any rock group in the near surface environment within the Fen Complex. Although this “unit” is far from uniform, neither texturally or compositionally, it will nevertheless be referred to as the FDC-unit below.

Most of the FDC-unit is covered by thick Holocene post-glacial marine / brackish water clay deposits, the thickness of which may exceed 50 meters (Fensmyra area). Within the central Fen area the thickness typically range between 0 and 8 meters (appendix 3A).

When the FDC is exposed it is usually deeply weathered. The weathering soil is yellowish-brown or ochre colored, and typically contains strongly weathered boulders of the underlying rock. Freshly made exposures quickly, i.e. already after a few years, become rusty brown.

The poor exposure and strong weathering of the FDC-unit makes apping of the FDC-unit difficult. The new geological map of the FDC-unit (figure 5.1.5) represents the **outline of the FDC unit** based on observations from:

- Exposures (in practise road-cuts, blasted areas for construction of dwellings, but also some natural exposures in steep terrain)
- Thick yellowish-brown soil formed by deep weathering of the FDC.
- Excavated trenches
- Drill-cores (Norsk Bergverk, REE Minerals 2012 and 2014, The Geological Advisor and NGU 2015-2018 shallow cores)
- Mapping within old subsurface mines (the ground level adit system of the western part of the old Fen iron mines, and the Tuftestollen adit).

Uncertainties in the present map

The present map includes both brecciated as well as more homogeneous and fine grained varieties within the FDC group. The boundaries are based on information from the different sources mentioned above, but in most parts of the area the information is still scarce and the boundaries to the surrounding rocks are in many places uncertain. See also the text to figure 5.1.5.

It must be emphasized that the geological map presented in figure 5.5.5 does not show damtjernites and hematitized FDC. The reasons for this are:

Damtjernites. In several drill-cores it has been observed that the damtjernites unquestionably post-date the FDC. It is evident that the damtjernites have been subjected to post-magmatic alteration with Fe-dolomite / ankerite, chlorite and “serpentine” as alteration products. Due to subsequent weathering some very altered damtjernites appear rusty brown and may look very similar to the FDC. Usually the remains of phlogopite, and certain breccia-textures, typical of damtjernites, makes it easy to distinguish altered damtjernite from FDC. In some places, however, (e.g. in the southern and eastern part of Rullekoll) the damtjernites apparently have been so strongly altered that the distinction between altered damtjernite and FDC is problematic. A map showing damtjernites and FDC is shown in figure 10.1.3.

Hematite alteration. Hematitization has affected different rocks within the Fen complex. Rocks of the FDC unit seems to be the rocks most commonly subjected to hematitization, but also some damtjernites, calcite-dolomite carbonatites and fenites have been hematitized. In most places it is fairly easy to identify whether a FDC or a damtjernite has been hematitized. The hematitization postdates the Fe-carbonate alteration of the FDC and damtjernites. In certain cases the hematite alteration event has been so strong that it is not possible to recognize what was the protolith. In such cases the rocks have been mapped as “red-rock”.

Altered Ca-Fe-Mg-carbonatites (CFM).

A special group of altered carbonatites has been mapped south of Rauhaug and in the vicinity of the Vibeto farms (and some other minor areas). In the field they may resemble FDC (=“rauhaugite”) or altered søvites. They characteristically contain more Ca than FDC, but less Ca than søvites, and more Fe than in a typical søvite, but less than typically found for rauhaugite. Their Mg content is variable, but is usually low. They have variable, but lower P than søvites. They have very low REE (only a few hundred ppm), and very low Th. Hematitization is widespread within this rock group. These rocks have previously been mapped as “rauhaugite” or “red-rock” by Sæther (1957), but they have no relevance in REE exploration. CFM, easily misinterpreted as FDC’s barren of REE, have also been observed within the Tuftestollen adit. In this study the CFM has been distinguished as a separate low-REE rock unit. Consequently, the map in figure 5.1.5 does not include this rock group in the FDC-unit. The boundary between FDC and CFM is highly uncertain in the strongly covered area between Vibeto and Rauhaug in south, and around Tufte, Borgjordet and Søvedalen in the north.

Comments to other parts of the boundary of the FDC-unit will be given on the pages following the general description of the FDC.

Figure 5.1.1
Deeply weathered hematitized FDC at Rullelkoll. The trench had been excavated by a fiber-net company. UTM: 517233 6569977

Figure 5.1.2
Rusty coloured weathering of FDC at Rullekoll. The soil had been somewhat removed during road construction. UTM: 517221 6569799

Figure 5.1.3
Typical rusty coloured surface of FDC near Fen Nordre farm
UTM: 517222 6570498

Figure 5.1.4
FDC in the road-cut west of Fenbukta. This is the “classical” road-cut that was sampled, drilled (“F1” and “F2”) and analyzed by FSJ. UTM: 517205 6570917

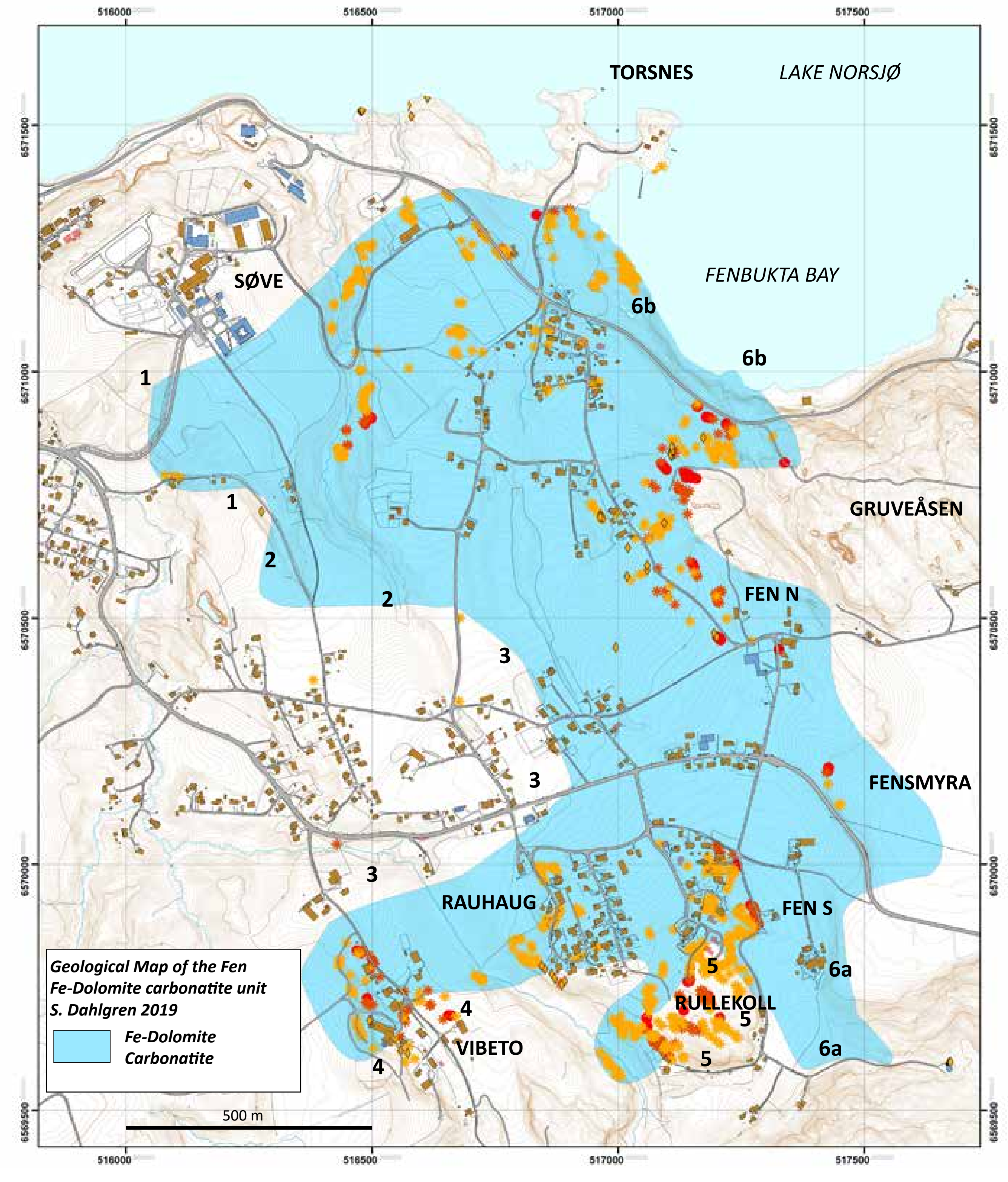


Figure 5.1.5
New geological map of the FDC unit (blue area), of the Fen Carbonatite Complex.

- *The area consisting of the FDC unit is shown in blue.*
- *Orange-coloured star-symbols represent FDC exposures on the surface.*
- *Red star symbols represent hematitized FDC-rocks.*

The younger damtjernites, and zones of hematitization, are not shown. See text for explanation, and figure 10.1.3 for visualization of damtjernites.

The outer limit of the unit covers 1.40 ±0.05 km² of the near surface of the complex.

See figure 5.4.3 for positions of drill-cores and old subsurface mine adits used to construct this map.
See map appendix 2 for place-names used in the text.

Some comments to the mapped boundaries of the FDC unit (see corresponding numbers on the map above):

1. *The boundaries south of Søve and in the western part of the old Fen Iron Mines have been extrapolated from observations made subsurface within the old mines.*
2. *The old drill-cores T17, T20 and T22 have been used for the boundary N of Tufte.*
3. *Due to the lack of exposures and drill-cores the boundary of the FDC unit is very uncertain in the area east and south of Tufte, and between Rauhaug and Vibeto .*
4. *Vibeto Midtre: Some "FDC-localities" (orange stars outside the FDC-area) rocks have recently been reinterpreted as CFM (see explanation in the text) and not FDC.*
5. *Rullekoll area: More work is needed to distinguish FDC from the highly altered damtjernites in this area.*
6. *In the vicinity of the Southern Fen farm and Skålås (6a), and in the south-western Fen bay area (6b), the boundaries of the FDC unit are based on field observations not yet shown with symbols on this map. The mapping at 6b is not yet finished.*

Further documentation and discussion of the boundaries of the FDC-unit is presented below.

5.2 Geology of the Fen Fe-Dolomite carbonatites (FDC) - Macroscopic textures

The macroscopic textures of the FDC-rocks vary immensely, and the FDC-unit is an extremely inhomogeneous rock group. A few examples of textures was recently shown in the report describing the two long drill-cores LHKB-1 and 2 (Coint and Dahlgren 2019). It is outside the scope of this report to make a full description of all FDC textural variations. The objective here is to point out some major characteristics and relationships.

Textural characteristics

In this study it can be concluded that the FDC typically shows breccia-textures. This is in accordance with previous descriptions by Sæther (1957) and Andersen and Qvale (1986). The various textural varieties and the transition from one textural type to another are not easily observed on weathered outcrops, but these relationships can be studied in detail in drill-cores and in old subsurface mine workings. However, the boundaries between different breccia-types are rarely sharp. The transition from one clearly defined textural variety to another must rely on a series of criteria. A mapping of different breccia varieties would have to rely on much more drill-core data than is available today. Texturally different types include both fragment-supported and matrix-supported types, varieties with angular or rounded fragments, and also textures showing brittle or ductile deformation of post-brecciation age.

Modal charcateristics

Both polymictic and monomictic breccias are common within the FDC unit. Fragments of chlorite-rocks and various carbonatites are abundant. Generally the fragments have been hydrothermally altered. Some of the fragments probably represent altered mafic silicate rocks, whereas others are altered søvites or other carbonatites. Fenite fragments are especially abundant in the FDC's near the northern margin of the FDC unit.

Some characteristic textures are shown on the photos on this page (figures 5.2.1 to 5.2.3; and also on the backside cover). Macroscopic textures will also be shown in the description of field relationships on the following pages. The textures of the REE-mineralization will be described in section 5.5.

Figure 5.2.1

FDC breccia at Rullekoll. The exposure was made by blasting in 2014 and the rock was gray. This photo was taken in 2016 and then the surface was already yellow . UTM: 517208 6569894

Figure 5.2.2

Polymictic FDC breccia from the Fen Iron Mines (FSS 152 SE). Dark fragments are chlorite-rocks and light-coloured fragments are altered carbonatites. Longest dimension of image is ca 15 cm.

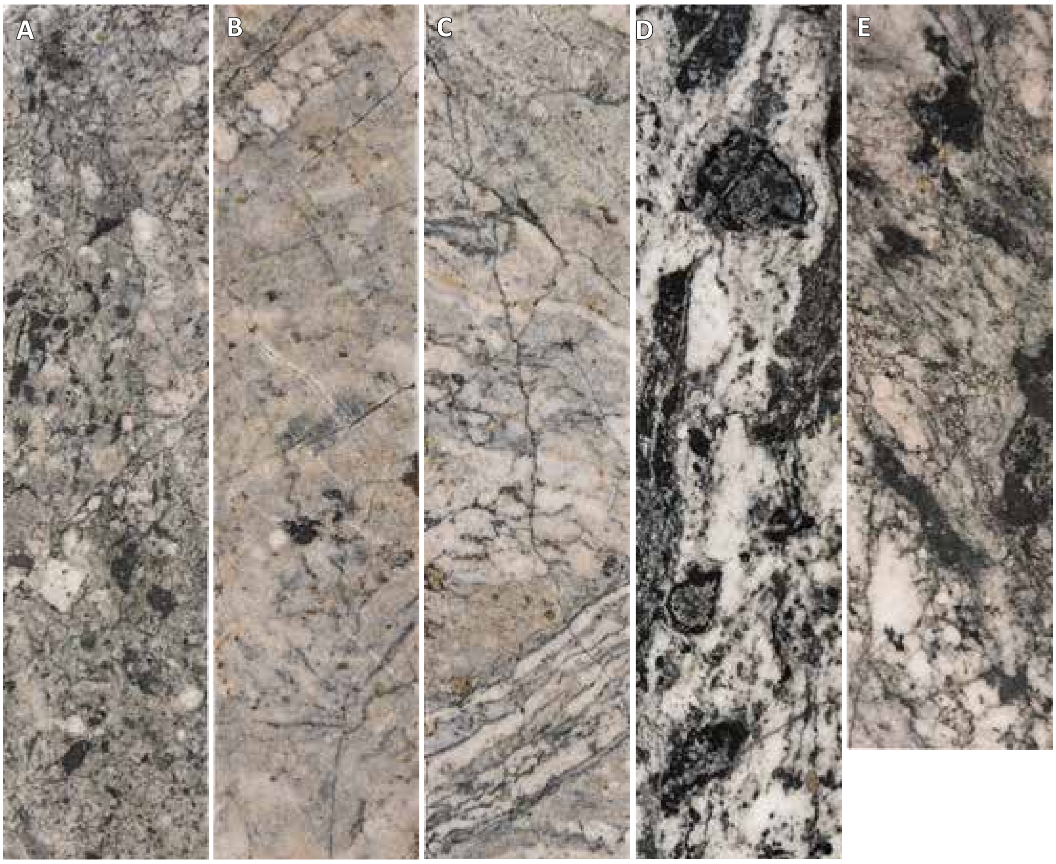


Figure 5.2.3 A to E

Examples of FDC textures from shallow drill-cores.

The beige to light gray domains consists mainly of Fe-dolomite, whereas the dark gray to black domains are dominated by chlorite. Some of the tiny yellow-brown spots in B and C are disseminated REE-minerals.

A-D are from the Fen 2016 SØVE-E6 drill-core; details from the following intervals:
A 15.77-16.00
B 20.51-20.76
C 20.77-21.00
D 49.79-50.00

E is from Fen 2016 SØVE-E7, interval 18.00-18.75.

The width of all cores is 35mm.

Figure 5.2.4
FDC rock texture. Slab of polymictic FDC breccia with fluorite (indicated by F's). Sample from outcrop at Rullekoll blasted in connection with construction of houses. UTM ca: 517179 6569875

5.3 Geology of the Fen Fe-Dolomite carbonatites (FDC) - A brief overview of the mineral associations of the FDC

Previous descriptions of the mineral composition of some of the FDC-rocks are found in Brøgger (1921). Sæther (1957), Andersen and Qvale (1986), Marien et al. (2018) and Dietzel et al (2019), but none of these descriptions are comprehensive.
In this section only a brief outline of the mineral composition of the FDC is presented. The detailed FDC petrography, and especially the petrography of the REE mineralization, is presented in chapter 6.

See mineral abbreviations in appendix 1.

Carbonates
Fe-Dolomite is the dominating mineral in the FDC. Calcite is also an ubiquituous phase in the FDC, but usually occur in minor quantities compared to Fe-dolomite.

REE-F-carbonates (=RFC)
The REE-fluoro-carbonates, parisite-synchysite and bastnäsite, are the principal REE-minerals in the FDC.

Phosphates
Phosphates occur as monazite and apatite in the FDC. In some FDC's monazite is the principal REE-mineral.

Silicates
Unlike in the søvite, the FDC typically contains quartz. Other common silicates are biotite and chlorite. Sæther (1957) reported albite and microcline as common feldspars. The REE-silicate allanite occur in minor quantities and thorite is found as an abundant accessory phase.

Oxides
Magnetite and hematite are typical Fe-oxides. Rutile is an accessoriy phase. Rare ilmenite was reported by Andersen (1984)

Sulfides
Pyrite is the prevailing sulfide. Pyrrhotite is much less widespread. Trace amounts of Cpy, Gl and Sl also occur.

Sulfates
Barite is a very common and widespread phase in most FDC. It may constitute several percent of the rock mass.

Fluorides
Fluorite is a common phase, but it varies strongly in abundance.

Other minerals
Åmli (1977) described thortveitite, niobian rutile and columbite in FDC from drill-cores from the Fen Iron Mine district.
Brøgger, Goldschmidt and Sæther had to rely on their optical identification of mineral phases in thin sections, or of separated mineral powders. All of the above were skilled in identifying even the tiniest mineral optically. In the "rauhaugites type 2" they reported mineral phases with uncertain identification:
- Brucite (Goldschmidt, mentioned by Brøgger p 259).
- Periclase (Sæther p 101)
- Melilite (Sæther p 103)

None of these minerals have been verified by modern analytical methods so far.

Literature on Fen FDC mineral chemistry
Some mineral analyses of minerals in the FDC was published recently by Dietzel et al. (2019), as a result of two master projects being a part of this present project. The reader will find numerous analyses of monazite, parisite-synchysite and bastnäsite in the supplementary material to that publication. For analyses of allanite the reader may look at the data in the paper by Andersen (1986).

5.4 Geology of the Fen Fe-Dolomite carbonatites (FDC) - Field descriptions

The field relationships in selected, mineralized parts of the FDC unit is described below.

5.4.1 Geology and REE-mineralization in FDC in the Tuftestollen adit

The Tuftestollen adit was constructed in the early 1950s for the purpose of transporting niobioum ores from the Tufte mine northwards to the shore of Lake Norsjø. The entire length of the adit plus the Tufte mine is slightly more than 1 km. Its entrance is close to 20 m a.s.l.
This adit transects fenites, søvites and Fe-dolomite carbonatites (FDC). In the 1980s the company "Fenco" performed exploration for REE and niobium ores within the Tuftestollen adit, but with no success.
When the present project started in 2015, the Geological Advisor immediately discovered that REE-mineralized FDC occurred in large parts of the Tuftestollen adit. As is usually the case in any mine also the mine walls of the Tuftestollen adit was covered with a cm-thick layer of mine-dust. The promising observations made in 2015 prompted a large effort to clean the walls of the adit and parts of the Tufte mine. This cleaning-work has been going on episodically until the spring of 2019, in total an effort of about one man-year, and was performed by several assistants, in particular Björn Strömberg and Håvard Grønnevik.

The FDC first appear at 381.5m (measured from the zero-mark near the entrance; i.e. the zero-mark established during mining). The FDC-unit can be followed continuously until 645m. The FDC unit is not homogeneous:

- Certain intervals consist of FDC veins transecting a black/dark gray chlorite rock. This applies especially to the inner parts and in the area around 475m.
- The interval from 390 to 446m, over a length of 56m, is partly or totally hematitized. (Figure 5.4.1h)
- ***Over most of the length of the FDC-unit a FDC-breccia is exposed. This breccia hosts REE-mineralizations at many sites. This unit is regarded as very important for the further exploration for REE in the Fen complex.***

The FDC-breccias vary considerably in texture and composition, but most of the breccias in Tuftestollen are fairly light-coloured. The content of dark matrix minerals, or dark fragments, is generally lower than e.g. in most of the FDC-breccias of the Fen Iron Mines described in the next section.

Some REE-mineralized zones:

Ts 510-512 E and Ts 504-505m W
This is the "discovery zone" from back in 2015. These mineralizations , found on the eastern and western mine-walls respectively, are separated by about 8 meters. They may have been a single vein, but structures in the mine roof suggests that there is a tectonic zone (fault? shear zone?) that separate the two mineralizations. These mineralizations are fairly enriched in REE mineral aggregates. See photo on the front cover of this report, and the photos in figures 5.4.1d-f.
Chemical analyses have been performed on a series of chip-samples from the eastern mineralization. Two big samples (each a few 100 kg) were drilled and blasted out with dynamite at this locality.

Ts 563 to 566 W
This mineralized zone is similar to the zones described above. It is not clear whether this is a vein or a dissemination (figure 5.4.1g). This zone has also been chip-sampled for chemical analysis.

Sulfide-oxide zone at Ts 535 W
A zone, 1-3 m wide, of pyrite and magnetite occur at about 535m W (figure 5.4.1i). This Py+ Mag zone is also enriched in REE, but so far it is the only one mineralization of this type known in the Fen complex.

Drillcore Ts-34, Tuftestollen, "Norsk Bergverk"
One of the cores, Ts-34, drilled by Norsk Bergverk in the 1950s, was drilled eastwards from the Tuftestollen adit at 881 E. This core was drilled (horizontally) into FDC at 110.7m, and it contained a dm-sized mineralization (figure 5.4.1b) of the same general type as found at Ts 505m W. This is interpreted as the boundary to the FDC complex was reached or approached.

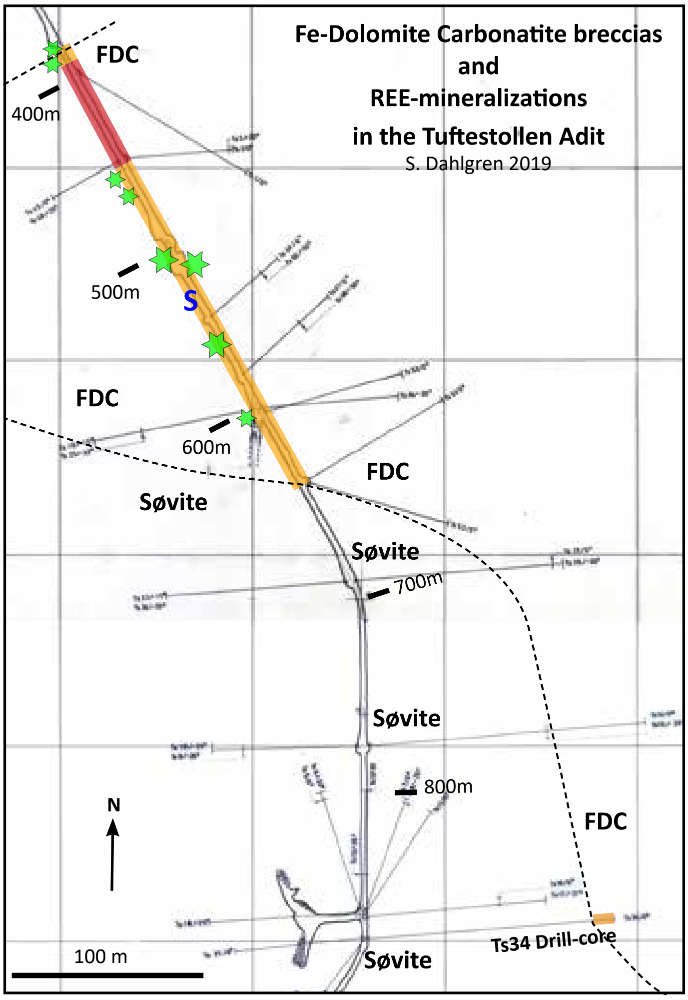


Figure 5.4.1a
Geological map of the Tuftestollen adit. The mine-map used as a background for the geology was prepared by Fenco in 1980. The samples are listed in appendix 3A.

Old drill-cores from Tufte, drilled by Norsk Bergverk, in the FDC-unit
The company Norsk Bergverk drilled a number of cores from the surface in the Tufte area east of the Tufte niobium mine during the 1950s. They explored for niobium deposits and were not interested in the "rauhaugite type 2". Several of these cores were analysed for REE by FSJ in the late 1960s (see page 12). Svinndal (1967), records high REE in T21, and an enriched zone in T23, and some enrichment in T16. All these cores were drilled along one profile (figure 5.1.5). Probably the "FSJ" used the entire cores (only 22mm in diameter) for analysis.
Boxes with cores drilled along the same profile as those analysed by FSJ, but with different dips still exists, and have been logged by the geological advisor. The pairs T16-T17, T20-T21 and T22-T23 were drilled from the same starting locations. FDC with considerable REE mineralizations has been observed in the core T17 (figure 5.4.1c). The core T20 mostly consists of CFM carbonatite with some zones of FDC with a little REE enrichment. The core T22 does contain FDC in the interval "160-170m", i.e. near its eastern end. Thus, the REE content of these cores are in the FDC. The cores analysed by the FSJ, and those logged in this project have been used to constrain the FDC map-boundary NE of Tufte.

Figure 5.4.1b
Drill-core Ts34, 120m, from the Tuftestollen adit drilled by Norsk Bergverk. The red aggregates are REE minerals. The core is 22mm wide.

Figure 5.4.1c
Drill-core T17, interval, from surface drilling at Tufte drilled by Norsk Bergverk. The red-brown aggregates are REE minerals. The core is 22mm wide.

Figure 5.4.1d
REE-mineralized FDC at Ts510 to 512 E (between the two dashed lines). Hand-held XRF shows the scale. The details within the rectangle is shown on photo figure 5.4.1d.

Figure 5.4.1e
Boundary between the non-mineralized FDC breccia (to left of the dashed line) and the REE-mineralized zone. Note that the REE minerals (red and yellowish) are enriched along the boundary at this spot of the vein. However, large REE mineral clusters do occur throughout the vein.

Figure 5.4.1f
REE-mineral clusters in FDC at Ts 505 W, about 3m above the sole.

Figure 5.4.1g
REE-mineralization at Ts 564,5 W at 0.7m above the sole.

Figure 5.4.1h
Partly hematitized FDC near 400m W in the Tuftestollen adit. Black rocks are chlorite-rich rocks. Matchbox for scale (5.5 x 3.5 cm).

Figure 5.4.1i
Pyrite-magnetite-REE vein at 535m W in Tuftestollen (between the white dashed lines). This vein is also highly enriched in REE.

5.4.2 Geology and REE-mineralization within the FDC in the old Fen Iron Mines

Mapping of the FDC and "red-rock" in the Fen Iron Mine district has been focused on the area between Fen old school and the western Fenbukta bay. At the surface dense vegetation and numerous mine-waste dumps cover the ground in this area. Although not easily accessible, the geology has been mapped at the ground level within the mine system of the former Fen Iron Mines (figure 5.4.2a).
The mapping was performed using the old mine-maps made by Teigen (1928). No names of the various cross-cuts and adits were found on this map. To ease the mapping, and the description, new names have been constructed (see map below):

- **AKS**, "Anne Katrine Stoll", the adit beow the Anne Katrine mine.
- **FSS**, "Fen Skole Stoll", the adit trending southwest-wards and ending somewhere near and underneath the Fen old school.
- **VS**, "Vest-Stollen", the adit system below and vest of the mine "Forenin-gen"
- **LLT**, "Lictloch Tverrslag", the only original name found so far, is the cross-cut between the Bolla mine, and the crossing between AKS and FSS.

The 1928 mine-map appears to be of good quality, but it is not straight forward to fit it to modern digital topographic surface maps. Nevertheless, the rock boundaries on figure 5.4.2a have been projected to the surface from boundaries mapped in the mine. See figure 5.1.5.
Typically, the mine-walls were covered with dense dust-layers. In large parts of the mine system this dust was of red color, which gave the immediate impres-sion that most of the rocks in mine system were hematitized. When removing the dust, however, it was discovered that FDC-rocks of different textures and that was not, or only slightly, hematitized, occurred in large parts of the westernmost mine system. See map figure 5.4.2a. To obtain good exposures it was therefore decided to clean parts of the FSS and LLT mines, and a few sites within the AKS ans VS mines.

An astonishing number of REE mineralized zones were discovered within the FDC rock unit, especially in the FSS mine, but also in the AKS and VS mines. See photos figures 5.4.2 d-f and map figure 5.4.2a. Numerous faults were also discovered, but they have not yet been mapped.

Fen Skole Stoll mine (FSS)
This adit is 195 meters long measured from the crossing with the AKS mine, and it is situated at an estimated depth of ca 70 m below the Fen old school. A completely hematitized rock, probably of a FDC breccia protolith, constitutes the first 121 meters of the adit. FDC-breccias, which are not hematitized occur from 122 meter to the end of the adit. Both fault-boundaries and infiltration boundaries occur between the hematitized rocks and the non-hematitized FDC breccias. REE-mineralized FDC veins occur in the intervals 163-166m, 169-171m, 184-186m, and 192-195m. See photos figures 5.4.2d and e.

Vest-Stollen (VS) and Anne Katrine Stoll (AKS) mines
A few square meters of mineralizations have been observed several places in this part of the mine system, but most of the mine-walls have not yet been cleaned for observations. Although the mineralizations in AKS and VS appear to be disseminations, they probably also in reality represent part of vein sys-tems. Further cleaning of the mine-walls, or eventually drilling from the mine, may solve this question.

Lichtloch tverrslag (=LLT= Lichtloch cross-cut)
FDC-rocks occur along the western half of this cross-cut, whereas tn the east-ern half all rocks are hematitized. Towards the iron-ore in the Bolla shaft the hematitization is particularly strong.
The western half of LLT contains conspicuous, large masses of violet fluorite (figure 5.4.2g). Flourite was described by Vogt (1911) from the Fen mines, but it is not clear whether Vogt made his observations in this part of the mine. To him also several lower levels of the mine were accessible, all of which today is filled with water.

Figure 5.4.2a
Geological sketch map of the westerns part of the Fen Iron Mines. In the Fen school area the mines are about 70m below the surface. See comments in the text

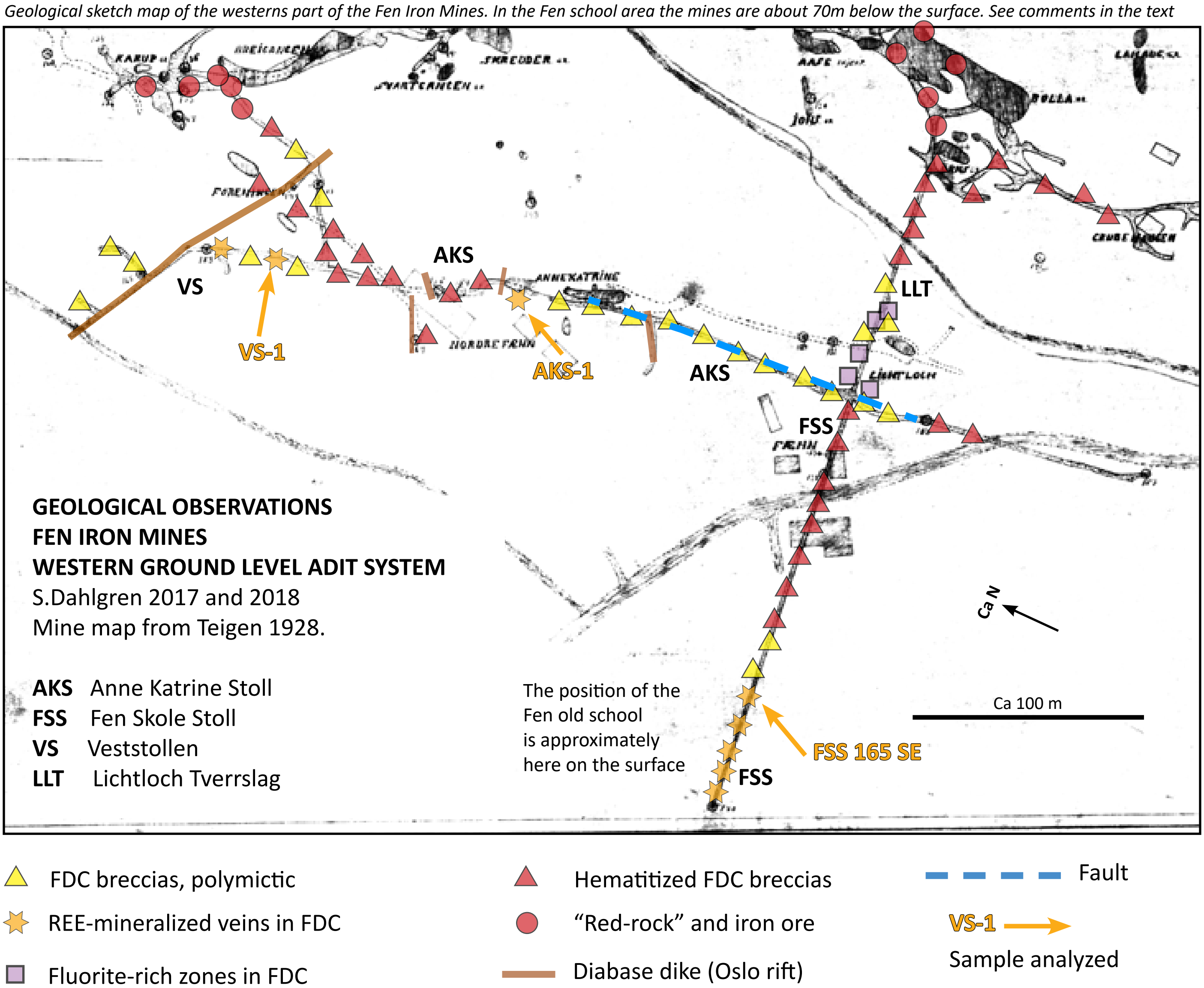


Figure 5.4.2b
Strongly hematitized rock in the Fen Skole Stoll (FS). The protolith was probably FDC breccia. White scale is 10 cm long.

Figure 5.4.2c
A wedge-shaped body of hematitized rocks with fault boundaries to the host FDC polymictic breccia (FSS). Note the abundance of dark-coloured fragments in the breccia. White scale is 10 cm long.

Figure 5.4.2d
Pink REE-bearing vein hosted by gray FDC-rocks. FSS mine.

Figure 5.4.2e
REE-mineralization in a vein in the FSS mine. The massive red-brown zone contains > 16 % REE (La+Ce+Pr+Nd measured by handheld XRF as elements).

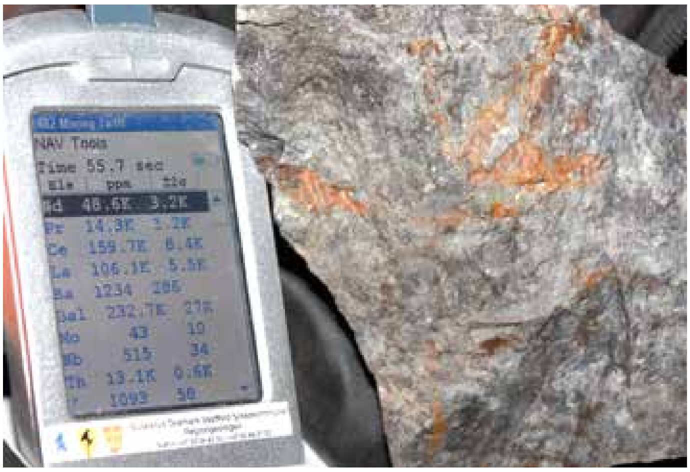


Figure 5.4.2f
REE-mineral aggregates at the AKS-1 site. Orange clusters contains > 33% REE (La+Ce+Pr+Nd measured by handheld XRF as elements).

Figure 5.4.2g
Fluorite mineralization in FDC breccia. Lichtloch tverrslag, LLT.

5.4.3 Shallow drill-cores relevant for mapping of the FDC unit

The shallow drill-cores have been essential for the mapping of the FDC unit. A new map of this unit is presented below and described on the next page.

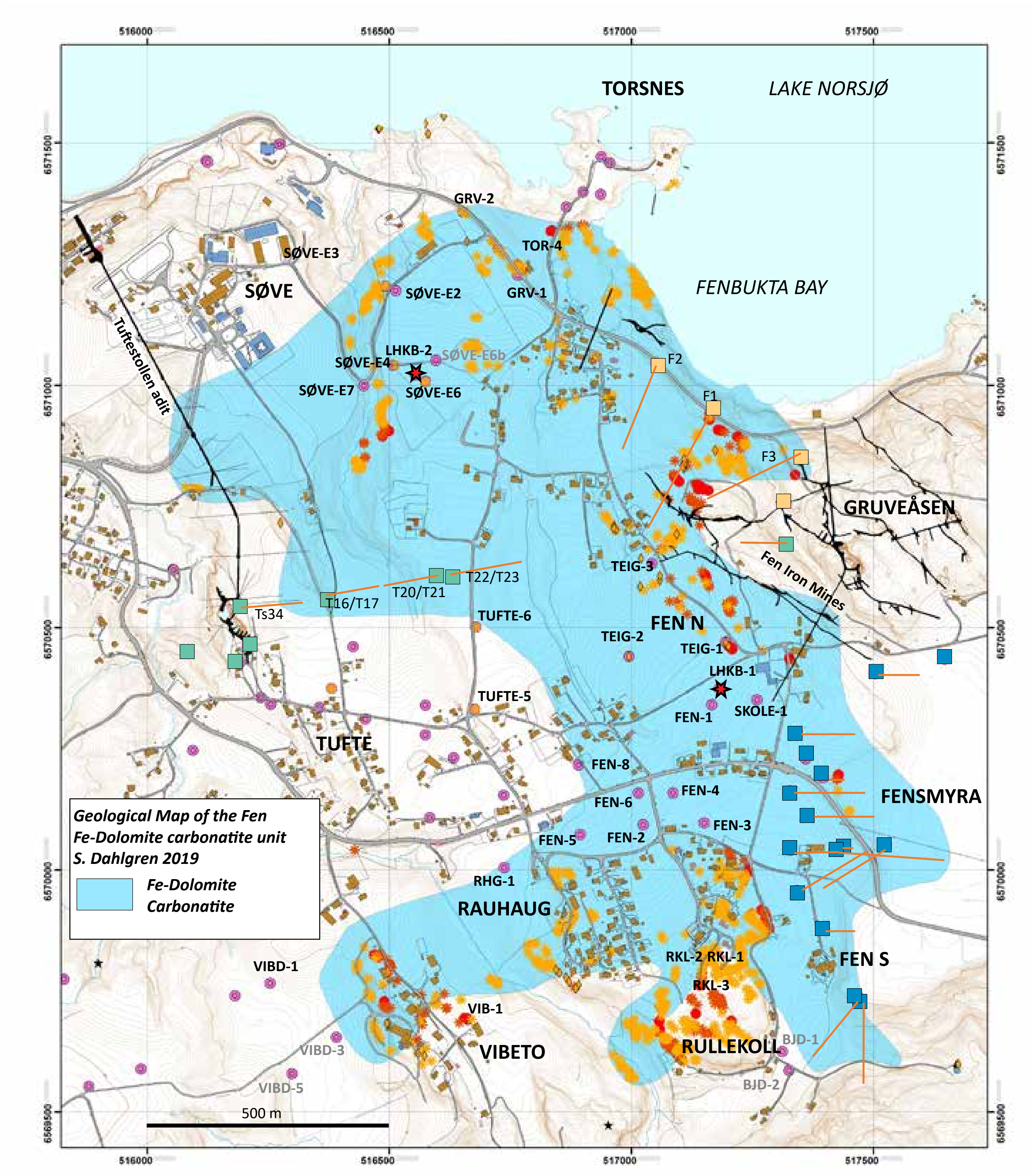


Figure 5.4.3 Drill-cores and old subsurface mine adits relevant for the geological interpretation of the Fen Fe-Dolomite Carbonatites (FDC)

Legend

Geological Advisor and NGU Shallow drill-cores 2015-2018
- Black ID labels shows cores drilled into FDC, or presumably altered FDC.
- Gray ID labels shows drill-sites where bedrock was not reached due to too thick clay deposits (>15-21 m), or due to shallow boulders.
- Drill-sites with no ID labels are not relevant for the distribution of the FDC-rocks

Sites of the NGU and Geological Advisor long drill-cores 2017-2018 (LHKB-1 and LHKB-2)

"REE Minerals" drill-cores 2012 and 2014

"Norsk Bergverk" cores (1950s)

"Forskningsgruppe for sjeldne jordarter (FSJ)" drill-cores ca 1970

Drill-core trace

Projection of old subsurface mine adits

Strategy for the shallow core-drilling campaign
Drilling of the shallow cores has been an important tool in the making of a new geological map of this complicated geological complex that is so densely covered with clay deposits. The shallow drilling as not aimed at REE mineralizations. The drilling of the REE mineralizations is a challenge for future exploration work.

Organization of the core-drilling program
During the years 2015 to 2018 the Geological advisor has been responsible for the planning, permissions and implementation of the drilling campaigns. The core-drilling was performed using the NGU litho-drill-rig operated by Geir Viken, NGU, and by Björn Strömberg from the Geological Advisor. Additional 1 to 2 persons engaged by the Geological Advisor were at all times engaged in the technical part of the drilling. The drilling equipment had some limitations. The rig was mounted on a truck and access was only possible near roads or on reasonably flat fields. Drilling in the fields was normally only possible during late fall, after the harvest. Heavy rain during the campaign in 2017 prevented us from drilling some planned cores on the fields in the central Fen area. In 2015 no casing could be used. Thus, the cores drilled in 2015 had to start from an accessible exposure, and was drilled 45 degrees downwards in the desired azimuth for 50 meters. In 2016 we could apply a casing up to 7 meters long, in 2017 up to 15 meters, and in 2018 up to 21 meters.

Most cores drilled with casing were drilled very shortly down into the bedrock (1.6 to 10.6 meters). Most of those drilled for 20 m or more were drilled as reconnaissance drilling preceding an eventual long core drilling project (at the time we did not know whether such a project could be financed).
The location of the different shallow cores is shown on figure 5.4.3, and the positions and technical details given in appendix 3A, and brief logs in appendix 3B.

All core ID's have a prefix identifying which year the core was drilled (e.g. Fen 2015, Fen 2016 etc) followed by an acronym specific for the actual drill-site. For simplicity only the acronym is used on the map (figure 5.4.3) and in the text. See appendix 3 for full ID's. See appendix 2 for place-names used in the text.

Brief comments to the geology of the shallow cores

Cores of FDC with abundant REE-mineralizations
Several of the shallow cores contain REE-mineral aggregates qualifying them to be termed mineralizations, or indications of mineralizations. Not surprisingly most of the REE-mineral aggregates have been found in the longest of the shallow cores: RKL-2 (at Rullekoll drilled with a westerly azimuth), TEIG-2, TEIG-3, SKOLE-1 (all three near the Fen old school), and SØVE-E2, SØVE-E3 (west of Søve sommerfjøs), and GRV-1 (Grønvollvegen). However, REE-mineral aggregates are also found in the relatively short cores SØVE-E7 east of Søve, and FEN-3 and FEN-4 (8,3 and 10.6m respectively), in the central Fen area south of the Fen old school and LHKB-1.
Of course, the longer the core, the higher the statistical chance of finding REE-mineral aggregates. Their presence in some of the very short cores may be pure luck. However, all those cores showing REE-mineral clusters fit nicely into a possibly REE-enriched zone called the "boomerang zone", defined in chapter 9. The RKL-2 core is the only one of the shallow cores that do contain REE-clusters that does not fit into the "boomerang zone".

Cores of FDC with no REE-mineralization
Several of the cores of FDC do not contain REE-mineral clusters, but tiny disseminated REE-grains are not uncommon. REE-poor cores include the relatively long cores RKL-1 and RKL-3 (both at Rullekoll; drilled with azimuths of easterly directions). The other cores in his group are FEN-2, RHG-1 and SØVE-E4. The SØVE-E4 core is, however, only 1.6 m long, and was drilled a few meters west of SØVE-E6 and LHKB-2 and a few meters east of SØVE-E7, which all contain abundant REE-mineral clusters.

Cores with partial or total hematitization
The cores FEN-5, FEN-6, FEN-8, TOR-4, TEIG-1, TEIG-3 and SKOLE-1 are totally or partially hematitized. Their protolith is interpreted to have been FDC breccia. In the cores TEIG-1, TEIG-3 and SKOLE-1 the REE-mineral aggregates are generally deeply red and hematitized. The core recovered at FEN-8 was only 0,2 m, very altered, and the identification of the rock as a hematitized FDC breccia is only tentative.

Cores of CFM carbonatites
The two southwesternmost cores VIB-1 (Vibeto midtre) and VIBD-1 (Vibetodalen) consists of CFM carbonatite, and especially the VIB-1 core is hematitized. Their REE-content is very low.

Cores possibly representing a border facies to damtjernite diatremes or to FDC breccias

RKL-3 was drilled at Rullekoll (near the end of the road that existed in 2015) with a south-easterly trending azimuth, at a dip of 45 degrees and for 50 m. It began in FDC breccia, but the last half of the core sampled very altered damtjernite. In 2018 the area where this core was drilled was cleared for forest and soil, because of construction of new houses, and the drill-core and surface geology mirror each other quite well.

The RHG-1 core consists of both a FDC breccia and a very altered damtjernite similar to that found at Rullekoll and north of Rauhaug. This core was drilled relatively near the Rauhaug damtjernite and may be a boundary-facies to this. However, it may also belong to the presumably large Tufte damtjernite, which is interpreted as a diatreme root zone. The area between Tufte and RHG-1 was drilled at two locations, but the clay deposits were too thick to penetrate at the time of the attempt, and no rock-cores were recovered.

The FEN-1 core sampled both FDC and damtjernite. It may have been located at the margin of a damtjernite breccia that intruded the FDC.

The cores TUFTE-5 and TUFTE-6, drilled at Borgejordvegen, both contain søvite xenoliths in a breccia where FDC is interpreted as constituting the matrix. The TUFTE-6 core contains veins with REE-minerals and thorium. These two cores probably were drilled near the boundary to the FDC complex.

SØVE-E7 contains FDC with REE clusters. The FDC is crosscut by damtjernite. These relationships are similar to what was found in the LHKB-2 core that was drilled only 109m ENE of SØVE-E7.

The GRV-1 core may contain a highly altered damtjernite in contact with FDC. A damtjernite breccia was recorded for the two first meters of the GRV-2 core, and the damtjernite was emplaced into fenite.

Cores from the boundary zones of the FDC-complex
The core GRV-2, drilled from a road-cut on Grønvoldvegen and towards southwest was drilled near the boundary of the FDC complex. The core sampled fenite with a few søvite dikes, FDC veins and a damtjernite breccia.
The cores TUFTE-6, FEN-8 and RHG-1 probably also were drilled in the boundary zones of the FDC unit.

Figure 5.4.3
Drilling of the short cores.
Image showing the two drill-crew workers employed by the Geological Advisor: Björn Strömberg (left) and Håvard Grønnevik (right). Chief driller Geir Viken, NGU, in the middle. The Geological Advisor was responsible for planning, permissions and administration and core-logging.

5.5 Macroscopic textures of the REE mineralization

5.5.1 Macroscopic textures of REE mineralization in the shallow cores

Like the textures of the FDC's in general, the textures of the REE-mineralization also show considerable variations. The distribution of the REE-mineralization looks random and heterogeneous in a core section. The variation in texture is best illustrated by images of drill-cores and sampled specimens (figures 5.5.1 A to G and 5.5.2 A to D)

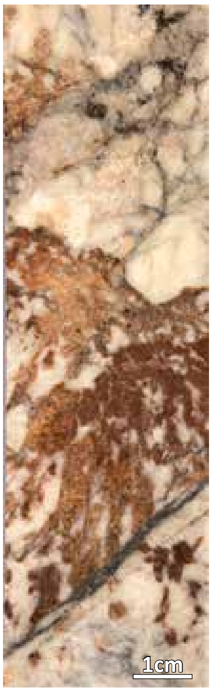


Figure 5.5.1 A
TEIG-2 19.60-19.77m

Figure 5.5.1 B
TEIG-2 19.90-20.00m

Figure 5.5.1 C.
GRV-1 8.75-9.00m

Figure 5.5.1 D
SØVE-E2 50.83-51.00m

Figure 5.5.1 A to G
The macroscopic textural variations of the REE-mineralizations in the Fen FDC's are shown on figures A to G. These are all photos taken of shallow drill-cores from this project, and the scale is the same for all images except for image G. The REE-minerals are concentrated within the aggregates of brownish-red, grayish-brown or yellowish gray colour. The REE minerals in these aggregates are monazite, parisite/synchysite and bastnäsite, mixed with other minerals, as will be documented in the next section of this report.

A, B and C: *Some REE aggregates are up to fist-sized. Similar-sized aggregates have also been found in the Fen Iron Mines.*

D: *A typical "standard REE-mineralized FDC". The REE-aggregates are up to 1, or in some samples 2-3 cm in size. Such aggregates seem to be concentrated in certain zones of the drill-cores, but frequently "lone" aggregates are observed.*

E and F: *Strongly REE-mineralized zones. Such textures are interpreted as the drill-core has sampled a vein or a vein system.*

G: *A granular variety of REE-mineralization. The REE-minerals typically occur in clusters up to 1 or 2 cm in diameter. They may be evenly or unevenly distributed throughout the rock volume. The content of pyrite is typical for this variety of REE-minralization. Such granular mineralizations may be found in veins apparently varying from cm to several meters in thickness.*

Some petrographic details of the samples in the figures 5.5.1 C, D and F will be discussed in chapter 6.

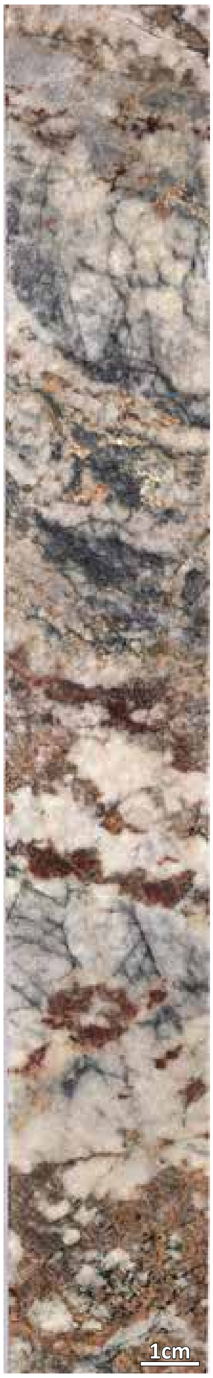


Figure 5.5.1 E
TEIG-2 54.26-54.56m

Figure 5.5.1 G
SKOLE1 20.28-20.50m

Figure 5.5.1 F
TEIG-2 22.46-22.83m

5.5 Macroscopic textures of the REE mineralization

5.5.2 Macroscopic textures of REE-mineralization from exposures

Figure 5.5.2 A to D
Typical macro-textures of the different REE-mineralized rocks from exposures sampled within the Fen Iron Mines and the Tuftestollen adit are shown on the images on this page. All images are shown on the same scale:

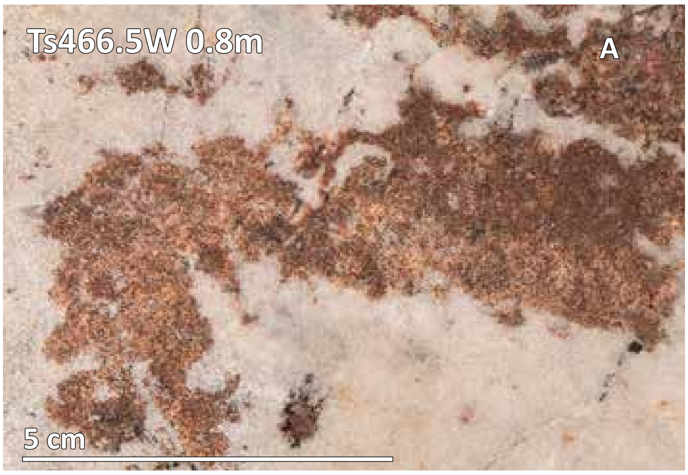
A. *Ts466.5W 0.8m, Tuftestollen adit. Large REE-clusters, frequently measuring several centimeters, occur apparently randomly distributed within the FDC rock volume. It may, however, belong to a REE-mineralized vein system, but this has to be investigated further by drilling from the adit.*

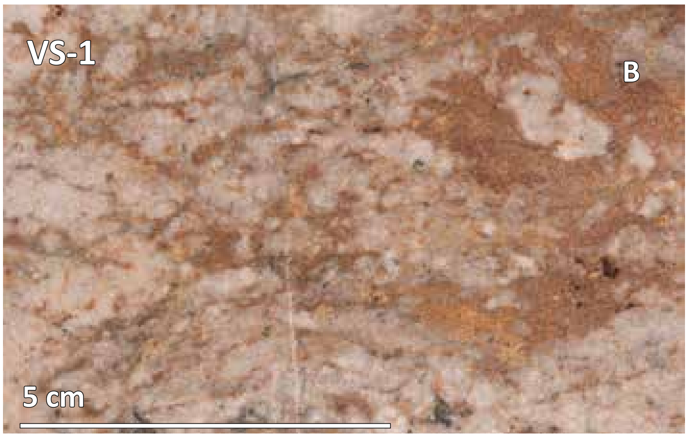
B. *VS-1, Veststollen, Fen Iron Mines. Pervasive REE-mineralization in the FDC. This is also possibly a part of a REE-mineralized vein system.*

C. *Ts511.5E, Tuftestollen. Mineralization from the site first discovered in 2015 within the Tuftestollen adit (also shown on the front-page of this report). REE-mineral clusters typically are 1-3 in diameter, but they may have clustered tightly to form bigger aggregates (dm-size). The mineralogy of these clusters will be documented in section 6.*

D*. FSS165SE, Fen Skole Stoll (FSS), the south-westernmost ground level adit of the old Fen Iron Mine system. Note the abundance of pyrite.*

All these mineralizations have been sampled and analyzed chemically. The mineralogy of the samples C and D, amongst with other samples, will be examined in chapter 6 of this report.





6. Petrography of the Fen FDC-rocks and their REE-mineralization

This section presents some basic petrological features of the FDC-rocks and their REE-mineralization. Emphasis is put on the domains containing the REE-minerals. Textural relationships and minerals of such domains, as well as some other important details from the FDC's are presented sample-wise over the next few pages. In the end of the section some implications of the petrographical observations are summarized.

Most of the petrographical observations have been performed on samples that also have been analyzed chemically. Many petrographical characteristics are shared by samples from different places of the FDC complex. I have tried to focus on samples that give information of the REE-mineralization of the Fen FDC in general, and avoided peculiarities as much as possible, although they may be interesting from a petrographical / petrogenetical point of view. The textures and minerals of the FDC's is very different from what is observed in "normal" rocks. The petrographical complexity of the FDC by far exceeds what is found for "normal rocks". The petrography presented here is only a glimpse into the complex world of FDC.

Analytical instruments

All observations and all images presented over the next few pages have been made at the lab-facilities of the Geological Advisor in Tønsberg. The equipment includes a Nikon polarizing microscope equipped with both transmitted and reflected light options, and a table-top Hitachi TM 4000 Plus SEM equipped with a Bruker Quantax EDX for semi-quantitative analysis, and element mapping. Very high-quality element mapping typically requires a run-time of several hours pr image. The EDX images presented here were all produced during only 5-15 min each.

Abbreviations

A key for mineral abbreviations used in this section is found in appendix 1.

NB! In the following all REE-fluoro-carbonates will be collectively called RFC.

Abbreviations accompanying the micro-images:
Polarization microscope (PM): TL = Transmitted light; RL = Reflected light
XP = crossed polars.
BSI = Backscatter image. EDX = EDX element map.

6.1 Carbonates in the FDC's

The main carbonate of the FDC's was described as "ankerites" by Sæther (1957). Relatively recently however, revision of the "ankerite" and dolomite nomenclature shows that most "ankerite" analyses from Fen actually classify as "ferroan-dolomite", with the general formula $Ca(Fe^{2+},Mg)(CO_3)_2$, here abbreviated Fe-Dol.

Fe-Dol is by far the dominant mineral in most light-coloured varieties of the FDC's. It occurs in many textural varieties, and the grain size varies from a few microns and up to a few cm. A grain-size between 0,1 mm and 1 cm is typical. Cal also occur in most of the FDC's but in minor quantities compared to the Fe-Dol.

The complex textures of the Fe-Dol, and probably also Cal, most likely formed during several stages related to different processes. It is not the scope of this study to discuss the carbonates in detail. Only a few major observations are shown on the images below.

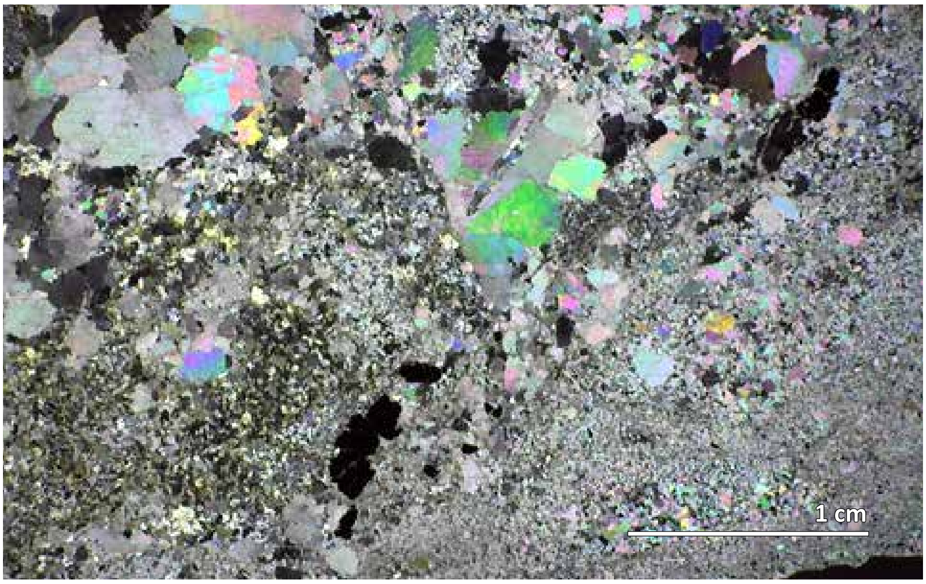


Figure 6.1.1.
Thin section image of FSS 165 SE A from a REE-mineralized vein in the old Fen Iron Mines. TL-XP. The grain-size of the Fe-Dol (high interference colours) varies substantially within this single thin section. This is typical for Fe-Dol in the FDC's in general.
The greenish-gray, fine-grained aggregate in the lower left part of the image consists of fine-grained minerals including Brt, Qz, Bt/Chl, RFC and Mnz.

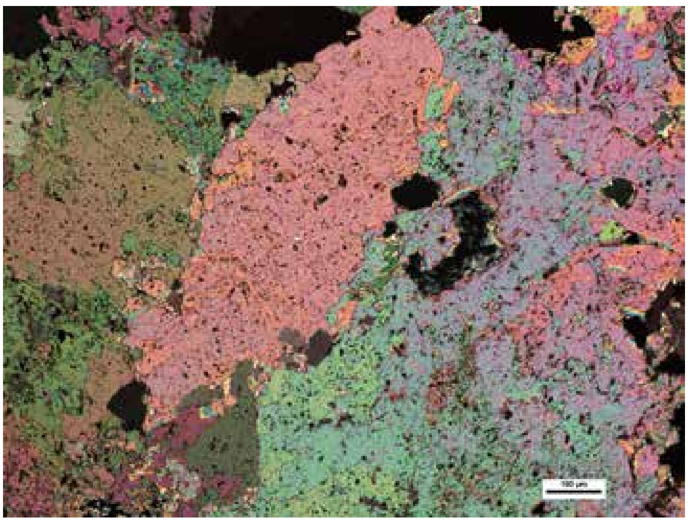


Figure 6.1.2
Fe-dolomite in the sample Ts510.7E 1.4m from the Tuftestollen adit showing early grains (ca 1mm) of Fe-dolomite containing tiny fluid and solid inclusions. The grains have fringed boundaries. PM-TL-XP. See also image to the right.

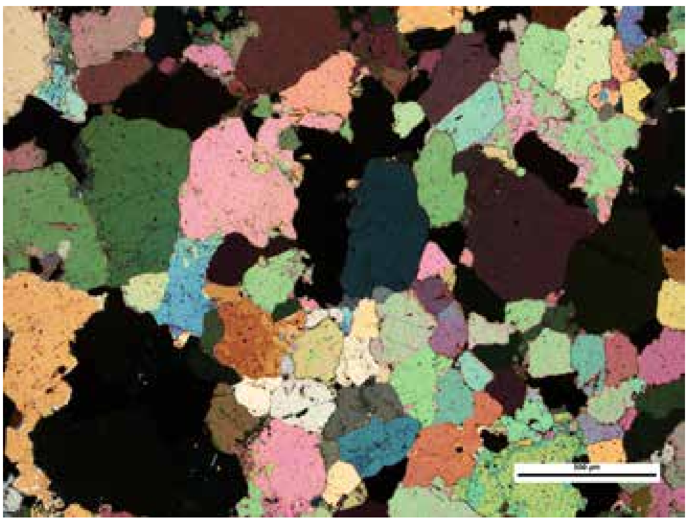
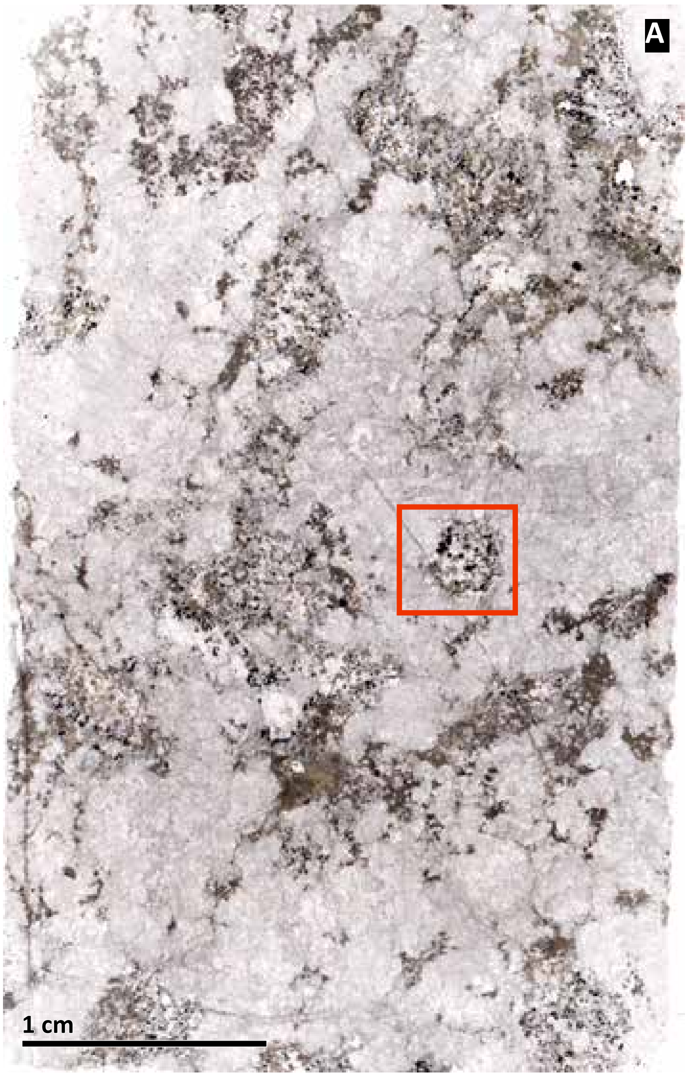
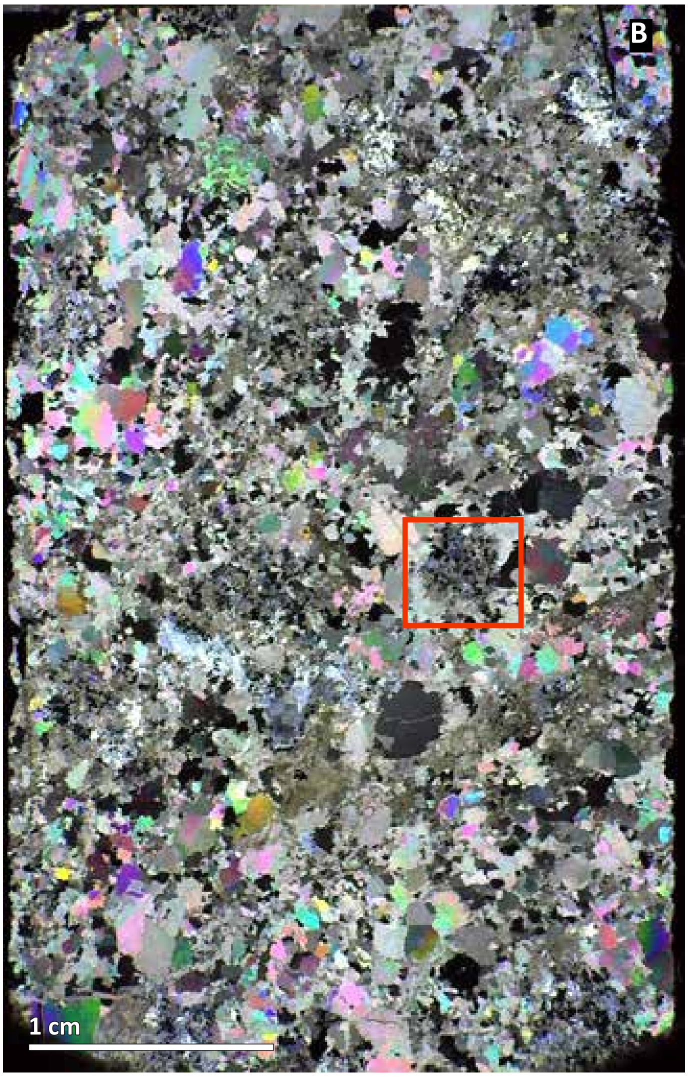


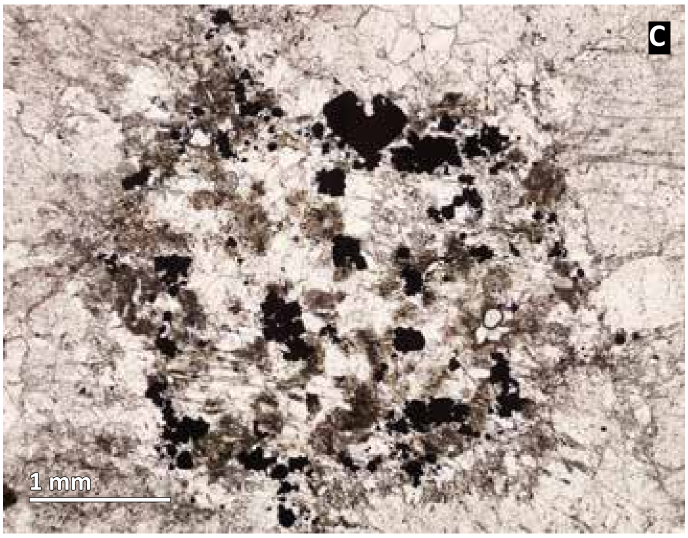
Figure 6.1.3
Fe-dolomite in the same sample as the image to the left. These grains represent a later generation of polygonal, recrystallized Fe-dolomite. These grains are 0.1.-0.2mm in size, and have very few inclusions. PM-TL-XP.



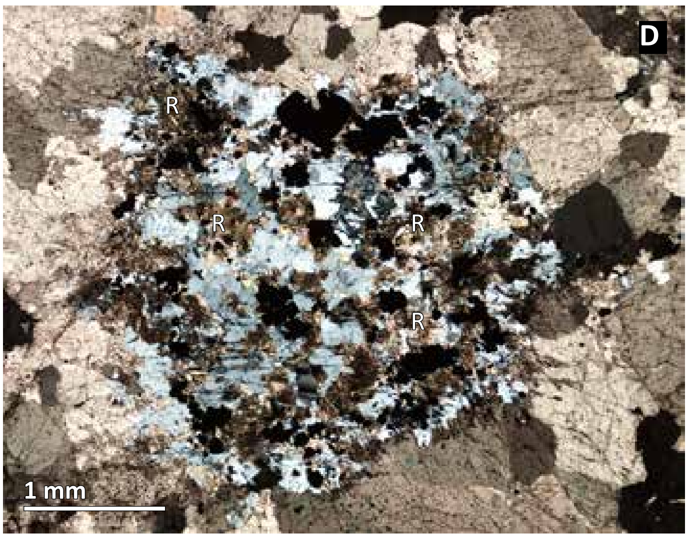
__A.__ Scanned image of a thin-section. REE-bearing domains appear as rounded or irregular "dotted" areas. TL. Red rectangle shows the position of the image in figure C



__B.__ Macrophoto of the same thin-section as in A. TL-XP. Red rectangle shows the position of the image in figure D



__C__. Image of the REE-bearing domain within the rectangle in image A. Optical microscope. PM-TL.



__D.__ The REE-beraing domain in C in optical microscope. PM-TL-XP. The domain consists of a light mineral, mainly Brt. The REF minerals appear as tiny grains with high interference colors (some examples shown with R) in a matrix with various shades of gray. Opaque grains are magnetite. This domain, which is rather typical of the REE-bearing domains of this mineralization, has been studied in some detail in SEM-EDX.

Figure 6.2.1
Micro-texture of REE-bearing domains in sample Ts511.5 E, Tuftestollen

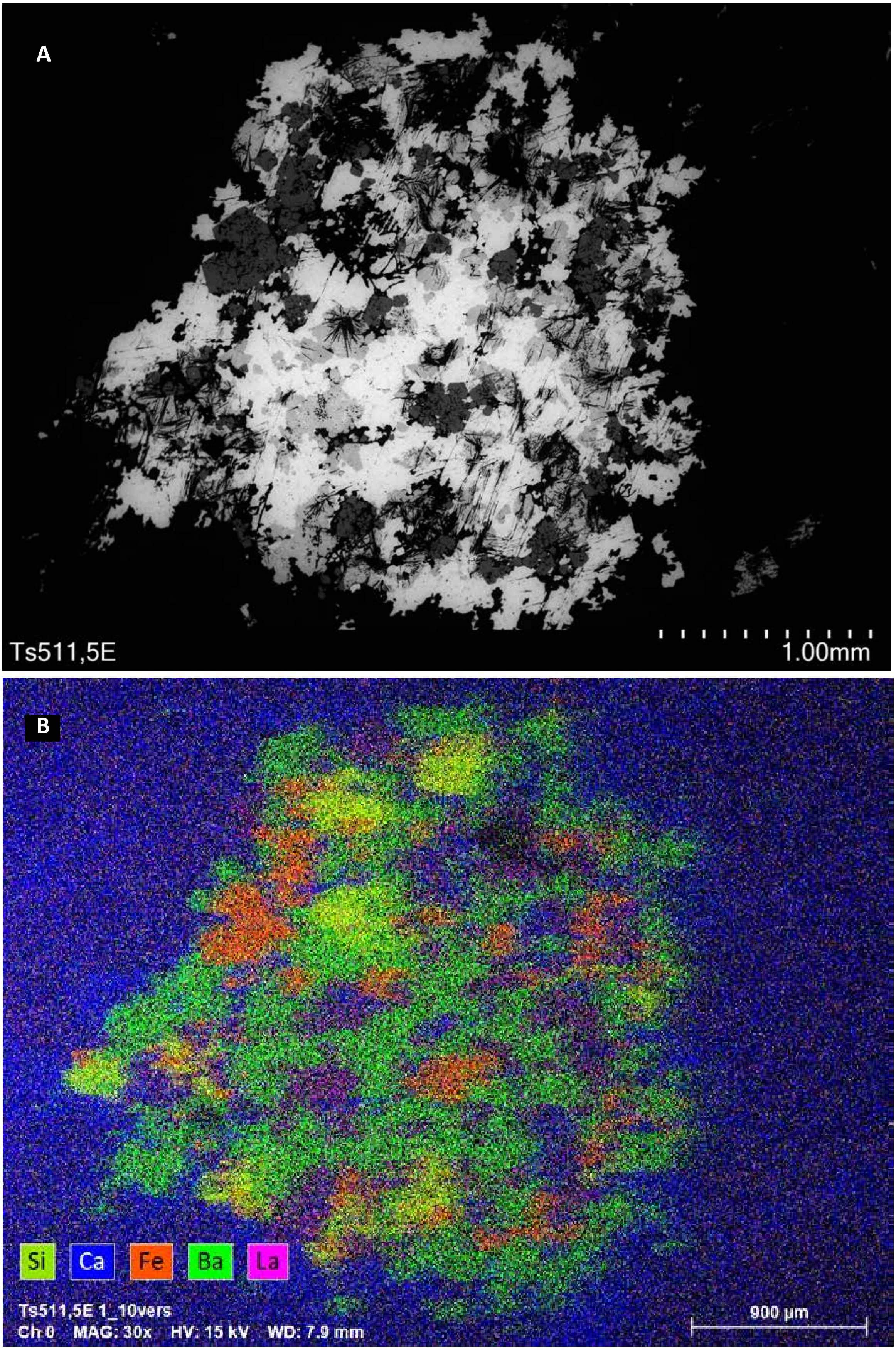
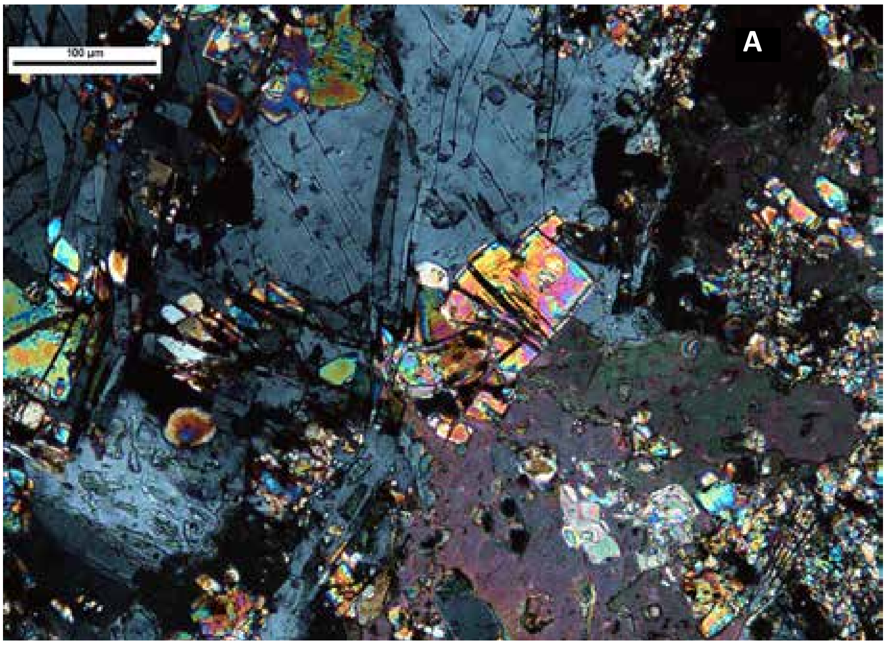


Figure 6.2.2
Ts511.5 E, Tuftestollen.
A. BSI of the REE-mineral-bearing domain shown in figures 6.2.1 C and D. Fe-Dol makes up most of the host (black). Within the domain the lightest colored minerals are Brt (brightest) and RFC.

B. EDX of the same domain as in A. This mapping shows that this domain consists of numerous tiny RFC-grains (La), which together with Mag (Fe) is embedded in a host consisting of Brt (Ba) and Qz (Si). The mineral hosting the domain is Fe-Dol (Ca).

Figure 6.2.3
Ts 511.5E, Tuftestollen

A. *Detail of a domain similar to the one described in figure 6.2.2. RFC-crystals (high interference colours) are poikilitically enclosed in Brt and Fe-Dol. PM-TL-XP.*



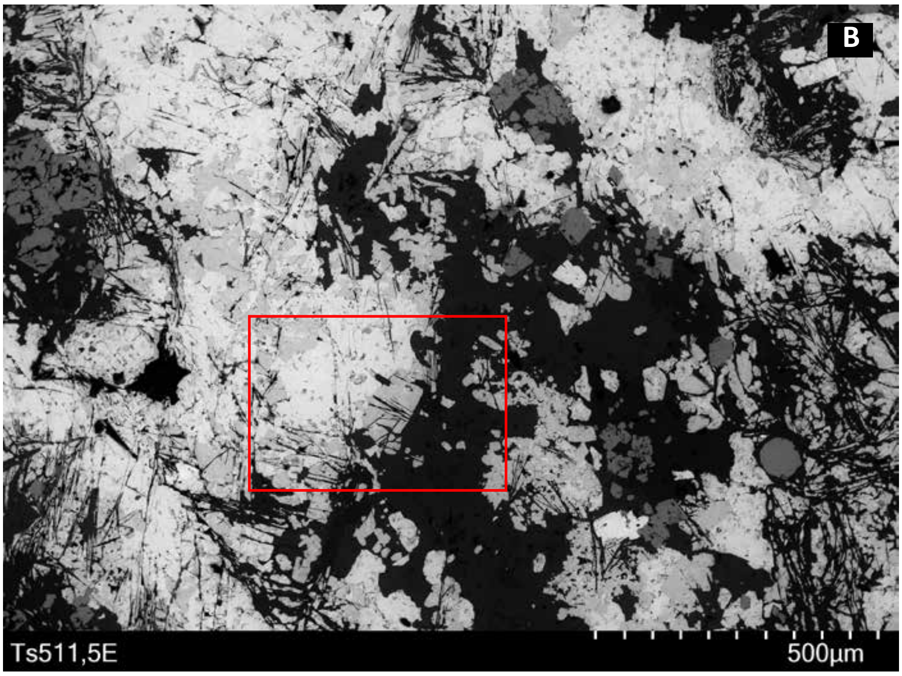
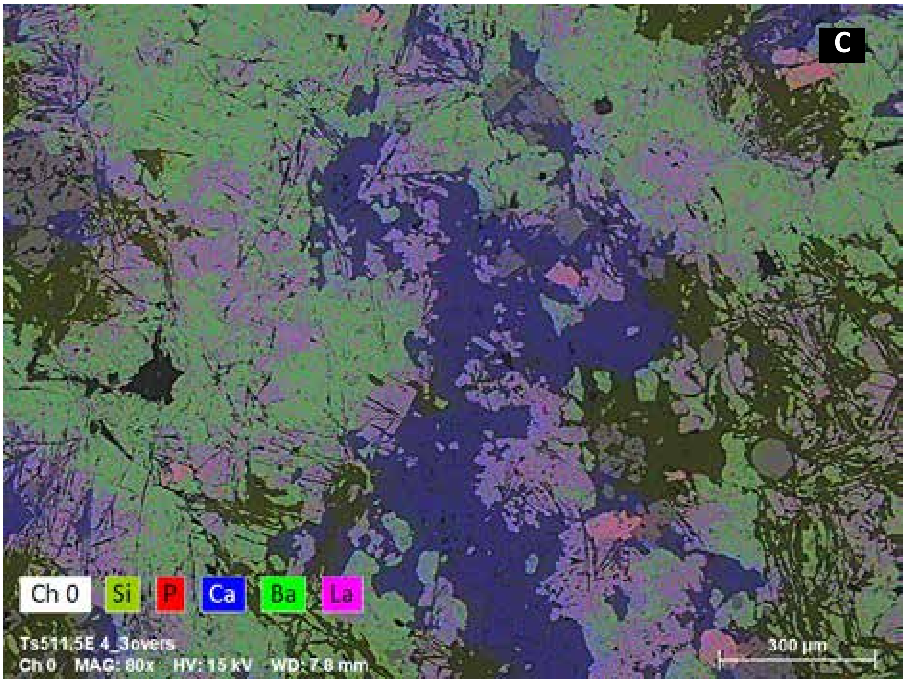
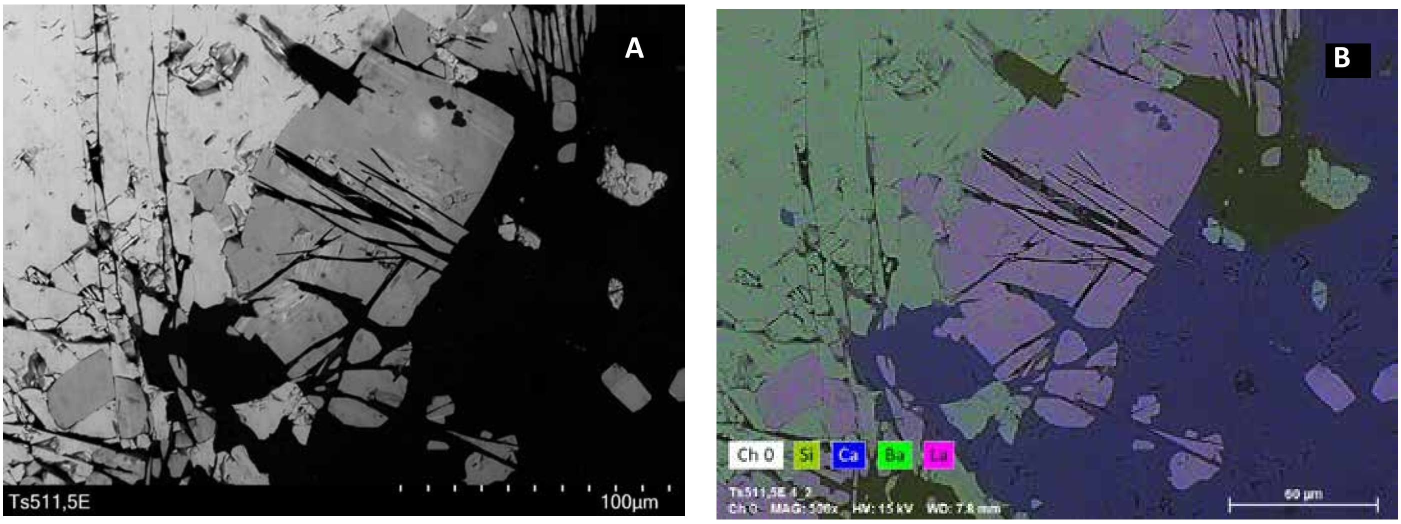


Figure 6.2.3
Ts511.5 E, Tuftestollen

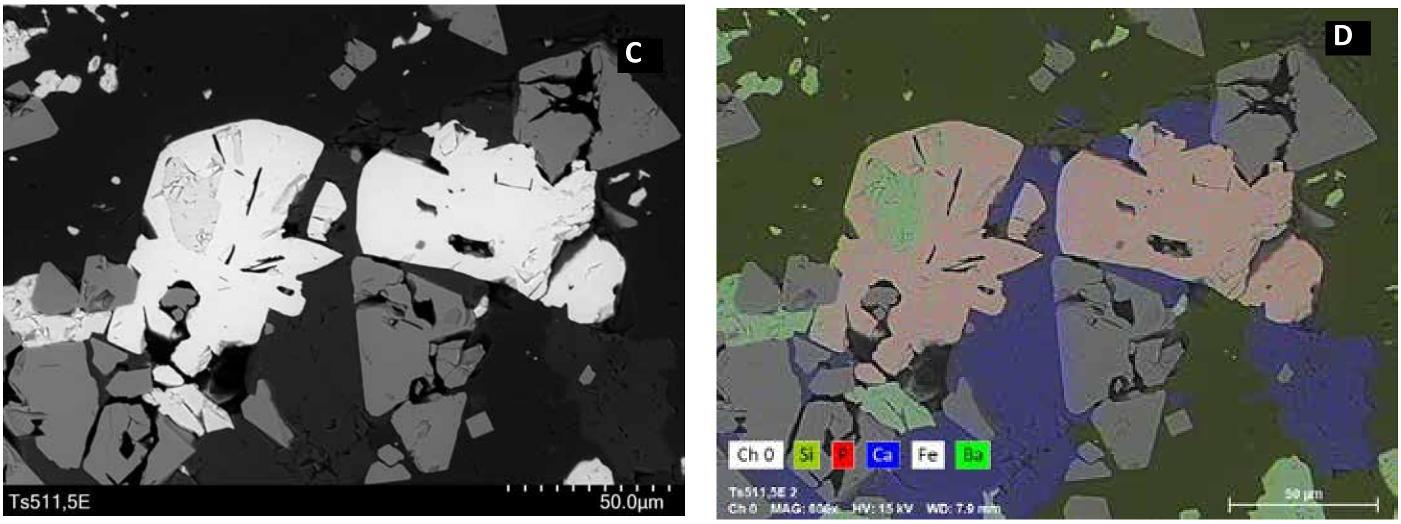
B. *BSI including the area shown in A (rectangle).*



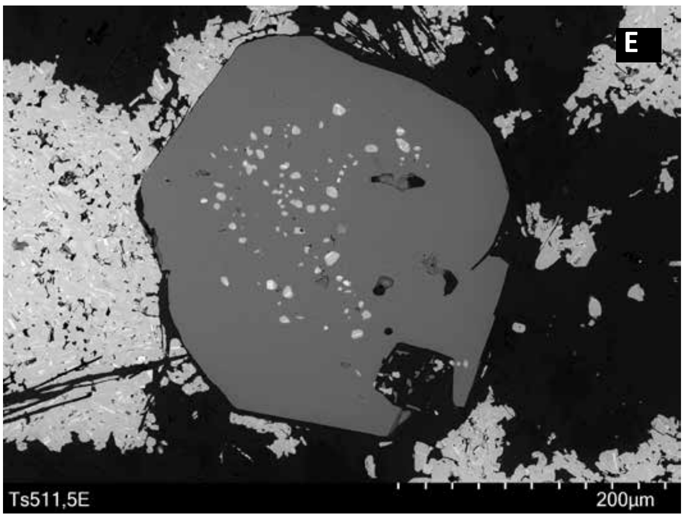
C. *EDX elemental map of the area shown in B. This shows that the RFC minerals (La) are enclosed both within Brt (Ba) and Fe-Dol grains (Ca). Qz (Si appear very dark with a yellowish tint) also occur as small grains scattered around in the domain. In this domain RFC (La) is more common than Mnz (P).*



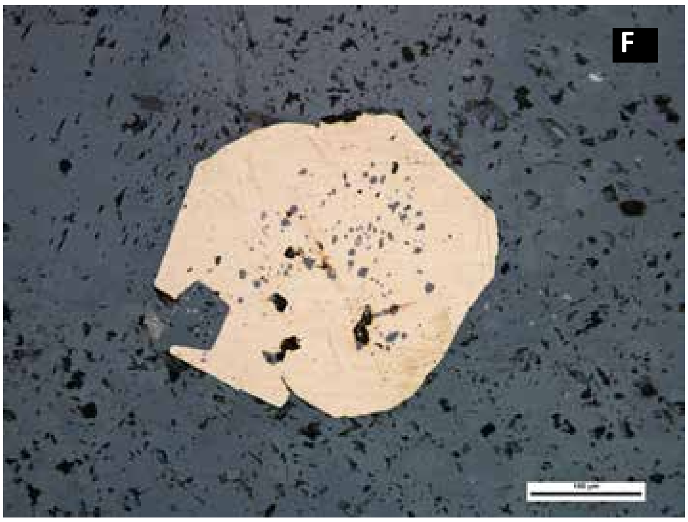
A. and B.
*BSI of the RFC-crystal (the same as in figure 6.2.3 a, b, c) shown in figure **A,** and the corresponding EDX-map (**B**). The RFC crystal (La) is about 70 micro-meter wide and slightly more than 100 micro-meter long. This is typical of the biggest single REF-crystals in these domains.*



***C.** (BSI) and **D**. EDX) Mnz-crystals (P), Mag (Fe) and Qz (Si) grains hosted by Brt (Ba) and Cal (Ca). Largest dimension of the Mnz-grains is 70 micro-meter.*



***E**. BSI of Py crystal surrounded by RFC crystal aggregates (bright) and Fe-Dol (dark). The inclusions within the Py are RFC.*



***F.** RL image of the same Py crystal as in E.*

Figure 6.2.4
Ts511.5E, Tuftestollen

Figure 6.2.5
REE-mineral-bearing domain from FDC in the shallow drill-core SØVE-E2 50.83

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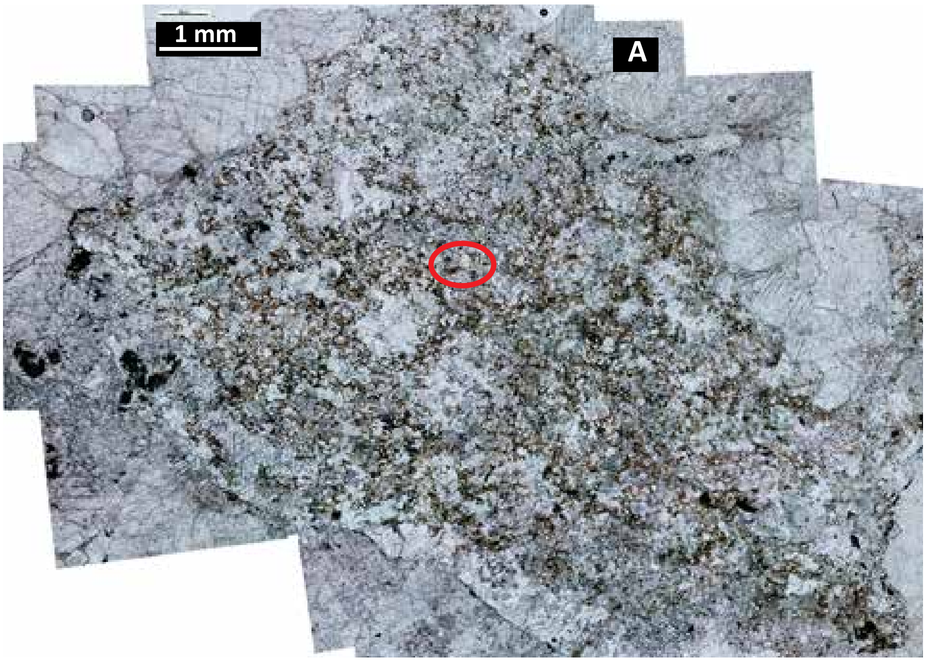
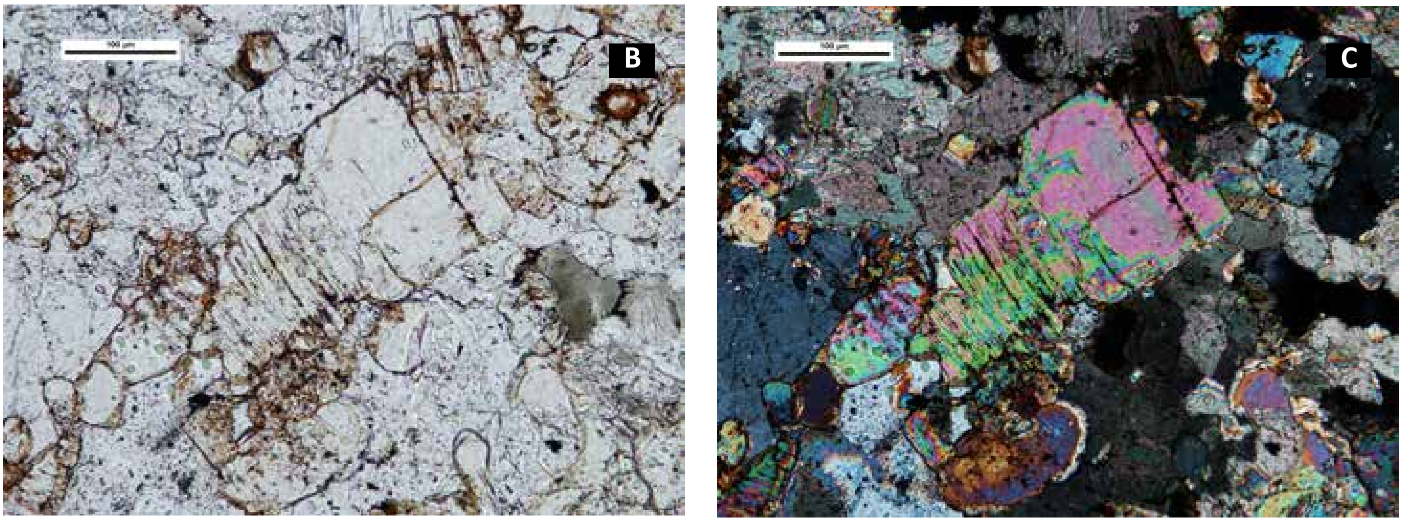
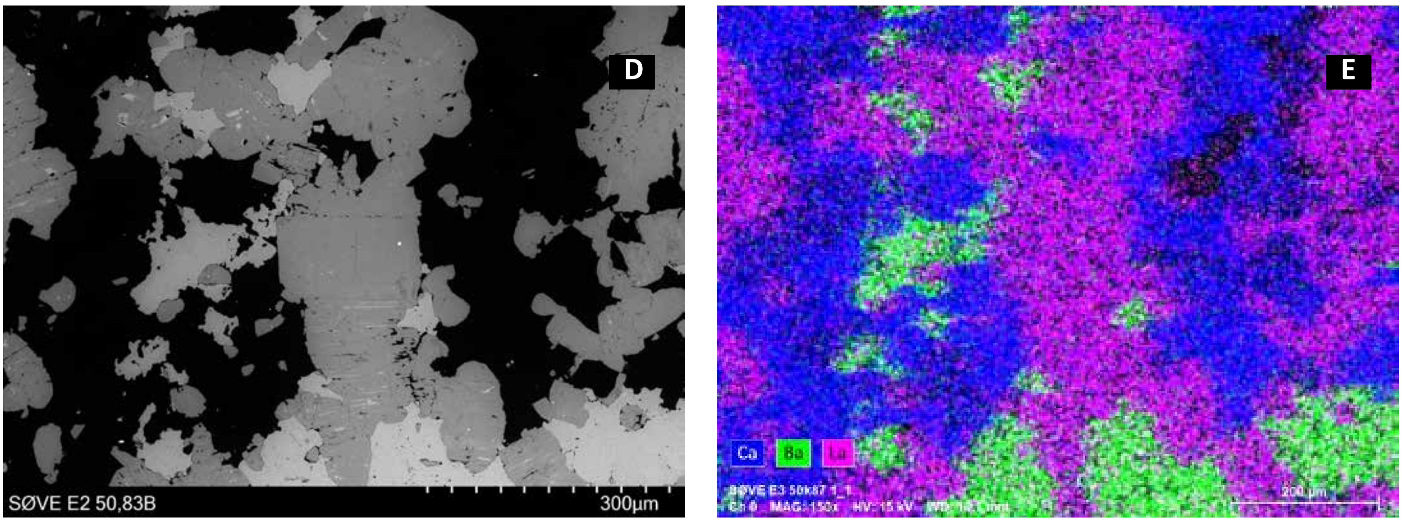
***A**. Photo-mosaic (PM-TL) of a REE-mineral-bearing domain measuring about 6 x 10 mm. The REE-minerals are seen as numerous, tiny slightly beige-coloured crystals. The RFC-crystals within this domain are very little altered.*
The crystals within the area limited by the red oval are displayed in the images B to E.



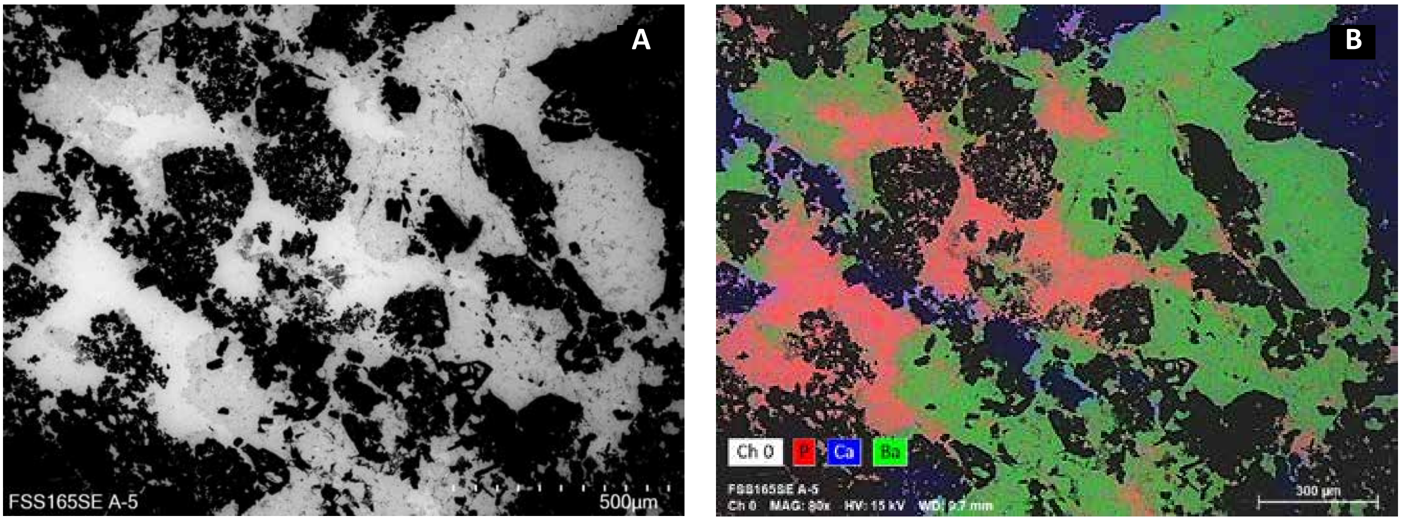


***B.** PM-TL image and **C**. PM-TL-XP image of one of the RFC crystals within the red oval in A. Single RFC crystals measure up to 200 micro-meter in length.*

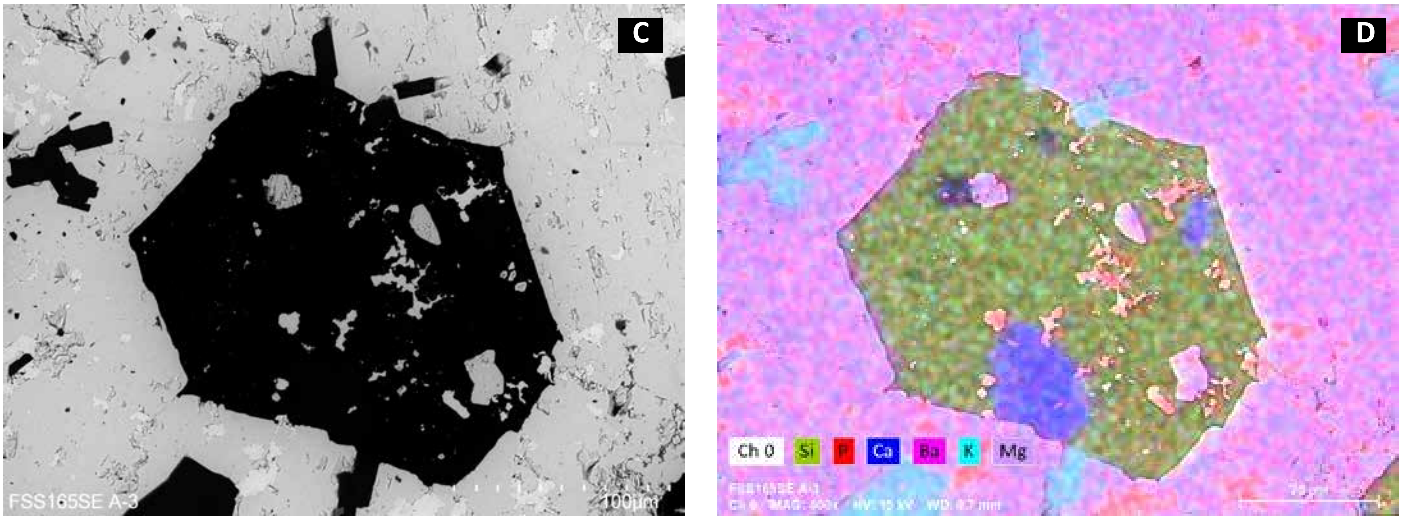


***D** (BSI) and **E** (EDX) of the same crystal as in B and C (though about 45 degrees rotated). The EDX-map in E shows that the RFC crystals are hosted by Fe-Dol (Ca) and Brt (Ba). Black domains in the EDX-map are Bt/Chl.*

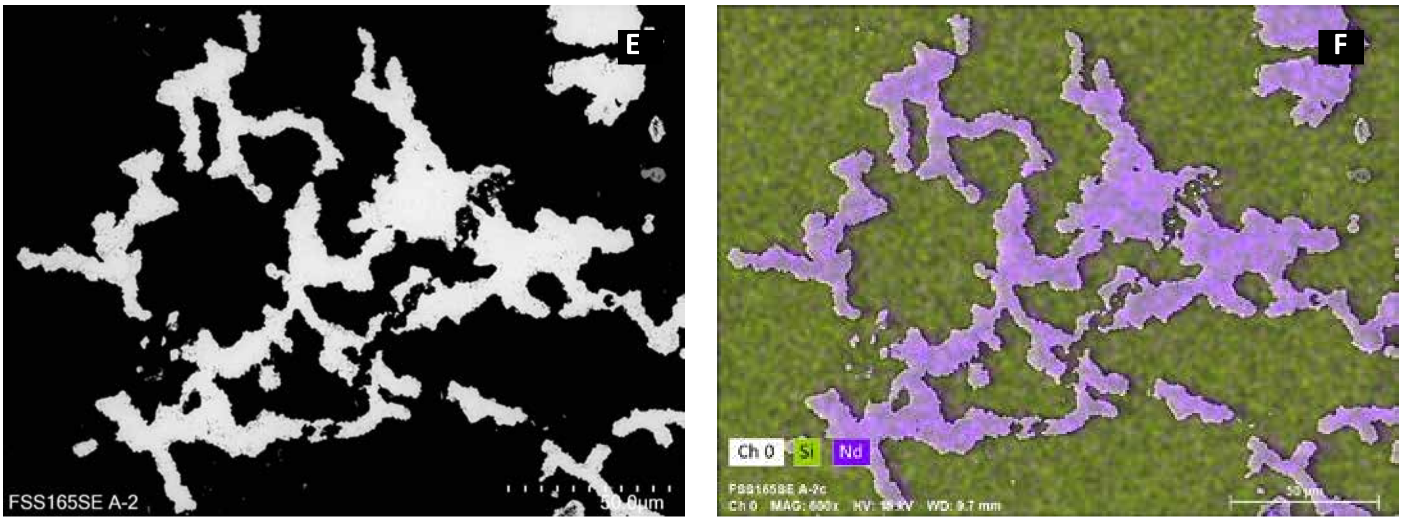
Figure 6.2.5
SØVE-E2 50.83 drill-core



A. *BSI with corresponding EDX,* ***B***. *Qz crystals appear black in both images, and the Qz crystals appear to be sieved euhedral crystals. They are hosted by Mnz (P) and Brt (Ba).*



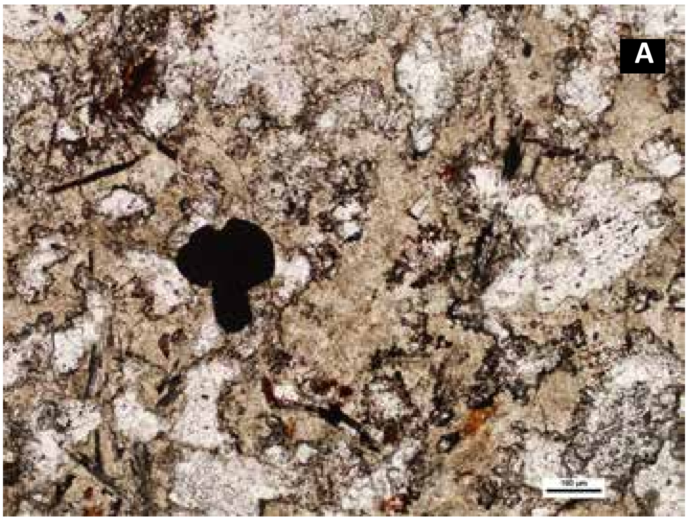
C. *A BSI of a Qz crystal with corresponding EDX (***D***). The Qz (Si) crystal, clearly euhedral, contains inclusions of Mnz (P), Fe-Dol (Ca and Mg) . Bt (K on EDX and black on BSI) and the Qz crystals are totally enclosed by Brt containg a few tiny grains of Mnz (P).*



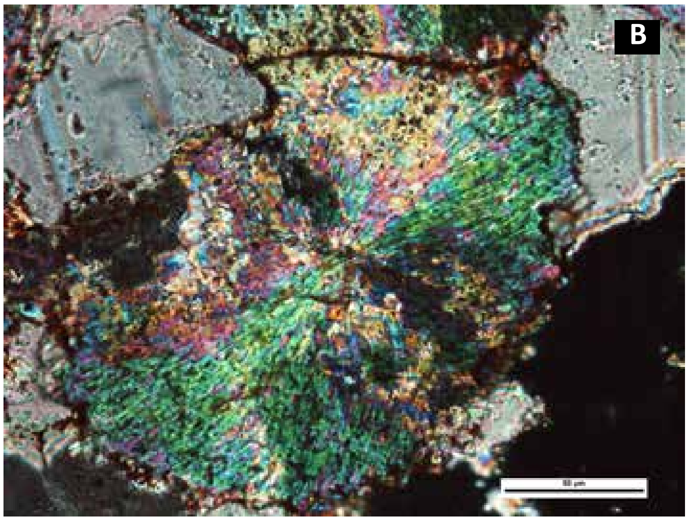
E *(BSI) and* ***F*** *(EDX) of a Qz domain measuring a few mm (Si). In this mineralization “worm-like” Mnz (Nd) is enclosed by Qz.*

Figure 6.2.6
FSS 165 SE, Fen Skole Stoll
REE-mineral-bearing domain from the Fen Iron Mines

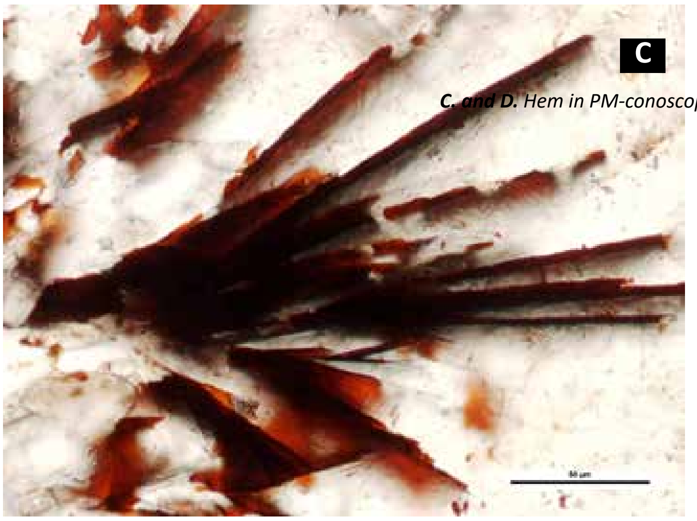
6.2 Petrography of the REE mineralization in the FDC unit



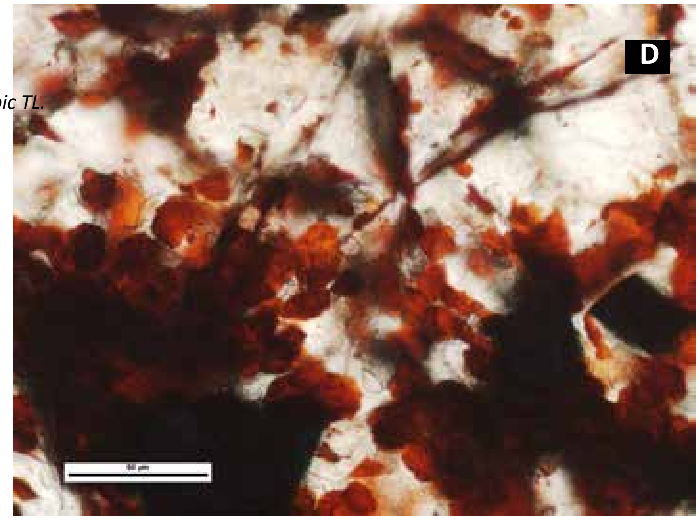
A. *The REE minerals appear as light brown masses with few distinct mineral grains PM-TL.*



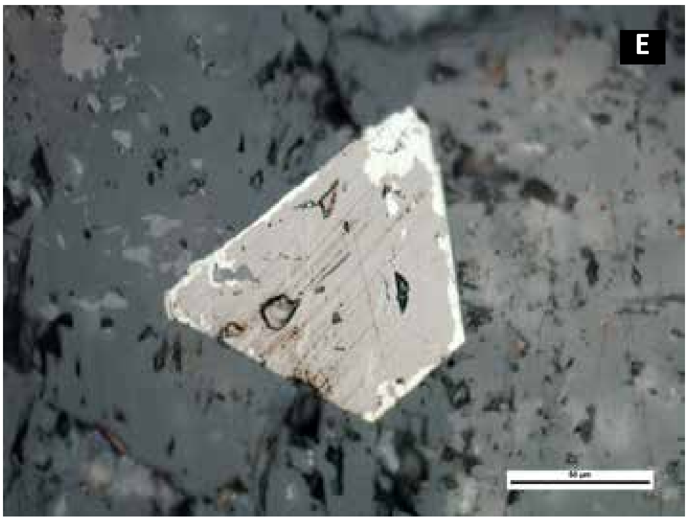
B. *Radiating RFC-crystals measuring 150-200 micro-meter. PM-TL-XP.*



C. and D. *Hem in PM-conoscopic TL.*



C. and D. *Hem in PM-conoscopic TL.*



E. *Mag crystal with Hem rim. PM-RL.*

Figure 6.2.7
Ts511E 3m, Tuftestollen
Slightly hematitized REE-mineral domain, Tuftestollen.

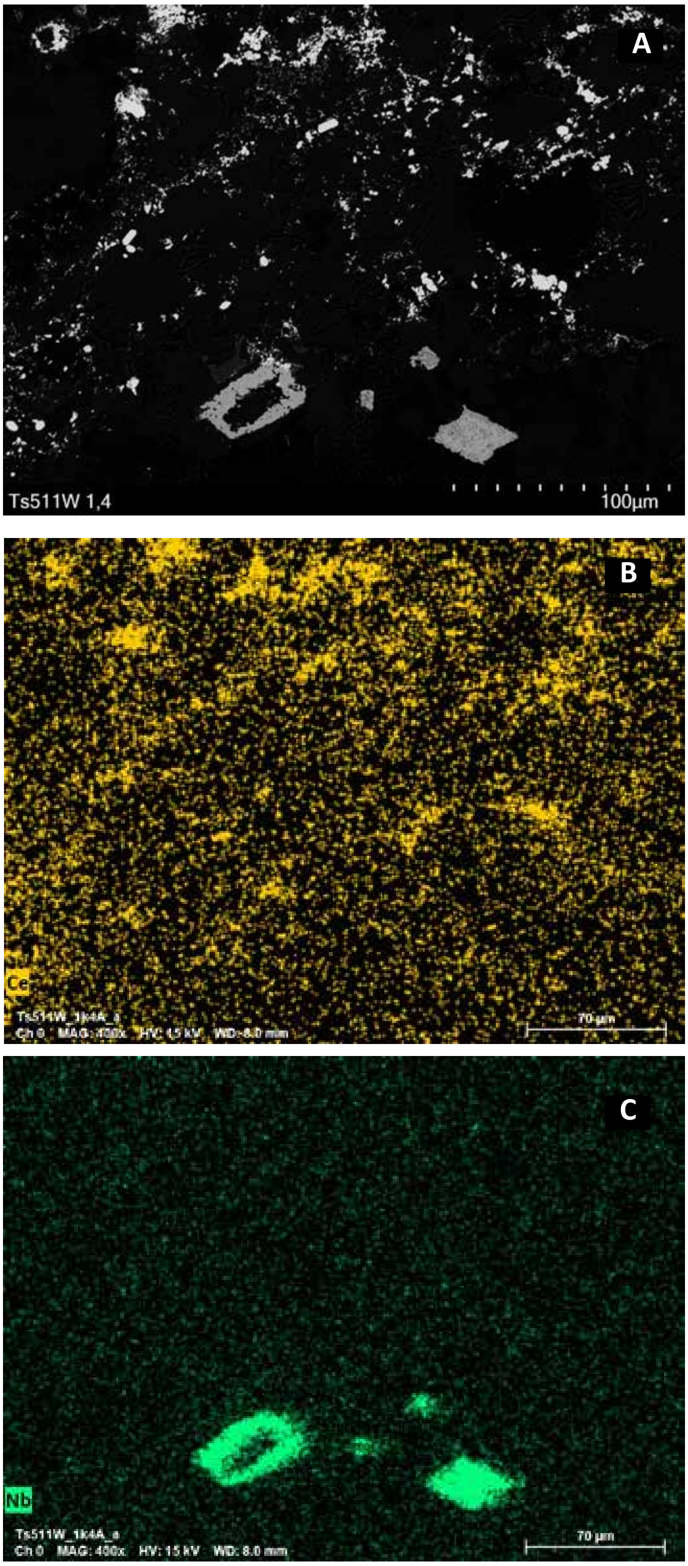


Figure 6.2.8
Ts511E 1.4m, Tuftestollen ▲

REE minerals "outside" the domains.

A. *REE-minerals (BSI) appear as numerous, tiny, dispersed, very bright spots in a dark matrix of Fe-Dol*

B. *EDX -map (Ce, yellow) of the same image as in A.*

C. *Not so bright minerals in the lower part of A are Nb-mineral grains, probably Cmb.*

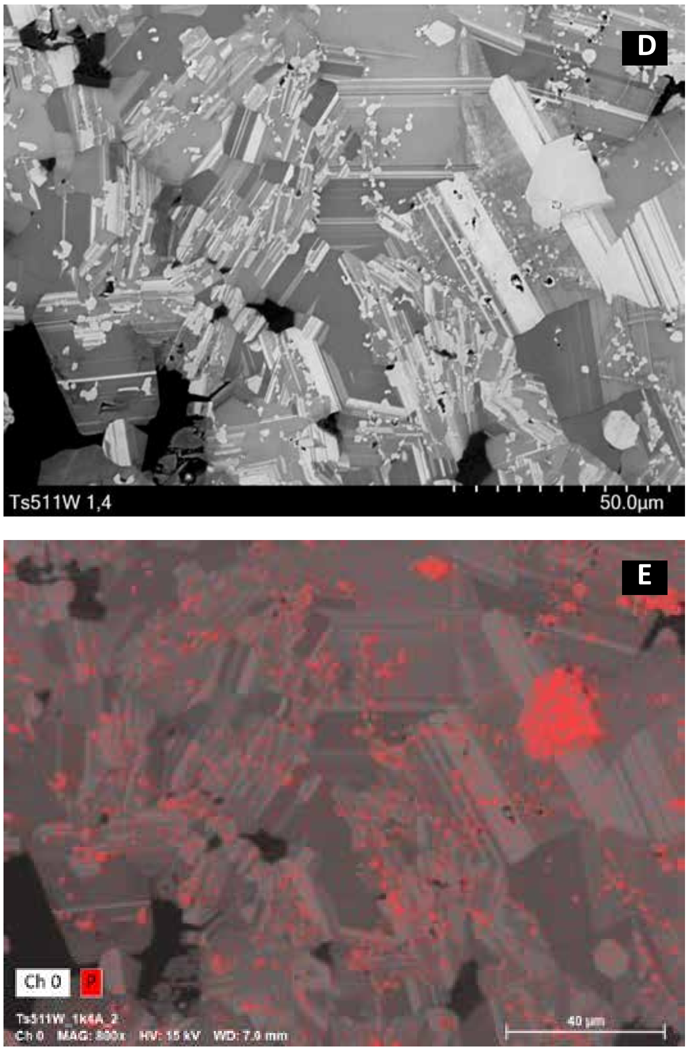


Figure 6.2.8, contd.
Ts511E 1.4m, Tuftestollen ▲

D and E. *D = BSI of "Massive" aggregate of RFC and Mnz crystals. E = EDX where Mnz appear as P (red).*

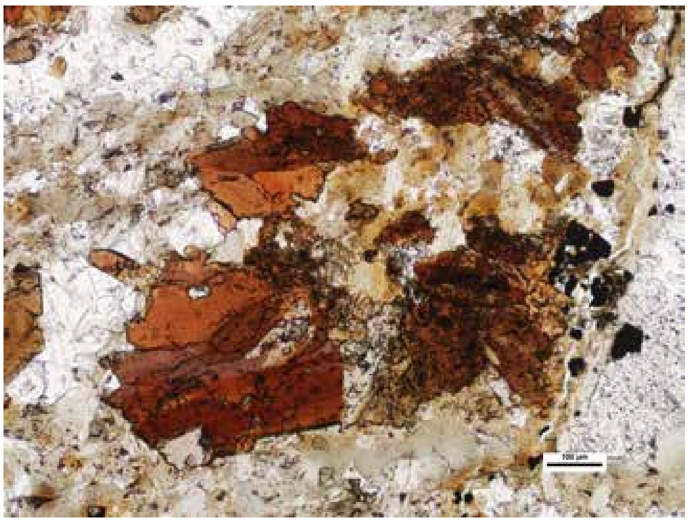


Figure 6.2.9
TOR-2
Allanite, the large brown mineral on this image (PM-TL), is commonly found in minor/trace amounts in the mineralization. Only one analysis of this mineral from Fen exists (Andersen 1986) and shows a content of 27% REE_2O_3.

6.2 Petrography of the REE mineralization in the FDC unit

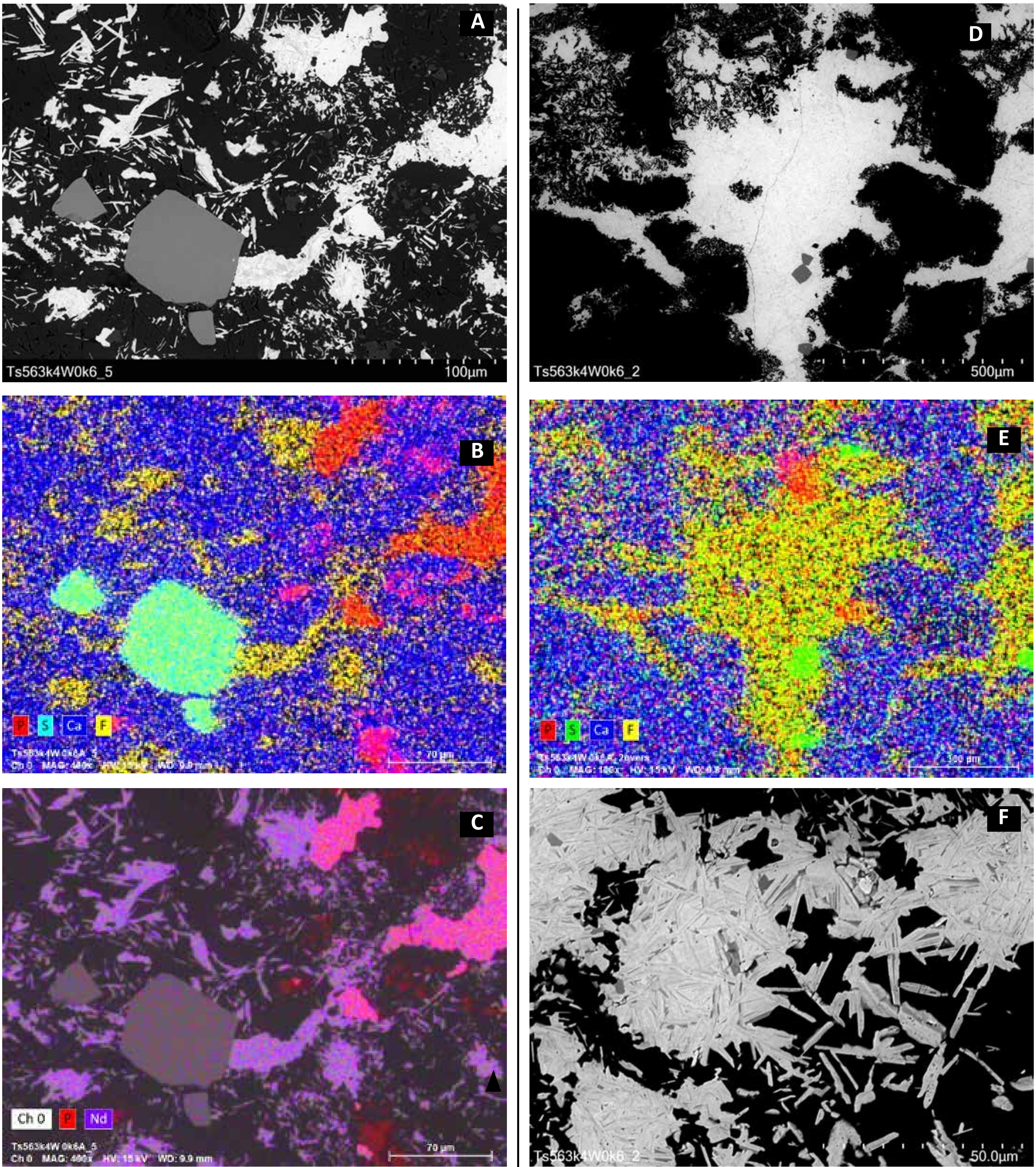


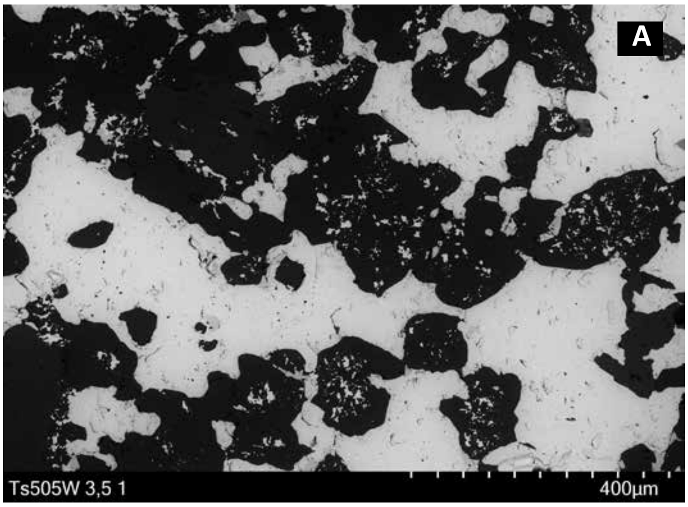
Figure 6.2.10
Ts563.4W 0.6m A, Tuftestollen ▲

A. *(BSI) and* ***B*** *and* ***C*** *(both EDX) from a mineralization where domains are not so prominent. Mnz (P in image B and C) and RFC (F in image B and Nd in image C) in a matrix of Cal (Ca). Large euhedral crystals are Py (S).*

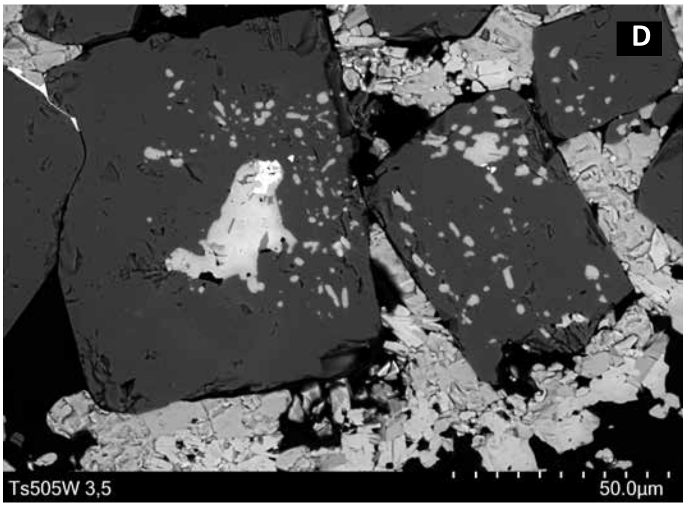
▲

D. and E*. RFC (F) with some crystals of Mnz (P) and Brt (S) in Cal (Ca). The RFC domain measures about 1 mm.*

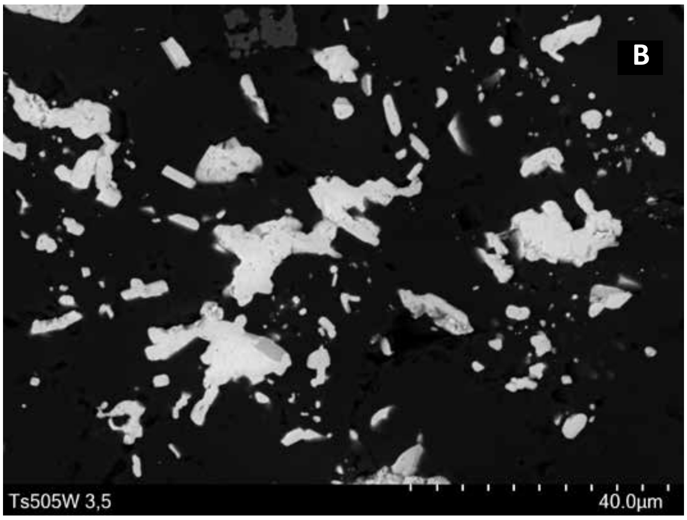
F. *BSI of RFC crystals (bright) in a Cal matrix (black).*



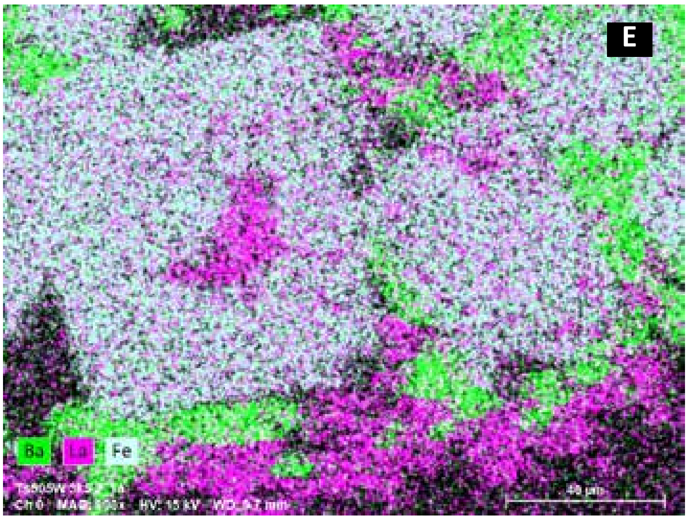
A. *BSI of RFC (bright) and Qz (black).*



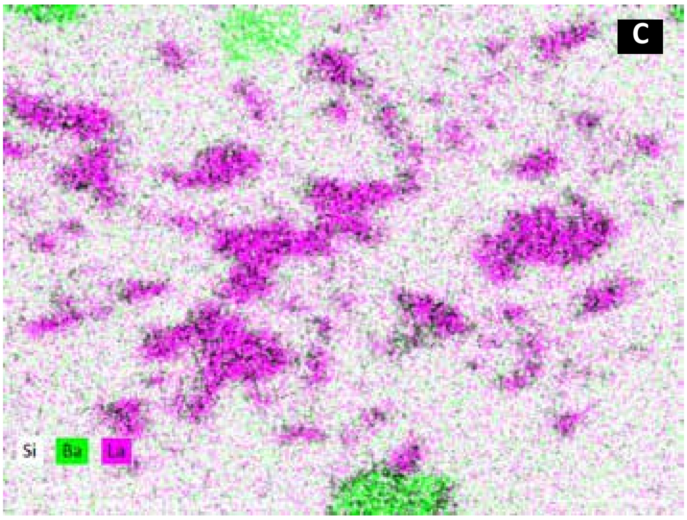
D. *BSI of Py crystals with inclusions. The largest inclusion in the Py contains a tiny, very bright spot of Thr. See image F.*



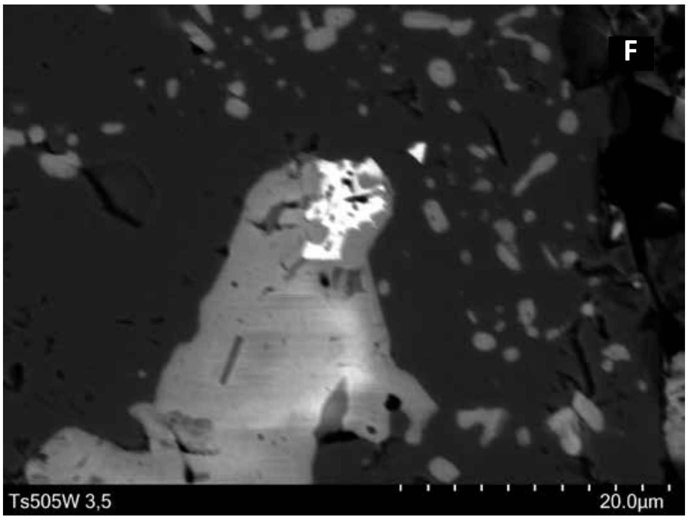
B. *Detail (BSI) of a Qz from A. The Qz has numerous, tiny, bright inclusions.*



E. *EDX of the area corresponding to D. The Py crystals (Fe) hosts inclusions of RFC (La). Brt and RFC also occur outside the Py crystals.*

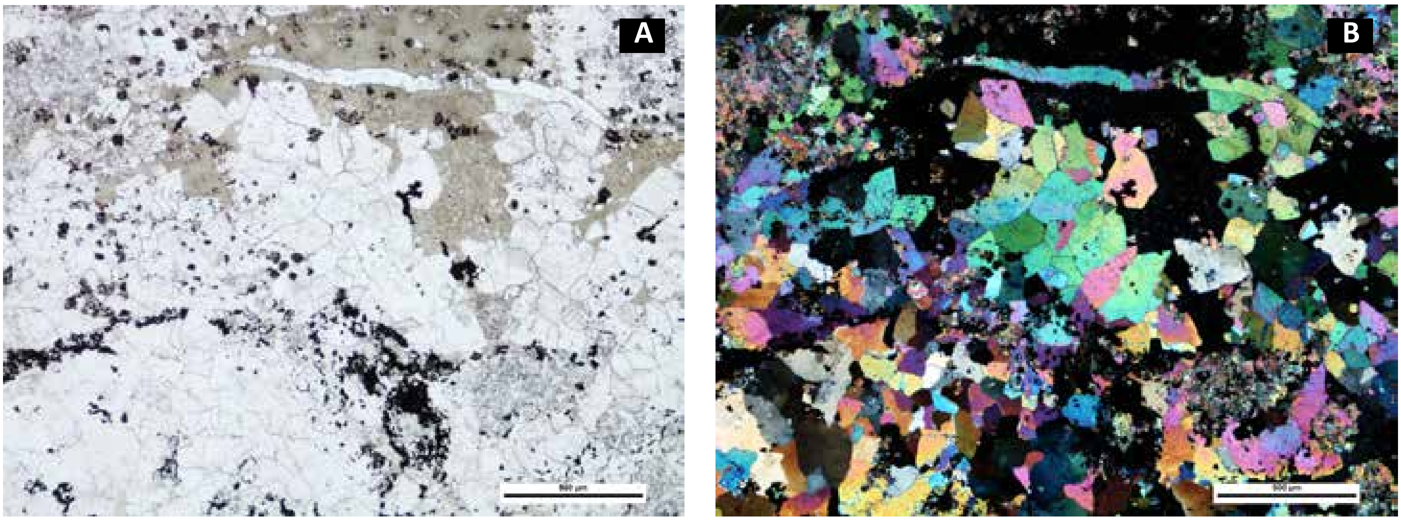


C. *EDX of the same area as B showing that the inclusions in Qz (Si) are RFC (La) and Brt (Ba)*

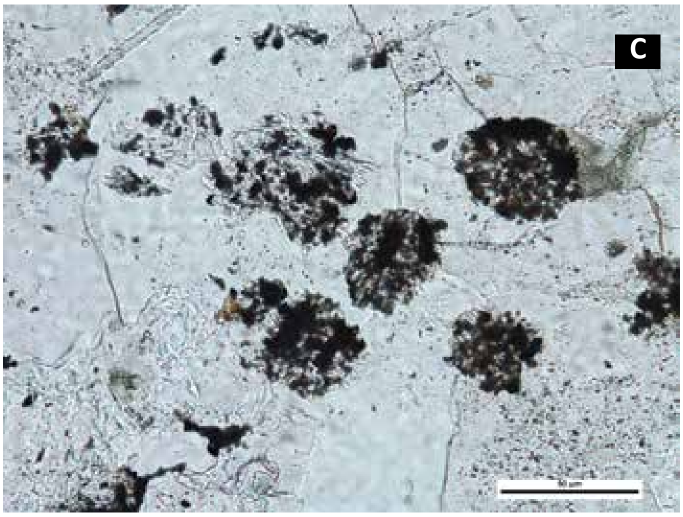


F. *BSI showing a bright area in the biggest inclusion in Py in image D. This is Thr.*

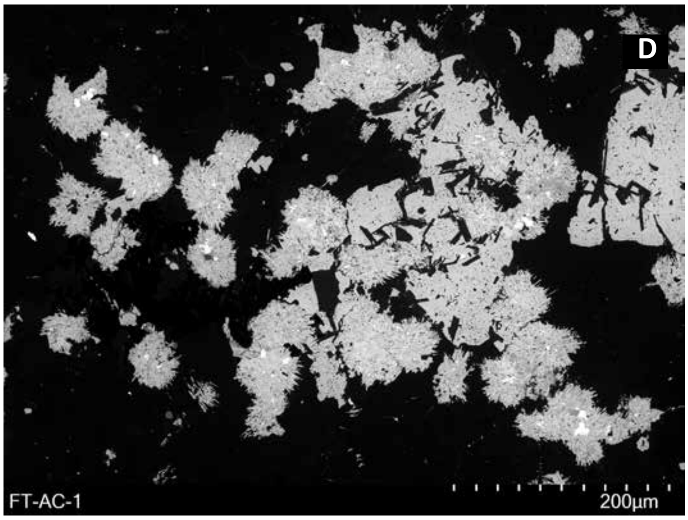
Figure 6.2.11
Ts505W 3.5m, Tuftestollen



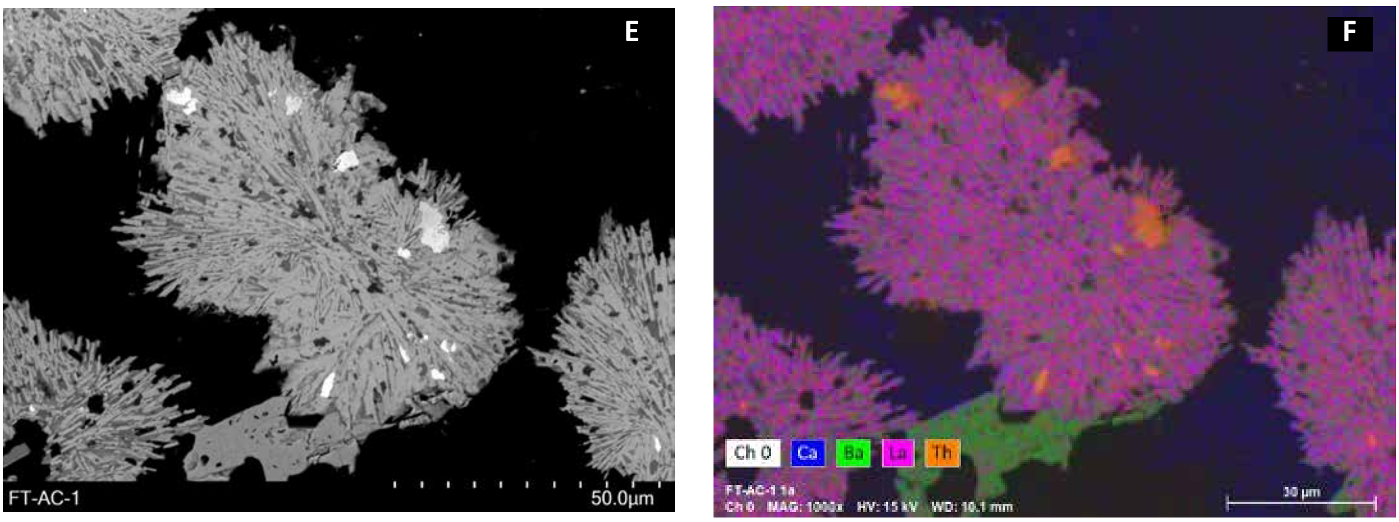
A. and B. *PM-TL and PM-TL-XP images of FDC texture. Light colored minerals in A are Fe-Dol, and the green mineral in the upper part of the image is Chl. Opaques are Fe-oxides mixed with RFC. The Fe-Dol in image B has a recrystallized and "metamorphic" texture.*



C*. PM-TL image of radiate RFC crystal aggregates mixed with Fe-oxides.*

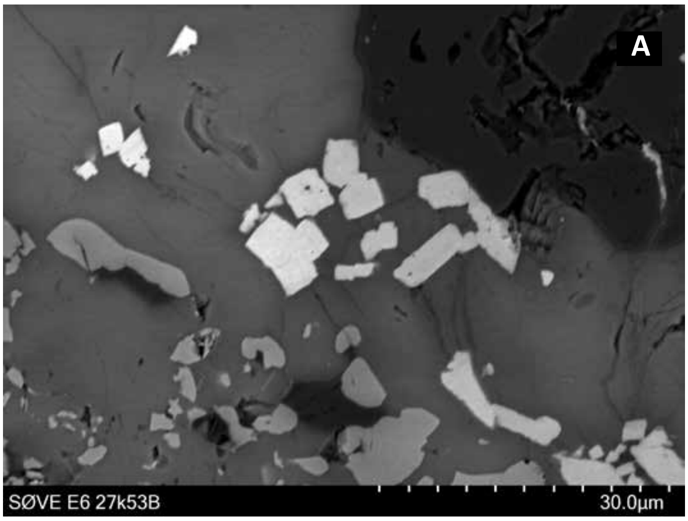


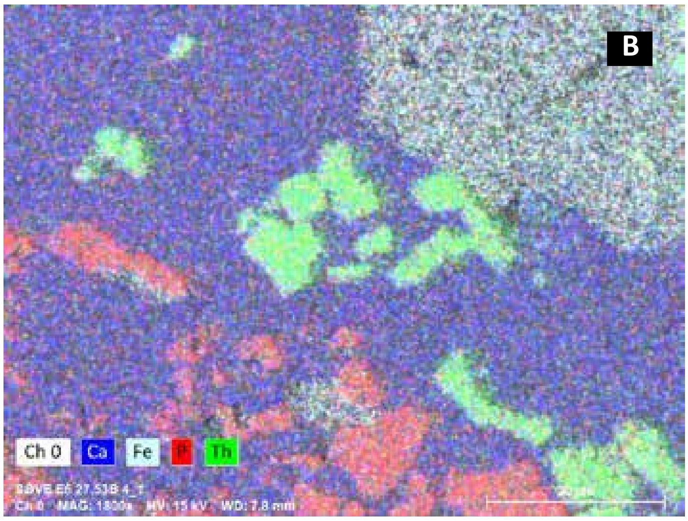
D*. BSI of radiating RFC crystals*



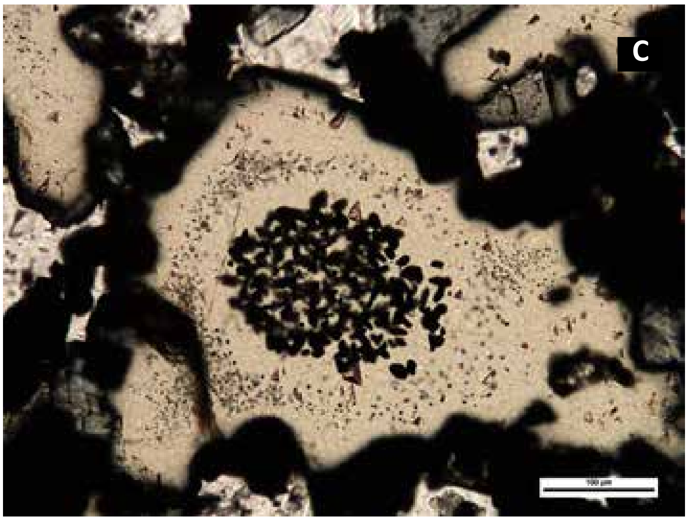
E. *(BSI) and* ***F.*** *(EDX) of radiate crystal aggregates of RFC (La) with Thr (Th) inclusions. Fe-Dol matrix (Ca) appear black. Brt (Ba) is also a common phase at this locality.*

Figure 6.2.12
FT-AC-1, the Fen Iron Mines, surface sample N of Karup mine

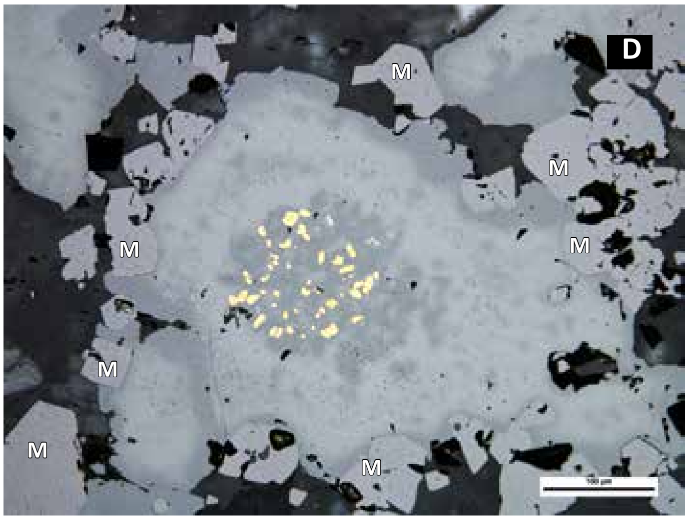




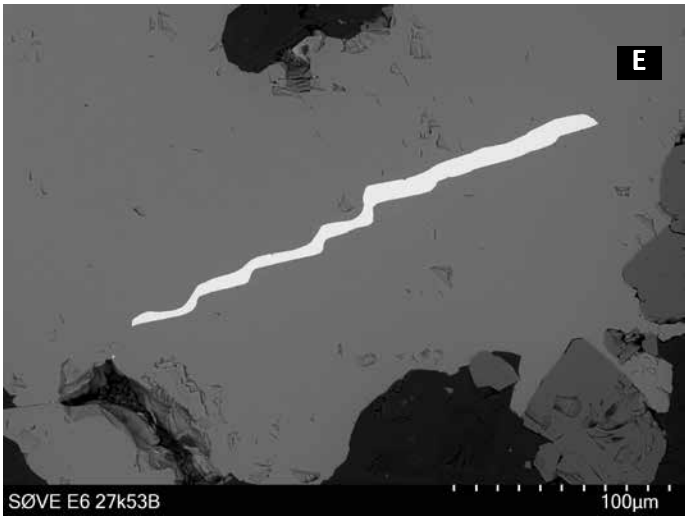
A. *BSI and* ***B****. EDX of euhedral Thr (Th), coexisting with Ap (P), Mag (Fe) and Cal (Ca).*



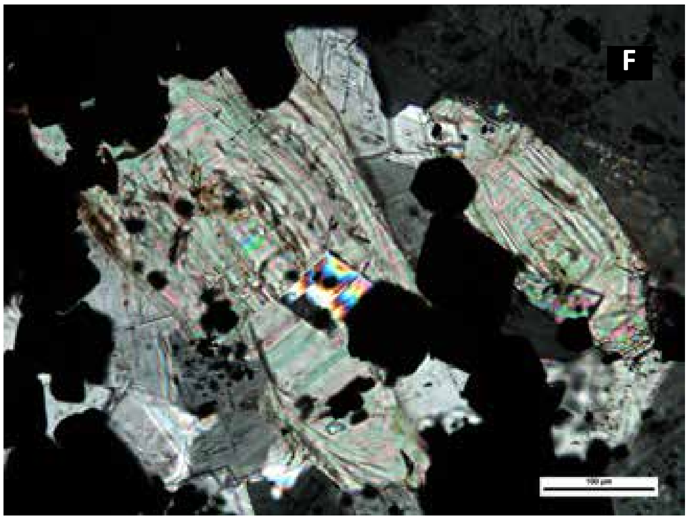
C. *TL image of Sl (yellow) with inclusions of Cpy (opaques in the centre). Other opaques rimming the Sl is Mag,*



D. *RL image of the same as in C (M = Mag; only a few grains labelled).*



E*. Elongate, bright Gl hosted by Sl (BSI).*



F. *Zoned RFC crystal surrounded by Mag (opaque). This and other RFC crystals in this sample are up to 0.5 mm.*

Figure 6.2.13
SØVE-E6 27.53B, Shallow drill-core east of Søve

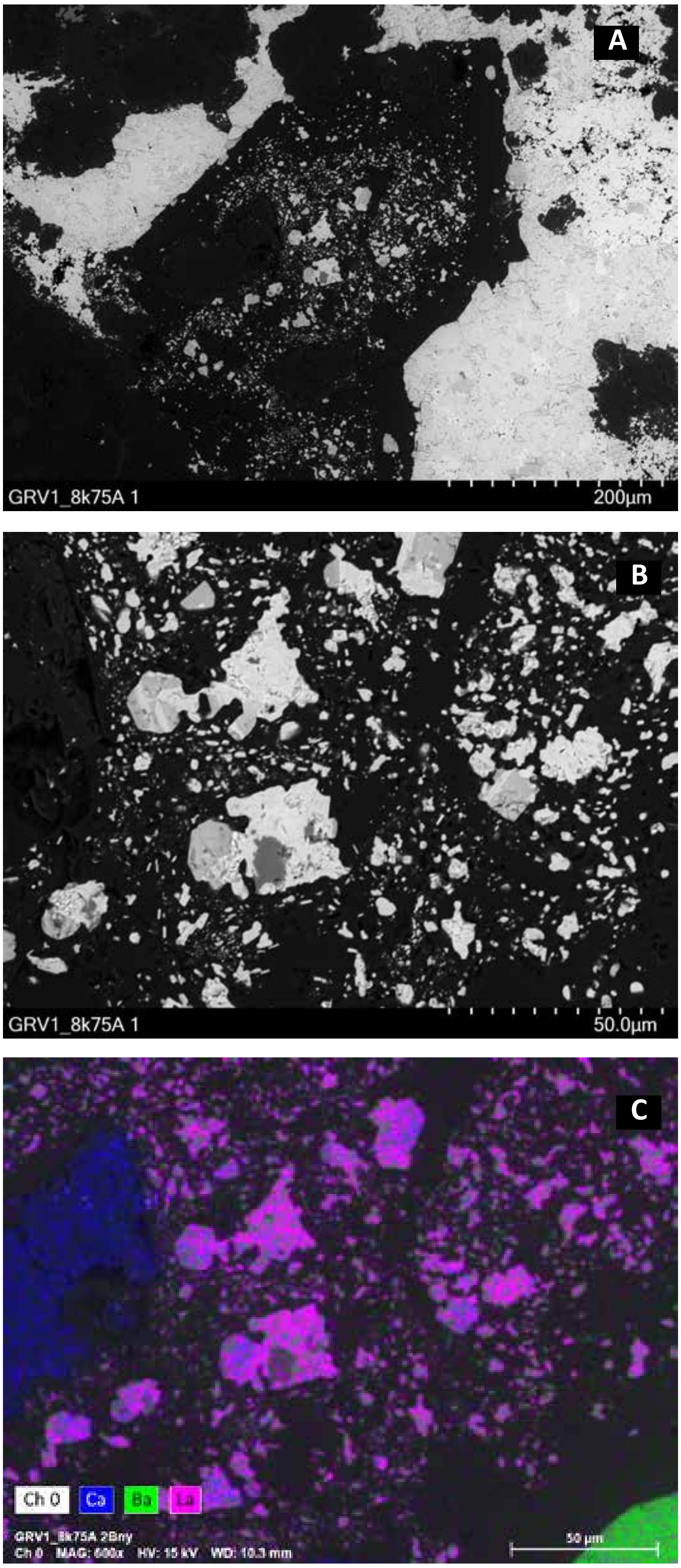


Figure 6.2.14 ▲
GRV-1 8.75, shallow drill-core, Grønvoldvegen, Skippervoll

A. *BSI of euhedral Qz (black) with numerous inclusions and hosted by a mixture of Brt and RFC (both bright)*
B. *Detail of Qz with inclusions (BSI)*
C. *EDX of same as B. Inclusions in Qz are Fe-Dol (Ca) and RFC (La). The Brt (Ba) occur outside the euhedral Qz crystal.*

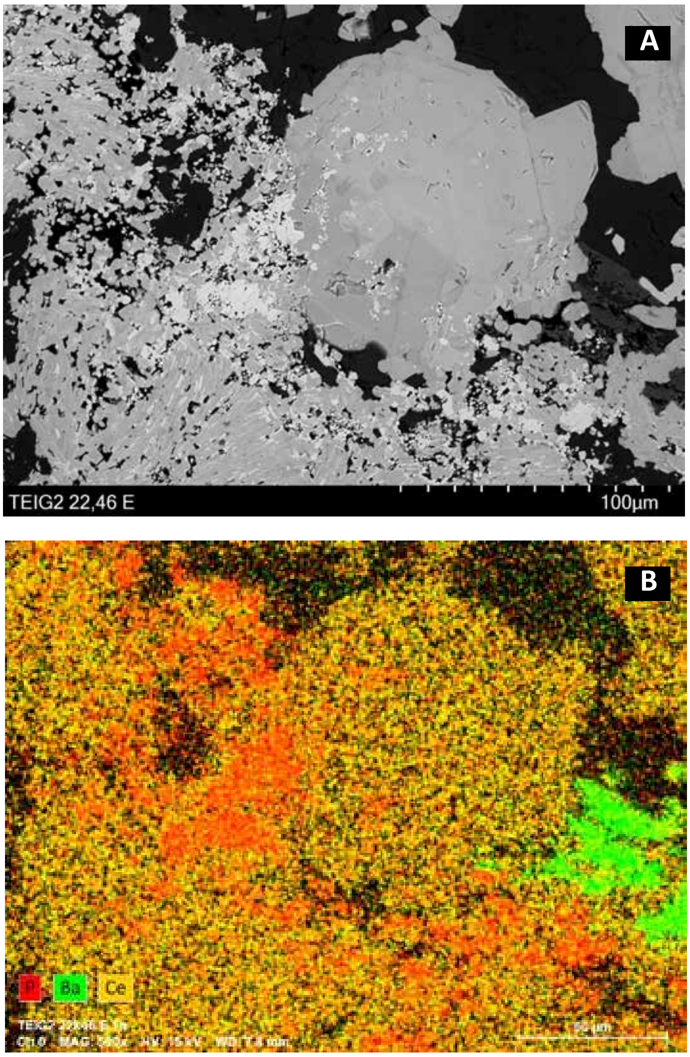


Figure 6.2.15 ▲
TEIG-2 22.46 E, shallow drill-core, Teigens property Fen Nordre, Central Fen area
A. *BSI and* ***B****. EDX images of two generations of RFC (Ce), mixed with Mnz (P), and Brt (Ba).*

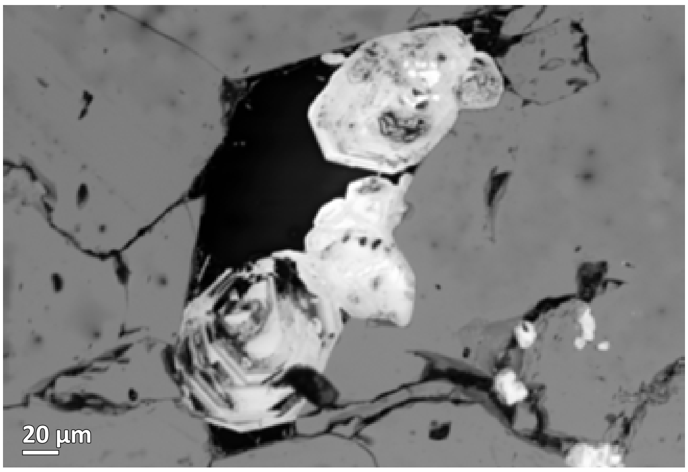
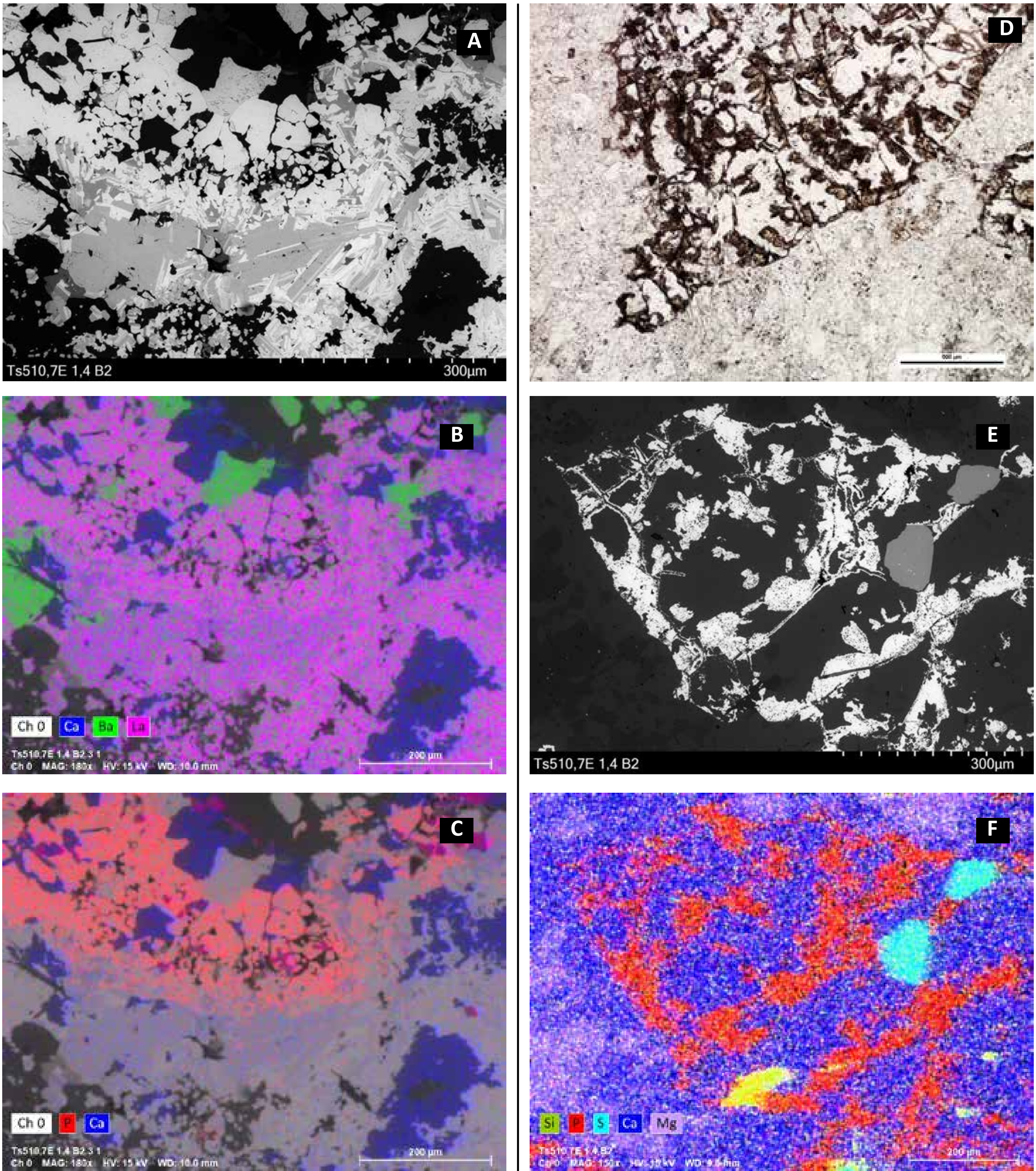


Figure 6.2.16
Ts530W, Tuftestollen

Zoned RFC crystals i(bright) n a vug (black) within Py (gray) from the Mag-Py-REE vein in figure 5.4.1h.



RFC and Mnz relationship

A. *(BSI),* ***B.*** *(EDX) and* ***C*** *(EDX) of the same area. Bright minerals are Brt (Ba in B), Mnz (P, red) in C, and RFC is the violet part in B (La) not being Mnz (red, P) in C.*

D. *PL image of "net-veined" Cal in a Fe-Dol host.*

E. *BSI of the net-veined Cal. The bright net-work is "secondary".*

F. *EDX map shows that Mnz has precipitated on fractures in Cal (Ca), but not in Fe-Dol (Mg). Py (S) and Qz (Si, appears yellow) are minor components.*

Figure 6.2.16
Ts510.7 1.4m, Tuftestollen

A precise understanding of the mineralogy is of fundamental importance in an effort to develop and to mine a mineral deposit. This is especially important for such unusual and multi-element minerals as the REE minerals. In the preceding pages some of the major mineralogical aspects of the REE- mineralization within the Fen FDC unit were documented. Some implications are summarized here.

Dolomite, calcite and chlorite/biotite
The bulk part of the mineralized FDC-rocks consist of Fe-Dolomite and Calcite. Chlorite / biotite may locally be very abundant within the "barren" FDC's, but these minerals appear to be present in only minor quantities within the REE-mineralization.

REE-mineral-bearing domains
The REE minerals have a tendency to cluster into aggregates up to a few cm in size. Most of the REE-mineral crystals are typically much less than a mm in size. The REE minerals within these aggregates constitute an estimated 20 to 60 % of the aggregate volume.

Major REE minerals
This study confirms earlier studies that the REE-fluoro-carbonates (Parisite-Synchysite and Bastnäsite) and monazite are the main REE-bearing minerals. Allanite occurs only in minor amounts.
The relative abundance of the different REE-minerals varies considerably. Parisite always occurs syntactically intergrown with synchysite. In several of the aggregates inspected these minerals appear to be the most widespread phases. Bastnäsite possibly is less common. However, too few probe analyses are yet available, and too few mineralizations have been studied so far to evaluate their relative abundance. For REE-exploitation bastnäsite is preferred (contains about 75 % REE_2O_3 compared to between ca 51,5 % and ca 61% for synchysite-parisite mixtures). Locally monazite appears to be more common than the REE-fluoro-carbonates. Monazite has a REE_2O_3 content of about 65%. (All the quoted percentages are theoretical contents calculated from ideal formulas and not from real analyses).
A few analyses of the Fen REE-minerals can be found in Dietzel et al. 2019, and in Andersen 1986. Those analyses were made by EMP and do not include all REE. The data suggests that the various REE minerals in the FDC's are synchysite-Ce, parisite-Ce, bastnäsite-Ce and monazite-Ce. The Y_2O_3 contents varies between the REE minerals: Mnz <0.02%, Bsn <0.17% and Prs/Syn <0.41% wt, and are usually much less than the highest concentrations. The silicate mineral allanite contains about 27% REE_2O_3, but the subordinate volume of this mineral suggests that it will not contribute very much to the loss of REE during mineral processing. However, the presence of allanite may have some serious effects. See section 10.4.

Micron-scale disseminated REE-minerals
The REE-bearing minerals also occur "outside" the REE-mineral aggregates and are enclosed by carbonate minerals. In some samples the REE-minerals appear to only occur disseminated as tiny grains, or the REE-minerals occur both "within" and "outside" the aggregates. Monazite has also been observed to net-vein calcite on a micro-scale. Such tiny grains may be volumetrically important, but may be very difficult to separate from the host carbonate without total rock leaching.

Inclusions of REE minerals within other mineral phases
The REE-minerals within the domains commonly form numerous micrometer-scale inclusions hosted by Qz and Brt. Qz and Brt are usually major minerals within the REE-bearing mineral domains.

Partition of REE in carbonates and apatite crystal lattices
Rare Earth Elements also partition directly into the crystal lattices of minerals where the REE's are not essential components. No analyses of the REE's in the Fe-Dolomite or calcite of the FDC's have been performed so far. However, the presence of REE in carbonates is observed in carbonatites elsewhere (Chakhmouradian et al. 2016), and has also been demonstrated for calcite from søvites from Fen (Hornig-Kjarsgaard 1998).
Apatite may be especially prone to host REE's, as is shown in carbonatites from elsewhere (Chakhmouradian 2017), and in søvite apatites (Hornig-Kjarsgaard 1998), but analyses of the FDC apatites are lacking so far.

Sulfides
The most common sulfide in the FDC's is pyrite. Pyrite may locally be abundant within some of the REE mineralization, whereas t may be almost absent from certain other mineralizations. Trace amounts of other sulfides are occasionally found: Sphalerite occurs as an accessory, and in some cases it is a minor phase. Accessory pyrrhotite, galena, chalcopyrite and molybdenite have been observed. Some of the pyrite grains contain inclusions of REE minerals. This implies that some REE will be removed during flotation during mineral processing. The content of Co range between 0.05 and 0.59 %, and Ni<0.19%, in 34 micro-probe analyses of pyrite, but most analyses are below detection limit (Dietzel and Kristandt 2018).

Tellurides
Hessite has been observed in one grain (Dietzel and Kristandt 2018).

Barite
Barite is a very common mineral and is frequently closely associated with the REE minerals. Barite a few cm in size have occasionally been observed in some zones in the FDC's, but these zones are rarely enriched in REE minerals.

Fluorite
Fluorite has only been observed in minute grains from the REE mineralization. The masses of fluorite of the type observed in the Lichtloch cross-cut (figure 5.4.2g) and in several drill-cores, is probably not associated directly with the REE mineralization.

Hematite and magnetite
Magnetite is a common mineral in the REE-mineralization. Magnetite grains are often oxidized to hematite. Hematite needles are common in several FDC's as discrete grains which do not show any textural evidence that they formerly were magnetite crystals. In some samples REE-minerals occur as inclusions within the magnetite. This implies that some REE will be lost during magnetic separation of the ores.

Thorite
Thorite occur as minute crystals, typically less than 5 microns in size. The thorite appear to be closely related to the REE minerals. 7 micro-probe analyses of thorite shows a range in Y_2O_3 of 0.16-0.64% wt, and Ce_2O_3 1.91-3.44% wt (Dietzel and Kristandt 2018). Consequently thorite is enriched in HREE.

Other minerals
Tiny niobium-minerals have been observed in a few samples. These are probably columbite (Åmli 1977). Åmli also documented the presence of Nb-rutile. Xenotime has been observed in FDC from Fen by the present author, but is not documented in this report.

7. Recent drill-cores of the FDC-unit, Fen complex
7.1 The drill-cores drilled by the company "REE Minerals".

The company "REE Minerals AS" started exploration in the south-eastern part of the Fen complex in 2011, and conducted core-drilling campaigns in 2012 and 2014. The exploration was performed by the Danish company "21st North". Successful exploration led to discovery of REE-mineralized "rauhaugite type 2" (=FDC in this report) (figure 7.1.1). This was within the same area that Wiik (1982) proposed that "Fenco" should perform extensive REE exploration.

The results from the drilling campaigns and chemical analyses were reported by Lie and Østergaard (2012, 2017). During the drilling-campaigns in 2012 and 2014 a total core length of 2472m was recovered from 14 drill-sites. One drill-core was vertical and reached a depth of 300.2m. All the remaining 13 cores were drilled with a dip of -45°. They varied in length from 32.5m to 267.75m, with an average length of 163m. This implies that the cores drilled at an angle of -45° reached a vertical depth below surface varying between 27.7m and 227.7m, with an average depth of 139m.

The south-eastern Fen boundary.
In the south-east the boundary of the Fen complex is extensively covered by marine clay deposits in the Fensmyra area. The first drilling attempt "REE Minerals" performed in 2012 (DDH-001) was carried out in the northern Fensmyra area with a dip of -45° down to 51m when they ran out of casing and still had not penetrated the clay deposits.
Since there are no exposures to the east of the escarpment east of the Fen southern farms, and the RV36 highway road-cuts, Sæther (1957) assumed that the boundary of the complex coincided with the easternmost exposures of "rauhaugite type 2" and "red-rock". The drilling by "REE Minerals" has demonstrated that this assumption is incorrect. The drilling of DDH-018 showed that the FDC-unit continues at least 160-170m east of the previously drawn boundary (figure 7.1.2). This boundary is still not known precisely.
The company "21st North" also proposed that the south-eastern boundary is complexly faulted (figure 7.1.2). This assumption is supported by the complex faulting observed within the Fen iron Mines during the present study (see section 5.4.2). Data from "REE Minerals" (figure 7.1.2) was used to determine the boundary in this area on the map figure 5.1.5 in this report.

Resource estimates
REE minerals has presented a REE resource estimate based on their relatively tightly clustered drill-cores. The model in figure 7.1.3 shows that the REE mineralization clusters in relatively large volumes at a cut-off of 1,2% TREO. The ore tonnage is calculated by "REE Minerals" to 18,3 Mt with an average grade of 1.6 % TREO in the model of figure 7.1.3). This corresponds to a contained TREO of 0.3 Mt in the rock volumes.

The view of the Geological Advisor
The "REE Minerals"/"21st North" has performed the best REE-exploration in the Fen complex to date. However, no open pit mining is feasible in the Fen area, and most of the inferred resources occur too close to the surface to be mined subsurface. It is not yet known how deep the shallowest subsurface mining eventually has to be at Fen. It must be well below the base of the clay deposits which is known to be several tens of meter thick in the Fensmyra area. Presumably, subsurface mining has to be confined to below 100m from the surface. Consequently the drilling performed by "REE Minerals" must be classified as only reconnaissance so far. A more extensive, and deeper core-drilling program must be performed.

Figure 7.1.1
A REE-mineralized core-sample (red minerals) from DDH-019 drilled by "REE Minerals" in 2014. This is core was from the interval with more than 4% TREO around 210m+ depth. See figure 8.6.

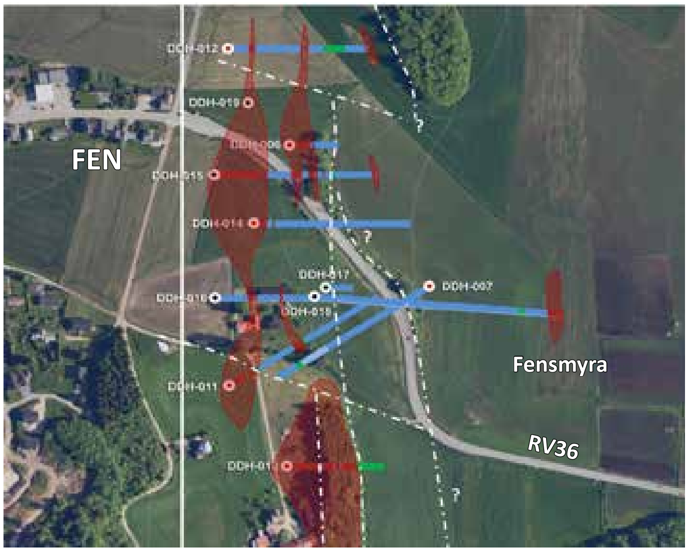


Figure 7.1.2
Map of the "REE Minerals'" drill-cores in the south-eastern Fen complex drilled in 2012 and 2014 (Figure and interpretations from Lie and Østergaard , 21st North 2017). Horizontal projections of the obliquely drilled cores are shown with lithological colour-codes as follows:

Blue: FDC-rocks
Red: "Red-rock"
Green: Fenite

Dashed white lines are proposed faults.
This map has been used to draw the FDC-unit boundary in this area in figure 5.1.5 in this report. Note that the FDC-unit is open-ended in the east, i.e. the drill-cores did not reach any wall-rocks in the east.

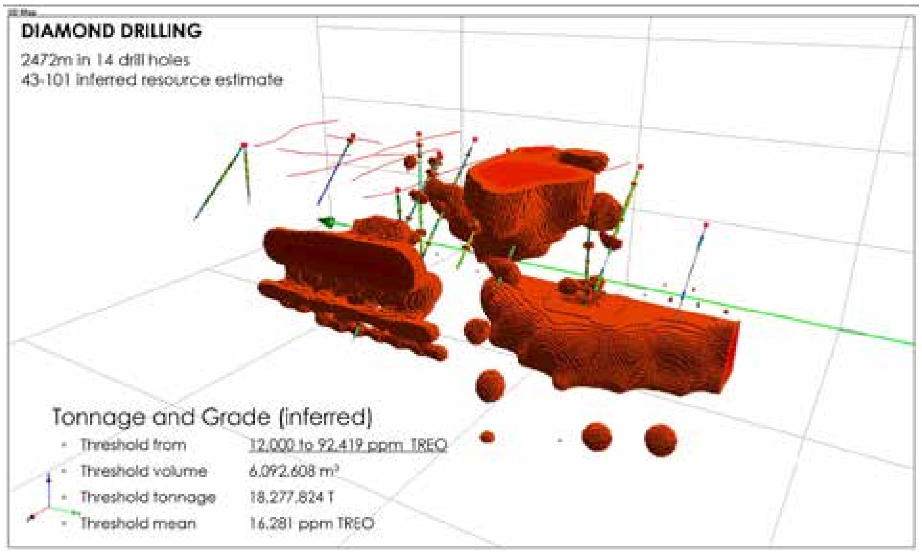


Figure 7.1.3
The REE resource distribution model and resource calculation presented by Østergaard (2016; power-point presentation in www.reeminerals.no).
The distribution of REE's in 3D has been constructed from the analyses of drill-cores and with a cut-off of 1.2% TREO.
The detailed background for this figure and the TREO calculation by "REE Minerals" is not known to this author.

All information on this page refer to reports and other information found on the "REE Minerals" website: www.reeminerals.no

7. Recent drill-cores of the FDC-unit, Fen complex
7.2 The long drill-cores LHKB-1 and LHKB-2

The results from the drilling of the two, long drill-cores at Fen has been published in a report recently (Coint and Dahlgren 2019). A brief summary is given below:

The rationale for drilling the two long cores.
When the geological mapping project by the Geological Advisor started in 2015 it was already clear that our knowledge of the continuation of the Fen-rocks towards the depth was very limited. Old gravity modelling (Ramberg 1973) suggested that the carbonatites were limited to the uppermost 500m, or possibly 1000m, of the complex. The new results from the core-drilling in 2012 and 2014 by the company "REE Minerals", and the discovery in 2015 of rich REE mineralizations in the Tuftestollen by the Geological Advisor, showed that REE mineralizations occur within the same geological unit, the FDC-unit, and the rich REE mineralizations were located more than one km apart. If we could drill two, vertical, long cores as distant from each other as possible within the FDC-unit we would find out:

- Does the FDC-unit exted down to 1km?
- Do we find REE-mineralizations deeper down or only near the surface?

If we could answer, "Yes", to these two questions we anticipated that this could trigger extensive exploration for REE in the Fen complex.

How financed?
The politicians from Telemark county council, Nome Municipality and members of the Norwegian Parliament from Telemark, together with the Geological Advisor, (figure 7.2.1) joined forces and applied to the Ministers of Oil and Energy, T. Lien and T. Søviksnes, for finances of the drilling. 8 million NOK was appropriated by the Minister of Industry and Fisheries. M, Mæland, for this purpose in the spring of 2017.

Drill-sites and performance of the project
The NGU became the project owner, and NGU and the Geological Advisor, immediately started the planning. Two drill-sites were selected (figure 7.2.2):

- LHKB-1: W of the Fen old school, on the peak of the gravity high (23 mgal residual anomaly)
- LHKB-2: E of Søve, as far N in the FDC complex as possible.

The Geological Advisor closely followed the drilling and logged the cores from mid November 2017 to May 2018.

Results
The LHKB-1 was drilled down to 1001m and the LHKB-2 down to 716m. Both drill-cores recorded rocks belonging to the FDC unit down to the end of the cores. Several REE mineralizations were observed along both core lenghts. Again, it was shown, like the evidence from the exposures and shallow drill-cores, that the rocks of the FDC -unit are texturally extremely inhomogeneous and varied, see photos figure 7.2.3, showing:

a. A polymictic FDC-breccia.
b. Laminated FDC.
c. Granular, REE-aggregate FDC.
d. Very REE-and pyrite enriched FDC.
e. FDC-rock with abundant REE-aggregates.

Image 7.2.3f shows a REE-FDC fragment in damtjernite breccia, i.e. an unequivocal evidence for that the damtjernite is younger than the FDC-rocks and the REE mineralizations.
Chemical whole-rock analyseis were performed by NGU/ALS of a split from every meter of the LHKB-1 core and from the damtjernite-free intervals of the LHKB-2 core. Average TREO was 1.08 % for LHKB-1 and 1.7% for the LHKB-2 FDC-rocks.

The report and all appendices can be downloaded from: www.ngu.no.

Figure 7.2.1
Political delegation from Telemark visiting the Minister of Oil and Energy T. Lien in February 2016, proposing the ministry to finance the two, long drill-cores at Fen. From the left: J. Ruud, B.T. Lundefaret, S.M. Olsen, G.A.R. Amundsen, Minister T.Lien, S. Dahlgren, S.T. Løkslid and K.M. Johansen. Photo: B. Hoksrud, Member of Parliament.

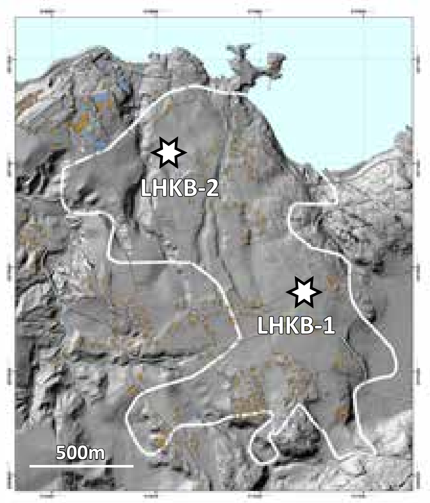


Figure 7.2.2
Location of the tow long drill-cores, LHKB-1 and LHKB-2 drilled in 2017-2018 in the FDC-unit (inside the white polygon) .

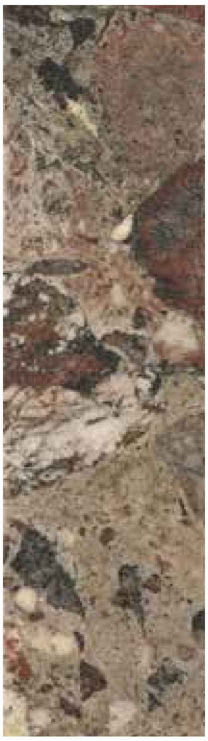


Figure 7.2.3a
LHKB-1
165.43-165.9m
Polymictic FDC-breccia

Figure 7.2.3b
LHKB-1
861.1-861.6m
Laminated FDC

Figure 7.2.3c
LHKB-1
101.0-101.2m
Granular REE-FDC. REE's occur in the red aggregates.

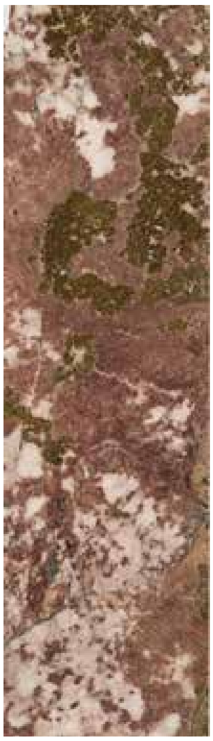


Figure 7.2.3d
LHKB-1
248.7-249.0m
Extremely REE-rich zone (red) and pyrite.

Figure 7.2.3e
LHKB-2
633.2-633.7m
FDC with REE-mineral aggregates (yellowish brown)

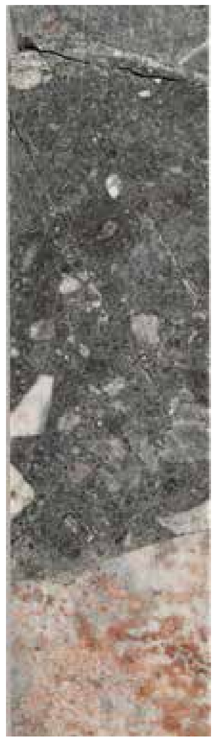


Figure 7.2.3f
LHKB-2
408.5-408.7m
REE-FDC-fragment (bottom) in damtjernite breccia (top).

Width of all core images 51mm

8. Whole rock geochemistry of the FDC complex, and its REE-mineralization

In this section whole-rock geochemical analyses of several REE-mineralized, and some "normal" FDC-rocks, will be presented and discussed. Most of the mineralized zones analyzed were also presented in the different chapters describing field relationships, textures and petrography. The objectives of this geochemistry chapter are to identify / demonstrate / calculate:

- The variations of TREO and selected chemical elements within the FDC-rocks, and their REE mineralization.
- The TREO-grades of the REE mineralization.
- The REE-compositions of the FDC-rocks and the REE mineralization.
- Comparison with other REE-mineralization from other REE-deposits.
- Correlation of chemical and mineralogical information
- Eventual chemical elements problematic in mineral processing / tailings.
- The presence of elements that may have potential to give "added value" to ores.
- Eventual spatial correlation between observed mineralizations.

The whole-rocks geochemical analyses from the FDC-rocks now amounts to more than 2000 (LHKB-1, LHKB-2; the analyses of the drill-cores from the company "REE-minerals"). The number of new chemical analyses in this project, however, is limited. The reader is reminded that the present report does not report from an exploration project, but rather from a geological mapping and evaluation project. Although the analyses of the few samples presented here gives poor statistics on most plots, several important relationships emerge from the data. The plots of the relatively few data presented here show similar trends to much larger data-sets including the LHKB-1 and LHKB-2 data. In fact, the plots involving the large data-sets generally become very crowded, and several trends are more visible when only using the few data presented here.

Chemical analysis

The chemical analyses of rock samples from the mines and surface exposures were performed by ALS Geochemistry on samples collected and prepared by the Geological Advisor. The chemical data is presented in appendix 4.

When the long drill-cores, LHKB-1 and LHKB-2, were analyzed, also a split of the shallow core Fen 2016 TEIG-2 was analyzed by ALS in the same batch. The TEIG-2 core was analyzed full length with 1 meter interval. These analyses were financed by NGU. A spreadsheet with the original data for Fen 2016 TEIG-2 drill-core can be requested from the NGU. The chemical data from TEIG-2 is presented in appendix 5. For comparison also a few data from the long drill-cores LHKB-1 and LHKB-2 will be presented, and the reader is recommended to see the report recently published for the description of those drill-cores (Coint and Dahlgren 2019). Some data from the company REE Minerals, namely the drill-core DDH-019, will also be used in figure 8.6.

8.1 TREO of "REE-mineralized" and "low-grade" FDC

In this discussion the samples from surface and subsurface (i.e. from mines) will be divided into two groups: "REE-mineralized" and "Low-grade". The distinction between these two groups has been set arbitrarily to those containing above or below 2% TREO respectively (see TREO-definition in section 1.3) . The data from the Fen 2016 TEIG-2 drill-core will be treated in a similar way.

8.1.1 TREO grades of the low-grade FDC-rocks

The "non-mineralized" rocks collected from surface exposures (including those from the mines) and from the TEIG-2 drill-core also show a substantial TREO content (average 0.81 and 0.72 % respectively; table 8.1). These are considered as low grade, REE-bearing rocks, but not as REE-mineralized. The average TREO of LHKB-1 is 1.08% and the LHKB-2 is 1.7% (Coint and Dahlgren 2019). These averages demonstrate that the TREO of the FDC-unit is generally high.

8.1.2 TREO of REE mineralizations

Data from all REE-mineralized zones from the Tuftestollen adit and from the Fen Iron Mines is shown in the summary ***table 8.1*** (min, max, average and median values). The average TREO for the REE-mineralized samples from exposures is 3,9 %.

The TREO in the Tuftestollen adit REE-mineralizations

A detailed discussion of the chemistry of the different mineralizations, e.g. those in the Tuftestollen adit and those in the Fen Iron Mines, is regarded as untenable because of the low number of samples. Nevertheless, some information about the sampling of the 3 Tuftestollen mineralizations is relevant for the estimation of REE-resources later in this report (see bold-faced data in table appendix 4B).

Two mineralizations occur close together, called TsM1E and TsM1W, and one about 50m farther into the mine:

Ts M1E: Chip-sampled mineralization.

4 samples of the vein between Ts 510.7E 1.4m and Ts 511E 3m.

The TREO of the Ts M1E mineralization is 3.7%

Ts M1W: Chip-sampled mineralization

2 samples from the mineralization Ts 504 W and Ts 505W 3.5m.

At this locality also some apparently "barren" samples collected from the FDC adjacent to the mineralized zone were also analyzed. These include

Ts 508W 2m; Ts 508W 2m; Ts 508.5 W 1.3m; Ts 510W 2.3m; Ts 512W. Some of these "barren" samples do contain more than 1% TREO, but they are treated as low-grade samples below.

The TREO of the Ts M1W mineralization is 2.6%

Ts M2W: Chip-sampled mineralization

This includes the samples from Ts 563W 1,7 to Ts 566.2W 1.2 (9 sub-samples).

The TREO of the Ts M2W mineralization is 4.4%

The TREO of REE-mineralizations in drill-cores

The TREO of a REE-mineralization in the Fen 2016 TEIG-2 dill-core

The mineralized zone is in the 19 to 23m depth interval in the TEIG-2 drill-core. From the mineralized zone in the TEIG-2 drill-core the average TREO is 4.49 %.

The TREO of a mineralization in the LHKB-1 drill-core

The 5m interval 198-203m has a TREO of 4.8%. See data in Coint and Dahlgren (2019).

The TREO of the DDH-019 drill-core

A 10m interval, from 206 to 215m, in the core DDH-019, has an average TREO of 5%. (Data from the company REE Minerals).

The TREO of the REE mineralizations

The TREO of the REE-mineralizations analyzed so far range from 2.6%, to 5%. A general TREO of 3-4% for the REE-mineralizations within the FDC-unit seems very plausible, whereas 5% is rather high, but not impossible. These data will be used in the calculations of potential REE resources in the Fen complex (chapter 9).

8. Whole rock geochemistry of the FDC complex, and its REE-mineralization

	1				2				3				4			
	REE-Mineralized FDC-rocks (n=21)				Low-grade exposed FDC-rocks (n=18)				TEIG-2 drill-core, low-grade (n=65)				TEIG-2 drill-core REE-mlzd zone 19-23m (n=4)			
	Min	Max	Average	Median	Min	Max	Average	Median	Min	Max	Average	Median	Min	Max	Average	Median
TREE ppm	2409	58481	30036	29689	1639	41429	10835	8454	1053	33645	6073	4900	16766	50494	38261	42891
TREO	**2,00**	**6,86**	**3,91**	**3,68**	**0,22**	**1,70**	**0,81**	**0,83**	**0,13**	**3,95**	**0,72**	**0,58**	**1,97**	**5,93**	**4,49**	**5,04**
LREE	16931	58253	33124	31080	1483	14348	6735	6961	1001	33316	5964	4819	16591	50144	37925	42483
HREE	61	425	196	173	14	252	86	61	37	329	110	100	176	430	336	369
MREE	162	836	479	449	45	414	180	156	72	692	201	186	351	844	690	782
(La/Yb)n	353	5957	3754	4243	93	5231	1324	916	77	1778	425	345	1265	2415	1622	1403
La	772	20800	10733	9735	305	15350	3626	2610	239	11350	1714	1390	5820	19000	13543	14675
Ce	1175	28500	14172	14075	697	20000	5121	4025	485	16000	2918	2395	7790	23800	18123	20450
Pr	108	2340	1229	1203	90	1560	463	423	55	1505	295	247	691	1805	1464	1680
Nd	307	6280	3439	3410	317	4130	1398	1295	191	4080	934	779	2100	5420	4418	5075
Sm	28	470	278	289	32	285	129	102	31	381	103	92	190	465	378	430
Eu	5	97	50	50	5	41	23	19	9	86	24	21	40	100	79	89
Gd	9,1	200,0	90,3	84,4	6,0	105,0	41,7	37,1	18,9	167,5	49,8	46,5	80,7	193,5	156,9	176,8
Tb	0,9	21,1	7,9	7,0	0,5	11,2	4,0	3,3	1,5	14,8	5,5	4,9	11,7	28,8	22,7	25,3
Dy	2,6	75,1	24,7	18,5	1,6	49,1	16,3	10,9	5,4	49,2	18,7	16,5	29,6	71,9	52,7	54,6
Ho	0,36	10,80	2,92	1,83	0,24	9,00	2,45	1,37	0,54	7,13	2,49	2,18	3,80	8,16	6,24	6,50
Er	0,72	21,60	5,52	3,36	0,48	21,50	5,53	2,79	0,90	15,70	5,18	4,25	6,40	15,70	10,48	9,90
Tm	0,10	2,32	0,56	0,34	0,07	2,63	0,69	0,31	0,12	1,69	0,56	0,47	0,50	1,64	1,04	1,00
Yb	0,66	11,90	3,11	1,97	0,47	14,70	4,06	1,66	0,80	9,40	3,16	2,65	3,10	8,90	5,70	5,40
Lu	0,10	1,58	0,44	0,29	0,08	1,87	0,57	0,24	0,08	1,14	0,39	0,32	0,39	1,23	0,77	0,72
Y	7	256	63	39	5	217	60	31	15	175	57	44	57,7	143	107	113
Sc	7,8	39,1	19,6	20,7	7,4	53,7	22,0	20,3	14,5	50,3	24,8	22,9	17,9	42,6	31,9	33,6
P	87	44275	6965	1091	218	13217	3657	2508	280	9790	3380	2490	1430	8390	3803	2695
F	430	7900	3306	2775	440	7990	2359	1760	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sr	572	4430	2538	2535	669	4020	2486	2735	466	5510	3319	3465	2280	3490	2703	2520
Ba	135	28400	5703	1670	176	51000	11719	7585	190	6150	2177	2045	90	560	268	210
Zr	2	129	34	16	6	210	50	22	1	101	26	24	59	194	108	90
Hf	0	2	1	1	0	4	1	1	0	3	1	1	1	3	2	2
Nb	3	498	68	17	8	3520	483	169	52	3670	607	424	154	821	357	226
Th	20	899	255	208	6	587	143	98	57	530	181	157	293	1140	666	615
U	1,1	63,8	10,4	4,4	0,6	50,9	12,1	3,8	1,8	30,5	7,2	5,7	11,5	23,7	15,4	13,2
S	0,1	2,7	0,6	0,4	0,1	1,1	0,4	0,3	0,0	1,8	0,6	0,5	0,3	2,2	1,2	1,1
Co	1	32	7	3	1	31	8	6	4	31	12	11	5	32	19	19
Ni	8	147	84	82	5	113	45	36	1	14	3	3	2	5	3	3
Cu	1	219	16	2	1	32	10	8	1	62	9	6	6	50	29	30
Zn	18	6240	335	44	13	455	129	55	98	1680	517	446	381	4320	1488	626
Cd	1	12	1	1	1	2	1	1	0	4	1	1	1	9	3	2
Ag	0,5	0,7	0,6	0,6	1,3	1,5	1,4	1,4	0,0	2,8	1,1	1,0	0,7	2,7	1,8	1,8
Hg	0,006	0,043	0,013	0,009	0,006	0,018	0,010	0,009	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Au	0,002	0,051	0,011	0,005	0,002	0,027	0,009	0,003	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
As	0	35	5	3	0	11	3	2	1	16	4	3	0	12	7	9
Pb	7	79	30	27	2	26	16	18	7	206	22	16	18	65	38	34
Mo	3	129	31	17	3	260	55	14	4	325	109	86	92	540	292	268

Table 8.1
Summary data table of all the chemical data in this report showing min, max, average and median values for various elements, element groups and ratios. See full data in appendices 4 and 5. All data (except TREO in ppm. The TREO includes Y. In the TREE, Y is not included in the table.

Data categories (referring to the boxes in the table):
1. REE-mineralizations from exposures on the surface or from within the mines
2. Low-grade FDC from exposures on the surface or from within the mines
3. Low-grade rocks from the Fen 2016 TEIG-2 drill-core
4. REE-mineralized interval from the Fen 2016 TEIG-2 drill-core
All or most samples were below detection limit for Ti, Li, Cr, Pt, Pd, Ge, Se, Sn, Ta, W.
n.a. = not analyzed.
b.d. = below detection limit.
(Note: Norwegian decimal, “comma”, notation is applied in the table)

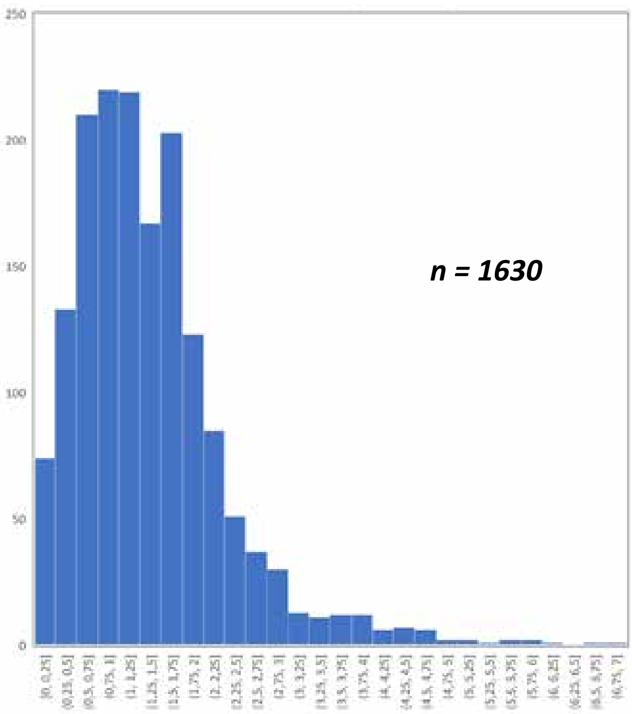


Figure 8.1
TREO of all analyses from exposure samples and the drill-cores LHKB-1, LHKB-2 and TEIG-2. One sample from the interval 199-200-m of LHKB-1 containing 10% TREO is omitted from the diagram.

8.2 The REE-composition of the FDC-rocks and the REE mineralization

n this section the composition of the REE in the FDC-rocks and in the REE-mineralization is described in relative and absolute values. The following discussion is limited to the new analyses presented in this report.

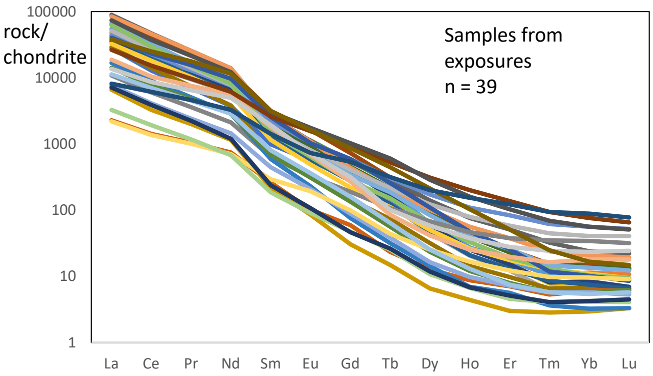


Figure 8.2.1 A
Chondrite-normalized plots of all analysed samples collected from exposures on the surface or from within old mines. Chondrite normalization factors are from Anders and Ebihara (1982).

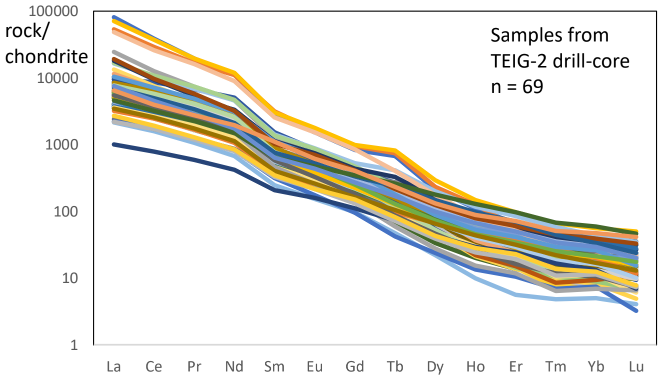


Figure 8.2.1 B
Chondrite-normalized plots All samples from the Fen 2016 TEIG-2 drill-core.

Strong LREE enrichment

All the Fen FDC-rocks, whether REE-mineralized or not, are strongly LREE-enriched (figures 8.2.1 A and B). This is typical for carbonatites in general. Figure 8.2.1C show REE-ores from Mountain Pass and Bear Lodge (e.g. Verplanck *et al*. 2016), and Bayan Obo (Yang *et al*. 2011). The Fen FDC REE-pattern is similar to the REE from these deposits.

The $(La/Yb)_n$ relationships

All Fen FDC-samples analyzed have very high $(La/Yb)_n$ ratios (table 8.1). The general trend is that the average $(La/Yb)_n$ ratios are higher for REE-mineralized than for the non-mineralized FDC. This may be due to the fact that the mineralized zones are richer in REE-minerals than the low-grade FDC. However, the average $(La/Yb)_n$ of the Tuftestollen mineralized samples, 4536 (n=19), is much higher than the average of the mineralized samples from the Fen Iron Mines which is 1468 (n=3). Whether this indicates that the REE-mineralizations generally are more HREE-enriched in the Fen Iron Mine district than in the Tuftestollen adit must await a larger number of analyses.

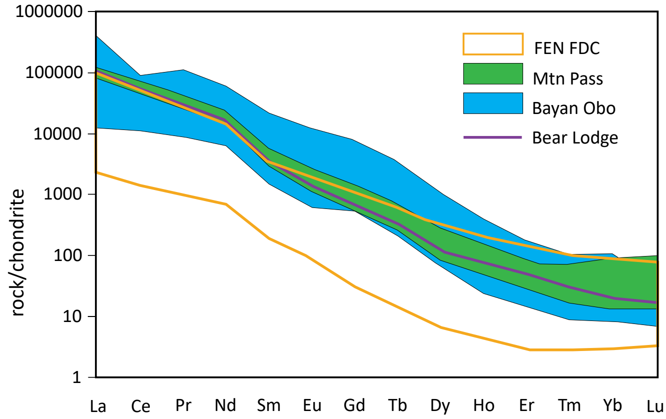


Figure 8.2.1 C
Chondrite-normalized plots of REE-ore from Mtn. Pass, Bear Lodge (Verplanck et al. 2016) and Bayan Obo (Yang et al. 2011). Fen FDC exposure samples plotted for comparison.

Absolute abundances of the REE from the FDC REE-mineralizations

The absolute abundances of the average REE composition of the REE-mineralization in the Fen FDC (table 8.1) are shown in figures 8.2.2 and table 8.2. The LREE accounts for 99.17% and the HREE 0.83% (including Y). Of the LREE the abundances of Pr and Nd are 4,08% and 11% respectively. The MREE (Sm, Eu, Gd, Tb, Dy) amounts to 1,5% of the total REE. The relative abundances of the MREE is shown in figure 8.2.3.

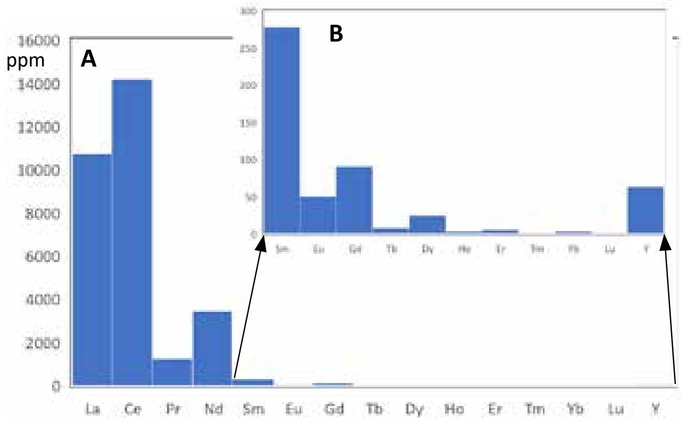


Figure 8.2.2
A. *Absolute abundances, in ppm, of the REE in an average Fen FDC-REE-mineralization (table 8.1). In* ***B,*** *the scale is expanded to show the absolute values of the HREE. Note that the LREE Sm is shown on both figures to illustrate the scale difference.*

Elmt	ppm	%
La	10733	35,66
Ce	14172	47,08
Pr	1229	4,08
Nd	3439	11,42
Sm	278	0,92
Eu	50	0,17
Gd	90	0,30
Tb	7,9	0,03
Dy	24,7	0,08
Ho	2,9	0,01
Er	5,5	0,02
Tm	0,6	0,00
Yb	3,1	0,01
Lu	0,4	0,00
Y	62,6	0,21

Table 8.2
Abundances in % of the various REE metals of an average Fen FDC REE-mineralization (table 8.1).

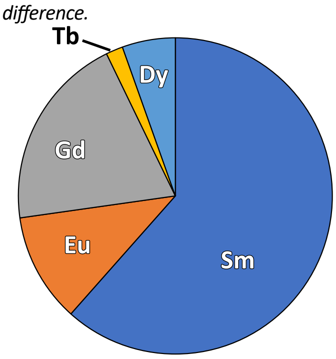


Figure 8.2.3
The relative weight abundance of MREE from the average Fen FDC REE-mineralization (table 8.1).

8.3 Geochemical and mineralogical control of the REE-mineralization

The modal abundances and the chemical compositions of the various minerals controls the geochemistry of the REE-mineralization. Here, the mineralogical control of certain chemical elements and element groups will be examined. Some important questions will be addressed below:

- Are the LREE, MREE and HREE controlled by the same minerals?
- Is the REE-mineralization dominated by monazite or REE-fluoro-carbonates?
- Is there a correlation between Ba, Nb and REE?

The following plots are based on data from samples from exposures and the TEIG-2 drill-core. However, some plots involve elements only analyzed for the exposure-samples. In each plot it is specified whether only exposure samples or also TEIG-2 samples are used.

The MREE / LREE relationship
Figure 8.3.1 shows the MREE plotted versus LREE. Up to 10,000-15,000 ppm LREE there appears to be a correlation with MREE, but at higher LREE concentrations the MREE does not increase stedily as LREE increases. One interpretation is that the LREE and MREE become mineralogically decoupled at some point, i.e. that at least one of the two REE-groups are controlled by different minerals.

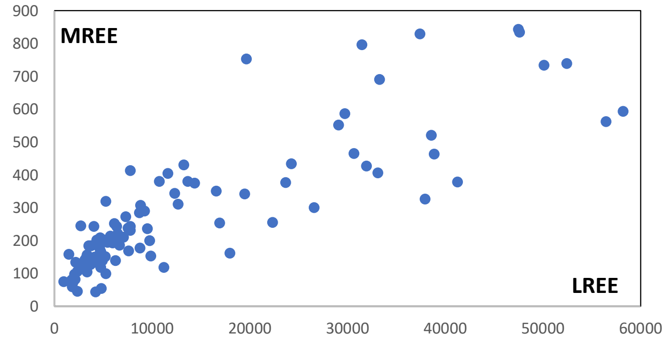


Figure 8.3.1
The plot of MREE versus LREE shows that the MREE is not increasing steadily when the LREE increase (both in ppm). Samples from exposures and the TEIG-2 drill-core.

Are the REE-mineralizations dominated by monazite or REE-fluoro-carbonates?
Unfortunately, only P-contents up to 2% was analysed for the drill-cores (TEIG-2 and the LHKB drill-cores). In figure 8.3.2 only samples from exposures have been plotted. There is no correlation between P and TREE. The scatter of samples containing up to 1% P may be due to the presence of minor Mnz, but the REE-mineralization is not dominated by Mnz. The two samples containing about 4,5% P are rich in Ap, and contains only traces of Mnz.

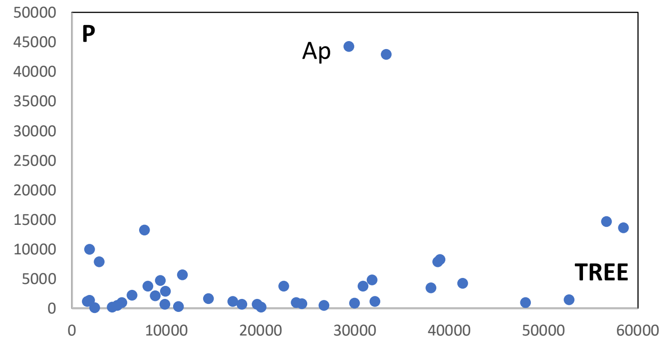


Figure 8.3.2
There is no apparent correlation of P with TREE (both in ppm). Samples from exposures. Y is not included in the TREE

In figure 8.3.3 ppm F is plotted versus TREE. There is a pronounced correlation between F and TREE. This is interpreted as a control of these elements by RFC. It is not known whether the RFC is Bsn or Prs-Syn. Samples plotting above the RFC-control trend are interpreted as being enriched in Fl or Ap, and samples plotting below are probably enriched in Mnz.

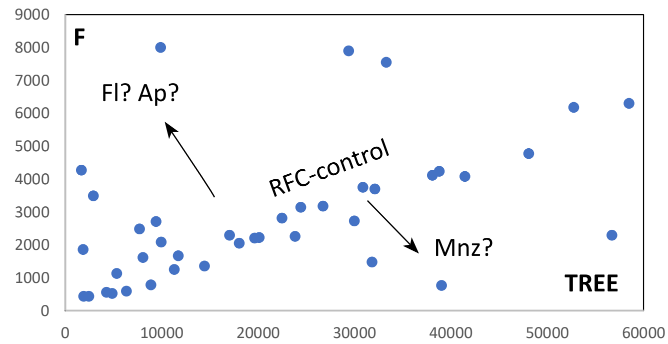


Figure 8.3.3
F versus TREE (both in ppm). See text for interpretation. Samples from exposures. Y is not included in the TREE

Is there a correlation between Ba, Nb and REE?

Barium and barite
Ba reaches a level of several percent in many samples (table 8.1). Most of the Ba is probably present in Brt as was demonstrated in the petrography section. If we had analyses of sulfate-bound sulfur, the variations in Brt could have been estimated. However, it is evident that there is no correlation between Ba and REE (figure 8.3.5). Consequently Brt seems not to be particularly enriched within the REE-mineralized zones of the FDC-rocks

Niobium
The Nb content of the FDC-rocks is generally low (table 8.1) compared to what is typically found in søvites (several thousand ppm). However, a few FDC samples also contain Nb above 3000 ppm. The Nb most likely resides in Cmb. Nb appears to be enriched in the low-grade FDC.

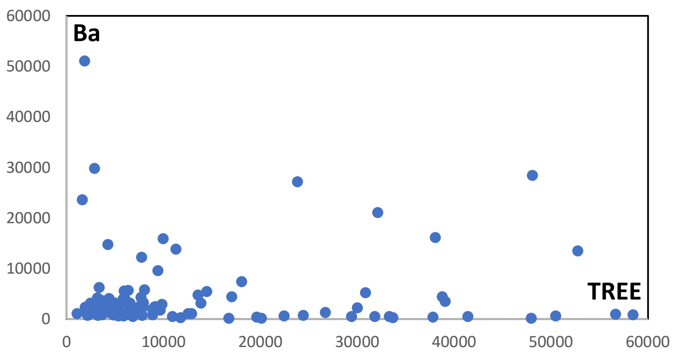


Figure 8.3.4
No correlation is observed between Ba (ppm) and TREE (ppm). Samples from exposures and the TEIG-2 drill-core. Y is not included in the TREE

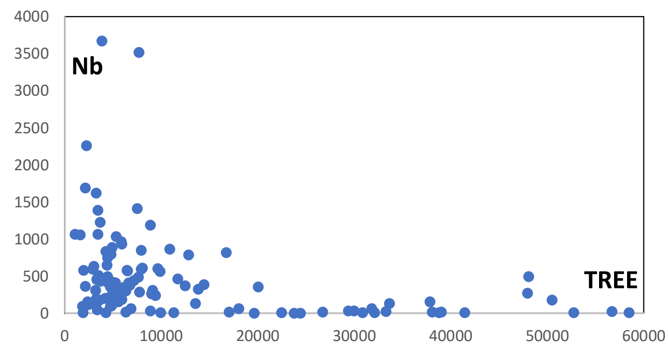


Figure 8.3.5
Nb (ppm) does not show any apparent correlation with TREE (ppm). Samples from exposures and the TEIG-2 drill-core. Y is not included in the TREE

This section examines the geochemical relationship between the two elements Sc and Y. These are strictly not REE-elements, but frequently they are included among the REE-elements. During the exploration at Fen by FSJ and "Fenco" (sections 4.1.2 and 4.1.3) both Y and Sc were given special attention.
Important questions to address here are:

- How do Y and P behave relative to the REE?
- Is there a relationship between Y and P?
- Are Sc and Y directly related?
- Is Fen an exploration target for Sc and Y?

Yttrium
Yttrium is generally classified among the HREE. In section 8.2 it was demonstrated that the Fen FDC REE-mineralizations are strongly LREE-enriched, but that Y is considerably more enriched than is the case for the other HREE (figure 8.2.2 and table 8.2). Y on average constitute about 60% of the HREE.
In the exposure samples, the Y range form 7 to 256 ppm, with an average of 63 ppm. In figure 8.4.1 Y is plotted versus TREE (not including Y). Some correlation seem to exist, but the wide scatter of Y clearly shows that Y must be controlled by other minerals than the dominating REE minerals. The plot in figure 8.4.2 examines whether this mineral could be Ap. A possible correlation with P is likely for some samples and may indicate that Y either is incorporated in Ap or Mnz lattices, or be present as very small Xen crystals (Xen has indeed been observed by this author in other Fen-rocks).
In the figures 8.4.3 and 8.4.4 Y is plotted versus Yb and Ce respectively. The Yb-Y-plot shows a good trend which is expected since both elements are HREE. They seem to be controlled by the same mineralogy. The Ce-Y-plot is very different from the Yb-Y plot and shows a decoupling of Y and LREE. In consequence, the Y seem not to be controlled only by Mnz and RFC. Could Aln, possibly also in combination with Xen/Ap, explain the behaviour of Y?

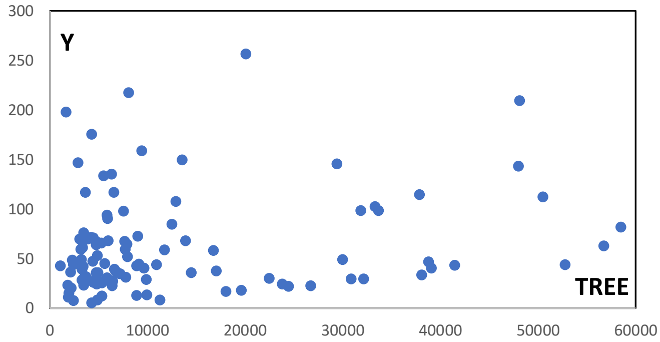


Figure 8.4.1
Y versus TREE (both as ppm; the TREE-total does not include Y). Samples from exposures and the TEIG-2 drill-core.

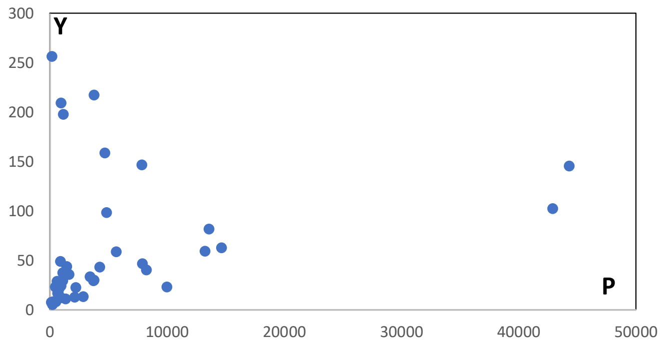


Figure 8.4.2
Y versus P. Both as ppm. Samples from exposures.

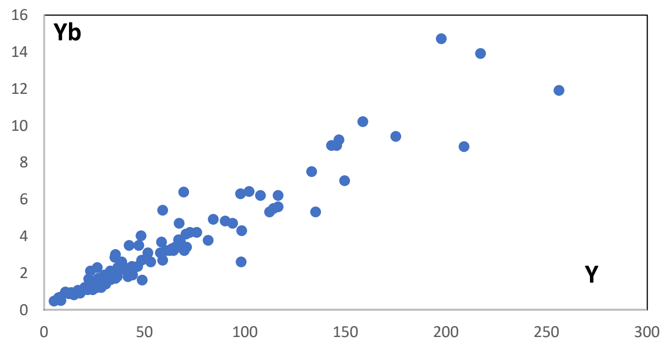


Figure 8.4.3
Yb versus Y. Both as ppm. Samples from exposures and the TEIG-2 drill-core.

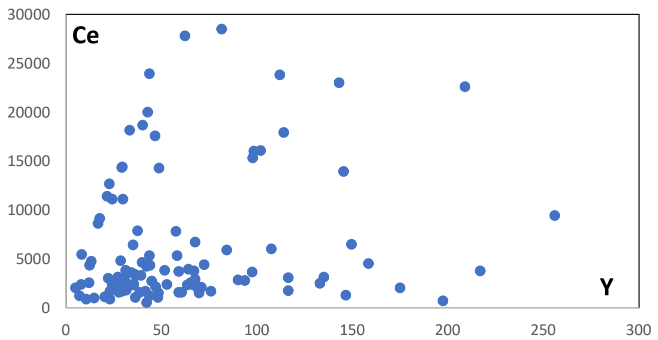


Figure 8.4.4
Ce versus Y. Both as ppm. Samples from exposures and the TEIG-2 drill-core.

Scandium
Analyses of Sc in 1630 samples (exposure samples + the TEIG-2, LHKB-1 and LHKB-2 drill-cores) range from 2.9 to 64.6 ppm, and the average is 19.8 ppm. There is no significant difference between REE-mineralized or low-grade FDC (table 8.1).
In figure 8.4.5 Sc is plotted versus Y. There is a faint correlation between the two elements indicating some mineralogical control. Previously the presence of Ttv has been documented from FDC by Åmli (1977). Is the Sc-Y relationship controlled by minute Ttv-crystals or by some other mineralogical controls?

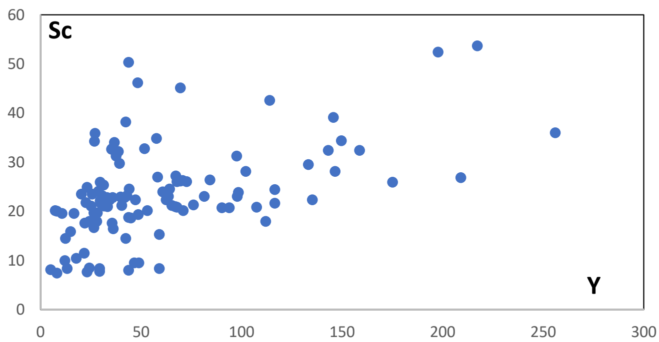


Figure 8.4.5
Sc versus Y. Both as ppm. Samples from exposures and the TEIG-2 drill-core.

Is Fen an exploration target for Sc and Y?
Even though the REE mineralization at Fen is LREE enriched, Y is also a potentially interesting element for exploration. Sc, however, due to its very low abundance, is of more doubtful interest for future exploration / exploitation of the FDC mineralizations.

8.5 Potentially problematic chemical elements

Some chemical elements may represent an environmental- or health-risk when deposited in the tailings. This risk largely depends on the stability of the minerals that contain these elements when exposed to surface air and water conditions. Some relationships between minerals and certain metals will be discussed below. The two elements thorium and uranium will be discussed separately in chapter 10.

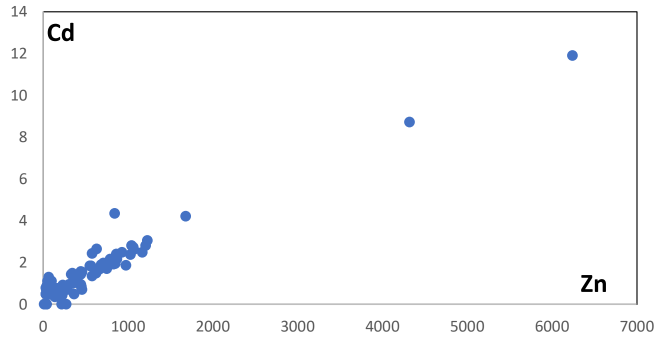


Figure 8.5
Cd, which occur in very small concentrations correlates well with Zn as is expected. The Cd must be camouflaged in Sl which is fairly abundant in several FDC samples. Samples from exposures and the TEIG-2 drill-core.

Sulfide-bound metals
The metals Pb, Cd, Ag, Hg, Tl, Ni, Cu, In, Mo and Zn all typically occur as sulfides or as minor elements included in sulfides. In the petrography section Gl, Cpy, Py, Po, Mbd and Sl were described, and these sulfides obviously account for the content of Pb, Cu, Ni, Mo and Zn in the analyses. These elements, and especially Hg, Tl, Co and As all occur in very low concentrations in the FDC mineralization. The only exception is Zn which occur in Sl. As can be expected, Cd and In occur camouflaged in Sl; see figure 8.5.2 for the case of Cd. Ag may occur in Gl, or as hessite (hessite was described by Dietzel et al 2019).
The sulfides most likely will be relatively easy to remove from the REE-ores during mineral processing, and thereby eliminating the problem of heavy metal leakage from future tailings.

8.6 Elements with a possible "added value" potential

Other minerals and metals than the REE-elements should be looked for in the mineralization, since also other minerals / metals may contribute positively to the economic assessment of the mineralization. A brief discussion of possible "added value" components is presented below.

Barite
Brt has been observed as a mineral both macroscopically (in drill-cores and in exposures) and microscopically (chapter 6). Brt is a potentially interesting commodity in the FDC. Ba was analyzed systematically in all samples from exposures and drill-cores. Although Ba is probably mainly occurring as Brt, also Cel has been observed. Ba may also occur in other minerals as carbonates and silicates. Consequently, the whole-rock Ba-content is not a reflection of the Brt content. Additionally, as was shown in figure 8.3.4, the Ba does not correlate with REE. This implies that mining of Brt will not be from the REE-ores, but from the low-grade FDC-rocks. Presumably Brt is the only sulfate mineral in the FDC's. Analysis of sulfate-bound sulfur may then be an efficient tool in future exploration analyses to assess the potential value of Brt.

Niobium
Relatively high Nb concentrations have occasionally been found in the FDC's. For example concentrations up to 3520 ppm Nb was found in low-grade FDC in the TEIG-2 drill-core (table 8.1). However, maximum Nb in the REE-mineralized FDC is only 498 ppm. Although Nb-minerals occur in the mineralized zones, and may be extracted during mineral processing, Nb is not likely to be an important metal in the REE-mineralizations. However, this should be investigated further.

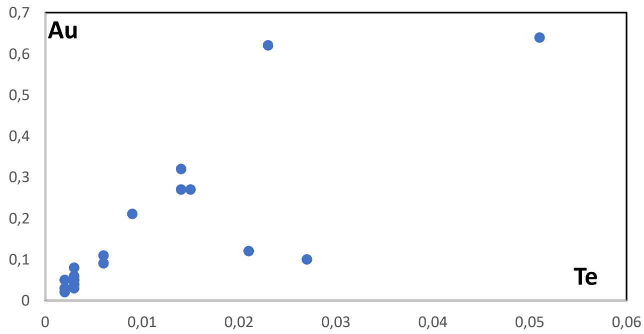


Figure 8.6
Gold (ppb) versus tellurium (ppm). Does this weak, and statistically poor correlation, indicate the presence of extremely small quantities of calaverite? Samples from exposures.

Precious metals
Pt, Pd and Au were analyzed for a limited number of the samples from exposures (appendix 4E). Pt and Pd were below detection limits, and thus the presence of PGE-elements do not appear to be promising. Au occur at ppb levels (in whole-rocks), and may reside in Py. Since Au and Te show a weak correlation (figure 8.6.3), it may indicate that Au occurs as calaverite. Ag may reside in hessite, a mineral that has been observed in one grain (Dietzel et al. 2019), but Ag may also reside in Gl. Bearing in mind that the present analyses are of whole-rocks, the sulfide concentrates should be thoroughly inspected for the eventual presence of "added value" elements.

8.7 Geochemical whole-rock analyses - Notes of caution and recommendations

Analytical methods - A note of caution
Traditionally REE whole-rocks analyses have been performed by either XRF or INAA/RNAA, or by a combination of these methods. For some of the REE's also isotopic dilution has been widely used (e.g. for Sm and Nd). During the last 2 decades ICP-MS-methods has gained an increasing importance. Inherent in all these methods are elemental interferences and other analytical problems. Certain analytical procedures also rely on analysis of a solution made by total dissolution of the rocks. However, total dissolution is not always achieved. Consequently, incomplete dissolution of refractory REE-bearing minerals or refractory minerals hosting REE mineral inclusions may cause severe, and possibly systematic, analytical errors.

Analytical methods - recommendations
Ideally, when analyses are performed for economical exploitation of such complex systems as REE- ores, analyses of at least a few samples by different methods is recommended. Then analytical uncertainties can become a part of the economic assessment.
Preferably the future whole-rock analyses should also include the full range of P_2O_5, and additionally, also fluorine and sulfate / sulfide-bound sulfur. The P and F analyses will provide important information about the distribution of monazite versus REE-fluorocarbonates. Sulfate-bound sulfur will be useful for assessment of the presence of barite.

8.8 Vertical element variation in the Fen 2016 TEIG-2 drill-core

The vertical element distribution of the LHKB-1 and LHKB-2 drill-cores has been reported recently (Coint and Dahlgren 2019). The downward distribution of selected elements in the TEIG-2 drill-core is presented below (figure 8.8.1). The plots of element variation downwards in the shallow drill-core Fen 2016 TEIG-2 gives good information about the relationships between TREO, Ba, Th and Nb. The TREO generally fluctuates around 1% in most of the core, but reaches a high level with an average TREO of 4,49 % between 19 and 23 m, and a smaller spike at 55m. The same applies to a certain degree for Th, whereas Ba and Nb do correlate with the REE. The lack of correlation between TREE and Ba and Nb was also shown in section 8.3. The hematitization observed in the TEIG-2 core does not affect the TREO, Ba, Th or Nb distribution (figure 8.8.1). For further examination of thorium, see figure 8.8.2 and the accompanying text.

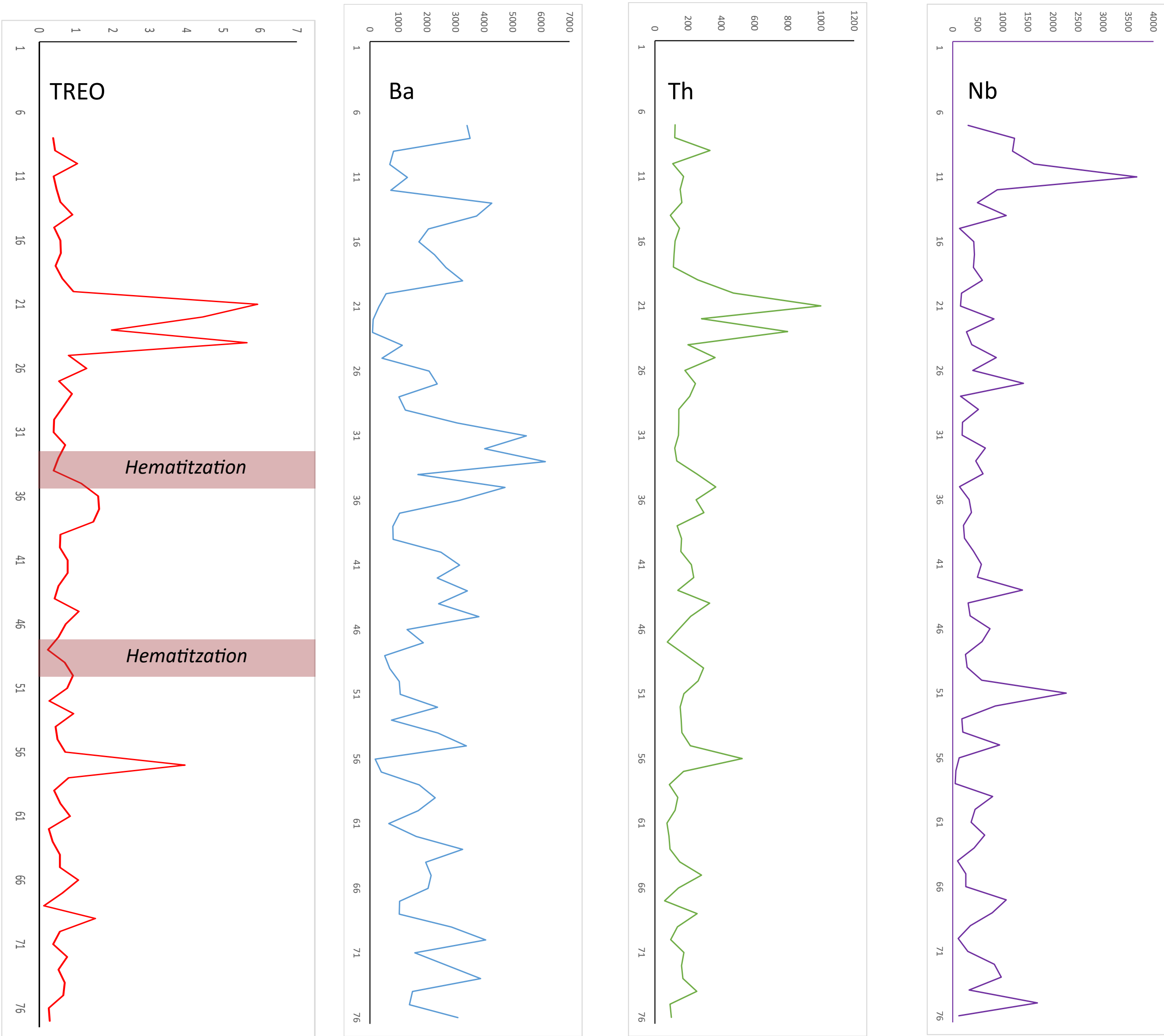


Figure 8.8.1
Vertical distribution plots of TREO, Ba ppm, Th ppm and Nb ppm, from the drill-core Fen 2016 TEIG-2. Red bars shows hematitized FDC levels ("red-rock"). The drill-core is 75m long and was drilled vertically. Chemical data in appendix 5.

REE and thorium - a correlation?

Figure 8.8.1 above suggests that there is a correlation between Th and REE, but this does not apply to all samples. In figure 8.8.2 it is evident that raised REE levels does not necessarily imply raised Th levels. Thus the REE's and Th must vary independently to some degree, and especially at high TREE, i.e. in the REE-mineralization. This observation suggests that Th is *not* a good guide to REE-ore, which is contrary to the view of FSJ and "Fenco" (see sections 4.1.2 and 4.1.3 for references). This correlation should be used with caution. The two elements thorium and uranium will be discussed further in chapter 10.

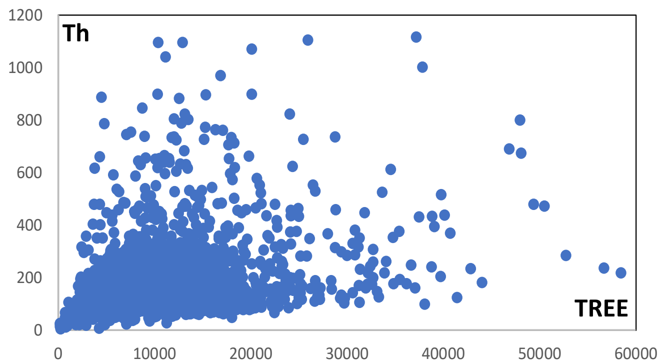


Figure 8.8.2
Th versus TREE (ppm) for all exposure-samples, and the drill-cores LHKB-1, LHKB-2 and TEIG2. Th and REE appear to correlate at low REE-concentration, but that Th does not increase substantially with increasing REE concentration.

8.9 Is there a correlation of the REE mineralizations with depth across the Fen Complex?

This represents the first attempt to determine if there is a correlation between the REE mineralization observed at depth in a few long cores and observations made subsurface in the old mines.

The various sites are shown in figure 8.6a and the drill-cores lie on a straight line from the south-east (DDH-019) to the north-west (LHKB-2). The distance from DDH-019 to LHKB-2 is 1130m. In addition the mineralization in Tuftestollen and the Fen Skole Stoll of the Fen Iron Mines are also included for correlation.

In the plots of DDH-019 and LHKB-1 prominent REE-mineralized intervals occur near 200m depth from the surface, 100m below sea level (figure 8.6b). The horizontal distance between these two drill-cores is 229m. Whether this could indicate a larger mineralization near 200m depth, or if this is a coincidence cannot be evaluated without further core-drilling. However, in the discussion in section 12.1 it will be argued that this is merely a coincidence. Several other, smaller mineralized zones are apparent in all the different drill-cores. The prominent REE-mineralization in the Fen 2016 TEIG-2 core is at a depth of 19-23m under the present surface, or 70-74m above sea level (see also figure 8.5). The mineralization in the Fen Iron Mines and the Tuftestollen adit do not have any obvious correlation to mineralization in any of the drill-cores.

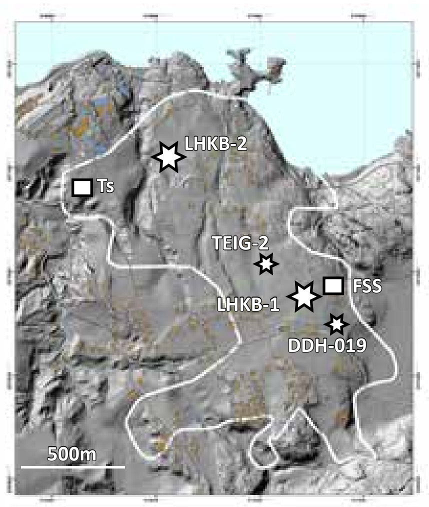


Figure 8.9a
Positions of the drill-cores (stars) and mineralized FDC in old mines (squares) shown in figure 8.9b and discussed in the text. Ts = Tuftestollen. FSS = Fen Skole stoll.

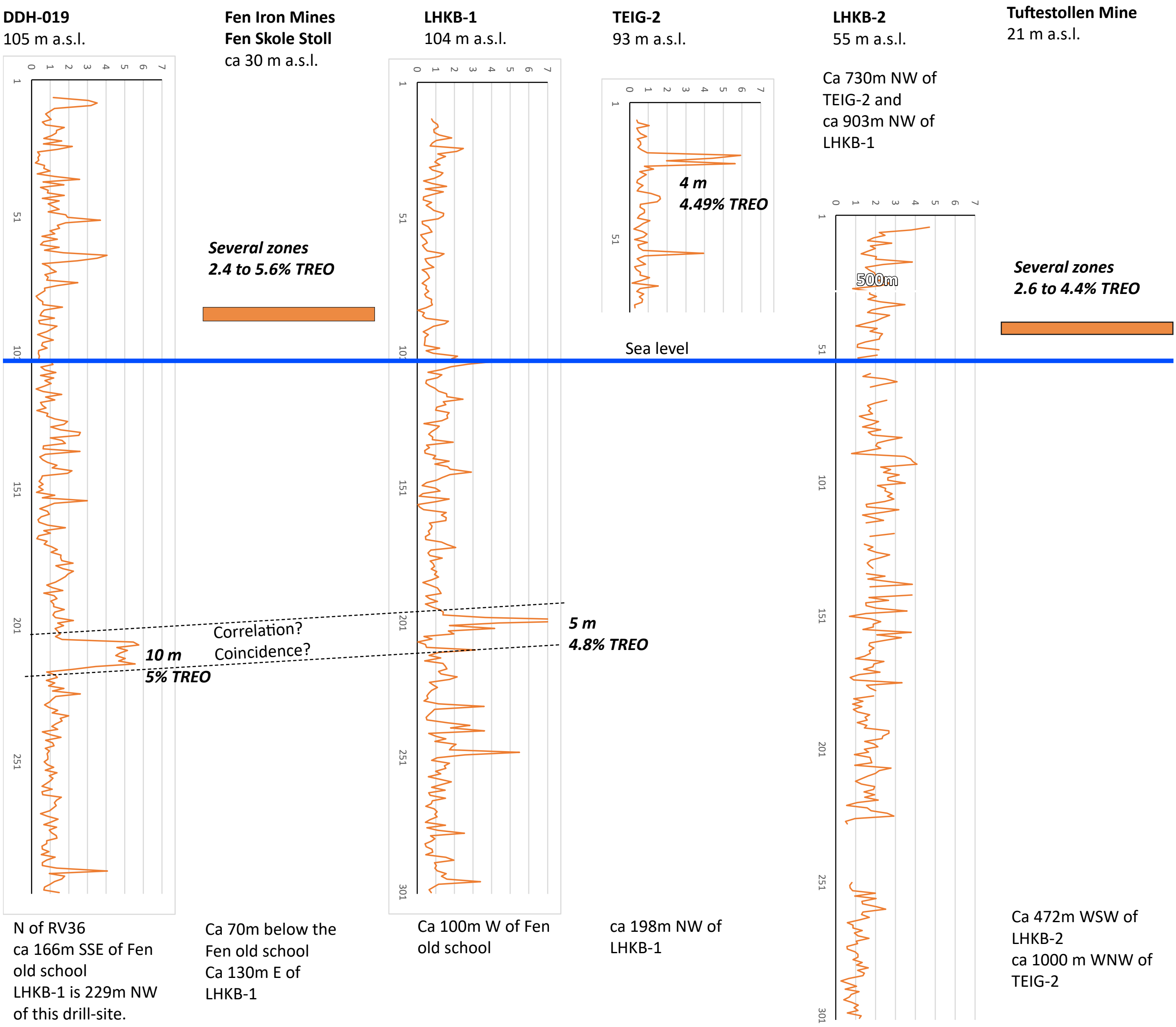


Figure 8.9b
Vertical distribution plots of TREO from the drill-cores DDH-019, LHKB-1, Fen 2016 TEIG-2, and LHKB-2. The plots are shown on an identical vertical scale, and on the TREO-scale. The plots are adjusted to sea-level (blue line). The mineralization within the old Fen Iron Mines and the Tuftestollen adit are indicated with the orange boxes. The location of the various sites is shown in figure 8.9a. The data from drill-core DDH-019 was provided by the company REE Minerals.

9. Estimates of possible REE resources in the Fen Complex

Based on the limited data presently available any calculation of possible REE resources within the FDC unit will be highly uncertain. Nevertheless, some attempts will be made in this report. Possible REE-resources in the "red-rocks" and in the søvites will not be included. Preliminary results have been presented in various conference talks by Dahlgren (2017, 2018, 2019). The calculation of ***possible in situ resources*** is based on a number of facts and assumptions:

Area of the FDC unit
The surface "outcrop area" (i.e. the area shown from mapped exposures, sub-surface mines and shallow drill-cores; figure 5.1.5) of the FDC unit is roughly 1,4±0,05 km^2. In the calculations the minimum area 1,35 km^2 is used as an initial area. Then subtracting 10% damtjernite, and 5% hematitized FDC, from this area, an area of 1.15 km^2 is assumed to approximate the FDC area. This area is also assumed to continue towards depth.

Vertical extension of the FDC unit
The long core-drilling of LHKB-1 and LHKB-2 demonstrated that the FDC unit extends to a depth of at least 1001 meter at LHKB-1 and at least 716m at LHKB-2. It is very likely that the entire FDC complex extends to at least 1000m depth. A cylidrical vertical distribution of the entire FDC complex is assumed.

The "Boomerang zone"
The "Boomerang Zone", is proposed in this report (figure 9.1). This is a boomerang-like, arcuate area at the surface where reasonably abundant REE mineralizations have been observed in mapped exposures, sub-surface mines (the Tuftestollen adit and the old Fen Iron Mines) and various drill-cores (the shallow cores described in this report, the 2012 and 2014 drill-cores from REE Minerals, and the LHKB-1 and LHKB-2 cores). .
The surface area of the "Boomerang Zone" is ca 0.7 km^2. Assuming that the damtjernites and hematitized parts constitute an area of 0.1 km^2, an area of 0.6 km^2 will be used in the calculations.
The "Boomerang Zone" is not very well-defined. It is based on observations / impressions of the abundance of mineralized zones from the near-surface environment, i.e. from the surface and down to about 100m (n addition to the two long cores LHKB-1 and LHKB-2, and the 300m vertical core DDH-019 drilled by REE Minerals).
The "Boomerang Zone" may or may not exist. The "Boomerang zone" actually corresponds to the zone of the FDC unit we presently do have most of the data. From the FDC unit outside the "Boomerang Zone" we only have very limited and poor out-crop data, and a very limited number of shallow drill-cores. The "Boomerang Zone", may, if it exists, be a number of separate REE-mineralized volumes.
Rough estimates made from the exposures within the Tuftestollen mine, and in the Fen Skole Stoll of the old Fen Iron Mines, suggests that at around 10% of the FDC in these volumes are REE-mineralized with high grade TREO. For the estimates of REE-resources a mineralized volume of 10 % is assumed for the "Boomerang Zone".

Calculation of volumes
It is obvious that eventual mining in the Fen complex must be under-ground, probably below about 100m from the surface. Allowing for mining in the depth interval 100-1000m subsurface, the following volumes will be used in the calculations:
- The total FDC-unit: 100-1000 m depth (1.15 km^2 x 900m), and 10% of this volume.
- The total volume of the Boomerang Zone 100 1000m depth (0.6km^2 x 900m), and 10 % of this volume.

The area and volume calculations used here does not include the "red-rocks" below the Gruveåsen area (central and eastern parts of the old Fen Iron Mine district), even though these rocks may contain considerable quantities of REE.

Density
The density of the FDC-rocks has been measured to be close to 3 g / cm^3, i.e. the rock weight is 3 ton/m^3.

Grade
Some attempts have been made to estimate the possible grade of the REE-mineralized zones within the FDC unit. From the discussion of the whole-rock geochemistry (section 8.1) grades of the mineralizations ranged between 2.6 and 4.5 % (all in TREO as defined in the introduction).

Calculation of contained TREO scenarios
All calculations are made for the 100-1000 m depth interval, and using grades discussed in section 8.1 and table 9 as guidelines.

Contained TREO in the total volume of the FDC-complex:
Assuming an average of 1.08% and 1.7 % TREO (averages from LHKB-1 and LHKB-2 respectively; see section 7.2) homogeneously distributed throughout the entire FDC volume from 100 to 1000 meters depth:
- 33.5 Mt TREO for a grade of 1,08%
- 52.8 Mt TREO for a grade of 1,7%

Contained TREO in 100% of the volume of the "Boomerang Zone":
- 32.4 Mt TREO for a grade of 2%
- 48.6 Mt TREO for a grade of 3%

Contained TREO in the "Boomerang Zone" assuming grades of 3, 4 and 5 % TREO in 10 % of the volume:
- 4.9 Mt TREO for a grade of 3%
- 6.5 Mt TREO for a grade of 4%
- 8.1 Mt TREO for a grade of 5%

Contained TREO in 10% if the entire FDC complex mineralized with a grade of TREO of 3% from 100 to 1000m depth.
- 9.3 Mt TREO for a grade of 3%

Warning and comments to the calculations!
The calculations presented above are based on very few data and should in no way be considered otherwise than being <u>possibilities</u> given the presently existing background data. These estimates do not comply to any international standard for resource classification.

The values of 33.5 and 52.8 Mt obtained for the total volume of the FDC unit is considered to be a realistic bracketing upper estimates of TREO for this entire volume. This volume is, of course, unrealistic for subsurface mining.

For the "Boomerang Zone" a subsurface mining of 10 % of the volume is considered technically possible if useful ore bodies exist. From the geochemical analyses of the mineralized zones a grade of 3% is likely to occur, 4 % is also possible, but 5% is regarded as very optimistic, but not impossible.

The estimate of 9.3 Mt with a grade of 3% TREO is not impossible if 10% of the entire FDC-complex is REE-mineralized, and that the "Boomerang Zone" does not exist. The estimates of 4.9 Mt and 6.5 Mt TREO within 10% of the volume of the "Boomerang Zone" is regarded as a useful estimate as a starting-point or future exploration.

The different estimates are plotted on figure 9.2 for comparison with other REE deposits. **The Fen FDC REE-mineralizations are potentially large in an international context. The Fen REE-mineralizations are likely to be the largest REE-F-carbonate / monazite deposits of continental Europe.**

Locality	Grade; % TREO	Source
Tuftestollen **Ts M1E** **Ts M1W** **Ts M2W**	 **3.7** **2.6** **4.4**	This report, page 44
Average of all mineralized, "exposed FDC" analyzed (including the Tuftestollen and Fen Iron Mine REE-mineralizations)	**3.9**	This report, table 8.1
The 4 m mineralization in the TEIG-2 drill-core	**4.49**	This report, table 8.1
Average of all Low-grade samples, "exposed FDC" (including the Ts and from surface samples	**0.81**	This report, table 8.1
Low-grade TEIG-2 drill-core	**0.72**	This report, table 8.1
Average LHKB-1	**1.08**	Coint and Dahlgren 2019
Average LHKB-2	**1.7**	Coint and Dahlgren 2019

Table 9.
Grades of various REE-mineralized zones and drill-cores from the Fen complex. See discussion of the data in the whole-rock section.

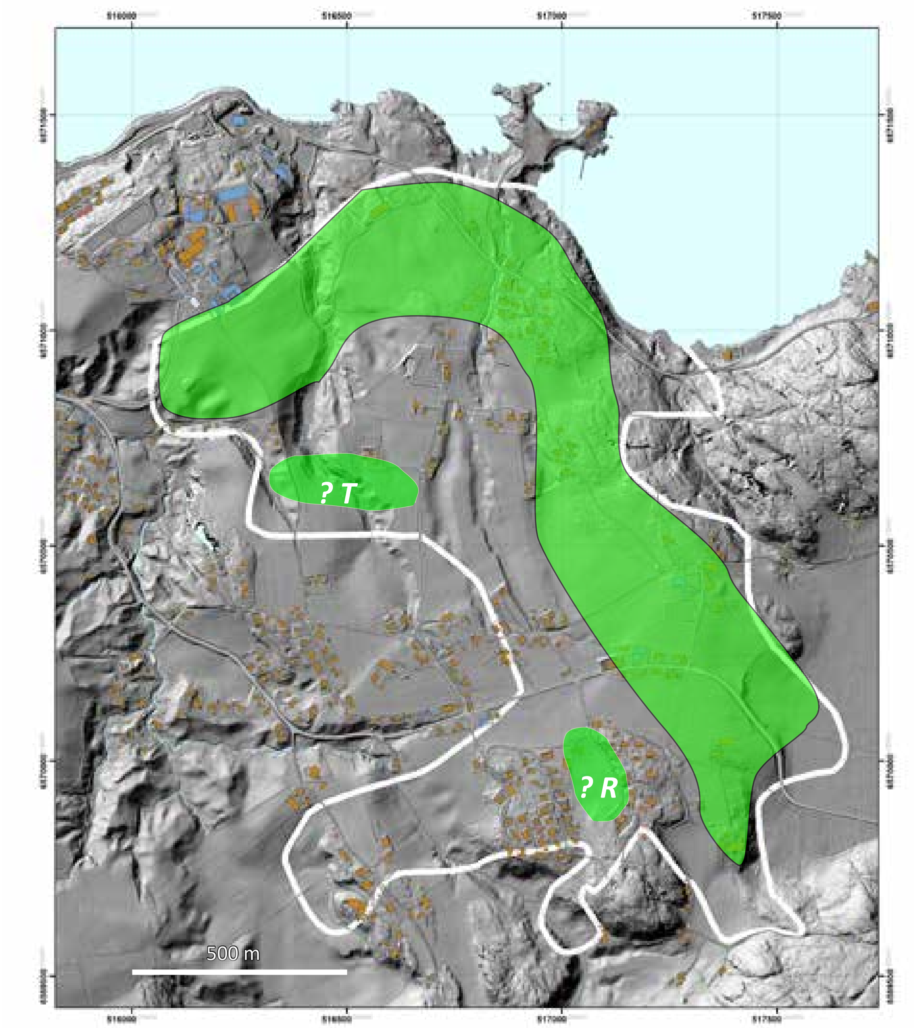


Figure 9.1
The "Boomerang Zone" (green area), is proposed to represent a REE-enriched zone of the FDC-unit. The surface area of this zone is 0.6-0.7 km[2]. The white line represents the outline of the entire FDC-complex. REE mineralization have also been observed in drill-cores from the two smaller, green areas with question marks (R = Rullekoll, the RKL-2 core; T = Norsk Bergverk , Tufte cores: T16, T17, T20, T21, T22, T23).

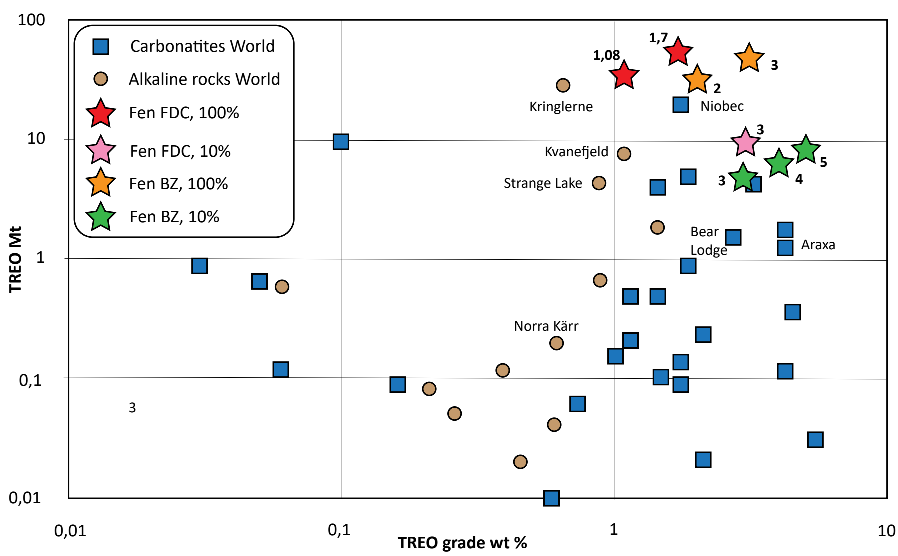


Figure 9.2
The estimated TREO, of the in-situ REE-mineralization in the Fen complex Fe-Dolomite carbonatites (stars) plotted for comparison with other REE-deposits world-wide. The numbers accompanying the stars are the grades, in TREO %, used for calculation. FDC = Fe-Dolomite Carbonatite Complex; BZ = Boomerang Zone. Data from other deposits after "Eurare" (Machacek and Kalvig 2017), and Kalashnikov et al (2016). To avoid crowding, only a few selected deposits are labelled with names. The data quality from the different deposits are highly variable, but this does not show up in the plot. Note the double-logarithmic scale.

10. Critical geological and geochemical factors
10.1 The damtjernites

The damtjernites were emplaced in the final stages of the formation of the Fen complex (Brøgger 1921, Sæther 1957, Dahlgren 1987). The relationship between FDC ("rauhaugite type 2") and the damtjernite was discussed by Sæther (1957). He argued that the formation of rauhaugite type 2 postdated the damtjernites. During the present study, and previously (Dahlgren 1987), ample evidence from drill-cores and exposures in the field shows, at least in the places studied, that the damtjernite post-date the FDC:

- Xenoliths of REE-mineralized FDC have been found in the long drill-core LHKB-2 (figure 7.2.3f) and in a freshly blasted exposure at Rullekoll (see photo figure 10.1.2).
- In the SØVE E7 drill-core a damtjernite dike, with chilled margins, has intruded the REE-FDC.

However, most of the damtjernites within the Fen complex have been extensively subjected to post-magmatic hydrothermal alteration. For this reason, and especially when observations are made on strongly weathered and poorly exposed outcrops, the age relationships between these two rock types may be difficult or impossible to unravel.
It should also be strongly emphasized that the damtjernite is rock-group that show very large compositional variations between localities (Dahlgren 1987). It is very likely that the damtjernites, which in some places are difficult to distinguish from the FDC-rocks, e.g. in the Rullekoll-Stinta area, actually was a damtjernite with a primary enrichment of carbonate(s) compared to other "normal" damtjernites.

The implication of these observations for the evaluation of the REE potential of the FDC is important for two reasons:

1. The damtjernites are younger than the FDC. The damtjernites are unlikely to be interesting for exploitation of REE even if they should contain a substantial volume of REE-FDC xenoliths. The argument is that the damtjernites, which in the cases studied constitute at least 50% of the rock volume, consists of a wide variety of heavy minerals like phlogopite, magnetite /spinel, apatite and alteration products like chlorite, "serpentine" and various carbonates. The damtjernites evidently cut the FDC complex as dikes and as diatremes / diatreme root zones (Dahlgren, on-going work). ***The volume of the damtjernite present within the FDC complex must be subtracted from the volume of FDC's, and lowers the possible volume containing REE-resources***

2. Some of the damtjernites contain abundant xenoliths of REE-bearing FDC. See figure 10.1.2 and 7.2.3f. These xenoliths most likely were derived from a REE-FDC situated below the levels they presently occur at (figure 10.1.1). This is a very encouraging relationship since it shows that REE-FDC must be fairly abundant at depth at widely separated localities (Søve and Rullekoll) within the FDC complex. The xenoliths may have been entrained in the damtjernite magma only a few meters below their present occurrence, but it is equally likely that they might have been entrained at a considerable depth, possibly deeper than any long drill-core drilled within the Fen complex so far.

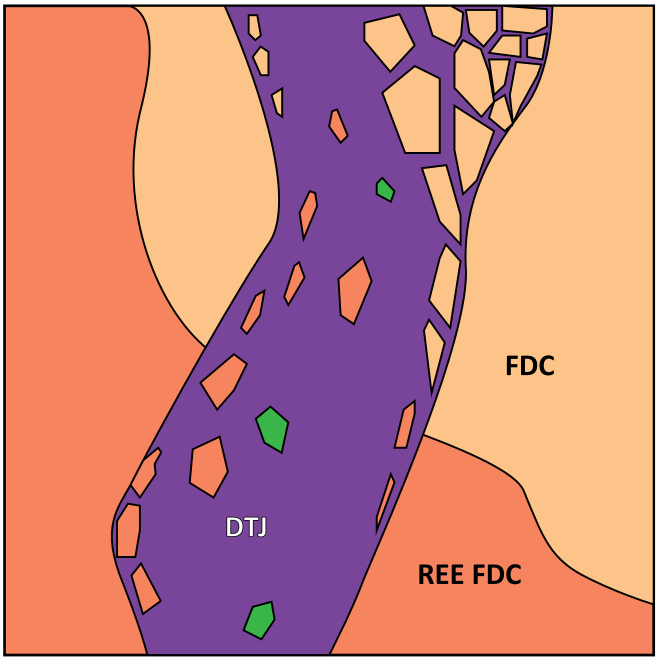


Figure 10.1.1
Schematic vertical profile showing a damtjernite (=DTJ) intrusion into REE-bearing FDC that has transported REE FDC xenoliths upwards into the FDC region. "Green xenoliths" represent a third rock type transported from below the base of the figure. These relationships may be on a scale varying from a few to several tens (hundreds?) of meters.

The damtjernites have, as mentioned above, been extensively hydrothermally altered within the complex. In certain areas, e.g. in the Rullekoll and Roligheten-Skippervoll areas, this alteration has been so intense that the FDC and damtjernites may look similar.

In the future exploration for REE it will be very important to map the damtjernites within the FDC complex. However, since most of the FDC complex is covered by thick clay deposits, their mode of occurrence (dikes, diatreme root-zones including damtjernite breccias), their distribution and size / volume is yet poorly known. A good 3D mapping of the FDC complex that has not been intruded by damtjernites will be crucial for any REE resource evaluation of the FDC complex. This can only be achieved by an extensive core drilling campaign, and possibly aided by geophysical surveys (ground or drone magnetometry? SkyTEM?).

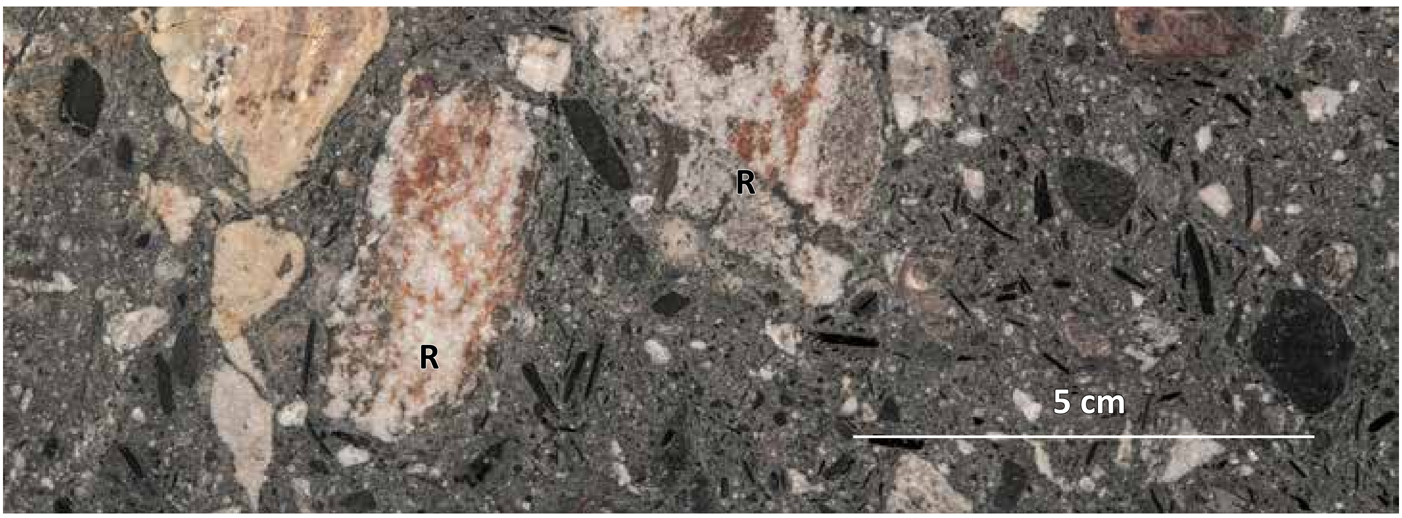


Figure 10.1.2
Photo of a typical damtjernite breccia. The fragments, labelled R, are REE-bearing Fe-dolomite carbonatites (REE-FDC). This sample demonstrate two important aspects: Firstly, that the REE-FDC occurs at depth and that fragments were entrained in the damtjernite magma during ascent, and, secondly, that the damtjernite, at least at this locality, is younger than the FDC. Elongate, dark minerals are phlogopite. This sample was collected in 2018 at Rullekoll UTM 517127 6570005, but a new house now covers that exposure.

Damtjernite and damtjernite "danger zones"

The damtjernites were not shown on the FDC map figure 5.1.5., although several damtjernites occur within the FDC area. These are indicated on figure 10.1.3.

At least some of the damtjernites are younger than the FDC rocks, but all damtjernites within the FDC area have been subjected to post-magmatic hydrothermal alteration. As was described earlier, this alteration, produced pervasive Fe-carbonatization and chloritization of the damtjernites. The most altered damtjernites may be very difficult to distinguish from FDC.
The damtjernites in the LHKB-2 core, some shallow cores at Tufte, and in exposures at Vibeto, Rullekoll, Fen Midtre, north of Rauhaug farm, in the Valley southeast of Søve, at Roligheten, and in southwestern hillside at Fenbukta, all have textures suggesting that they represent diatreme root-zones. The wall-rocks, i.e. the FDC has been brecciated, near the damtjernite diatremes, and there are good reasons to anticipate that numerous damtjernite veins anastomosingly transects the FDC. This may be a problem for exploitation of REE from FDC in such cases. Such zones are indicated as "damtjernite danger zones", violet colour, on the map (figure 10.1.3).
Due to poor exposure these zones are by no means accurate. Some of them may be wider than indicated. Other damtjernites not yet recognized should also be expected within the FDC area.

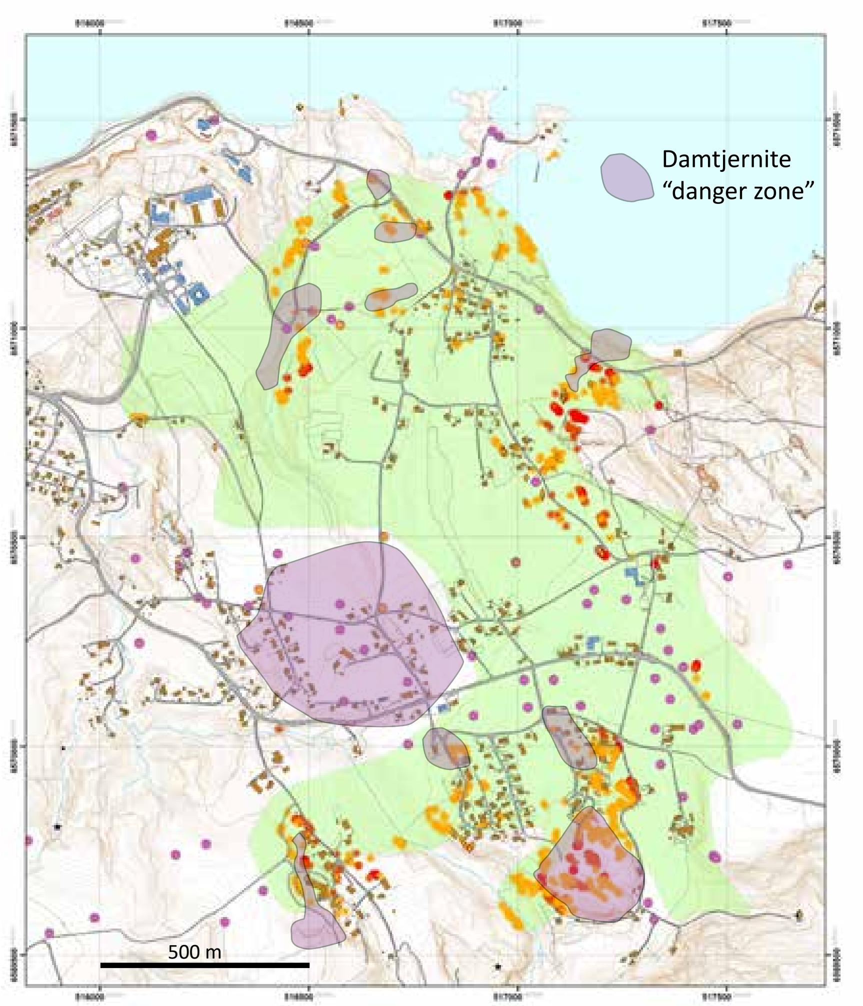


Figure 10.1.3
"Damtjernite danger zones"
Map of the FDC-unit and relevant damtjernites. The boundaries of the damtjernites are generally poorly known because of the lack of exposures.

10. Critical geological and geochemical factors
10.2 Hematitization / alteration

Hematite rocks, "Red-rocks", of the Gruveåsen area, i.e. the old Fen Iron Mine district, is well known to host very finely dispersed REE minerals (section 4.1.2).
The drill-cores from the eastern part of the Fen FDC unit many places show sign of hematitization of the FDC-rocks and accompanying REE mineralizations (figures 10.2.1 and 10.2.2). Some preliminary work indicate that the mineralogy and textures change considerably during hematitization (Dietzel et al. 2019). This process should be studied in detail since this may affect the physical properties of these rocks /minerals considerably. This in turn may require a different processing technique for extraction of the extensively hematitized REE-clusters compared to e.g. the less hematitized REE-mineralized rocks from Tuftestollen adit.
From the observations in the drill-cores it is likely that hematitization is more widespread at a shallow depth than deeper down in the complex (e.g. in LHKB-1). This raises the interesting scenario that also the hematitized rocks, the "red-rocks" at Gruveåsen, i.e. the Old Fen Iron Mine area, also are confined to a relatively shallow depth. The deepest shaft in the old Fen Iron Mines was worked down to 158m. No geological description does exist from this depth of the mines. It is not unlikely that REE-rich FDC may also occur below the hematitized rocks of the Gruveåsen area. This may eventually add considerably to the potential REE resources.

Figure 10.2.1
Hematitized REE mineral aggregates from drill-core (35 mm wide).

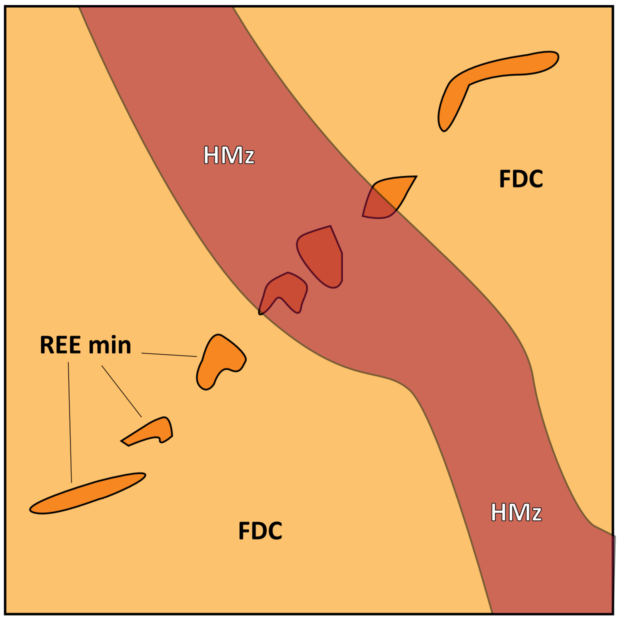


Figure 10.2.2
Sketch illustrating a trail of REE-mineral clusters within a FDC and a cross-cutting zone of hematitization that also affects the REE FDC clusters. The scale may vary from cm to tens of meters, and the relationships could be of any orientation in three dimensions.

10.3 Radioactive elements and radioactivity

The Fen Complex is well known in the media for radioactivity. The geology of the Fen Complex is very complicated and diverse. This also applies to the distribution of uranium and thorium, which vary extremely from one rock type to another within the complex. Additionally, the radioactive slag at Søve is also frequently discussed in the media. The relationships between the radioactivity and the geology is complex and these relationships are often poorly understood both by journalists and others. For any consideration of mining in the Fen complex, radioactivity will be a topic of discussion.

In this section an attempt will be made to clarify the relationships between rock types and radioactivity, where these rocks do occur, and also shed some light on other relevant aspects of radioactivity in the area. For this discussion reference will be made to the geological map figure 5.1.5, to table 10.3 and to the figures 10.3.3., 10.3.4 and 10.3.5.

All rocks on the Earth are radioactive
All rocks on Earth contain the radioactive elements uranium, U, and thorium, Th, and all rocks are thus per definition radioactive. However, the concentration of these elements varies considerably from one rock-type to another. Thus some rocks are more radioactive than others. The average continental crust contains 9.7 ppm Th and 2.7 ppm U.

The granites of the Telemark area and Østfold
Uranium and thorium were analysed from several granites in Telemark and Østfold by Killeeen and Heier (1975). Their data is summarized in table 10.3. The average Th is 41.8 ppm and average U is 8.8 ppm in the granites. The U and Th levels of the Fen complex will be discussed with the granites as a reference.

Low radioactivity rocks in the Fen Complex
The fenites , damtjernites, melteigites and ijolites contain low concentrations of U and Th. The parts of the Fen complex where these rocks occur have a radiation similar to the rocks in "normal" areas elsewhere in Norway.

Rocks with extremely high thorium in the Fen complex
Already in the 1950s it was recognized that the "red-rocks" ("rødberg" of the Gruveåsen area contain extremely high amounts of thorium (Bjørlykke 1955). This has been confirmed in several subsequent studies (Svinndal 1978, Dahlgren 1983, 2012, Heincke et al. 2008, Berg et al. 2012). Thorium concentrations may reach as much as 4000 ppm in certain samples, but the average of 511 samples is 872 ppm. (Dahlgren 2012). This is a high content of thorium also in a global context, and the thorium-rich rocks are confined to the Gruveåsen area, and to some extent to the Rullekoll area. (See map figure 10.3.3).

Thorium and uranium in the søve slag
The slag produced industrially through a metallurgical process based on niobium concentrate from the Søve mine are extremely rich in U and Th; up to 0.75% U_3O_8 and 1.7% ThO_2 (Dahlgren 2005). The slag s not a natural product, and is not comparable to any rocks anywhere. An eventual future mining of REE will be from a different rock type, and of different minerals than was used to make the Søve slag. ***Comparison of the Søve slag with eventual future REE mineral mining and processing is not relevant***.
The niobium minerals mentioned above were extracted from søvites. The søvites contain variable amounts of U and Th in pyrochlore. Scintillometer measurements in the field shows that this rock type is relatively rich in uranium, higher than in most granites, but few analyses are presently available.

Uranium and thorium in the FDC-rocks ("Rauhaugite)"
A large number of analyses of U and Th in the FDC's has been obtained from the drill-cores and the samples collected from exposures. (See the summary data in table 10.3).
Average Th ranges between 160 to 233 ppm for the FDC from different localities. For 11 samples out of 1788 the Th concentration is >1000 ppm, This may in part be due to the fact that "red-rocks" occur in some intervals in some of the cores. These are clearly outliers which do not change the average values significantly when omitted (from 208 to 201 ppm). The average is about 5 times higher than for granites in SE-Norway.
The thorium content of the FDC resides to a large extent in thorite, a thorium silicate. The average U in the FDC range between 8 and 11.5 ppm, and is comparable to the average of the granites. However, a few samples (14 of 1788) contain U above 100 ppm. The reason for this is not known.
Clearly, when considering mining of the REE from the FDC, thorium will be an issue that must be resolved. The presence of relatively high uranium in some FDC samples also requires that uranium must be considered. Most likely it will be possible to handle both elements during mining and mineral processing.

Radon and thoron
The gases radon and thoron are produced by radioactive decay of U and Th respectively. Very high thoron concentrations has been measured in the Fen Iron Mine district (Haanes et al. 2016). The very thorium-rich rock, the "red-rock", is found in more that 99% of the Fen Iron Mine area. The thoron-data from this area is therefore not directly comparable to eventual future mining areas in the FDC unit. Studies more relevant for assessment of thoron in eventual future mining of the FDC-rocks should be conducted.

	TEIG-2	DDH-019	LHKB-1	LHKB-2	REE Mineraliz.	All FDC	All FDC Th<1000; U<100	Granites Telemark and Østfold	Average upper contiental crust
Thorium									
Min	57	5	5	11	6	5	11 omitted	8,4	
Max	1140	694	2150	1255	796	2150		95	
Average	208	218	233	160	195	208	201	42	10
Median	163	185	182	129	168	163	162	44	
n	69	157	988	532	38	1788	1777	130	
Uranium									
Min	2	0	1	1	1	0	14 omitted	3	
Max	30	57	235	181	64	235		31	
Average	8	12	10	12	11	10	9	8,8	3
Median	6	8	6	7	4	6	6	7	
n	69	157	988	532	38	1788	1774	130	

Table 10.3
Summary table of the U and Th content of the Fen FDC rocks. See text for discussion.

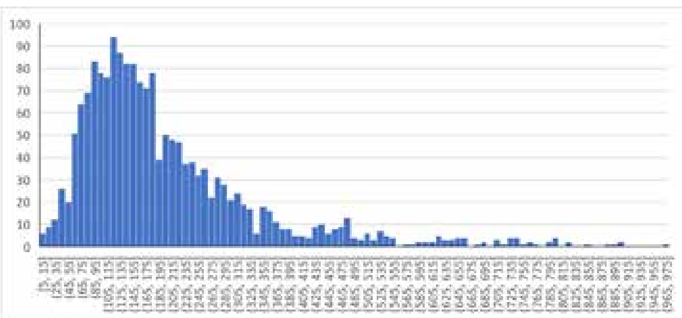


Figure 10.3.1
Histogram of 1777 analyses of thorium in the Fen FDC-rocks.

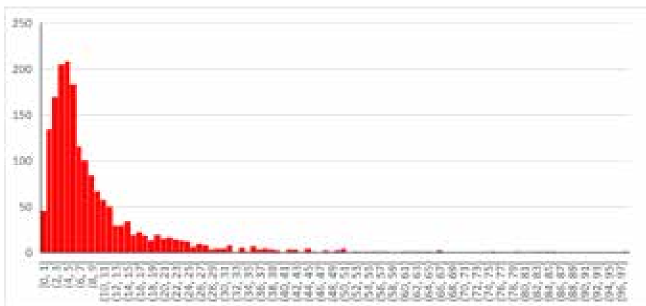


Figure 10.3.2
Histogram of 1774 analyses of uranium in the Fen FDC-rocks.

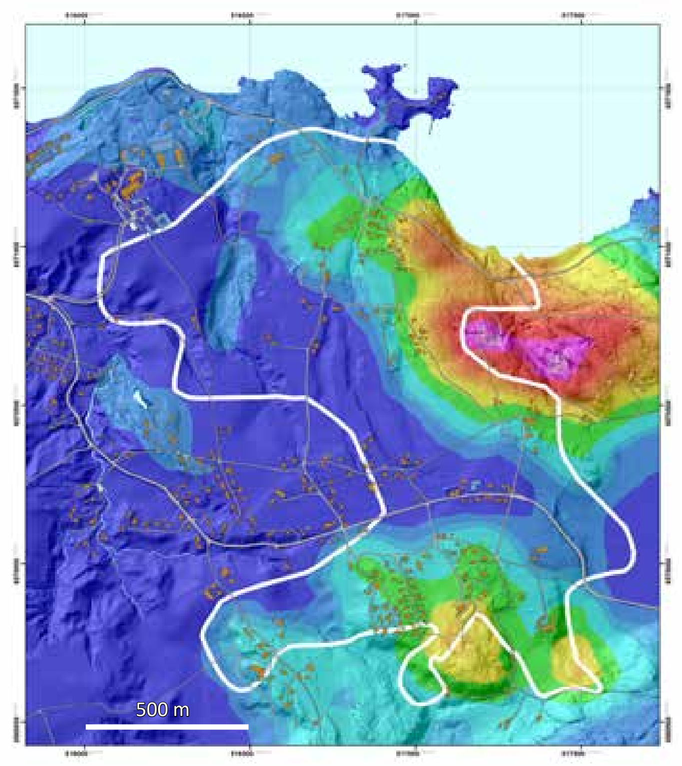


Figure 10.3.3
Air-borne gamma-ray map of the Fen FDC complex. This is a map reprocessed from the data of Heincke et al (2008), and shows the thorium variations on a linear scale. The FDC-complex is outlined with the white polygon. Over the FDC-unit the gamma-radiation from thorium is very low (blue and green colour), whereas in the Gruveåsen the gamma-radiation from thorium is high to very high (orange, red and violet). Also high radiation is present at Rullekoll, These high thorium areas coincide with the presence of the thorium-rich "red-rock" on the surface.
See the text to figure 10.3.5 for explanation of the very low thorium radiation of the "blue area" within the FDC polygon.

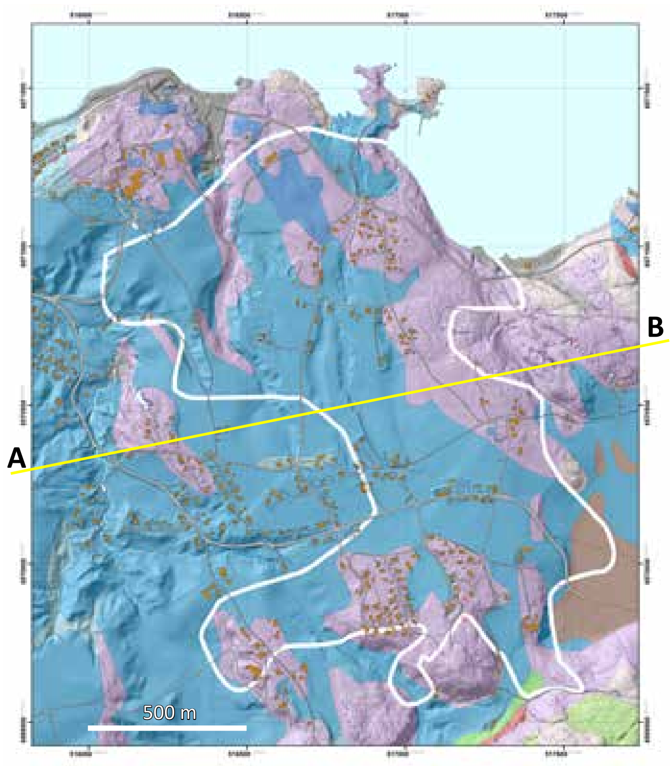


Figure 10.3.4
Map of Quaternary deposits covering the FDC-unit (white polygon) of the Fen complex (quaternary data from www.ngu.no; downloads).
Violet colour is soil weathered from the underlying bed-rocks.
Blue colour is Holocene clay deposits which may be more than 50m thick.
Compare with the gamma-ray map to the left and with the profile below (figure 10.3.5). The profile below was drawn along the yellow profile line on this figure.

Air-borne gamma-ray maps of the Fen FDC-complex

The anomaly map of gamma-rays from thorium measured from helicopter in 2006 (Heincke et al. 2008) is not useful as a map of gamma-radiation from the FDC-unit. The reason is that most of the FDC-unit is covered by thick clays (see map figure 10.3.4). Only a 1 m thick clay blanket is necessary to completely shield the gamma-rays from the underlying bed-rocks, a relationship shown by Dahlgren (1983). See figure 10.3.5. Thus airborne gamma-ray mapping is not useful for mapping of radioactivity of the entire FDC complex.

Summary of thorium and uranium in the FDC's

The average thorium content of the FDC-rocks is 208 ppm. This is about 5 times higher than in granites elsewhere in Telemark and Østfold (average 42 ppm). This is far lower than in the "red-rocks" (which contain up to 4000 ppm). The uranium concentration in the FDC-unit is low (average 10 ppm), and comparable to normal granites in southern Norway (8.8 ppm).
Nevertheless, the thorium and uranium of the REE mineralizations needs to be thoroughly investigated as a part of future exploration at Fen.

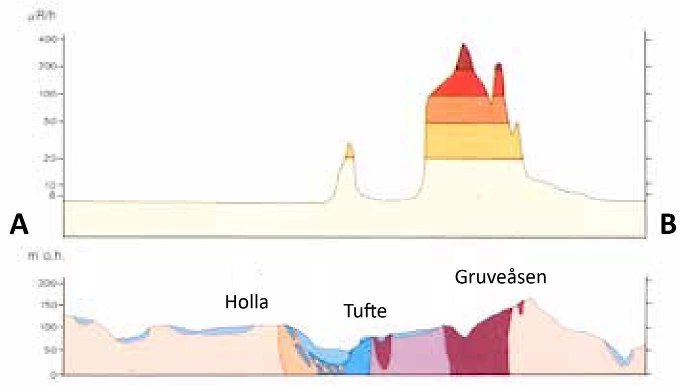


Figure 10.3.5
East-west profile across the "red-rocks" of the Gruveåsen area (to the right on the profile) and over the FDC unit (in violet). Profile-line is shown in figure 10.3.4. The Holocene clay blanket, shown by blue layers on the figure, completely shields the gamma-radiation from the underlying bed-rocks. Adapted from Dahlgren (1983). This explains why the airborne gamma-ray measurements do not record the radiation from the FDC-rocks.

In this chapter a few aspects related to the importance of further mineralogical investigations as a part of future exploration will be presented.

Composition of the REE minerals
It has been known for many years that bastnäsite, parisite-synchysite and monazite represent the principal REE minerals of the FDC-rocks in the Fen Complex. From an exploration point of view, the detailed REE compositional variations of these minerals will be of primary importance for the REE composition of the concentrate of these minerals. To date, only partial chemical mineral analyses have been performed using microprobe which is less capable of analyzing the HREE. A series of high quality LA-ICP-MS mineral analyses must be performed.
The REE also resides in the silicate allanite which may contain more than 30% REE. Allanite may also contain a substantial amount of Y. This implies that this mineral also may be a repository for the HREE. Modally the allanite does not appear to be an important phase, but it should not be neglected since it may be the main sink for more valuable REE.
The carbonate minerals are volumetrically the most important minerals of the FDC. It is known from various studies that REE may be incorporated in the carbonate lattices (Chakhmouradian *et al.* 2016). The partition of REE into the carbonate lattices is low, but since the volume of carbonates is high, a substantial amount of REE may be lost to the tailings.
Also apatite may contain substantial amounts of REE. The content of apatite in the FDC is highly variable, but these apatites should also be analyzed with LA-ICP-MS. Barite is generally assumed to contain relatively little REE in its lattices, but this mineral is so abundant that it must also be analyzed for REE.

Relative abundances of the REE minerals
The relative abundances of the different REE minerals is not known.
Bastnäsite is the favourable mineral for REE exploitation since this contains close to 75% REE (this and the following percentages are from www.webmineral.com). Monazite contains ca 65% REE. The parisite-synchysite, always syntactically intergrown, contains between ca 61 and 51 % REE. Thus a favourable ore contains dominantly bastnäsite or monazite, and less parisite-synchysite.

Inclusions of REE minerals in other mineral phases
Minute crystals of all the different REE mineral phases found occur as inclusions in other minerals. In the stereography section it was shown that quartz is an abundant phase in many of the REE mineralized zones, and that it may host an appreciable amount of tiny REE mineral inclusions. The carbonates also in many cases contain numerous REE-mineral inclusions. This also applies to barite. Thus an appreciable amount of REE minerals may be lost by gravity separation of quartz and carbonate minerals, and possibly barite. In several cases REE minerals have been observed as mineral inclusions within magnetite and pyrite. These minerals do not appear to contain large amounts of REE mineral inclusion, but REE may also be lost during magnetic separation or flotation.

Sulfides
Pyrite is a common sulfide in the FDC, and sphalerite occur in minor quantities. The content of the heavy metals is generally very low, and the Cd is camouflaged in sphalerite (figure 8.5). Sulfides should be analyzed since they may represent a problem. They may weather in the tailings and release heavy metals; if they contain heavy metals. However, the sulfides may indeed contain economically interesting elements. (See chapter 11).

Radioactivity
Minerals containing thorium or uranium require special attention. Thorite is a ubiquitous phase in most FDC, and other thorium-bearing mineral phases are likely to be found upon further study. Thorium is also contained in the crystal lattices of some REE minerals (Dietzel et al 2019). In any case ,thorium and uranium, the latter in very low concentrations, must be extracted from the ores and not sent to the tailings.

Quality of whole-rocks chemical analyses
When existing REE analyses from Fen are compared there appears to be a considerable discrepancy between REE-analyses from different methods. Accurate REE-analysis is probably still a challenge. In a future exploration program it would be wise to apply several different analytical methods, at least for a few representative samples, to evaluate precision and accuracy of the REE data obtained.

In conclusion: Whole-rock analyses must be combined with high quality mineral analyses, including the REE's, of all minerals. A substantial amount of REE is likely to be lost during processing, and valuable REE's my be incorporated into minerals which are not exploitable.

11. Evaluation of possible "added values" in potential REE-ores

The REE minerals represent the principal target of the potential ores. However, the REE minerals may at most constitute up to 5 % of the ore volume, and one should look for other minerals that may give "added value" to the ore. In the case of the Fen FDC-REE-ores this will most likely represent more than 95% of the rock volume. A preliminary discussion of possible "added values" is presented below.

Barite
Barite is an ubiquitous mineral in the REE mineralized rocks, but also within rock volumes that are not REE mineralized. Geochemical analyses show that there is no correlation between Ba and REE (e.g. figures 8.3.4 and 8.8.1). The modal content and the grain-size of barite varies appreciably. Typically some barite is intimately associated with the REE minerals in the REE-mineral aggregates, and a process for extraction of REE minerals will inevitably involve separation of barite either as a by-product or as waste. Commonly the Ba in geochemical analyses reflects the modal content of barite, but in some cases also other Ba-minerals, like celsian, has been observed. For evaluation of the distribution of barite future analyses should include analyses of sulfur as both sulfide and sulfate.

Fluorite
Fluorite is a common mineral in the FDC's, but usually occurs only as a few very small grains dispersed throughout the rock volume. There is no correlation between F and REE. In rare cases fluorite has been observed in impure masses (not veins) up to several m^3 in size (figure 5.4.2g). Whether this type of fluorite is pure enough to be useful for any industrial purpose remains to be investigated.

Sulfides
As already pointed out in the previous section the sulfides may be repositories for elements like Co and Ni which may be hosted by pyrite or pyrrhotite (possibly pentlandite). Sphalerite is also a common sulfide, and it has been shown that it contains chalcopyrite inclusions. Galena has been also observed as tiny grains within sphalerite, and the galena may be the host for the small quantities of silver seen in some analyses. Hessite has been found in one grain (Dietzel et al 2019). The gold found at ppb levels in a few whole rock analyses (appendix 4E) may also be located in the sulfides, or eventually as calaverite (figure 8.6). During mineral processing the sulfides must be removed and not disposed in the tailings. It should be looked into whether the sulfides could contribute to added value of the ores.

Scandium
Åmli (1977) reported scandium in thortveitite from Fen. No thortveitite has been observed in this study, and the Sc content of the FDC's is generally less than 20-30 ppm. However, there may be a correlation between Y and Sc (figure 8.4.5) which indicate a mineralogical control og both elements. Sc is a valuable element and it should be looked into which mineral this phase is incorporated.

Phosphates
Phosphate occur in variable amounts in the FDC analyses, and the phosphorous is contained in monazite and apatite. Apatite may be a useful mineral, and it may have incorporated some of the yttrium seen in several analyses. The apatite content varies greatly and apparently unpredictably. Xenotime is probably rare at Fen, but has been observed (Dahlgren, unpubl.).

Niobium
Niobium in the FDC's is far from as common as in the søvites. However, some intervals of the cores, e.g. in the TEIG-2 core, show relatively high Nb contents (up to about 3500 ppm). This element probably is concentrated in columbite (figure 6.2.8), but other Nb-mineral species may also be expected.

Thorium
Thorium is presently not used for any purpose in any quantity. This may change, however, if the 4th generation nuclear reactors will produce electric power from thorium. Nevertheless, the thorium has to be extracted from the ore and not deposited in the tailings. Thorium can then either be stockpiled or used in the future. Most of the thorium is hosted by the silicate thorite.

12. Exploration models

In this section several basic geological relationships of the REE-mineralizations, and their implications for exploration, will be discussed.

12.1 How to interpret the mineralization observed in the drill-cores?

Generally the FDC-rocks are very inhomogeneous. In the drill-cores the mineralization in the FDC-rocks rapidly changes along the core length. Do the mineralization change equally rapidly and randomly in every direction or are they arranged in a geologically systematic way, as veins for example?
With the limited information presently available the geometry of the REE mineralization may be interpreted in very different ways. Three different models are shown in figure 12.1. A mineralization recorded for an interval of e.g. 10 meter, may be interpreted as:
A. A horizontally mineralized layer 10m thick;
B. A spherical or similarly shaped body;
C. A steeply dipping thin dike / vein.

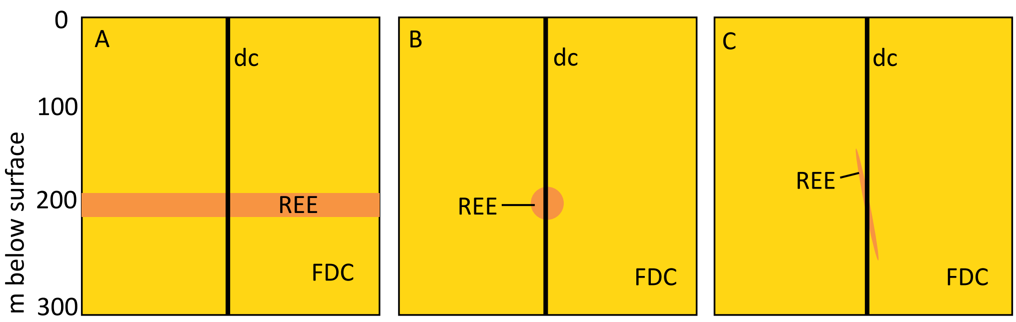


Figure 12.1
Sketch showing a vertical section from the surface (0m) and to a depth of 300m. The "normal" FDC-rocks are shown in yellow, and REE-mineralized zones are shown in orange. The black vertical lines centrally within each of the boxes represent drill-core traces (dc). Three geometrically different REE-mineralized bodies are shown in the boxes:
- ***A.*** *A large horizontal mineralized layer*
- ***B.*** *A spherical, mineralized body*
- ***C****.* *A steeply inclined, thin dike-like mineralized body*

See discussion in the text.

Model A is regarded as unlikely to represent an exploration model. The apparent correlation between mineralization at about 200m depth between the two drill-cores shown in figure 8.9b is interpreted as a coincidence, and not a correlation. Their textures suggests that they represent two different steeply dipping veins.No "REE-layer" has been documented by the data presently available (figure 8.9b). The field observations within the old mines rather suggests that model C represents a very likely model, i.e. that the REE is largely enriched in veins / vein systems. However, if some of the mineralized volumes represent disseminations "blobs" like model C may also apply as an exploration model. Such "blobs" may eventually be of variable shapes and size. Exploration should aim to identify veins, vein density and mineralized "blobs" in 3D.

12.2 The damtjernite and "red-rock" challenges

It was shown in section 10.1 that at least some of the damtjernites are younger than the FDC-rocks. Although these damtjernites may contain some xenoliths of REE-bearing FDC (e.g. figure 10.1.2), the damtjernites are rocks largely consisting of a mass of strongly altered (chloritized, serpentized and carbonatized) ferro-magnesian minerals. Such rocks will not be favorable for REE-mineral processing. The FDC-volumes which are densely intruded by damtjernite are considered as unsuitable for REE exploitation, and therefore should be avoided. It has also been shown that the FDC-rocks in several zones are strongly hematitized. Hematitized FDC is also regarded as unfavourable for REE exploitation, but this should also be investigated further.

Exploration for REE should aim for REE-mineralized zones which are not hematite-altered or intruded by damtjernites.

The relationship between the FDC, "the Boomerang Zone", i.e. the proposed part of the FDC complex containing abundant mineralization, the damtjernites and the hematitization that produced the "red-rocks" is shown on the cartoon figure 12.2. See figure caption for explanation.

The target zone for exploration, if this model is correct, will be the zones of the boxes C1 and C2 which are within the "Boomerang Zone", and that are not intruded by damtjernite and/or that have not been hematitized. Such target zones should be followed up with exploration drilling. Areas southeast and east of Søve, between Ødegård and the Fen old school, and further to the south-eastern margin of the complex are considered favorable for exploration. The Roligheten-Søvestrand area probably has a high risk of problematic damtjernites.

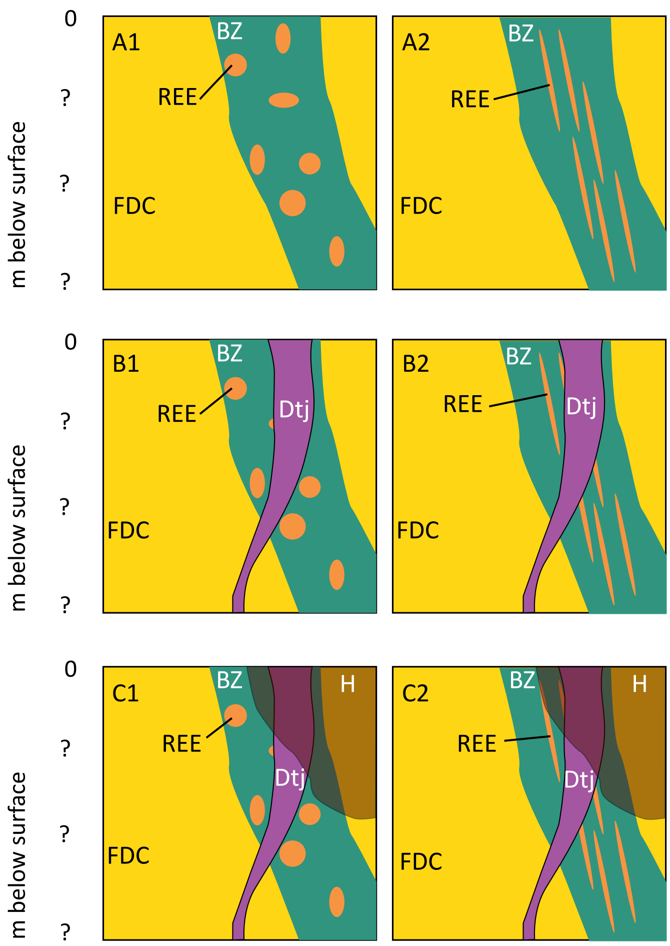


Figure 12.2 Sketch of the Fen FDC and subsequent
The "Boomerang Zone (BZ, in green) within the FDC unit (yellow). This "Boomerang Zone" is yet only a hypothetical zone.
A *Shows two interpretations of the mineralized zones (in orange), spherical "blobs" (REE, left box) and a vein-swarm (REE,right box).*
B*, Damtjernite (Dtj, violet color) has intruded and "digested" the rocks, including the mineralized veins, within the Boomerang Zone.*
C. *A considerable volume of the rocks has been hematitized , i.e. "red-rocks"(H, brown area).*

Basic preconditions for future mining at Fen

The Fen complex is an area of farmland, farms, roads, dwellings and other infrastructure on the surface. It is clear that any future mining in the Fen complex must be performed subsurface and not in an open pit. Furthermore there must be sufficient rock overburden to support the surface infrastructure from collapsing down into the mine system. A minimum depth of mining at Fen is not yet established, but it must be taken into consideration that the clay deposits may be very thick (up to several tens of meter) and that the underlying rock topography may be rather rugged and quite different from the smooth topography on the surface. Furthermore one should expect the bedrock to be faulted and fractured, and eventually deeply weathered in fault/fracture zones. Thus mining from an estimated depth of 100m below the surface and downwards is a useful assumption at this stage.

The present geological information on the FDC's below 100m depth

Any information about the geology deeper than a depth of 100m below the surface must come from drill-cores or from old mine workings. The status of the various sources are evaluated below:

Information from mines below 100m
The shafts and adits of the Fen old Iron Mines below the base level, which is at about 25-20 m a.s.l., are all water-filled. No geological information exists from these mines which extends down to ca 243.5m below the surface at Gruveåsen. Presumably the iron mines followed the hematite iron ores, and then it is likely that the "red-rocks" are present down to 243.5m depth in this area. However, no reliable information at depths below 100m depth from the surface exist.
The Søve and Tufte niobium mines were operated between 1953 and 1965. The Tuftestollen / Tufte mine does not extend below 20 m a.s.l., but the Søve mine was mined down to ca 180m below the surface. The søve mine is completely inaccessible and was furthermore mined in søvite which is irrelevant for the discussion of REE resources. Consequently no relevant information exists from depths below 100m under the surface from the niobium mines either.

Drill-core information below 100m:

- Norsk Bergverk cores (1950s). None of the cores which still are preserved yield any information below 100m.
- The "FSJ-cores" (section 4.1.2) were all drilled with a very gentle dip (10-15°), and they yield no information at depths below 100m from the surface
- "Fenco" (section 4.1.3) drilled one core (DDH2-81) at Gruveåsen where 115m was recovered from a depth below 100m.
- The "REE Minerals"-cores from 2012 and 2014 yield a total of 560m of cores recovered from a depth below 100m.
- The shallow cores drilled by the geological Advisor and NGU 2015-2018 (Appendix 3A) give no information at depths below 75m below the surface.
- LHKB-1 and LHKB-2 cores from 2017-2018 records rocks of 901m and 616m below 100m respectively (section 7.2).

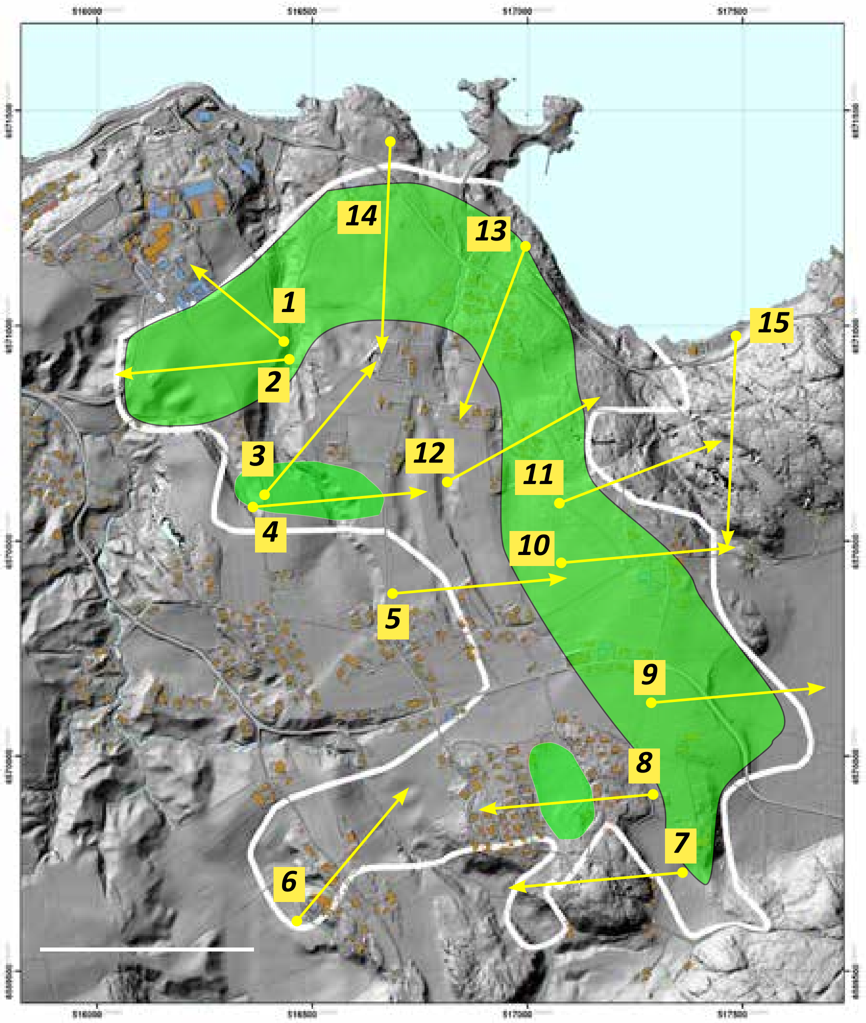


Figure 12.3
Proposed early exploration core-drilling assumed to be essential for identification of exploration targets. Drill-site numbers corresponds to the numbers in the text below. See place-names in appendix 2.

In conclusion: No reliable geological information of the FDC-rocks below a depth of 100m exists from any old mine workings. Cores from below a depth of 100m have been recovered from the following drill-cores/drilling campaigns: Fenco (1 core) 115m, REE Minerals (12 cores) 56.,6m and the LHKB-1 (901m) and LHKB-2 (616m); a total of 2195.5m of cores. <u>This is far to little to characterize any mineral deposit</u>.

Drilling strategy for REE exploration at Fen
Exploration drilling for REE at Fen must involve a massive amount of core-drilling. It is proposed that this should be performed in two major steps:

1. Reconnaissance exploration drilling to identify possible targets.
2. Drilling campaigns at localized targets.

Substantiated suggestions for various sites for reconnaissance drilling follows below and the numbers refers to figure 12.3. The numbering is random and not an indication of priority. Generally the suggested cores should be at least 500m long and drilled with a 45° dip:

1 and 2: Drilling from Fensdalen towards W and NW. Testing the mineralization found in shallow drill-cores and in the Tuftestollen adit; the boundary of FDC W of Tuftestollen.
3 and 4: Drilling from Søvedalen towards NE and E. Testing the central, northern part of the FDC unit where very little data exists so far.
5: From Borgejordvegen towards E, i.e. towards the TEIG-2 shallow core and the "red-rocks" to determine if the "red-rocks" replace the FDC at depth.
6: From Vibeto midtre towards NE. Will test whether there is a REE potential in this area.
7 and 8: From E of Rullekoll towards W. Will test the REE-potential beneath the Rullekoll-Rauhaug area.
9: From Fen towards Fensmyra. This will define how far E the FDC-unit extends in the SE part of the Fen complex where several REE-mineralized zones are known.
10 and 11: From the eastern, central part of the FDC unit towards E, i.e. towards the "red-rocks". In order to determine if the mineralized non-hematitized FDC-rocks occur beneath the hematitized FDC-rocks at the surface.
12 and 13: Testing of the "Boomerang Zone" in the NE-part of the FDC unit.
14: Drilling from Søvestranda towards S. REE-mineralization is abundant in the shallow cores in this area, but damtjernites may ay be problematic. This core may be important for further planning of drilling of target FDC-volumes devoid of damtjernite.
15: This is the ultimate test whether actually non-hematitized, REE-mineralized FDC-rocks occur at depth beneath "red-rocks" of the Fen Iron Mine area. May be drilled with a steeper dip than 45° to avoid drilling into old iron mines.

13. Conclusions and recommendations

The favourable rock for REE exploration in the Fen complex is the Fe-Dolomite carbonatite unit. Exploration of the “red-rock” is not recommended at this stage. The søvite, damtjernite or any other Fen rocks are unlikely to be targets for REE exploration.

A new geological map of the Fe-Dolomite-carbonatite (FDC) unit within the Fen complex has been presented in figure 5.1.5. The FDC unit has a surface outcrop area of 1.35-1.45km^2. Most of the unit is covered by thick layers of Holocene clay deposits. The long drill-cores have shown that this rock-type persists from the surface o a depth of at least 1000m. Total tonnage down to 1000m is ca 3100 million tons of FDC-rock.

The FDC-rocks are very inhomogeneous, and very variable in both texture and modal composition. Various breccia textures are common. The FDC-rocks have previously been called “rauhaugite type 2”, “ferrocarbonatite”, or “ankerite carbonatite”.

The main minerals are Fe-Dolomite (which is by far the most common mineral), calcite, chlorite / biotite, barite quartz, magnetite / hematite, pyrite, pyrrhotite. Other minerals include fluorite, apatite, sphalerite, thorite and REE-minerals. The principal REE-minerals are bastnäsite, parisite-synchysite and monazite. In some samples allanite is present, but is rarely abundant. The REE minerals occur in veins, in some places up to a few meter wide, and in aggregates of up to dm-size.

Previously unknown REE-mineralized zones have been discovered in several places within the Tuftestollen adit and within the western part of the old Fen Iron Mines at base-level. These all appear to be vein-like bodies, but in some places the mineralization may be interpreted as disseminations within the FDC-rocks.

The REE-mineralized FDC appear to occur relatively abundantly within a speculative zone called “the Boomerang Zone”.

The grade of several mineralized zones sampled within the Tuftestollen adit and in the Fen Iron Mines, range between 2.6 and 4.4 % TREO, and a 4m mineralized zone in the Fen 2016 TEIG-2 drill-core has a grade of 4.5% TREO. This compares well to the 10m with 5% TREO in the DDH-019-core drilled by the company "REE Minerals", and to the 5m zone of 4.8% TREO in the LHKB-1 drill-core.

The Fen FDC REE mineralization strongly LREE-enriched like any other carbonatite-related REE-mineralizations world-wide. This is also the case for the minerals bastnäsite, parisite-synchysite and monazite, but no full REE analyses have yet been performed on these minerals. LA-ICP-MS analyses of these minerals will be essential. The MREE and HREE may reside in other minerals such as allanite, Fe-Dolomite or other minerals.
The relative volumetric abundance between the REE minerals bastnäsite, parisite-synchysite and monazite is not known. The value of the ores will probably be higher the more bastnäsit and monazite it contains, since these minerals are richer in REE than parisite-synchysite.

Tiny REE mineral grains are commonly included, frequently in large amounts, within quartz, barite, and Fe-Dolomite hosts. REE-minerals inclusions also occur within pyrite and magnetite. This implies that a substantial amount of REE minerals may be lost through processing of the ores. If the HREE and MREE to a large degree are included in allanite, then these valuable REE’s may be lost and the economic value of the extracted REE’s will be subsequently lower.

Possible added values should be looked for in barite, apatite and fluorite, and possibly niobium minerals.

The sulfides require special attention. Although the whole-rock analyses indicate very low contents of heavy metals, such metals are likely hosted by sulfides. Ideally the sulfides should be removed during rock processing and not deposited in the tailings. The only common sulfide, in addition to the very abundant pyrite, is sphalerite, frequently observed with chalcopyrite inclusions. The Cd is clearly camouflaged in the sphalerite, which should be an easy phase to remove during mineral processing.
The sulfides may also be of economic interest. Ni, Co, and gold, the latter not found in the whole-rocks in more than at a ppb level, should be looked for in the sulfides.

At least some of the damtjernites are younger than the FDC-rocks and their REE mineralization. The damtjernites may be problematic since damtjernites are of no interest for REE exploitation and “subtract” from the FDC rock volume. This also is likely to be the case for the volumes of the FDC-unit that are hematitized.

The thorium content of the FDC-rocks and the REE mineralization is far lower than the thorium content in the “red-rocks”. The radioactivity from thorium may still e problematic and early evaluations must be made for this element regarding ore-value, mining, ore-processing, waste etc.

Some very preliminary calculations of the possible *in situ* REE resources has been performed:
A prerequisite is that eventual mining must be subsurface, and that no mining can take place at a shallower depth that 100m from the surface. Calculation of TREO in the total volume of FDC’s from 100 to 1000m below the surface:

- The entire FDC unit may contain 33.5 Mt TREO, if the grade is similar to the average grade (1.08%) in the 1000m drill-core LHKB-1
- The entire FDC unit may contain 52.8 Mt TREO, if the grade is similar to the average grade (1.7%) in the 1000m drill-core LHKB-1

Furthermore, a more realistic calculation is made for the “Boomerang Zone” potentially being mineralized in 10% of its volume, which is regarded as a conservative assumption:

- 4.9 Mt for a grade of 3% TREO
- 6.5 Mt for a grade of 4% TREO

These calculations indicate that the TREO of the Fen complex represent the highest TREO contained in any REE-flouro-carbonate and monazite deposit in Europe.

NOTE: None of these calculations, or any other calculations made by others, of the contained TREO in the whole, or in any part of, the FDC unit, are based on sufficient data to comply to any international resource reporting standard. <u>The Fen FDC unit, however, clearly and only qualifies as an exploration target at the present time.</u>

The future exploration work should include:
Extensive field-studies:

- ***An exploration drilling program to discover potential large-volume bodies of high-grade mineralization. This will involve a massive amount of core-drilling, many tens of kilometres, to a depth of at least 500m.***
- ***It is recommended that this drilling should test the proposed “Boomerang Zone”***
- ***Geophysical studies (ground / drone magnetic profiling).***
- ***A more detailed study of the field relationships of FDC and damtjernites, and how the damtjernites have affected the FDC unit.***

Whole-rock chemical analyses

- ***Whole-rock REE analyses should be performed by different analytical methods, at least on a subset of samples, to obtain full control of the accuracy of the REE concentrations.***
- ***A full range of P and F, and potentially total S and SO_4, should routinely be analyzed in mineralized samples.***

Very detailed mineralogical / mineral chemical studies:

- ***The full REE compositions of the REE minerals, and all other important mineral phases in the REE-mineralized zones.***
- ***The effect of hematitization on the REE mineralization.***
- ***The trace elements of sulfides***
- ***Radioactivity from thorium, and potentially uranium.***
- ***Recovery of very fine grained and disseminated REE minerals and REE minerals included in quartz and barite***

Many challenges for the possible REE-exploitation at Fen are known, and many more will emerge. The solution to all these challenges can only be achieved through close cooperation between the industry, academia, R&D institutions, government agencies, the local residents and politicians.

Og så en konklusjon på norsk:
Nome kommune har nå et kart, figur 5.1.5, som viser utbredelsen av bergartsenheten der det er mest sannsynlig å finne REE-ressurser. Dette kartet anbefales brukt i kommuneplanens arealdel og legges inn som hensynssone for mulig framtidig REE-utvinning. Nome kommune mottar dette kartet digitalt.

14. References

Scientific and review papers, reports, theses and conference abstracts published as a part of the present project by the Geological Advisor and co-workers:

Scientific and review papers in international journals:

Dahlgren, S., 2015. REE and thorium potential of the Fen Complex. In: Norway – A supplement to Mining Journal February 2015, p12.

Haanes, H., Finne, I., Kolstad, T., Mauring, Dahlgren, S., Rudjord, A.L. 2016. Outdoor thoron and progeny in a thorium rich area with old decommissioned mines and waste rock. Journal of Environmental Radioactivity 162-163, 23-32.

Elliott, H.A.L., Wall, F., Chakhmuradian, A.R., Siegfried, P.R., Dahlgren, S., Weatherley, S., Finch, A.A., Marks, M.A.W., Dowman,E., Deady, E. 2018. Fenites associated with carbonatite complexes: A review. Ore Geology Reviews 93, 38-59.

Dietzel, C.A.F., Kristandt, T., Dahlgren, S., Giebel, R.J., Marks, M.A.W., Wenzel, T., Markl, G. 2019. Hydrothermal processes in the Fen alkaline-carbonatite complex, southern Norway. Ore Geology Reviews 111, 1-18.

Reports and theses:

Dahlgren, S., 2016: Fensfeltet. Kjerneboringer Tufte 2016. Regiongeolograpport 1-2016. 20pp.

Dahlgren, S., 2017: Geologiske ressurser og næringsutvikling i Fensfeltet - Statusrapport 2015-2016. Regiongeolograpport 1-2017. 24pp.

Dietzel , C., and Kristandt, T. 2018. Hydrothermal processes in the Fen carbonatite complex, southern Norway. Master thesis. Department of Geosciences Eberhard Karls University Tübingen, Germany. 59 pp + Appendices.

Coint, N., and Dahlgren, S. 2019. Rare earth elements (REE) in two long drill-cores from the Fen Carbonatite Complex, Norway. Norwegian geological survey report 2019.008, 36 pp + Appendices. www.ngu.no

Conference presentations and abstracts:

Dahlgren, S., 2016, The Fen Carbonatite Complex: Geology and Resources in the Past, at present, and in the Future. In: Fenite and Geophysics as Exploration Tools. HiTech AlkCarb Expert Council 2, Malawi. Programme and abstract volume, 45-48.

Dahlgren, S., 2017. The Fen Carbonatite Complex, Norway - An important future REE, Th and Nb resource? 11th Fennoscandian Exploration and Mining Conference, Levi, Finland.

Dahlgren, S., 2018. The Fen carbonatite Complex, Norway: A potential world-class REE-mineral deposit. Nature Geioscience Conference «Minerals and Materials for a Sustainable Future», Trondheim, September 12th 2018.

Dahlgren, S., 2019. The Fen Carbonatite Complex, Norway. A potential world-class REE mineral deposit. Is it the future Norwegian contribution of raw materials to the global green technology industries? Norwegian Geological Winter Conference, Geological Society of Norway, Bergen January 7th.

Other references cited in the text:

Anders, E., Ebihara, M., 1982. Solar-system abundances of the elements. Geochimica et Cosmochimica Acta 46, 2362-2380.

Andersen, T., 1983. Iron ores in the Fen central complex, Telemark (S. Norway): Petrography, chemical evolution and conditions of equilibrium. Norsk geologisk tidsskrift 63, 73-82.

Andersen, T., 1984. Secondary processes in carbonatites: petrology of "rødberg"(hematite-calcite-dolomite carbonatite) in the Fen central complex, Telemark (South Norway). Lithos 17, 227-245.

Andersen, T., 1986. Compositional variation of some rare earth minerals from the Fen complex (Telemark SE Norway): Implications for the mobility of rare earths in a carbonatite system. Mineralogical Magazine 50, 503-509.

Andersen, T., 1987a. A model for the evolution of hematite carbonatite, based on whole-rock major and trace element data from the Fen complex, southeast Norway. Applied Geochemistry 2, 163-180.

Andersen, T., 1987b, Mantle and crustal components in a carbonatite complex, and the evolution of carbonatite magma: REE and isotopic evidence from the Fen complex, southeast Norway. Chem. Geol. 65, 147-166.

Andersen, T., Qvale, H., 1986. Pyroclastic mechanisms for carbonatite intrusion: Evidence from intrusives in the Fen central complex, SE Norway. The Journal of Geology 94, 762-769.

Berg, Ø., Bjørnstad, T., Dahlgren, S., Nøvik, S., Rondeel, W. og Totland, A., 2012: Thorium - En framtidsressurs i Oslofjordregionen? Regiongeologen Buskerud Telemark Vestfold, Rapport 2-2012, 1- 24.

Bjørlykke, H., 1955. Undersøkelser av radioaktive bergarter, Søve. Notat. 3pp. Directorate of Mining archive, BV 7081.

Bloodworth, R. and Schmidt, R., 1971. Determination of quantitative Rare Earth mineralogy of drill core no 2 from the Fen Deposit. 21pp + appendices. Directorate of Mining archive, BV 1333.

Brøgger, W.C., 1921. Die Eruptivgesteine des Kristianiagebietes. 4. Das Fengebiet in Telemark, Norwegen. Videnskaps-Selskapets Skrifter 9, 1-402. Academy of Science, Oslo.

Braaten, O., 1985. Fen-prosjektet sluttrapport, fase I, 30.6.83-1.4.85. 24pp + appendices. Directorate of Mining archive, BV 5164.

Chakhmouradian, A.R., Reguir, E.P., Coueslan, C., Yang, P. 2016. Calcite and dolomite in intrusive carbonatites. II. Trace-element variations. Mineral. Petrol. 110, 361-377.

Chakhmouradian, A.R., Reguir, E.P., Zaitsev, A.N., Coueslan, C., Xu, C., Kynicky, J., Mumin, A.H., Yang, P. 2017. Apatite in carbonatitic rocks: Compositional variation, zoning, element partitioning and petrogenetic significance. Lithos 274-275, 188-213.

Dahlgren, S., 1983. Naturlig radioaktivitet i berggrunnen. Gamma-strålingskart. Fensfeltet, Telemark, m 1:10 000. Prosjekt temakart, Telemark. Fylkeskartkontoret i Telemark.

Dahlgren, S., 1987. The satellitic intrusions in the Fen carbonatite - alkaline rock province, Telemark, Southeastern Norway. Distribution, emplacement, compositional characteristics and petrology. Unpubl. Cand. Scient. Thesis, Univ. of Oslo, 1-350.

Dahlgren, S., 1994. Late Proterozoic and Carboniferous ultramafic magmatism of carbonatitic affinity in southern Norway. Lithos 31, 141-154.

Dahlgren, S.,2005*:* Miljøgeologisk undersøkelse av lavradioaktivt slagg fra ferroniobproduksjonen ved Norsk Bergverk på Søve 1956-1965. Regiongeologen Buskerud Telemark Vestfold, Rapport 1-2005, 1-48.

Dahlgren, S., 2006. Fenvulkanen. In: Ramberg, I.B., Bryhni, I., Nøttvedt, A. (eds): Landet blir til. Norges geologi, p146. Norwegian Geological Society.

Dahlgren, S.,2012: Thorium i Fensfeltet. - Ressursanslag. Regiongeologen Buskerud Telemark Vestfold, Rapport 1-2012. 1-24.

Davris, P., Marinos, D., Balomenos, E., Alexandri, A., Gregou, M., Panias, D., Paspaliaris, I. 2018. Leaching of rare earth elements from "Rødberg" ore of the Fen carbonatite complex deposit, using the ionic liquid HbetTf2N. Hydrometallurgy 175, 20-27.

Goodenough, K., Schilling, J., Jonsson, E., Kalvig, P., Charles, N., Tuduri, J., Deady, E., Sadeghi, M., Schiellerup, H., Müller, A., Bertrand, G., Arvannitidis, N., Eilopoulos, D.G., Shaw, R.A., Thrane, K., Keulen, N. 2016. Europe's rare earth element resource potential: An overview of REE metallogenetic provinces and their geody,namic setting. Ore Geology Reviews 72, 838-856.

Heincke, B.H., Smethurst, M.A., Bjørlykke, A., Dahlgren, S., Rønning, J.S., Mogaard, J.O., 2008. Airborne gamma-ray spectrometer mapping for relating indoor radon concentrations to geological parameters in the Fen region, southeast Norway. Geology for Society, Geological Survey of Norway Special Publication 11, 131-143.

Hultin, I., 1981. Fen, Gruveåsen, diamond drilling 1981 and gammaray surface measurements. 7pp + appendices. Directorate of Mining archive, BV 421.

Hultin, I.G., 1985. Scandium-Europium-og Nedymium-undersøkelser i Gruveåsen, Ulefoss, Telemark. 5pp+ appendices. Directorate of Mining archive, BV 5675.

Kalashnikov, A.O., Konopleva, N.G., Pakhomovsky, Yu. A. and Ivanyuk, G. Yu., 2016. Rare earth deposits of the Murmansk region, Russia - A review. Economic Geology 111, 1529-1559.

Killeen, P.G. and Heier, K.S., 1973. Radioelement distribution and heat production in Precambrian granitic rocks southern Norway. Det Norske Videnskaps-Akademi I Mat.-Naturv. Klasse.Skr. Ny serie 35, 1-32.

Hornig-Kjarsgaard, I., 1998. Rare earth elements in sövitic carbonatites and their mineral phases. Journal of Petrology 39, 2015-2021.

Landreth, J.O., 1979. Mineral Potential of the Fen Alkaline Complex, Ulefoss, Norway. 55pp. Directorate of Mining archive, BV 1332.

Lie, A., and Østergaard, C., 2012. The Fen Carbonatite Complex, Ulefoss, South Norway. Exploration drilling, March 2012. 21st North Mineral Consulting and Exploration, Svendborg, 50pp + Appendix A, Geochemistry.

Lie, A., and Østergaard, C., 2017. The Fen Carbonatite Complex, Ulefoss, South Norway. Drilling campaign February- March 2014. 21th North Mineral Consulting and Exploration, Svendborg, 51pp + Appendix A, Geochemistry.

Machacek, E. and Kalvig (eds.) 2017. Eurare. Development of a sustainable exploitation scheme for Europe's rare earth ore deposits. http://www.eurare.eu/docs/T1.1.2_Report-final-280217.pdf

Marien, C., Dijkstra, A.H., Wilkins, C., 2018. The hydrothermal alteration of carbonatite in the Fen Complex, Norway: mineralogy, geochemistry, and impilications for rare earth element resource formation. Mineralogical Magazine 82, 115-131.

Mitchell, R.H., Brunfelt, A.O., 1975. Rare earth element geochemistry of the Fen alkaline complex, Norway. Contributions to Mineralogy and Petrology 52, 247-259.

Möller, P., Morteani, G., Schley, F., 1980. Discussion of REE distribution patterns of carbonatites and alkalic rocks. Lithos 13, 171-179.

Mørk, K., 1982. The Fen Project: Geology of the northeastern sector of the Fen complex, the Gruveåsen-Bolladalen subarea. 21pp + appendices. Directorate of Mining archive, BV 416.

Ramberg, I.B., 1973. Gravity studies of the Fen complex, Norway, and their petrological significance. Contributions to Mineralogy and Petrology 38, 115-134.

Schuiling, J. 2013. Petrography, mineralogy and whole-rock data of the major lithologies of the Fen Complex.Norwegian geological survey report 2013.034, 18 pp. www.ngu.no

Smith, M.P., Moore, K., Kavecsanszki, D., Finch, A.A., Kynicky, J. and Wall, F. 2016. From mantle to critical zone: A review of large and giant sized deposits of the rare earth elements. Geoscience Frontiers 7, 315-324.

Svinndal, S., 1967. Undersøkelser etter sjeldne jordartselementer (RE) i Fensfeltet, Ulefoss, Nome, Telemark. 23pp + appendices. NGU-report 776.

Svinndal, S., 1968a Undersøkelser etter sjeldne jordartselementer (RE) i Fensfeltet, Ulefoss, Nome, Telemark. 42pp + appendices. NGU-report 820A.

Svinndal, S., 1968b. Undersøkelser etter sjeldne jordartselementer (RE) i Fensfeltet, Ulefoss, Nome, Telemark. 46pp, incl. appendices. NGU-report 820B.

Svinndal, S., 1971. Undersøkelser etter sjeldne jordartselementer (RE) i Fensfeltet, Ulefoss, Nome, Telemark. 18pp + appendices. NGU-report 966.

Svinndal, S., 1973. Thorium i Fensfeltet, Ulefoss, Nome, Telemark. 28pp + appendices. NGU-report 1162.

Sæther, E., 1957. The alkaline rock province of the Fen area in southern Norway. I kommisjon Hos F. Bruns, Bokhandel, Trondheim. Det Konglige Norske Vitensksap-Selskaps Skrifter 1, 1-150. The Royal Academy of Science, Trondheim.

Teigen, O., 1928. Oversigtskart over Fæhnsgrubefeltet med muthingsmerker samt hovedstollplanet. Scale 1:1000. Norwegian commissioner of Mines, Archive map BV11569.

A.E.Verplanck, P.L., Van Gosen, B.S., Seal, R.R. and McCafferty, A.E., 2014. A deposit model for carbonatite and peralkaline intrusion-related rare earth element deposits. Scientific Investigations Report 2010-5070-J. 58pp. US Geological Survey.

Verplanck ,P. L., Mariano,A.N. and Mariano, A., 2016. Rare Earth Element ore geology of carbonatites. Reviews in Economic Geology 18, 5-32.

Vogt, J.H.L., 1910. Norges Jernmalmforekomster. Norges geologiske undersøkelse, Kristiania.

Wiik, V.H., 1982. The Fen project: A geological survey of the Vipeto-Rullekol sub-area. 34pp + appendices. Directorate of Mining archive, BV 415.

Yang, K.-F., Fan, H.-R., Santosh, M., Hu, F.-F., Wang, K.-Y., 2011. Mesoproterozoic carbonatitic magmatism in the Bayan Obo deposit, Inner Mongolia, North China: Constraints for the mechanism of super accumulation of rare earth elements. Ore Geology Reviews 40, 122-131.

Østergaard, C., 2016. The Fen REE Deposit, South Norway. Resources, metallurgy & OPEX/CPEX. REE Minerals - 21st North. Power-point presentation (incomplete). www.reeminerals.no

Åmli, R., 1977. Carbonatites. A possible source of scandium as indicated by Sc mineralization in the Fen peralkaline complex, southern Norway. Economic Geology 72, 855-869.

Links:

www.ngu.no
www.dirmin.no
www.reeminerals.no
www.eurare.eu
https://publications.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1/language-en

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ALL eventual errors in this report belongs to me.

Geological advisor Sven Dahlgren.
Buskerud Telemark Vestfold County Councils

The EU Horizon 2020 Programme HiTech Alk Carb project-meeting in Malawi, 2016

Prof. G. Markl (left), student T. Kristandt, S. Dahlgren and student C. Dietzel at Fen in 2017. Professor Markl and the two students were from the Univ of Tübingen, Germany. The two students performed their master study on rocks from Fen.

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Field assistants at Fen in the spring 2015. From the left Björn Strömberg, Oda Bjerva, Bergljot Storruste Kulsrud, Tone Marit Haugland Strand, Ida Hope, Ingvild Schmidt, and the project leader Sven Dahlgren (far right).

Drill-crew at Fen in the fall 2015. From the left Sven Dahlgren (drilling strategy, administration and core-logging), drill-crew: Tone Marit Haugland Strand, Ingrid Sætersdal, Björn Strömberg, and chief driller Geir Viken, NGU.

Field team at Fen 2017 to 2019. From the left: Björn Strömberg, Håvard Grønnevik and the Geological Advisor Sven Dahlgren. Here in the Tuftestollen adit.

Håvard Grønnevik saw-splitting the shallow drill-cores.

Appendices

Appendix 1: Rock and mineral abbreviations

Rock abbreviations

FDC = Fe-dolomite carbonatite
="ferrocarbonatite" = "ankerite"-carbonatite = "Rauhaugite type 2"

CFM = Ca-Fe-Mg carbonatites (these are not corresponding to rauhaugite / FDC or søvites)

Abbreviations accompanying the micro-images:

PM = Polarization microscope
TL = Transmitted light
RL = Reflected light
XP = Crossed polars

BSI = Backscatter image
EDX = EDX element map.

Mineral abbreviations

Aln Allanite
Ank Ankerite
Ap Apatite

Brt Barite
Bsn Bastnäsite
Bt Biotite

Cal Calcite
Cel Celsian/Ba-feldspar
Chl Chlorite
Cmb Columbite
Cpy Chalcopyrite

Dol Dolomite

FeDol Fe-rich dolomite
Fl fluorite

Gl Galena

Hem Hematite

Kfs K-Feldspar

Mag Magnetite
Mbd Molybdenite
Mnz Monazite

Pcl Pyrochlore
Prs Parisite
PSy Parisite-Synchysite in syntactic intergrowths
Py Pyrite
Po Pyrrhotite

Qz Quartz

RFC REE fluoro-carbonates
Rt Rutile

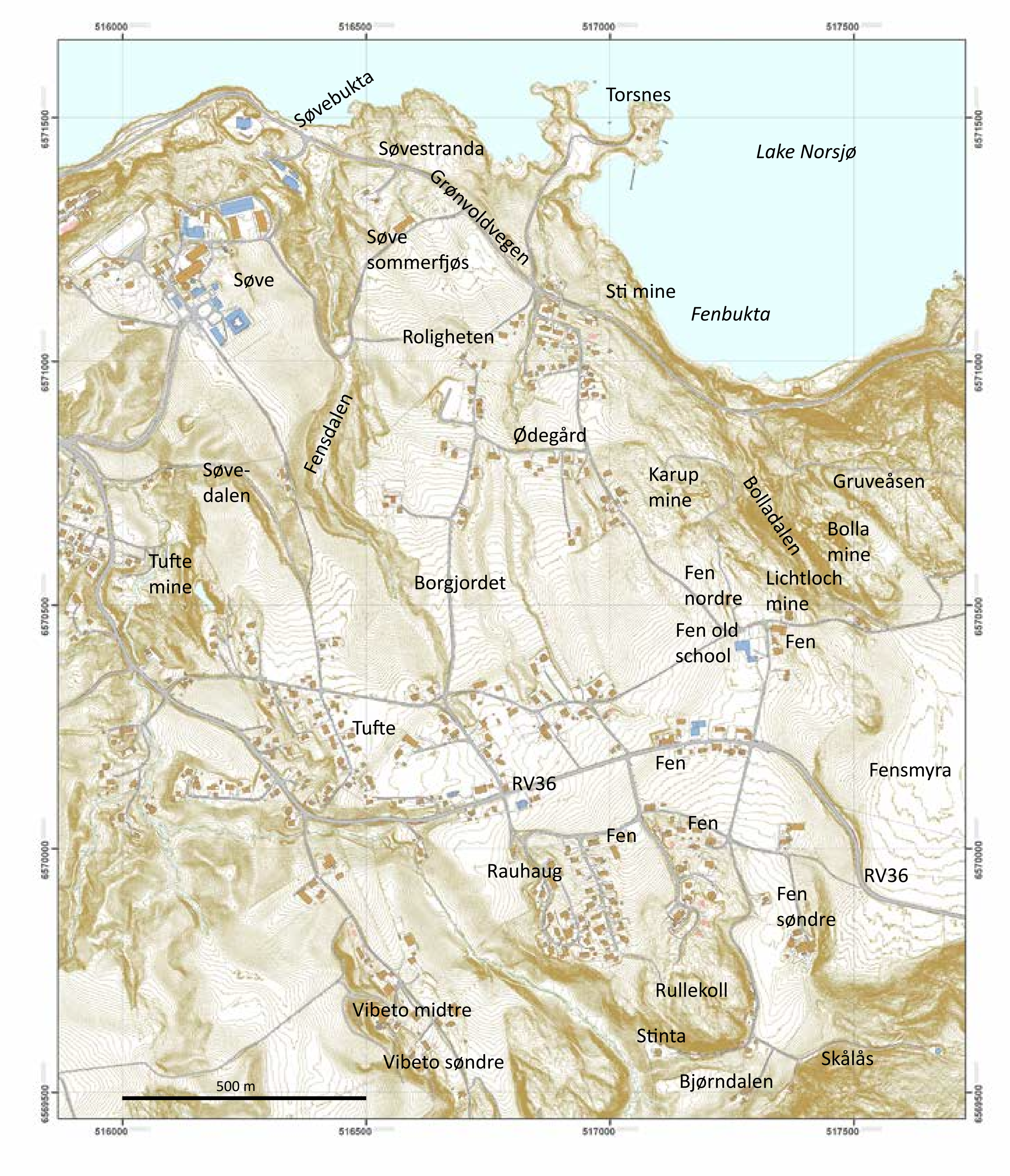
Sl Sphalerite
Srp Serpentine
Syn Synchysite

Thr Thorite
Tlc Talc
Ttv Thortveitite

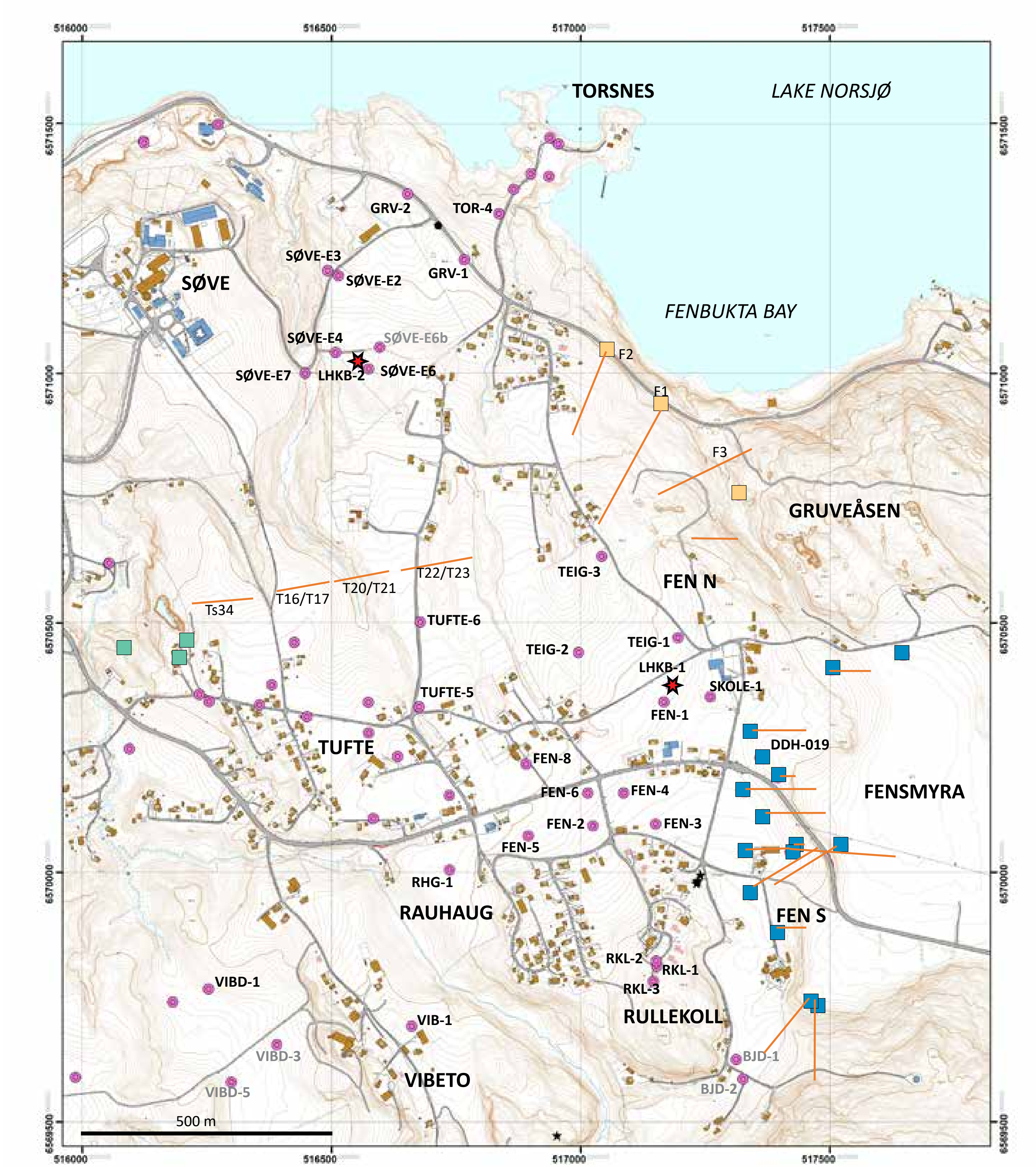
Xen Xenotime

Zrc Zircon

Appendix 2
Topographic map with place-names used in the text



Appendix 3A
Drill-cores relevant for the discussion of the Fen FDC-unit
Map of drill-sites relevant for FDC



Legend

- Geological Advisor and NGU Shallow drill-cores 2015-2018
  - Black ID labels shows cores drilled into FDC, or presumably altered FDC's.
  - Gray ID labels shows drill-sites where bedrock was not reached due to too thick clay deposits (>15-21 m).
  - Drill-sites with no ID labels are not relevant for the FDC's
- Sites of the NGU and Geological Advisor long drill-cores 2017-2018 (LHKB-1 and LHKB-2)
- REE Minerals drill-cores 2012 and 2014
- Norsk Bergverk cores (1950-ies)
- Forskningsgruppe for sjeldne jordarter drill-cores ca 1970 (not available)

Orange lines are horizontal projections of drill-core traces

Appendix 3A
Drill-cores relevant for the discussion of the Fen FDC-unit
Fen shallow core drill-sites Geological Advisor and NGU 2015-2018: Coordinates and technical core details
(Note: Norwegian decimal, "comma", notation is applied in the tables.)

Core ID	CPOS-GPS Northing UTM zone 32	CPOS-GPS Easting UTM zone 32	Azimuth degrees	Dip degrees	Bedrock Start depth m	EOC m	Core length m
Fen 2015 RKL-1	6569810,7690	517153,2685	130	45	0,00	50,00	50,00
Fen 2015 RKL-2	6569821,2689	517151,8533	345	45	0,00	50,00	50,00
Fen 2015 RKL-3	6569780,4617	517146,4415	134	45	0,00	50,27	50,27
Fen 2015 VIB-1	6569690,5637	516661,8706	65	45	0,00	50,00	50,00
Fen 2015 GRV-1	6571226,8219	516766,4063	220	45	0,00	50,00	50,00
Fen 2015 GRV-2	6571358,4640	516653,0613	220	45	0,00	50,00	50,00
Fen 2015 TEIG-1	6570469,5211	517195,4788	246	45	0,00	63,67	63,67
Fen 2016 SØVE E2	6571195,0997	516514,0295	125	45	2,00	69,70	67,70
Fen 2016 SØVE E4	6571041,0287	516508,4679	88	45	3,90	5,50	1,60
Fen 2016 SØVE E6	6571008,3861	516575,1127	180	45	1,00	73,90	72,90
Fen 2016 SØVE E6b	6571051,4084	516586,7795	180	45	x	x	0,00
Fen 2016 SØVE E7	6570999,0448	516447,5520	270	45	1,60	22,00	20,40
Fen 2016 TEIG-2	6570439,6922	516995,7567	x	90	6,25	74,8	68,55
Fen 2016 TEIG-3	6570632,2182	517043,0354	270	45	1,00	73,80	72,80
Fen 2016 SKOLE-1	6570350,5320	517260,1704	270	88	7,00	60,00	53,00
Fen 2016 FEN-1	6570340,4523	517167,1127	x	90	16,20	29,40	13,20
Fen 2016 TUFTE-5	6570331,4540	516676,6520	x	90	8,40	12,15	3,75
Fen 2016 TUFTE-6	6570501,6340	516680,8850	x	90	7,90	12,75	4,85
Fen 2016 BJD-1	6569623,9951	517312,3899	x	90	x	x	0,00
Fen 2016 BJD-2	6569584,7679	517326,3879	x	90	x	x	0,00
Fen 2017 FEN-2	6570092,3652	517025,0408	x	90	4,97	12,00	7,03
Fen 2017 FEN-3	6570095,7916	517150,8748	x	90	1,80	10,11	8,31
Fen 2017 FEN-4	6570158,2640	517086,5929	x	90	7,40	18,00	10,60
Fen 2017 FEN-5	6570072,2962	516895,0777	x	90	8,40	13,37	4,97
Fen 2017 FEN-6	6570158,0769	517014,9509	x	90	7,79	11,86	4,07
Fen 2017 FEN-8	6570215,4537	516891,1224	x	90	20,00	20,20	0,20
Fen 2017 RHG-1	6570004,2259	516737,4767	x	90	6,00	11,86	5,86
Fen 2017 SØVE E3	6571204,7953	516492,8240	340	45	1,10	54,39	53,29
Fen 2017 TOR-4	6571319,4421	516836,4071	240	45	3,00	11,15	8,15
Fen 2018 VIBD-1	6569764,8375	516253,9039	12	72	15,55	22,2	6,65
Long Cores 2017-2018							
Fen 2017 LHKB-1	6570373,315	517182,5535	x	90	13,24	1001,30	988,06
Fen 2018 LHKB-2	6571021,768	516554,2487	x	90	4,90	716,40	711,50

All drill-cores are stored at the national drill-core facilities.
Norwegian Geological Survey

EOC = End of core

Appendix 3B
Drill-cores relevant for the discussion of the Fen FDC-unit
Fen shallow drill-cores: Brief geological descriptions / logs

"Core-logs" of the shallow cores relevant for the discussion of the FDC's are presented in this appendix. The description uses a number of abbreviations. See below.

Abbreviations used

General:
- Var Various
- Diff Different
- w With
- Min minerals
- Mlz Mineralizations
- Alt Altered
- EOC End of Core

Rocks
- FDC Fe-Dolomite Carbonatite
- Sø Søvite
- CFMC Ca-Fe-Mg carbonatite with low REE, Ba, Nb, Th, and variable P
- Fnt Fenite
- Dtj Damtjernite
- AMS Altered mafic silicate / chlorite-carbonate rocks

Structures
- Br Breccia
- Frc Fractures
- Xen Xenoliths
- Plm Polymictic
- Mom Monomictic
- Grb Grain boundaries
- Cl clusters
- Def Deformed / foliated
- Prla Igneous flow parallel alignment of minerals
- Ve Veins
- fgr fine grained
- mgr medium grained
- vfgr very fine grained

Minerals
- REC REE mineral clusters
- REM REE Minerals
- S Sulfides abundant / cluster / vein
- Flu Fluorite occasionally in veins or clusters
- Phl Phlogopite / mica
- Mnz Monazite
- REF REE-fluoro-carbonate
- Hem Hematite
- Mag Magnetite
- Ap apatite
- Srp "Serpentine"

Alt Alteration
- XAlt Extremely altered
- CB Carbonatization
- Chl Chloritization
- Hmz Hematitized
- WHmz weakly hematitized
- SHmz strongly hematitized

HXRF: Handheld XRF Niton XL3t GOLDD+ using Hf-Ta program and especially calibrated for La, Ce, Pr and Nd. Semiquantitative spot analysis. REE given as the approximate sum of La, Ce, Pr and Nd.

Note: Norwegian decimal, "comma", notation is applied in the tables.

Appendix 3B; log page 1 of 3 (Note: Norwegian decimal, “comma”, notation is applied in the tables).

FEN CARBONATITE COMPLEX. SHALLOW DRILL-CORES. Fe-DOLOMITE CARBONATITES

Log by S. Dahlgren 2019

Core ID	Interval	Interval	Description	HXRF	Spot	REE	Ba	Th	Nb	P
	From m	To m		Anlz No	m	%	%	ppm	ppm	%
Fen 2015 RKL-1	0	50	FDC Br, Plm and Mom Br, Var Br types, No REM Cl observed SHmz at 24,8-25,0 m Red Fnt xenol at 39,95-40,35 39,95-40,35 Xen(?) w white Ap Ve and Cl							
Fen 2015 RKL-2	0	50	FDC Br, Plm and Mom Br, Var Br types, REM Cl scattered along length. Some Ap Cl also scattered SHmz at 9,3-9,7 m Diabase dike 10,9 to 12,7 m Y in anlz 4646 941 ppm Anlz 4645 of gray heterog vein 4647 U 43 ppm; 4648 U 32 ppm, Pb 1156, Zn 8407, Ni 921	4645 4646 4647 4648	2,84 14,47 18,53 41,70	0,23 11,7 11,4 5	0,6 4,7 5,8 4,5	155 3587 4574 2204	1938 292 695 246	0,2 0,1 0,2 0,1
Fen 2015 RKL-3	0	50,27	FDC Br, Gray, Plm and Mom Br, diff types. From 24,5 m to EOC Br with XAlt Phl? Only ghost remains? XAlt Dtj Br? Only a few Hem Ve a few cm thick No REEC obs Diabase 13,8-15,1 m Mag Cl 15,1-15,2 m							
Fen 2015 VIB-1	0	12,4	CFMC WHmz, some Hem/Mag Ve up to 3 cm	4630 4631	4,71 8,35	0,25 1,7	0,02 0,04	76 291	197 17	- -
	12,4	18,55	CFMC, Gray, fgr, Heterogeneous, some Def?, Gray Ve, thin Ap Ve, Chl. Low Ba, REE, Th, Nb, Var P	4624 4625	14,67 15,61	0,03 0,15	0,58 0,1	73 114	13 223	- 2,1
	18,55	20,5	CFMC ÏHmz	4632	19,72	0,2	0,38	119	75	-
	20,5	23,35	CFMC, Gray, fgr, Heterogeneous, some Def?, Gray Ve, thin Ap Ve, Chl. Low Ba, REE, Th, Nb, Var P	4626	21,55	0,15	,04	107	127	1,7
	23,35	50	CFMG, WHmz ti SHmz, Hmz in veins, increased, but Var Ba, Th, REE	4633	27,41	0,2	0,01	243	172	2,4
Fen 2018 VIBD-1	15,55	22,2	Sø and Ca,MgFe carb, Very Fract, WHmz,. Near boundary to FDC?							
Fen 2016 FEN-1	16,2	18,1	FDC Br, parts Hmz, S							
	18,1	19,3	Dtj very Alt							
	19,3	21,15	FDC Br, very Frc, parts Hmtz							
	21,15	EOC	Scattered pockets of Dtj, mingled w FDC Br; = Dtj wet Br? Some S, very little REC							
Fen 2017 FEN-2	4,97	5,85	FDC Br, partly Hmz							
	5,85	12,00	FDC Br SHz							
Fen 2017 FEN-3	1,8	6,0	FDC Br, some REC	4446	3,66	11	0,33	1916	-	0,3
	6,0	10,12	FDC SHz							
Fen 2017 FEN-4	7,4	10,21	FDC Br Parts Hmz REC							
	10,21	18,21	FDC Br REC	4444 4445	15,35 17,50	0,3 0,9	- 0,6	1130 1622	- -	8,2 13
Fen 2017 FEN-5	8,40	13,37	SHz FDC Br?							
Fen 2017 FEN-6	7,79	11,86	SHz FDC Br							
Fen 2017 FEN-8	20,00	20,12	SHz FDC Br?	4448	0,4			148		
Fen 2017 RHG-1	6,00	13,25	FDC Br, w Alt Dtj Br? (Rullekoll type?)	4443	9,05	1	-	145	-	-

Appendix 3B; log page 2 of 3 (Note: Norwegian decimal, “comma”, notation is applied in the tables)

FEN CARBONATITE COMPLEX. SHALLOW DRILL-CORES. Fe-DOLOMITE CARBONATITES
Log by S. Dahlgren 2019

Core ID	Interval	Interval	Description	HXRF	Spot	REE	Ba	Th	Nb	P
	From m	To m		Anlz No	m	%	%	ppm	ppm	%
Fen 2016 SØVE-E2	2	8,5	FDC Br Gray w Chlr							
	8,5	12	FDC Gray							
	12	27	Chlr w FDC Ve							
	27	31,2	FDC Gray							
	31,2	32,1	WHmz FDC							
	32,1	35,55	FDC Gray, some REC							
	35,55	37,5	SHmz FDC							
	37,5	69,7	FDC Gray w some Chlr REC especially abundant 51,2-52,1 and 63,2-68,7 Ap Ve especially abundant 54 m to EOC Fluorite especially abundant 50-50,3; 56,45-56,8; 59,5-59,9 m	4664 4665 4666 4667 4668	40,82 51,51 51,83A 54,62 66,12	1,8 8,7 8,7 1 4,2	0,3 0,1 0,2 0,02 0,04	948 1103 948 162 558	104 83 210 15 99	3 - 0,25 8,1 0,7
Fen 2017 SØVE-E3	1,1	13,4	FDC Br Gray Def, some DRE + REC	4669	7,78	8,5	0,05	1364	69	1
	13,4	15,7	FDC w DRE and REC	4670	15,52	1,4	1,5	262	37	-
	15,7	19,7	FDC w abundant Chlr							
	19,7	20,8	Pink FDC w DRE	4671	20,32	1,6	0,03	195	547	0,14
	20,8	33,6	Chlr w FDC Ve Def, some REC							
	33,6	37,6	FDC w DRE + REC Def	46,72	33,90	6,3	6,2	629	350	-
	37,6	54,39	FDC w abundant Chlr + some REM							
Fen 2016 SØVE-E4	3,9	5,5	FDC Br, some traces of REM							
Fen 2016 SØVE-E6			Close to LHKB-2. See LHKB-2							
Fen 2016 SØVE-E7	1,6	3,1	Dtj							
	3,1	7	Gray Def FDC w scattered REC							
	7	7,3	Dtj							
	7,3	22	Gray Def FDC w scattered REC							
Fen 2015 GRV-1	0	6	Dtj(?), alt CB/Chl, Prla or Def, Alt Phl, Xen of FDC?, Fl Ve / Grb w REE (Mnz Alt of Ap?)	4454	3,55	10,5	0,23	416	73	0,15
	6	50	Diff FDC Br, REE cl abundant in intervals 8,75-10 m and 20,6 to 25,3 m; otherwise scattered REE min	4451 4452 4453 4455	8,95 22,42 24,27 23,88	9,7 15,6 0,3 2,4	1,0 11,0 0,03 0,8	667 1497 88 417	313 222 9 218	0,9 - 13,7 6,0
Fen 2015 GRV-2	0	2,1	Plm Dtj Br, CB, Chl							
	2,1	11,6	Fnt wFDC Ve							
	16,6	22,7	Sø dikes cutting AMS w Frc Fnt							
	22,7	50,0	Fnt Br and AMS w few small FDC Ve							
Fen 2017 TOR-4	3	11,15	FDC?? SHmz							

Appendix 3B; log page 3 of 3 (Note: Norwegian decimal, "comma", notation is applied in the tables)

FEN CARBONATITE COMPLEX. SHALLOW DRILL-CORES. Fe-DOLOMITE CARBONATITES

Log by S. Dahlgren 2019

Core ID	Interval	Interval	Description	HXRF	Spot	REE	Ba	Th	Nb	P
	From m	To m		Anlz No	m	%	%	ppm	ppm	%
Fen 2015 TEIG-1	0	8,1	FDC Br Gray Br, Pink FDC, Chl rock xenols(?)							
	8,1	17,5	SHmz FDC Br							
	17,5	19,7	Gray FDC Veined							
	19,7	42,25	WHmz to SHmz FDC Br							
	42,25	52,1	Gray FDC Br w some Hmz zones							
	52,1	57,1	SHmz FDC Br							
	57,1	63,67	FDC gray; Pink granular FDC veins w S and REC							
Fen 2016 TEIG-2	6,25	32,5	FDC Br, var types plm/mom,	4530	8,17	5,0	0,08	1830	217	0,5
			REC at 8,14-8,22; 19,6-23,85 (many) w S, massive REC up to 10 cm	4531	8,20	8,0	0,1	2535	146	0,8
				4532	19,69	8,9	8,7	1114	71	0,5
				4533	19,87	13	0,9	676	25	0,47
				4534	21,75	11,7	0,2	1099	131	0,6
				4536	22,07	9,1	1,5	582	30	1,1
				4535	22,77	12,2	0,17	850	183	0,6
	32,5	35,65	Hmz FDC	4537	32,73	13,6	0,1	3075	511	2.6
			SHmz FDC, SHmz Ve (3cm) w REE at 32,73							
	35,65	46,2	FDC Br, var types plm/mom,	4538	35,85	10,2	2,1	1323	178	0,1
			35,85 (5cm) WHmz REE Ve	4539	39,90	0,4	0,14	979	145	11,4
				4540	40.05	2,8	0,06	475	20	-
	46,2	50,10	SHmz, «Red-rock»; Niton analysis of red cluster	4541	46,33	1,4	0,06	414	47	0,4
	50,10	74,8	FDC Br, var types plm/mom, Ap Cl /Ve Ap Cl 543 ppm Y	4542	51,83	0,36	0,07	467	225	11,2
			ApCl + Xnt? 2449 ppm Y	4543	60,17	0,3	0,06	765	128	10,5
			144 ppm Y	4544	60,15	2,0	1	587	112	0,4
			Nb min at 65,8 m 3 cm REMVe	4553	67,55	4,4	0,4	653	41	-
			White Ap Ve	4554	68,51	0,6	0,06	466	83	9,1
Fen 2016 TEIG-3	1	73,8	FDC Br, Gray-Beige-Brown. Many diff Br varieties.	4649	2,58	19,8	13,5	1979	156	-
			Scattered WHmz to SHmz zones	4650	5,96	0,6	1,3	485	180	2,8
			Thin Hem Ve occasionally	4651	17,47	15	6,5	3461	302	-
			Darkgray vfg Chlr rock 51,1 – 52,3 m and 63,3 – 64,7 m	4653	45,45	11,3	4	1742	1592	1,1
			A few REC scattered; mostly the first 12 m of core. Dissemin REE in places							
Fen 2016 SKOLE-1	7	60	FDC Gray Plm Br + Pink Br/Ve up to 2m thick w disseminated or Cl REE. About ¼	4660	8,30	1,5	2,5	1089	37	0,2
			of core this rich REE-rock. REM Hem	4661	20,47	8,8	10	3550	105	0,8
				4662	32,31	11,4	12	1210	121	-
				4663	51,65	5,6	5,4	873	62	-
Fen 2016 TUFTE-5	8,45	12,15	Very Br. Probably Sø (?), but likely at contact to FDC Br							
			FDC in "matrix"?							
Fen 2016 TUFTE-6	7,90	12,00	Very strongly Br Sø. Nb-min.							
			Most likely at margin od FDC Br (or eventually Dtj Br).							
	9,75	9,90	FDC Ve w REEM + Th							

Appendix 4A Whole-rock geochemical analyses of sampled exposures
Sample localities

FEN REE-FDC WHOLE-ROCK SAMPLES

SD 2019.08.24

Sample ID	Location	Sampled	Coord	
			Easting	Northing
REE-FDC, Fen Iron Mine area				
FT-AC-1	Fen Iron Mines, N of Karup	Surface	517137	6570870
AKS-1	Fen Iron Mines, Anne Katrine stoll	In mine		
VS-1	Fen Iron Mines, Veststollen	In mine		
FSS 165 SE	Fen Iron Mines, Fen skole stoll	In mine		
TEIGEN MBH-3	Fen, Nordre	Surface	517221,862	6570497,945
REE-FDC, Tuftestollen				
Ts 381,9 W coarse	Tuftestollen	In mine		
Ts 381,9 W fine	Tuftestollen	In mine		
Ts 389,3 W	Tuftestollen	In mine		
Ts 453,2 E 1,1m	Tuftestollen	In mine		
Ts 453,2 E 1,1	Tuftestollen	In mine		
Ts 466,5 W L	Tuftestollen	In mine		
Ts 466,5 W H	Tuftestollen	In mine		
Ts 598,7 W	Tuftestollen	In mine		
REE-FDC, Tuftestollen mineralized-zone, M1E				
Ts 510,7 E 1,4m	**Tuftestollen**	**In mine**		
Ts 510,7 E 1,5m	**Tuftestollen**	**In mine**		
Ts 511,3 E 1,7m	**Tuftestollen**	**In mine**		
Ts 511 E 3m	**Tuftestollen**	**In mine**		
REE-FDC, Tuftestollen mineralized zone, M1W				
Ts 504 W	**Tuftestollen**	**In mine**		
Ts 505 W 3,5m	**Tuftestollen**	**In mine**		
REE-FDC, Tuftestollen adjacent to mineralized zone, M1W				
Ts506 W	Tuftestollen	In mine		
Ts 508 W 2m	Tuftestollen	In mine		
Ts 508,5 W 1,3	Tuftestollen	In mine		
Ts 510 W 2,3m	Tuftestollen	In mine		
Ts 512 W	Tuftestollen	In mine		
REE-FDC, Tuftestollen mineralized zone M2W				
Ts 563 W 1,7	**Tuftestollen**	**In mine**		
Ts 563,4 W 0,5	**Tuftestollen**	**In mine**		
Ts 563,4 W 0,6	**Tuftestollen**	**In mine**		
Ts 564,3 W 1,4	**Tuftestollen**	**In mine**		
Ts 564,5 W 0,7	**Tuftestollen**	**In mine**		
Ts 565,2 W 1,0	**Tuftestollen**	**In mine**		
Ts 565,5 W 1,8	**Tuftestollen**	**In mine**		
Ts 566 W 0,7	**Tuftestollen**	**In mine**		
Ts 566,2 W 1,2	**Tuftestollen**	**In mine**		
REE-FDC, Tuftestollen adjacent to mineralized zone, M2W				
Ts 556,3 E 0,5	Tuftestollen	In mine		
Ts 562,6 W 1,8	Tuftestollen	In mine		
Ts 562,7 W 0,6	Tuftestollen	In mine		
FDC, Rauhaug				
RHG-1	Rauhaug	Surface	516878	6569897
FDC, Søve east - Ødegårdsfeltet				
F 1245.17	E of Søve sommerfjøs	Surface	516660,7431	6571296,485
F 1549.17-3	Ødegårdsfeltet, Fen	Surface	516102,68	6570785,08
511.80	Søve sommerfjøs	Surface	516580	657178

The positions of the samples collected on the surface is given by UTM coordinates, zone 32, Euref 89.
See map appendix x for place-names.

Mine samples:
For the mine samples collected subsurface within the Tuftestollen adit and the Fen Iron Mines, see the maps figures x and x respectively.

The Tuftestollen (Tufte adit) ID's precisely refer to the sampling positions within the mine: Ts + meters from the entrance + eastern (E) or western (W) side. An eventual additional number indicate meters above mine floor.

Appendix 4B Whole-rock geochemical analyses of sampled exposures
REE analyses of FDC samples
(Note: Norwegian decimal, “comma”, notation is applied in the tables)

Sample ID	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
REE-FDC, Fen Iron Mine area															
FT-AC-1	1925	3740	426	1490	208	40,7	105	11,15	49,1	8,36	19,5	2,32	13,9	1,87	217
AKS-1	6230	9380	894	2780	387	87,2	186	18,65	75,1	10,8	21,6	2,32	11,9	1,58	256
VS-1	17150	22600	1995	5460	447	96,8	200	21,1	70,6	8,72	16,3	1,68	8,85	1,23	209
FSS 165 SE	8830	15300	1645	5230	470	90,6	169	15,8	52	5,59	8,1	0,61	2,61	0,36	97,9
TEIGEN MBH-3	2780	4470	445	1385	151,5	31,9	66,7	7,37	33,8	5,47	13,35	1,8	10,2	1,46	158,5
REE-FDC, Tuftestollen															
Ts 381,9 W coarse	6610	7820	643	1710	147,5	31	57,9	4,59	12,35	1,44	3,04	0,36	2,17	0,31	37,5
Ts 381,9 W fine	530	866	95,8	337	38,6	5,66	11,65	0,83	3,08	0,47	1,13	0,13	0,96	0,15	10,7
Ts 389,3 W	2560	3670	330	963	93,8	17,85	37,1	3,77	16,45	2,53	5,96	0,86	5,4	0,77	59
Ts 453,2 E 1,1m	1535	1990	183,5	523	32	4,74	5,98	0,52	1,6	0,24	0,48	0,07	0,47	0,08	5
Ts 453,2 E 1,1	3960	5440	468	1295	87,4	12,7	15	1,12	3,5	0,38	0,89	0,09	0,51	0,08	8,2
Ts 466,5 W L	3290	4740	441	1300	101,5	17,2	26,4	1,97	5,69	0,66	1,25	0,14	0,93	0,15	13,3
Ts 466,5 W H	11150	14300	1275	3650	309	51,2	84	6,01	14,95	1,48	2,7	0,26	1,78	0,26	29,3
Ts 598,7 W	9370	14250	1420	4350	379	56,8	116	9,03	26,7	2,59	4,1	0,29	1,61	0,21	48,8
REE-FDC, Tuftestollen mineralized-zone, M1E															
Ts 510,7 E 1,4m	**12850**	**14350**	**1195**	**3290**	**268**	**49,6**	**87,6**	**6,85**	**15,4**	**1,48**	**2,73**	**0,26**	**1,66**	**0,22**	**29,4**
Ts 510,7 E 1,5m	**15550**	**17550**	**1415**	**3750**	**320**	**62,4**	**108**	**9,15**	**22,4**	**2,23**	**3,93**	**0,37**	**2,34**	**0,33**	**46,6**
Ts 511,3 E 1,7m	**8420**	**11050**	**1015**	**2940**	**239**	**42,4**	**75,6**	**5,76**	**14,4**	**1,37**	**2,39**	**0,2**	**1,33**	**0,17**	**24,1**
Ts 511 E 3m	**20500**	**23900**	**2040**	**5570**	**470**	**89,9**	**143**	**10,9**	**25,4**	**2,48**	**4,05**	**0,38**	**2,35**	**0,31**	**43,8**
REE-FDC, Tuftestollen mineralized zone, M1W															
Ts 504 W	**6600**	**9140**	**875**	**2660**	**230**	**37,2**	**60,5**	**4,33**	**10,8**	**1,11**	**1,94**	**0,15**	**0,89**	**0,16**	**17,8**
Ts 505 W 3,5m	**8320**	**11350**	**1080**	**3230**	**285**	**49,2**	**80,2**	**5,56**	**14,15**	**1,4**	**2,41**	**0,19**	**1,07**	**0,16**	**21,6**
REE-FDC, Tuftestollen adjacent to mineralized zone, M1W															
Ts 506 W	1810	2520	221	658	65,5	11,5	17,3	1,34	4	0,53	1,15	0,14	0,91	0,13	12
Ts 508 W 2m	4420	6410	697	2550	271	38,4	52,9	3,01	10,1	1,38	3,13	0,4	2,85	0,44	35,3
Ts 508,5 W 1,3	3160	5310	599	2260	285	40	61,9	3,59	14,15	2,03	4,43	0,6	3,68	0,59	58,3
Ts 510 W 2,3m	517	835	92,2	317	43,4	10,8	19,55	1,54	6,19	0,91	1,95	0,24	1,52	0,22	23
Ts 512 W	2660	4310	420	1295	118,5	20,2	31,5	2,25	6,14	0,7	1,2	0,14	0,86	0,14	12,3
REE-FDC, Tuftestollen mineralized zone, M2W															
Ts 563 W 1,7	**20800**	**28500**	**2340**	**6230**	**383**	**61,3**	**105,5**	**10,3**	**34,1**	**4,13**	**8,04**	**0,79**	**3,78**	**0,54**	**81,5**
Ts 563,4 W 0,5	**15350**	**20000**	**1560**	**4130**	**246**	**39,9**	**66,8**	**6,52**	**20,3**	**2,21**	**4,07**	**0,36**	**2,15**	**0,3**	**42,9**
Ts 563,4 W 0,6	**14500**	**18150**	**1405**	**3690**	**217**	**35,3**	**53,8**	**5,32**	**15,85**	**1,79**	**3,02**	**0,32**	**1,64**	**0,23**	**33,3**
Ts 564,3 W 1,4	**6870**	**8600**	**682**	**1720**	**104,5**	**18,3**	**28,4**	**2,58**	**7,77**	**0,77**	**1,55**	**0,16**	**1,05**	**0,14**	**16,7**
Ts 564,5 W 0,7	**10150**	**12650**	**983**	**2630**	**198,5**	**32,5**	**54,2**	**4,32**	**11,6**	**1,13**	**2,05**	**0,21**	**1,19**	**0,16**	**22,6**
Ts 565,2 W 1,0	**14850**	**18650**	**1430**	**3650**	**293**	**52,9**	**88,6**	**7,61**	**21,5**	**2,18**	**3,68**	**0,38**	**2,16**	**0,32**	**40,3**
Ts 565,5 W 1,8	**10100**	**13900**	**1210**	**3600**	**324**	**58,4**	**116,5**	**10,65**	**42,1**	**5,93**	**13,2**	**1,51**	**8,91**	**1,27**	**145,5**
Ts 566 W 0,7	**19700**	**27800**	**2330**	**6280**	**385**	**60,3**	**84,8**	**7,21**	**24,7**	**3,06**	**5,95**	**0,58**	**3,22**	**0,47**	**62,4**
Ts 566,2 W 1,2	**12000**	**16050**	**1310**	**3530**	**245**	**44,9**	**78,8**	**7,59**	**30**	**4,29**	**9,23**	**1,1**	**6,43**	**0,98**	**102**
REE-FDC, Tuftestollen adjacent to mineralized zone, M2W															
Ts 556,3 E 0,5	7630	11100	938	2540	169,5	27	43,4	3,9	12,15	1,42	2,82	0,31	1,72	0,23	29,7
Ts 562,6 W 1,8	772	1175	108	307	27,7	4,99	9,28	0,89	2,61	0,36	0,72	0,1	0,66	0,1	7,2
Ts 562,7 W 0,6	1675	2360	205	544	35,1	5,99	9,07	0,92	2,86	0,37	0,81	0,1	0,67	0,11	8,1
FDC, Rauhaug															
RHG-1	758	1255	133,5	468	102	27,1	73,5	8,4	35,2	5,17	11,85	1,59	9,21	1,47	146,5
FDC, Søve east - Ødegårdsfeltet															
F 1245.17	2060	3010	284	865	86,1	16,2	27	2,14	7,52	0,96	2,16	0,29	1,68	0,24	22,1
F 1549.17-3	305	697	89,5	339	52,9	13,3	37	7,18	48,5	9	21,5	2,63	14,7	1,78	197,5
511.80	3140	4770	440	1305	121,5	22,2	41,9	3,57	11,65	1,36	2,56	0,26	1,46	0,22	28,8

Analyses shown in bold were used to calculate grade TREO at the different sites.

Appendix 4C Whole-rock geochemical analyses of sampled exposures
P, F, Ba, Sc, Nb, Th and U analyses of FDC samples
(Note: Norwegian decimal, “comma”, notation is applied in the tables)

Sample ID	**P2O5**	**F**	**Ba**	**Sc**	**Nb**	**Th**	**U**
	%	ppm	ppm	ppm	ppm	ppm	ppm
REE-FDC, Fen Iron Mine area							
FT-AC-1	0,86	1610	5670	53,7	608	587	14,3
AKS-1	0,03	2220	134,5	36	354	899	11,05
VS-1	0,21	4780	28400	26,9	498	673	39,6
FSS 165 SE	1,10	1480	430	23	64,7	446	6,95
TEIGEN MBH-3	1,07	2700	9500	32,4	240	245	5,82
REE-FDC, Tuftestollen							
Ts 381,9 W coarse	0,25	2290	4300	31,3	18	198,5	3,87
Ts 381,9 W fine	0,30	440	2240	19,6	12,9	52,5	2,09
Ts 389,3 W	3,03	2480	12200	8,4	3520	168	50,9
Ts 453,2 E 1,1m	0,05	560	14700	8,1	8,5	6,2	0,59
Ts 453,2 E 1,1	0,06	1260	13800	7,4	8,6	26,8	1,3
Ts 466,5 W L	0,65	2090	15800	8,3	13,6	63,2	1,84
Ts 466,5 W H	0,85	3750	5120	7,8	13,8	286	3,73
Ts 598,7 W	0,20	2730	2130	9,5	34,1	284	3,82
REE-FDC, Tuftestollen mineralized-zone, M1E							
Ts 510,7 E 1,4m	**0,25**	**3690**	**21000**	**8,4**	**8,3**	**174**	**6,44**
Ts 510,7 E 1,5m	**1,80**	**4230**	**4290**	**9,5**	**10**	**241**	**15,55**
Ts 511,3 E 1,7m	**0,21**	**2250**	**27100**	**8,5**	**2,7**	**163,5**	**1,65**
Ts 511 E 3m	**0,33**	**6170**	**13400**	**8**	**11,8**	**285**	**3,47**
REE-FDC, Tuftestollen mineralized zone, M1W							
Ts 504 W	**0,16**	**2200**	**321**	**10,4**	**4**	**146,5**	**1,06**
Ts 505 W 3,5m	**0,18**	**3150**	**669**	**11,5**	**5,1**	**197,5**	**1,69**
REE-FDC, Tuftestollen adjacent to mineralized zone, M1W							
Ts 506 W	0,21	1130	538	10	1035	59,1	20,7
Ts 508 W 2m	0,37	1360	5340	32,6	387	278	42,7
Ts 508,5 W 1,3	1,29	1670	176	27	462	321	45,8
Ts 510 W 2,3m	2,28	1850	51000	7,7	97,6	19,9	8,59
Ts 512 W	0,48	780	1795	14,5	33,2	113	3,99
REE-FDC, Tuftestollen mineralized zone, M2W							
Ts 563 W 1,7	**3,11**	**6300**	**795**	**23**	**13,1**	**218**	**6,76**
Ts 563,4 W 0,5	**0,97**	**4070**	**453**	**23,1**	**7,7**	**123,5**	**4,18**
Ts 563,4 W 0,6	**0,78**	**4120**	**16100**	**20,9**	**14,5**	**98**	**3,69**
Ts 564,3 W 1,4	**0,15**	**2050**	**7360**	**19,6**	**63,3**	**48,8**	**2,49**
Ts 564,5 W 0,7	**0,10**	**3170**	**1210**	**21,8**	**16,1**	**188,5**	**4,84**
Ts 565,2 W 1,0	**1,88**	**760**	**3410**	**21,2**	**15**	**394**	**17,15**
Ts 565,5 W 1,8	**10,15**	**7900**	**489**	**39,1**	**34,5**	**297**	**63,8**
Ts 566 W 0,7	**3,35**	**2290**	**931**	**22,3**	**26**	**237**	**24,7**
Ts 566,2 W 1,2	**9,83**	**7550**	**476**	**28,1**	**26**	**125,5**	**6,27**
REE-FDC, Tuftestollen adjacent to mineralized zone, M2W							
Ts 556,3 E 0,5	0,86	2820	501	25,9	10,4	66,7	1,21
Ts 562,6 W 1,8	0,02	430	860	20,2	160,5	25,3	1,3
Ts 562,7 W 0,6	0,11	530	2140	20	101	20,1	1,42
FDC, Rauhaug							
RHG-1	1,79	3490	29700	28,1	594	155	2,28
FDC, Søve east - Ødegårdsfeltet							
F 1245.17	0,50	600	5610	17,6	21,7	61,8	3,31
F 1549.17-3	0,26	4270	23500	52,4	1060	93,7	2,58
511.80	0,14	7990	2820	24,1	562	98,6	3,65

Appendix 4D Whole-rock geochemical analyses of sampled exposures
Co, Ni, Cu, Zn, Cd, Hg, Pb, As and S analyses of FDC samples
(Note: Norwegian decimal, "comma", notation is applied in the tables)

Sample ID	**Co**	**Ni**	**Cu**	**Zn**	**Cd**	**Hg**	**As**	**Pb**	**S**
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
REE-FDC, Fen Iron Mine area									
FT-AC-1	11	55	32	366	0,5	0,014	11,2	25	0,31
AKS-1	25	75	7	229	0,7	0,043	34,6	79	0,84
VS-1	6	133	2	18	<0.5	0,01	3,8	46	0,30
FSS 165 SE	21	139	219	6240	11,9	0,027	9	47	2,67
TEIGEN MBH-3	4	37	9	272	<0.5	0,008	1,4	22	0,33
REE-FDC, Tuftestollen									
Ts 381,9 W coarse	11	40	1	48	0,7	0,012	6,9	14	0,59
Ts 381,9 W fine	6	5	<1	90	0,7	0,011	2,2	6	0,39
Ts 389,3 W	7	22	<1	38	<0.5	<0.005	3,8	10	0,51
Ts 453,2 E 1,1m	<1	11	<1	54	0,9	0,011	0,2	6	0,13
Ts 453,2 E 1,1	1	34	<1	51	0,9	<0.005	<0.1	12	0,35
Ts 466,5 W L	3	28	1	52	1,1	0,009	1,3	9	0,35
Ts 466,5 W H	1	89	2	39	0,7	0,008	3,8	26	0,91
Ts 598,7 W	32	118	9	33	0,5	0,01	5,4	32	1,56
REE-FDC, Tuftestollen mineralized-zone, M1E									
Ts 510,7 E 1,4m	**1**	**80**	**2**	**34**	**<0.5**	**0,008**	**2,1**	**25**	**0,53**
Ts 510,7 E 1,5m	**2**	**87**	**2**	**34**	**0,5**	**0,006**	**4,7**	**28**	**0,52**
Ts 511,3 E 1,7m	**2**	**73**	**1**	**61**	**0,5**	**0,012**	**1,4**	**21**	**0,22**
Ts 511 E 3m	**4**	**140**	**2**	**35**	**<0.5**	**<0.005**	**2,3**	**39**	**0,51**
REE-FDC, Tuftestollen mineralized zone, M1W									
Ts 504 W	**2**	**64**	**1**	**62**	**1,2**	**0,006**	**1,1**	**20**	**1,08**
Ts 505 W 3,5m	**3**	**79**	**3**	**66**	**1**	**0,008**	**2,2**	**22**	**0,98**
REE-FDC, Tuftestollen adjacent to mineralized zone, M1W									
Ts 506 W	13	13	1	69	1,1	0,007	2,3	9	0,73
Ts 508 W 2m	6	61	1	33	<0.5	0,012	4,6	24	0,17
Ts 508,5 W 1,3	6	53	<1	13	<0.5	<0.005	3,7	24	0,10
Ts 510 W 2,3m	4	5	<1	37	0,5	0,009	1,3	2	0,21
Ts 512 W	10	32	<1	55	0,9	0,006	1,8	17	0,47
REE-FDC, Tuftestollen mineralized zone, M2W									
Ts 563 W 1,7	**2**	**143**	**<1**	**32**	**0,5**	**<0.005**	**1,4**	**36**	**0,10**
Ts 563,4 W 0,5	**1**	**98**	**<1**	**32**	**0,8**	**<0.005**	**0,7**	**25**	**0,08**
Ts 563,4 W 0,6	**12**	**85**	**<1**	**41**	**0,9**	**<0.005**	**1,9**	**21**	**0,89**
Ts 564,3 W 1,4	**1**	**42**	**<1**	**45**	**0,9**	**<0.005**	**0,4**	**9**	**0,21**
Ts 564,5 W 0,7	**3**	**62**	**<1**	**38**	**<0.5**	**<0.005**	**1,6**	**20**	**0,11**
Ts 565,2 W 1,0	**5**	**93**	**3**	**44**	**0,6**	**<0.005**	**4,7**	**38**	**0,21**
Ts 565,5 W 1,8	**2**	**85**	**3**	**76**	**0,5**	**<0.005**	**4**	**39**	**0,14**
Ts 566 W 0,7	**16**	**147**	**3**	**43**	**0,6**	**<0.005**	**3,6**	**46**	**0,71**
Ts 566,2 W 1,2	**2**	**84**	**1**	**26**	**<0.5**	**<0.005**	**4,3**	**29**	**0,16**
REE-FDC, Tuftestollen adjacent to mineralized zone, M2W									
Ts 556,3 E 0,5	1	62	<1	35	0,7	<0.005	0,9	14	0,05
Ts 562,6 W 1,8	2	8	<1	66	1,3	<0.005	0,6	7	0,05
Ts 562,7 W 0,6	3	13	<1	60	1	0,006	1,5	23	0,22
FDC, Rauhaug									
RHG-1	31	113	11	214	<0.5	0,007	5,6	23	1,07
FDC, Søve east - Ødegårdsfeltet									
F 1245.17	3	22	<1	97	1,1	<0.005	0,9	18	0,22
F 1549.17-3	12	84	21	455	0,7	<0.005	4,2	26	0,11
511.80	5	57	6	346	1,5	0,018	0,2	17	0,09

Appendix 4E Whole-rock geochemical analyses of sampled exposures
Ag, Au, Pt and Pd analyses of FDC samples
(Note: Norwegian decimal, "comma", notation is applied in the tables)

Sample ID	**Ag**	**Au**	**Pt**	**Pd**
	ppm	ppm	ppm	ppm
REE-FDC, Fen Iron Mine area				
FT-AC-1	<0.5	0,027	<0.0005	<0.001
AKS-1	<0.5	0,051	<0.0005	<0.001
VS-1	<0.5	0,014	<0.0005	<0.001
FSS 165 SE	<0.5	0,015	<0.0005	<0.001
TEIGEN MBH-3	<0.5	0,002	<0.0005	<0.001
REE-FDC, Tuftestollen				
Ts 381,9 W coarse	<0.5	0,006	<0.0005	<0.001
Ts 381,9 W fine	<0.5	0,003	<0.0005	<0.001
Ts 389,3 W	<0.5			
Ts 453,2 E 1,1m	<0.5	0,002	<0.0005	<0.001
Ts 453,2 E 1,1	<0.5			
Ts 466,5 W L	<0.5	0,003	<0.0005	<0.001
Ts 466,5 W H	<0.5	0,003	<0.0005	<0.001
Ts 598,7 W	<0.5	0,023	<0.0005	<0.001
REE-FDC, Tuftestollen mineralized-zone, M1E				
Ts 510,7 E 1,4m	**<0.5**	**0,003**	**<0.0005**	**<0.001**
Ts 510,7 E 1,5m	**<0.5**	**0,003**	**<0.0005**	**<0.001**
Ts 511,3 E 1,7m	**<0.5**	**0,002**	**<0.0005**	**<0.001**
Ts 511 E 3m	**<0.5**	**0,006**	**<0.0005**	**<0.001**
REE-FDC, Tuftestollen mineralized zone, M1W				
Ts 504 W	**<0.5**	**0,003**	**<0.0005**	**<0.001**
Ts 505 W 3,5m	**<0.5**	**0,003**	**<0.0005**	**<0.001**
REE-FDC, Tuftestollen adjacent to mineralized zone, M1W				
Ts 506 W	<0.5	0,014	<0.0005	<0.001
Ts 508 W 2m	<0.5	0,021	<0.0005	<0.001
Ts 508,5 W 1,3	<0.5			
Ts 510 W 2,3m	<0.5	0,003	<0.0005	<0.001
Ts 512 W	<0.5	0,009	<0.0005	<0.001
REE-FDC, Tuftestollen mineralized zone, M2W				
Ts 563 W 1,7	**<0.5**			
Ts 563,4 W 0,5	**1,5**			
Ts 563,4 W 0,6	**1,3**			
Ts 564,3 W 1,4	**0,5**			
Ts 564,5 W 0,7	**0,7**			
Ts 565,2 W 1,0	**<0.5**			
Ts 565,5 W 1,8	**<0.5**			
Ts 566 W 0,7	**<0.5**			
Ts 566,2 W 1,2	**<0.5**			
REE-FDC, Tuftestollen adjacent to mineralized zone, M2W				
Ts 556,3 E 0,5	<0.5			
Ts 562,6 W 1,8	<0.5			
Ts 562,7 W 0,6	<0.5			
FDC, Rauhaug				
RHG-1	<0.5			
FDC, Søve east - Ødegårdsfeltet				
F 1245.17	<0.5			
F 1549.17-3	<0.5			
511.80	<0.5			

Appendix 5
Whole-rock geochemical analyses of the TEIG-2 shallow drill-core
(Note: Norwegian decimal, "comma", notation is applied in the tables)

Interval From	To	La ppm	Ce ppm	Pr ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm	Er ppm	Tm ppm	Yb ppm	Lu ppm	Y ppm
6,25	7,00	857	1510	156,5	541	66	16,7	38,3	4,16	16,7	2,13	4,5	0,48	2,7	0,31	58
7,00	8,00	967	1770	183,5	632	70,6	16,5	33,7	3,31	12,3	1,43	2,5	0,32	1,9	0,27	34
8,00	9,00	2400	4180	456	1525	165,5	35,3	60,9	5,25	18,6	2,12	4	0,52	3,5	0,5	51
9,00	10,00	836	1560	162	560	65,8	16,7	33,3	3,16	11,7	1,59	3,3	0,38	2,6	0,36	41
10,00	11,00	947	1840	196,5	702	86,6	22,6	48,6	5,15	22,2	3,06	7,4	0,98	6,4	0,87	80
11,00	12,00	1330	2420	250	764	81,9	20,6	39,5	3,86	12,3	1,77	3,6	0,44	3	0,45	39
12,00	13,00	2060	3760	413	1175	123,5	29,1	60	5,71	20	2,96	6,2	0,75	4,7	0,59	73
13,00	14,00	944	1680	172	525	55	13,3	26,3	2,5	8,2	1,1	2,2	0,26	2,1	0,29	24
14,00	15,00	1280	2290	245	786	101	26	55,6	5,53	20,6	3,02	6,2	0,62	3,8	0,51	72
15,00	16,00	1435	2460	244	741	72,4	18,2	36,1	3,33	10,5	1,3	2,5	0,28	2,3	0,27	29
16,00	17,00	977	1850	192	602	66,1	15,6	32,2	3,18	10,7	1,45	2,9	0,29	1,9	0,29	35
17,00	18,00	1430	2630	268	823	80,3	19,6	38,4	3,3	10,2	1,28	2,3	0,18	1,5	0,19	28
18,00	19,00	2470	3800	351	1070	119,5	27,2	54,7	7,76	22,4	2,95	5,7	0,5	3,1	0,34	55
19,00	20,00	19000	23800	1795	5140	409	84,9	165	24,1	52,3	6,03	10,7	0,96	5,3	0,66	128
20,00	21,00	12500	17900	1565	5010	465	92,6	188,5	26,4	56,9	6,97	9,1	1,04	5,5	0,78	120
21,00	22,00	5820	7790	691	2100	189,5	39,5	80,7	11,65	29,6	3,8	6,4	0,5	3,1	0,39	64
22,00	23,00	16850	23000	1805	5420	450	99,9	193,5	28,8	71,9	8,16	15,7	1,64	8,9	1,23	165
23,00	24,00	1870	3300	327	1080	100,5	21,2	42,8	6,12	15,6	1,98	3,4	0,32	2,3	0,27	39
24,00	25,00	2280	5310	623	2310	227	47,1	77,5	9,55	19,2	2,36	4	0,39	2,3	0,23	46
25,00	26,00	1180	2200	229	804	86,6	17,9	34,6	4,48	10,1	1,25	2,5	0,26	1,7	0,18	28
26,00	27,00	2020	3600	373	1220	130,5	30,7	68,1	9,56	34,2	4,76	10,2	1,16	6,3	0,78	107
27,00	28,00	1520	2700	266	900	101	21,8	48,4	6,59	16,6	2,47	4,5	0,48	2,3	0,39	47
28,00	29,00	949	1660	165,5	580	68,1	14,7	30,7	3,73	9,8	1,33	2,8	0,32	1,6	0,19	31
29,00	30,00	904	1570	153	517	63,6	13,6	29	4,06	10,4	1,6	2,9	0,35	1,6	0,24	30
30,00	31,00	1620	2860	284	982	99,1	21,2	44,7	6,78	22,7	3,22	6,6	0,65	3,7	0,51	74
31,00	32,00	1230	2130	206	687	66,3	14,7	32	4,86	15,9	2,25	5,2	0,57	3,5	0,43	49
32,00	32,50	922	1550	154	541	67	15,2	37,6	5,4	21,3	2,97	5,4	0,63	3,2	0,34	68
32,50	33,00	3140	4620	412	1245	125	29,6	56,7	7,37	18,2	2,04	3,8	0,42	2,3	0,3	40
33,00	34,00	3850	6480	638	2110	213	49,3	104,5	14,75	49,2	6,4	13,7	1,43	7	0,86	153
34,00	35,00	3960	6670	688	2160	202	48,6	92,9	8,68	27,8	3,38	6	0,53	3,4	0,42	79
35,00	36,00	4280	5850	509	1505	167	41,4	85,2	11,7	38,9	4,88	9,7	0,95	4,9	0,65	98
36,00	37,00	1440	2310	222	736	83,3	18	36,6	4,51	12,1	1,37	2,5	0,25	1,2	0,19	28
37,00	38,00	1320	2290	228	772	83,9	18,5	39,7	5,02	13,5	1,61	3,2	0,31	2,1	0,26	35
38,00	39,00	1490	3250	373	1280	125	24,8	48,7	6,38	15,6	1,96	3,6	0,4	2,2	0,3	43
39,00	40,00	1930	3070	295	988	112	26,9	62,8	8,43	32,8	4,7	10,3	1,19	5,6	0,76	111
40,00	41,00	1210	2090	209	730	103,5	23,2	48,3	5,94	20,5	2,91	6,2	0,83	4,1	0,48	74
41,00	42,00	904	1650	169	576	72,1	18	39,5	5,27	21,7	3,08	7,2	0,77	4,2	0,46	76
42,00	43,00	2690	4320	423	1375	161	34,9	71,8	8,19	20,3	2,01	3,8	0,34	1,9	0,24	44
43,00	44,00	1780	2910	273	920	101,5	23,3	48,7	5,81	14,9	1,38	2,5	0,24	1,2	0,16	29
44,00	45,00	1160	2160	220	754	81,3	17,5	36,3	4,63	11,8	1,17	2,2	0,24	1,3	0,12	27
45,00	46,00	511	975	98,1	307	37,1	8,6	19,3	1,67	5,4	0,54	0,9	0,12	0,8	0,1	16
46,00	47,00	1590	2840	302	937	106	25,2	50,7	4,39	12,1	1,32	2,3	0,26	1,4	0,17	32
47,00	48,00	2250	3800	373	1115	128,5	29,6	60,9	5,18	13,3	1,41	2,6	0,31	1,7	0,28	32
48,00	49,00	1780	3120	325	1000	111,5	25,6	53,1	4,25	12,7	1,22	2,4	0,21	1,5	0,28	29
49,00	50,00	570	1050	115	392	59,7	16,7	37	4,25	16,2	2,28	4,9	0,56	4	0,55	50
50,00	51,00	1980	3940	419	1315	134	28,3	56,5	5,52	19,6	2,53	5,5	0,58	3,2	0,37	67
51,00	52,00	880	1740	192,5	627	78,9	20,3	49,6	6,39	28,9	4,45	10,1	1,16	6,2	0,68	116
52,00	53,00	1180	2050	202	599	70,1	16,9	40,2	4,5	18,9	2,71	5,9	0,67	3,4	0,37	71
53,00	54,00	1800	2820	268	796	96,7	26	57	6,85	27	3,86	8	0,87	4,8	0,53	96
54,00	55,00	11350	16000	1505	4080	381	86,2	167,5	14,25	42,6	4,69	8,1	0,74	4,3	0,54	102
55,00	56,00	1820	3370	356	1090	116	25,9	51,4	4,2	12,6	1,45	3	0,28	2,1	0,24	38
56,00	57,00	848	1640	179	577	69,1	16,3	33,8	3,33	12,4	1,63	3,5	0,26	1,8	0,15	42
57,00	58,00	1300	2360	243	749	82,6	19,8	43,4	4,42	16,7	2,22	4,7	0,45	2,6	0,25	53
58,00	59,00	1830	3570	385	1180	115,5	27,1	51,3	4,12	13	1,4	3	0,34	1,8	0,19	37
59,00	60,00	523	1070	115,5	376	47,1	9,9	18,9	1,51	5,8	0,74	1,7	0,17	1,2	0,08	21
60,00	61,00	757	1510	157	491	57,4	13,4	29,5	3,46	16,3	2,64	6,3	0,66	3,2	0,29	73
61,00	62,00	1390	2370	237	704	68,4	14,3	27,8	2,1	6,8	0,84	1,9	0,16	1,1	0,16	24
62,00	63,00	1240	2290	248	772	89,5	21,4	44,5	4,5	17,1	2,42	5,2	0,59	3,3	0,38	66
63,00	64,00	2440	4370	457	1410	166	37,8	76	6,36	21,7	2,92	6,6	0,73	4,2	0,38	78
64,00	65,00	1390	2540	264	847	105	25,2	49,3	4,56	17,8	2,48	5,5	0,62	3,4	0,43	70
65,00	66,00	239	485	55,3	190,5	31,1	8,9	22,1	2,61	10,5	1,62	3,9	0,41	2,1	0,17	44
66,00	67,00	4540	6000	537	1460	152	39,6	81,7	7,71	30,6	4,3	9,7	1,1	6,2	0,8	114
67,00	68,00	1290	2290	243	772	86,3	18,5	35,8	3,09	11,3	1,44	2,6	0,29	1,7	0,18	39
68,00	69,00	815	1560	163	512	60,6	14,5	31,9	3,71	16,1	2,39	5,1	0,55	2,7	0,32	62
69,00	70,00	1690	3080	314	965	112,5	29	65,9	8,42	36,5	5,31	11,2	1,11	5,3	0,58	146
70,00	71,00	1090	1980	211	687	95,4	26,6	69,1	9,29	43,8	7,13	15,7	1,69	9,4	1,14	184
71,00	72,00	1790	2770	266	796	94,9	24,6	53,7	5,96	24,4	3,62	8	0,85	4,7	0,49	93
72,00	73,00	1540	2440	256	899	164,5	34,5	80,2	8,24	32,1	4,84	11,4	1,25	7,5	1,01	142
73,00	74,00	516	1050	110,5	365	48,7	12	26	2,57	9,5	1,33	3,1	0,27	1,8	0,18	39
74,00	75,00	634	1180	120	390	51,4	12,2	29,8	2,91	10,5	1,56	3,7	0,34	2	0,19	43

A spread-sheet of the TEIG-2 analyses may be purchased from the NGU.

Appendix 5
Whole-rock geochemical analyses of the TEIG-2 shallow drill-core, contd.
(Note: Norwegian decimal, “comma”, notation is applied in the tables)

	Interval		Ba	P	Nb	Th	U	S	Ag	As	Cd	Co	Cu	Ni	Pb	Zn
NGU ID	From	To	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
199534	6,25	7,00	3400	1630	309	121	30,5	0,4	0,84	1,9	2,41	9,7	9,2	2,3	15,8	861
199535	7,00	8,00	3510	1140	1230	119	28,7	0,31	2,31	1,7	2,62	7,6	19,4	2,9	15,7	1070
199536	8,00	9,00	830	4200	1190	331	18,1	0,86	2,8	3,7	3,06	18,8	35,4	5,5	23,7	1230
199537	9,00	10,00	690	3950	1620	107,5	10,7	0,49	0,57	4,8	1,86	11,2	7,7	2,2	13,3	733
199538	10,00	11,00	1310	8590	3670	172	26	1,13	0,99	4,5	2,8	25,7	13	8,2	14,4	1210
199539	11,00	12,00	730	4190	886	152	11,8	1,76	1,44	7,3	4,22	31,4	43,5	12,5	19,9	1680
199540	12,00	13,00	4270	5890	492	163	4,4	0,35	0,22	1,2	2,48	7,7	20,8	1,9	14,9	928
199541	13,00	14,00	3740	580	1065	93,2	8,7	0,4	0,44	2,1	1,69	8,7	7,6	2,5	13,9	661
199542	14,00	15,00	2050	9380	138	148	3,3	0,15	0,34	1,1	1,5	4,1	5,9	2,5	11	625
199543	15,00	16,00	1720	890	422	121	4,8	0,73	1,33	2,4	2,49	12,7	12,9	14,3	14,4	1170
199544	16,00	17,00	2260	1260	433	115	3,9	0,75	1,4	2,4	2	12,8	8,1	2,8	13,4	847
199545	17,00	18,00	2670	280	411	111	8,1	0,67	1,31	2,4	1,86	10,8	17,8	2	23	977
199546	18,00	19,00	3250	1830	595	259	22,1	0,55	1,32	5,6	1,71	10,7	7,9	2,3	18,9	748
199547	19,00	20,00	560	2400	177	473	11,5	0,25	0,7	5,8	1,28	5,3	5,6	1,7	18,3	406
199548	20,00	21,00	310	2990	154	1000	14,8	0,66	2,74	0,3	8,72	10,2	43,9	2,3	64,7	4320
199549	21,00	22,00	110	1430	821	281	11,6	2,24	2,25	11,6	1,96	32,3	15,3	5,1	27,9	845
199550	22,00	23,00	90	8390	275	800	23,7	1,63	1,38	11,5	1,08	27,6	49,6	4,1	40,1	381
199551	23,00	24,00	1140	1040	382	200	7,5	0,84	1,65	5	2,37	17,2	62,1	3,8	24,7	1030
199552	24,00	25,00	420	770	869	363	8,5	0,64	2,2	7,2	0,44	12,6	8,4	3,5	61,7	222
199553	25,00	26,00	2070	820	402	181,5	6	0,56	1,39	9,2	0,71	10,6	6,5	2,6	45,3	286
199554	26,00	27,00	2360	>10000	1410	244	8,3	0,65	1,49	8,5	0,35	14,8	16,7	3,3	34,8	135
199555	27,00	28,00	1010	3030	156	209	3,2	0,98	0,82	5,5	0,92	22,1	11,8	2,6	38,4	227
199556	28,00	29,00	1240	1250	515	143,5	2,8	0,94	1,43	5,2	0,79	24	8	2,5	72,3	197
199557	29,00	30,00	3060	1180	193	144	4,7	0,33	0,56	1,7	0,66	8,3	3,4	1,6	17,9	132
199558	30,00	31,00	5480	6850	187	141,5	9,3	0,33	0,56	1,9	0,65	6	4,8	1,6	25,5	163
199559	31,00	32,00	4020	4410	652	120,5	6,3	0,36	0,99	1,7	0,68	8,6	3,7	2,7	13,2	122
199560	32,00	32,50	6150	3460	457	132	5,9	0,33	0,95	2,9	0,77	7,5	6,1	2,1	17,2	137
199561	32,50	33,00	1680	1950	604	254	4,2	0,07	1,2	2,4	2,44	7,7	7,9	1,5	206	573
199562	33,00	34,00	4730	9790	136	366	5,6	0,17	1,45	2,1	4,35	7,3	1,8	2	57,2	842
199563	34,00	35,00	3140	2720	329	248	3,9	0,31	1,58	3	2,66	9,8	2,6	2,1	40,8	630
199564	35,00	36,00	1040	6970	374	296	8,2	0,73	0,95	12	1,43	17,7	4,7	3,9	43,7	333
199565	36,00	37,00	800	370	213	135	8,9	1,03	0,56	2,6	0,77	19,3	6,2	2,3	12,3	160
199566	37,00	38,00	810	1770	236	160	5,5	0,88	1,25	2,4	0,64	16,1	7,8	2,6	19	239
199567	38,00	39,00	2490	2230	411	157,5	5,1	0,52	0,92	2,3	0,83	10,1	9,9	2,1	15,7	452
199568	39,00	40,00	3140	>10000	572	219	9,3	0,6	1,38	2	0,94	12	7,9	3,9	17,4	302
199569	40,00	41,00	2360	4310	494	234	6,1	0,66	0,97	3,9	0,72	12,4	4,5	2,6	16,7	244
199570	41,00	42,00	3410	>10000	1390	139	3,7	0,41	0,7	2,3	0,6	9,4	4,9	2,2	11,9	131
199571	42,00	43,00	2410	2270	310	330	3,4	0,35	0,73	1,4	0,48	10,1	7,3	1,5	10,5	109
199572	43,00	44,00	3820	1440	350	215	2,7	0,31	0,63	1,4	0,68	6,9	6,4	1,2	8,1	139
199573	44,00	45,00	1300	1590	747	144	6,7	1	2,33	3	0,51	19,7	5,6	3,3	15,6	157
199574	45,00	46,00	1870	440	584	74,6	6,4	0,73	1,08	1,7	0,56	14,3	1,9	2,2	7,3	100
199575	46,00	47,00	520	1030	252	187	4,7	0,03	0,76	0,7	0,63	5,2	1,8	1,3	14,7	170
199576	47,00	48,00	700	1290	285	293	2,1	0,04	0,62	2,7	1,43	10,2	3,5	2	36,7	446
199577	48,00	49,00	1030	1010	578	261	4,7	0,02	0,24	1,9	1,01	9,5	5,9	3,5	19,8	346
199578	49,00	50,00	1060	7320	2260	174	7	0,09	0,58	2,9	0,96	12,6	7,1	11,5	16,2	427
199579	50,00	51,00	2370	6630	852	153	5,9	0,4	1,85	3,1	0,43	8,6	1	2,3	14,3	118
199580	51,00	52,00	760	>10000	182	158,5	4,3	0,87	0,64	15,7	0,56	14,8	2,4	2,9	14,1	100
199581	52,00	53,00	2380	8630	201	162	5	0,57	0,42	7,3	0,73	11,6	2,4	2	10,5	152
199582	53,00	54,00	3380	>10000	938	214	5,8	0,33	1,27	3,7	0,74	7,5	3,1	2,1	11,4	184
199583	54,00	55,00	190	4790	133	525	14,2	1	2,41	3,5	1,53	18,6	14,6	2,6	26,4	454
199584	55,00	56,00	400	1130	61	173,5	6,3	1,36	1,74	3,6	2,8	25,6	10,4	3,2	19,6	1040
199585	56,00	57,00	1730	4940	52	86,2	1,8	0,11	0,31	0,7	1,04	3,7	3,1	1,6	8,9	357
199586	57,00	58,00	2290	5720	795	137,5	4,9	0,89	1,54	7,6	2,15	14,3	11,3	2,8	15,7	786
199587	58,00	59,00	1690	900	446	121,5	7,5	0,8	1,72	3,4	1,72	14,8	13,7	3	12,2	668
199588	59,00	60,00	660	500	367	72,3	4	0,58	0,68	2,2	0,95	14,1	2,6	2,5	7,3	442
199589	60,00	61,00	1620	3510	638	85	8,7	0,69	1,44	3,2	1,65	17,6	7,8	2,4	13,2	612
199590	61,00	62,00	3250	720	425	91,7	3,4	0,33	0,75	0,7	1,83	6,1	5,6	1,7	9,1	560
199591	62,00	63,00	1950	6150	97	150,5	2,5	0,49	1,03	6,6	2,73	7,8	10,4	1,9	22,5	1060
199592	63,00	64,00	2140	5810	265	280	6,5	0,76	1,54	9,1	1,96	12,4	5,7	2,9	19,9	725
199593	64,00	65,00	2040	6690	261	142,5	4,7	0,5	0,97	3,1	1,98	8,6	6,2	1,9	12,2	706
199594	65,00	66,00	1040	7930	1070	58,9	2	0,16	0,94	2,3	1,11	4,1	3,3	2,5	7,4	353
199595	66,00	67,00	1030	>10000	789	255	5,7	0,83	0,97	6,8	1,9	12,9	6,1	2,8	16	681
199596	67,00	68,00	2860	2510	356	136,5	3,4	0,61	0,85	5,2	1,83	9,8	4,5	1,6	7,9	547
199597	68,00	69,00	4060	>10000	110	95,5	2,1	0,34	0,49	2,1	1,57	5,3	4,6	1,1	6,9	446
199598	69,00	70,00	1570	>10000	304	175,5	5,2	0,67	0,67	9,8	2,15	14,2	9	3	13,5	870
199599	70,00	71,00	2720	>10000	832	160	5,4	0,22	0,33	5,9	1,34	8,6	7,4	3,8	16,1	573
199600	71,00	72,00	3880	>10000	965	168	11,8	0,42	1,43	3,4	1,91	7,1	14,9	1,7	11	830
191503	72,00	73,00	1490	>10000	325	252	4	0,57	0,5	9,7	1,05	10,4	6,2	2,9	14,2	380
191504	73,00	74,00	1380	2490	1690	91,4	8,8	0,5	0,05	3,5	0,62	8,6	6	2,9	9,7	201
191505	74,00	75,00	3080	3740	122	98,9	2,1	0,51	0,03	2,9	0,48	8,3	1,9	1,9	7,7	98

Appendix 6
Photos TEIG-2 shallow drill-core

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Photos TEIG-2 shallow drill-core

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Photos TEIG-2 shallow drill-core

Appendix 7
Veien videre på Fensfeltet - Regiongeologens vurderinger

Fylkeskommunen er opptatt av å bidra til å skape arbeidsplasser i fylket. Det omfatter også å vurdere de mulighetene vi har som samfunn for å bruke unike, lokale naturressurser. En slik mulighet kan være å utvinne råstoffer essensielle for “det grønne skiftet “på Fensfeltet. Skal vi utvinne råstoffer så må vi først vite om slike råstoffer faktisk finnes i utvinnbare mengder der. Dette må begynne med geologiske undersøkelser.

Denne rapporten fra Regiongeologen er et bidrag til å øke den geologiske kunnskapen om forekomstene av REE, sjeldne jordartsmetaller, på Fensfeltet. Det er et lite skritt på veien, men de geologiske undersøkelsene i Fensfeltet har såvidt startet.

Det er naturlig at lokalbefolkningen, mediene, politikere og storsamfunnet har en hel del spørsmål om forhold rundt mulig framtidig gruvedrift på Fensfeltet. De aller fleste av disse spørsmålene stiller også Regiongeologen og det må også mulig industriutviklere gjøre. Det er derfor viktig å få fakta på bordet.

En framtidig gruvedrift må ha full samfunnsaksept. Det er ikke fort gjort å starte gruvedrift i det moderne Norge, og det bør heller ikke være det. Fakta først!

Med vårt store forbruk av moderne miljøteknologi og høyteknologi er nordmenn i verdenstoppen i forbruk av kritisk viktige mineralråstoffer. Ikke minst gjelder det råstoffer for å produsere el-biler, alle mulige former for elektronikk, framstille energi på miljøvennlige måter etc.. Alt dette krever at vi tar ut mineralråstoffer for å lage den teknologien vi bruker.

Mange av disse mineralressursene utvinnes i land der helse og miljø ved gruvedrift ikke er så viktig. I alle fall ikke for dem som ikke blir direkte berørt av uforsvarlig gruvedrift. Alle miljøbevisste nordmenn bør derfor være opptatt av å finne muligheter her i landet for utvinning av noen av de råstoffene som er helt essensielle for at VI skal nå de klimamålene vi og verdenssamfunnet setter oss. Vi bør ha som mål å vise verden at gruvedrift og mineralutvinning kan gjøres på en miljøvennlig og likevel økonomisk forsvarlig måte. Hvis ikke vi kan klare det, hvem skal da klare det?

Jeg får stadig spørsmål om mulig gruvedrift på Fensfeltet fra ulike kanter. Her har jeg samla noen av dem, og så svarer jeg på dem slik jeg vurderer dette.

Finnes det noen internasjonale regler for hvordan en gjennomfører undersøkelser av mineralforekomster?
Ja, bl.a. har FN laget en oversikt som deles inn i tre hovedkategorier:

- Geologiske faktorer. Det må være en teknisk utvinnbar ressurs der.
- Økonomiske faktorer. Ingen ønsker å starte et underskuddsforetak eller bygge et luftslott.
- Gjennomførbarhet, herunder miljø, helse, og tekniske aspekter av alle slag.

Alle disse hovedpunktene består av et vell av underpunkter. Alle problemstillinger må være tilpasset lokale forhold. Alle disse må belyses, og alle problemer må finne en løsning. Dette tar tid.

Hvor i prosessen er vi på Fensfeltet nå?
Denne prosessen har knapt begynt. Vi er fremdeles på rekognoseringsstadiet. Gjennomføring kommer til å ta mange år. Dersom den lar seg gjennomføre.

Har vi påvist en økonomisk utvinnbar REE-ressurs på Fensfeltet?
Svaret er klart NEI! Vi vet ikke om vi har en utvinnbar ressurs. Vi har bare indikasjoner på at det kan være en ressurs der.

Hva må gjøres?
Det er nå de omfattende geologiske undersøkelsene kan begynne. For at det i det hele tatt skal være aktuelt å gjøre andre omfattende studier eller legge store planer, så må en vite om det er utvinnbare ressurser til stede. Dette krever spesielt to store innsatser til å begynne med:

1. Svært grundige geologiske undersøkelser. Det vil blant annet bety veldig magnge kjerneboringer, geofysiske målinger, kjemiske analyser etc. Det må finnes et stort nok bergartsvolum med høy nok konsentrasjon av REE til at det kan være forsvarlig å investere i utvikling av gruveanlegg
2. En må snarest mulig finne ut av om det er teknisk mulig å ta REE-mineralene ut av bergarten på en forsvarlig måte. Dette vil bl.a kreve masse arbeid i laboratoriet. Så må en være sikker på at det er mulig å ta REE-mineralene ut av bergarten på industriell basis. Ikke bare i laboratoriet. Klarer en ikke å ta ut de verdifulle mineralene så hjelper det ikke at forekomsten av dem er stor.

Er gruvedrift nært forestående?
Nei.

Vil en eventuell gruvedrift likne den gamle gruvedrifta på Gruveåsen eller på Søve / Tufte?
En eventuell ny gruvedrift vil bli noe helt annet enn det som var i de gamle gruveanleggene.

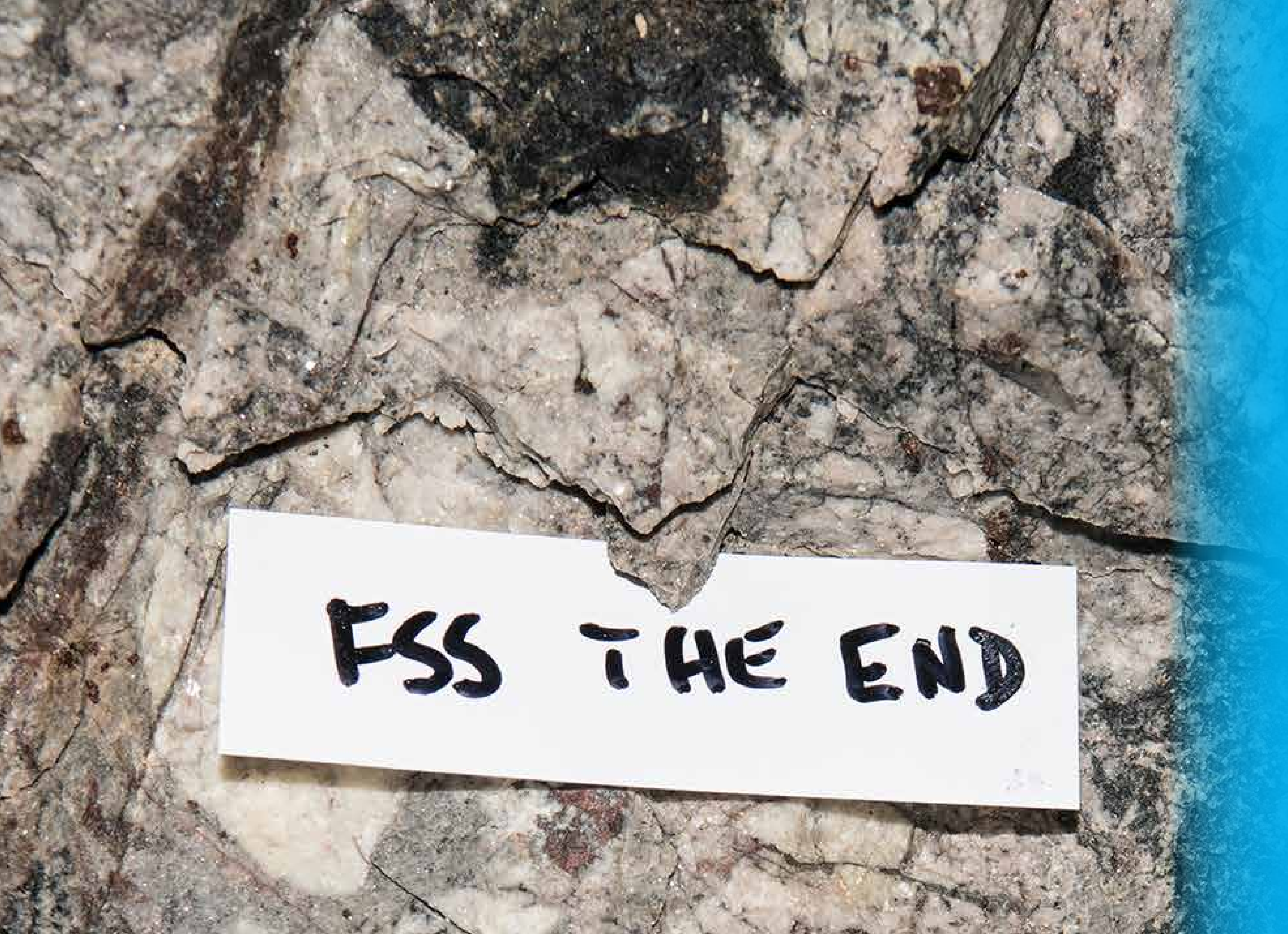
Hvor skal gruva ligge?
Det kan ingen svare på før en vet om en har en ressurs og hvordan denne eventuelt ser ut mot dypet. Alle forekomster er unike og alle gruver må finne tekniske driftsmåter som er tilpassa den aktuelle forekomsten. Det eneste sikre på Fensfeltet er at ei evntuell gruve må være underjords.Den må ligge dypt nok nede under overflaten til at det ikke er noen fare for boliger, veier, jordbruk eller annet på overflaten.
Det finnes mange former for gruvedrift og det finnes mange måter å drive gruver på. Ei framtidig gruve på Fensfeltet MÅ være den “grønneste” gruvedriften som kan tenkes.

Er det en risiko for at vi får mer slagg av typen som ligger deponert på Søve?
Nei. Det er et avfall fra en metallurgisk prosess som gikk ut på å framstille ferroniob fra niobkonsentrat med høyt innhold av uran og thorium. Det var fra helt andre mineraler fra en helt annen bergart (søvitt) og med totalt forskjellige framstillingsmetoder enn det som er potensielt aktuelt for REE.

Er du for eller i mot gruvedrift på Fensfeltet?
For å svare på det spørsmålet må jeg ha Fakta Først!

Jeg har valgt å ta med disse synspunktene i denne rapporten. De står for min regning. Siden det sannsynligvis er beboere i nærmiljøet som har mest interesse av disse temaene så er denne delen skrevet på norsk.

Sven Dahlgren



THE END or THE BEGINNING?

This image was taken at "The End" of the Old iFen Iron mine adit at a depth of 70m beneath the old Fen school. This adit was terminated nearly a century ago when the miners had left the iron-ore bearing "red-rocks" and entered the barren "rauhaugites". Obviously the lack of iron ore made no promises for their future of iron mining. The abundance of REE-mineralization in this adit may actually represent the entrance to <u>OUR</u> future.

This mine certainly marked the end of an era, but it may also represent a New Beginning.

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