Norwegian anorthosite as possible source for Al – a review

Presentation at Hydromet seminar
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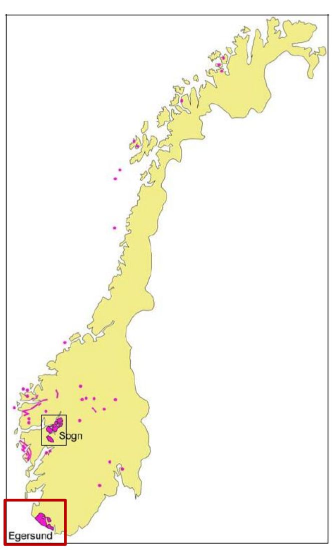
What is anorthosite?

- Anorthosite (An) is a feldspar type rock (containing Al and Si-oxides)
- The main mineral is anorthite, $CaAl_2Si_3O_8$
- Large deposits of Anorthosite are found in Norway, Greenland and Canada, but also Sweden, Finland and India
- Locally called «Kvitstein» (White stone) in Sogn, W. Norway
- Rock with high degree of anorthite is known to be leachable in acid

Short historic overview of anorthosite (An) in Norway

- V.M. Goldschmidt was the first to acknowledge the possibility of using An as source for Al or alumina (Al_2O_3) in 1917 – 100 years ago!
- AS Elektrokjemisk (now Elkem) carried out regional survey until 1920 of the Sogn area for An.
- During WWI a mine was established at Kinsedal in Luster by Norsk Hydro to serve their new Al-producing plant at Høyanger.
  - The mine was closed during the economic depression after the war.
  - In 1940 it was reopened to serve Al-production at Herøya, Porsgrunn. After Herøya was bombed in 1944 the mine was closed and never reopened.
  - The process Norsk Hydro used is not known, but nitric acid was probably used to dissolve An.
- In the mid 1960s a mine producing white rock was established in Nærøydal (Gudvangen Stein AS).

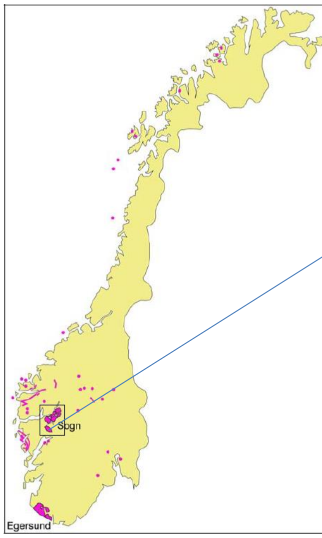
Main anorthosite deposits in Norway



Wanvik, NGU 2010

- The Egersund deposit:
  - Same site as the ilmenite ($FeTiO_3$) deposit exploited by AS Titania
  - An lower in anorthite than the one in Sogn, not easy dissolvable in acid
- Lot of other smaller deposits along the coast of Norway

Main anorthosite deposits in Norway



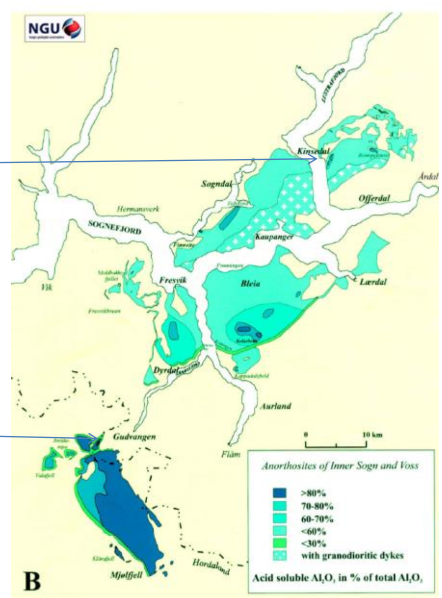
Jordalsnuten, Gudvangen

Nærøyfjord is world heritage area

Inner Sogn deposits of anorthosites

Kinsedal

Jordalsnuten



ANORTAL-project (ANORThosite-ALuminium)

- Established in the mid 1970s by Elkem AS and Årdal og Sundal Verk AS and others
- Experimental work was performed at IFA (Institute for Atomic Energy, now IFE – Institute for Energy Technology)
- Based on IFA-patent
- H_2SO_4 and HCl were used as acids
- Alumina, Al_2O_3, was the only cost carrier, acids were recovered and recycled. Silicate and gypsum produced for cement production.

ANORTAL-patent

United States Patent [19] — [11] **4,110,399**

Gaudernack et al. — [45] **Aug. 29, 1978**

[54] **PROCESS FOR THE EXTRACTION OF ALUMINA FROM ALUMINUM-CONTAINING SILICATES**

[75] Inventors: **Bjorn Gaudernack; Norvald Gjelsvik,** both of Oslo; **Leif Farbu,** Strommen, all of Norway

[73] Assignee: **Institutt for Atomenergi,** Kjeller, Norway

[21] Appl. No.: **782,826**

[22] Filed: **Mar. 30, 1977**

[30] **Foreign Application Priority Data**

Apr. 2, 1976 [NO] Norway 761136

[51] **Int. Cl.**[2] **C01F 7/22;** C01F 7/26

[52] **U.S. Cl.** **423/112;** 423/126; 423/128; 423/132; 423/139

[58] **Field of Search** 423/112, 126, 139, 132, 423/128

[56] **References Cited**

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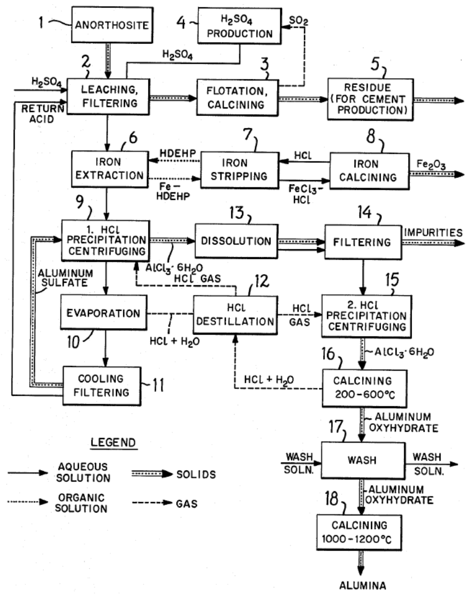
Primary Examiner—Herbert T. Carter
Attorney, Agent, or Firm—Eyre, Mann, Lucas & Just

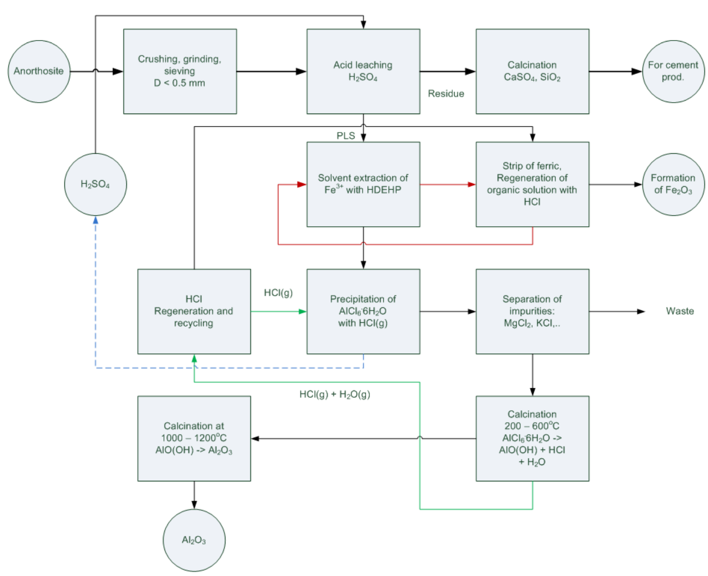
[57] ABSTRACT

A process for the extraction of alumina from aluminum-containing silicates is disclosed. The process comprises acid leaching of the raw material, iron extraction, precipitation of the aluminum fraction as the aluminum chloride hexahydrate, removal of sodium chloride and calcination to alumina. The process can be made continuous with substantial regeneration and recycling of process components.

12 Claims, 1 Drawing Figure



Simplified ANORTAL-block diagram

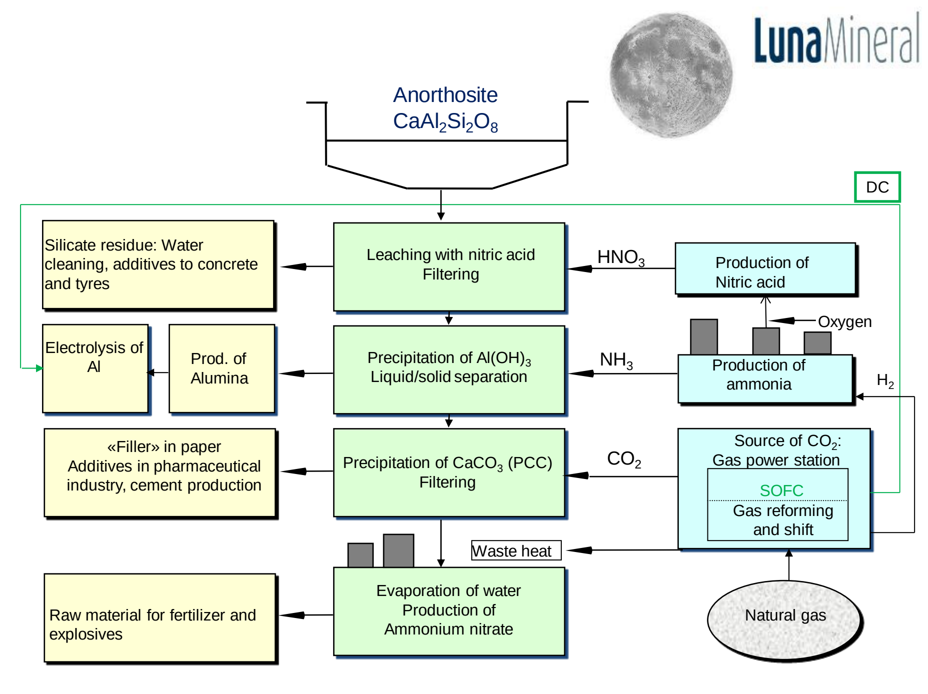


Some views concerning ANORTAL

- The process was demanding in the choice of materials. Graphite was used to withstand HCl-gas at high temperatures.
- The process was almost decided to be build, but would probably have been an economical disaster.
- The R&D work represented a significant build up of Norwegian hydrometallurgical competence. Institutions involved were IFE, SINTEF, UiO and NTH (now NTNU).

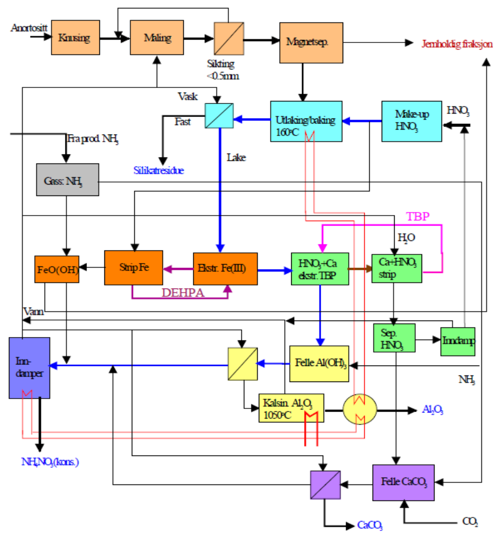
New concept for use of anorthosite Second half of 1990s

- How to find sources of Ca not of carbonate origin? Sequestration of CO_2
- Main inventors at IFE: Arne Råheim and Ingleiv Hundere
- Holistic approach: all outgoing flows should be products
- «Borrowing» HNO_3 and NH_3
- To produce NH_4NO_3-fertilizer natural gas is a starting point:
- Reactions:
  $CH_4 + 2H_2O = CO_2 + 4H_2$
  $N_2 + 3H_2 = 2NH_3$
  $4NH_3 + 7O_2 = 4NO_2 + 6H_2O$
  $3NO_2 + H_2O = NO + 2HNO_3$

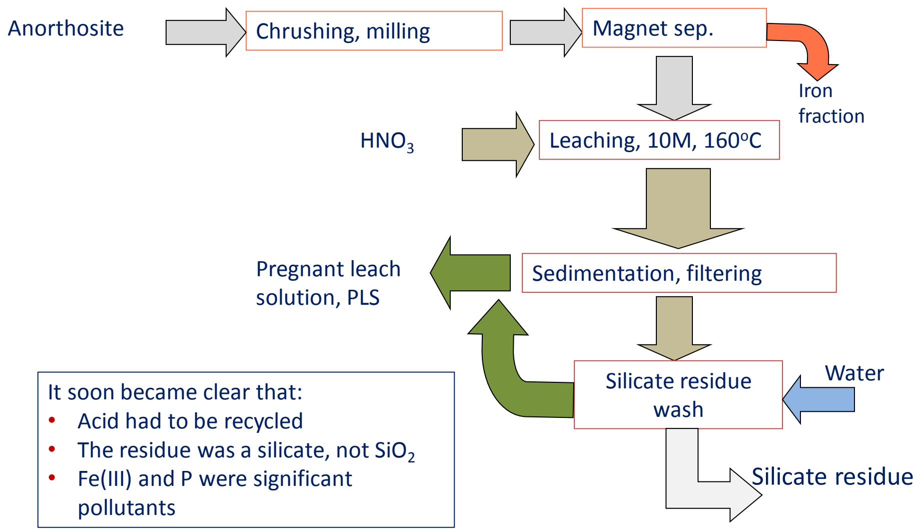


The process in block diagram

(In Norwegian)

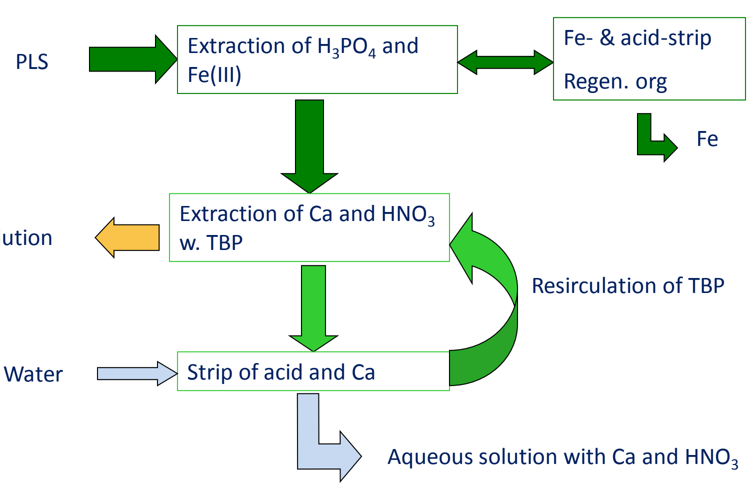


Process description in details

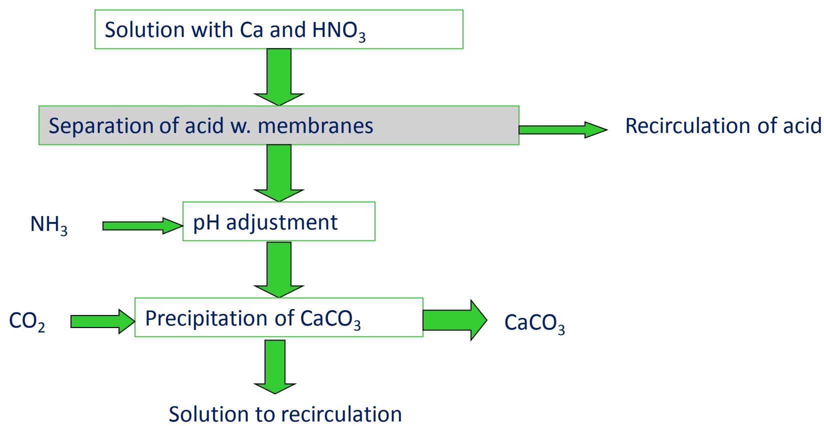


It soon became clear that:
- Acid had to be recycled
- The residue was a silicate, not SiO_2
- Fe(III) and P were significant pollutants

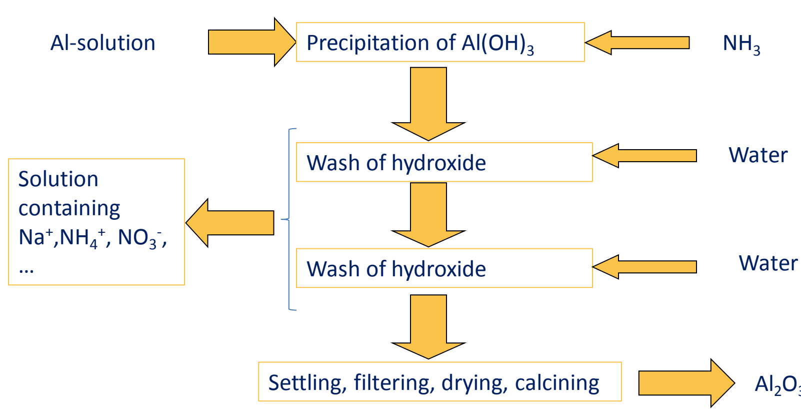
Process description, cont.

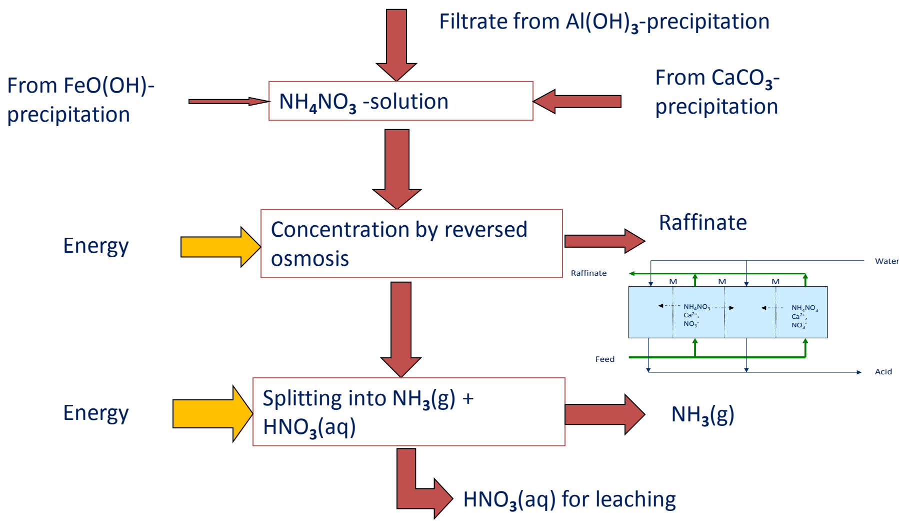


Process description, cont.

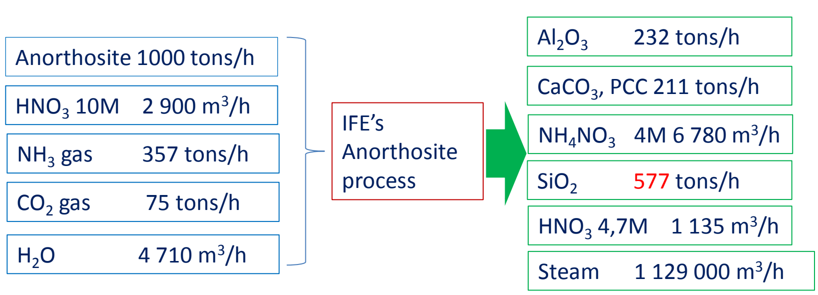


Process description, cont.





Mass balance



Annually, this would correspond to a production of:
1,8 Mtons alumina (= Norway's production 2% of world's)
1,7 Mtons PCC (World's production > 80 Mtons)
4,6 Mtons silica
per 8 Mtons anorthosite processed

Patent awarded

(12) **PATENT**

(19) NO (11) **323417** (13) **B1**

NORGE

(51) Int Cl.
C01F 7/24 (2006.01)
C01F 7/18 (2006.01)
C01F 11/18 (2006.01)
C22B 3/06 (2006.01)
C22B 3/26 (2006.01)
C22B 3/38 (2006.01)

Patentstyret

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(54)	Benevnelse	**Fremgangsmåte for å produsere alumina, PCC og silikat fra silikatbergarter**
(56)	Anførte publikasjoner	"The Extraction and Refining of Metals", Colin Bodsworth (1994) CRC Press, Inc., 18-19
(57)	Sammendrag	

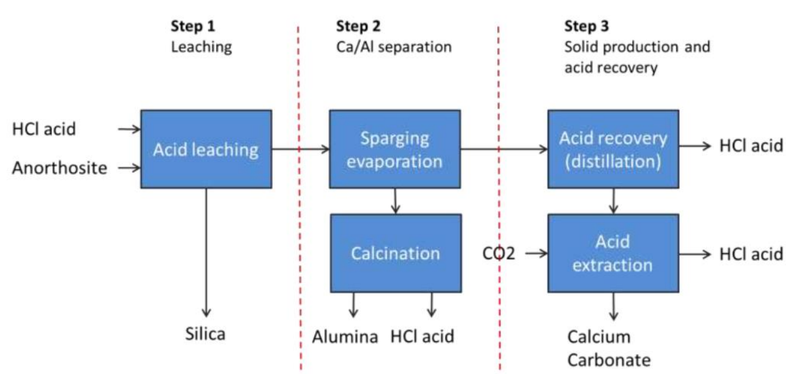
Conclusions on the holistic approach

- Teltek, an engineering consultant, estimated the investment and operation costs. They refined and simplified the process. Still a need for sales of the silicate (58 % of input) is imperative.
- With so many products (Al_2O_3, PCC, NH_4NO_3 and silicate) the volumes are difficult to tune according to market needs.

The continuing story of Anorthosite

- Nordic Mining, a Norwegian mining company, purchased Gudvangen Stein AS.
- Together with IFE they started a new project on extraction of Al from anorthosite.
  - Initial idea was to leach Al with CO_2/H_2CO_3
- Key components in the new approach became HCl (Anortal) and CO_2 for production of PCC.

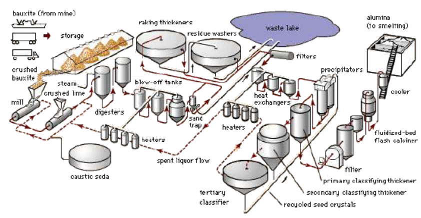
The Nordic Mining - IFE process



Courtesy of Nordic Mining

- Advantages of the new technology

- Availability of a new alumina source
- Sourcing from local mineral resources
- Potential for better infrastructure/less transportation
- Moderate process conditions (2-5 atm and 100-160ºC)
- Potentially close to total use of the mineral resource
- Production of commercial by-products
- Mining with little waste, processing with less tailings
- Reduced CO_2 footprint, (consumption of 0.5 ton of CO_2 per ton of alumina)



Courtesy of Nordic Mining

Conclusions from the Norwegian anorthosite projects

- Industrial projects with potential of large scale production needs industrial competence from the initial stage
- New processes should NOT aim at large portions of world market from the start
- Production volume must be tuned according to the lowest market share
- A complex production needs all products to carry the cost, otherwise it will be too vulnerable to changes in markets

Is there a future for making alumina from anorthosite?

- Use of bauxite creates huge ponds of red mud. These are severe environmental issues.
- The world needs aluminium and sources other than bauxite.
- If anorthosite should be used as source rock, the silicate residue must find a market.
- Sustainable production requires all outputs as useful products. We must avoid red mud ponds and gypsum mountains. Therefore, anorthosite offers an alternative, but the solution is yet to come.

Thanks to Nordic Mining for providing data

Thanks to IFE

Thank you for your attention!

Be a part of the solution, not the residue!