NGU Rapport 95.116
Opportunities in development of Mineral Resources in Norway

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REPORT

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Summary:

The report describes the Norwegian mineral extractive industry, and its principal products especially those for export. Opportunities for future development are outlined. The natural and infrastructural advantages of Norway are shown to be considerable, and the need for detailed prospecting for a variety of mineral resources is focused.

Keywords: Min. resources	Geology	Infrastructure
	Prospecting	Development

1 INTRODUCTION

Norway is remarkably well-endowed with mineral resources, and has a long tradition in mining, quarrying and mineral processing. The types and distribution of mineral resources are related to the complex geological history of the country. Mining has been important in many areas, and indeed the mining of metals dates back to Viking times.

There has been significant production of the following metals: iron, copper, lead, zinc, nickel, molybdenum, cobolt, niobium, chromium, gold and silver. Only a few mines are open, but many of the metallogenic provinces represent attractive areas for prospecting with modern techniques (Fig. 1).

Much present industrial activity relates to deposits of industrial minerals and rocks (Fig.2), including: limestone, dolomite, quartzite, olivine, nepheline syenite, graphite, talc, quartz, a wide variety of dimension stones and slates, soapstone, sand, gravel, clays, etc. Many rocks are also quarried for aggregate, and there is an important potential for development of coastal superquarries for the production of aggregate for export (Fig. 3). Norway also has considerable inshore deposits of sand, gravel and carbonate shell sand. Coal deposits are found on Bear Island and Spitzbergen, and are still actively mined in the latter area which also contains large deposits of gypsum.

The Norwegian mineral industry can be divided into two main sectors, i.e. the mineral extractive industry and the mineral processing industry.

The mineral extractive industry produces coal, metals, industrial minerals, dimension stone, slate and construction minerals. The total production value of this industrial sector is around US$ 880 million (1994) with approximately 5000 employees. The production is dominated by low unit value/large tonnage materials for the construction industry (Fig. 4). Norwegian production of olivine, ilmenite and nepheline-syenite dominates the European market. The Norwegian share of the market for carbonate fillers and crushed rock aggregate is increasing. Fig. 5 shows the development (1989-1993) of Norwegian mineral exports.

The mineral processing industry, which is mainly based on imported raw materials, contributes significantly to the economy of Norway. The basis of the industry is inexpensive hydroelectric energy; it is utilized in the production of i.a. aluminium, magnesium, nickel, copper, zinc, silicon metal, titanium oxide, carbides, ferroalloys, and fertilizers.

The Norwegian mining- and mineral processing industries have a combined production value of about US$ 5350 million (1993) and approximately 24.000 employees. About 50% of the industry, calculated on the basis of number of employees, is based totally or partially on processing of domestic raw materials.

METALLIC ORES IN PRODUCTION

Fig. 1

INDUSTRIAL MINERALS IN PRODUCTION

Fig. 2

ROCK AGGREGATES IN PRODUCTION

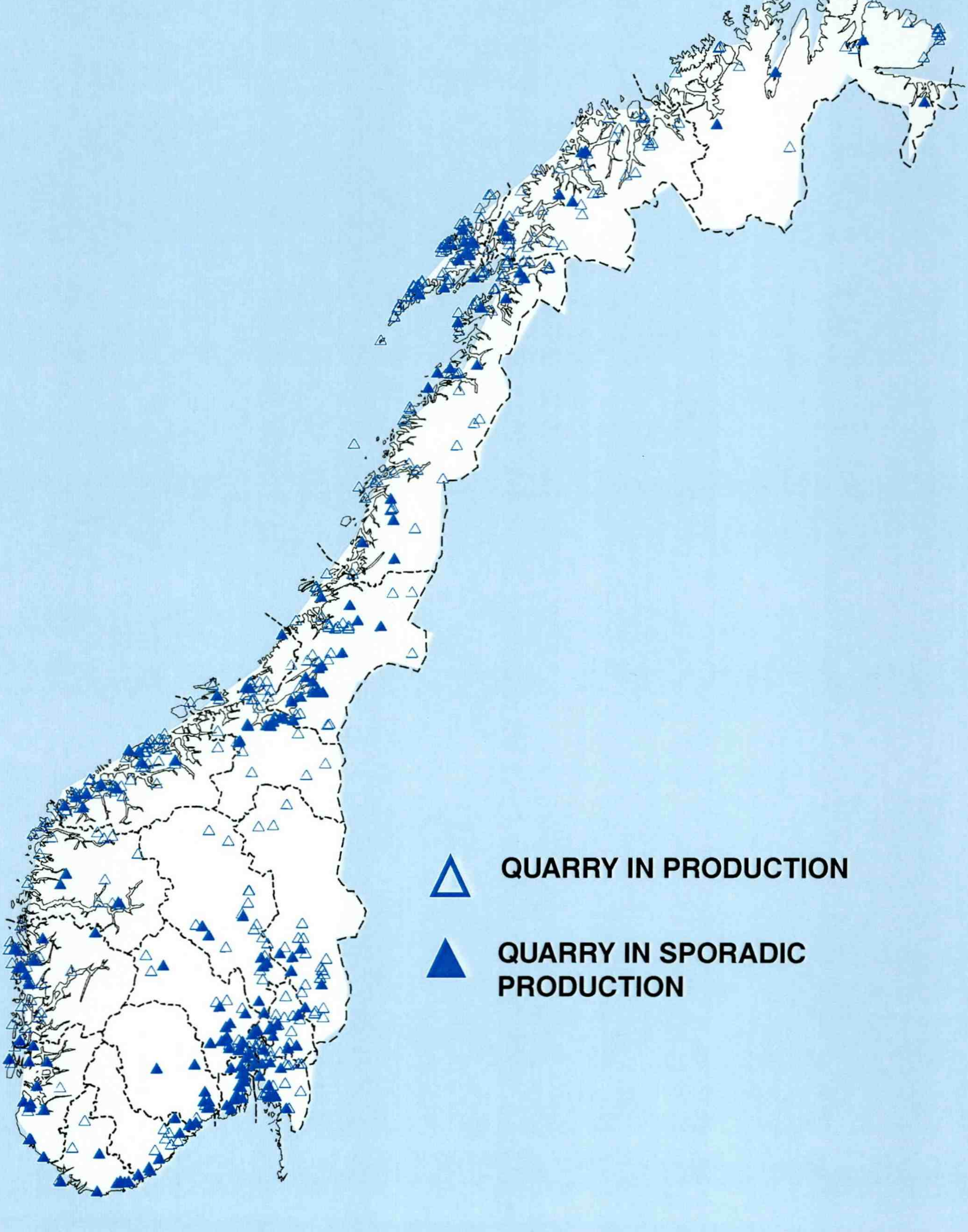


Fig. 3

GROSS PRODUCTION VALUE OF NORWAY's MOST IMPORTANT MINERAL PRODUCTS

(1993, MILL.NOK)

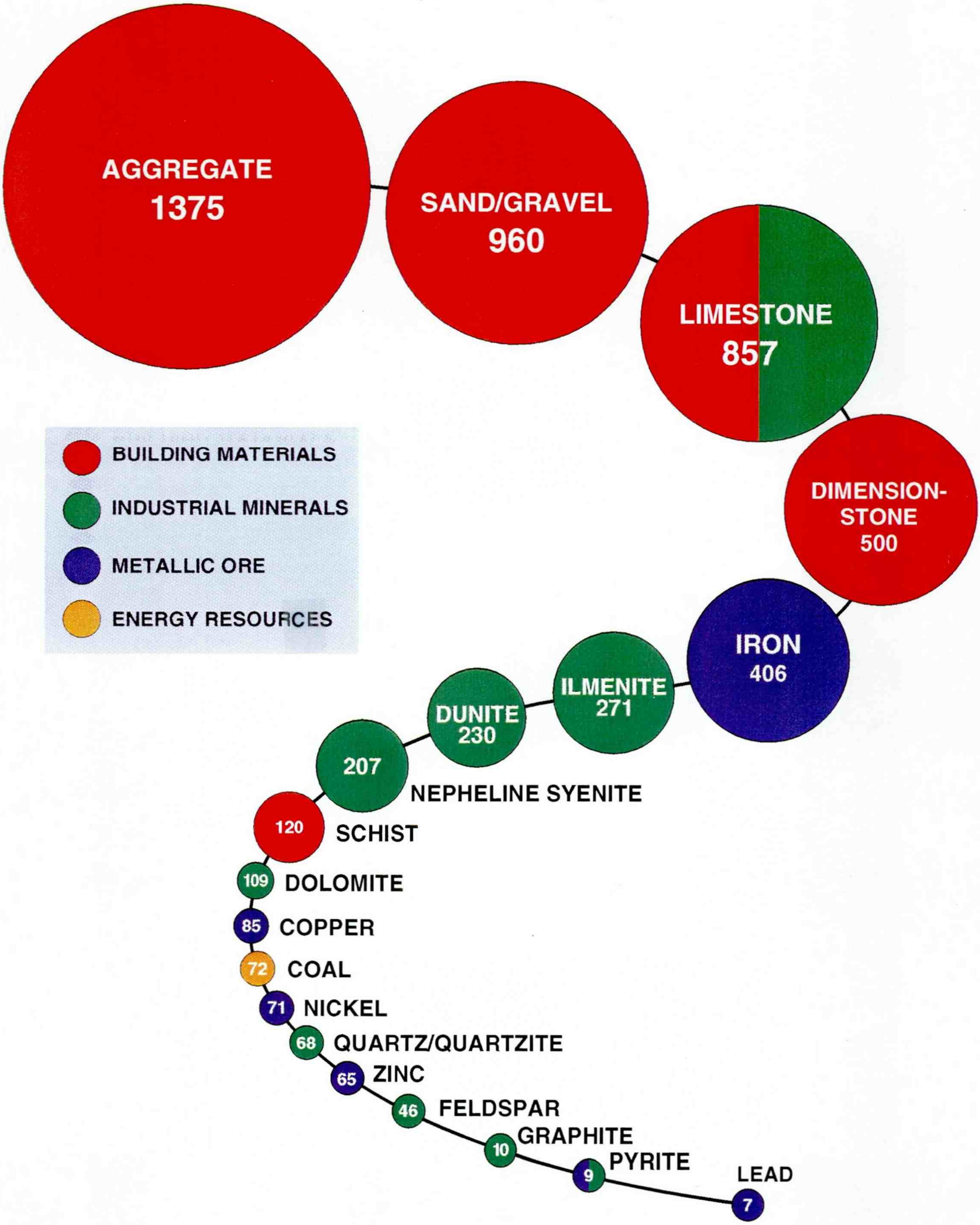
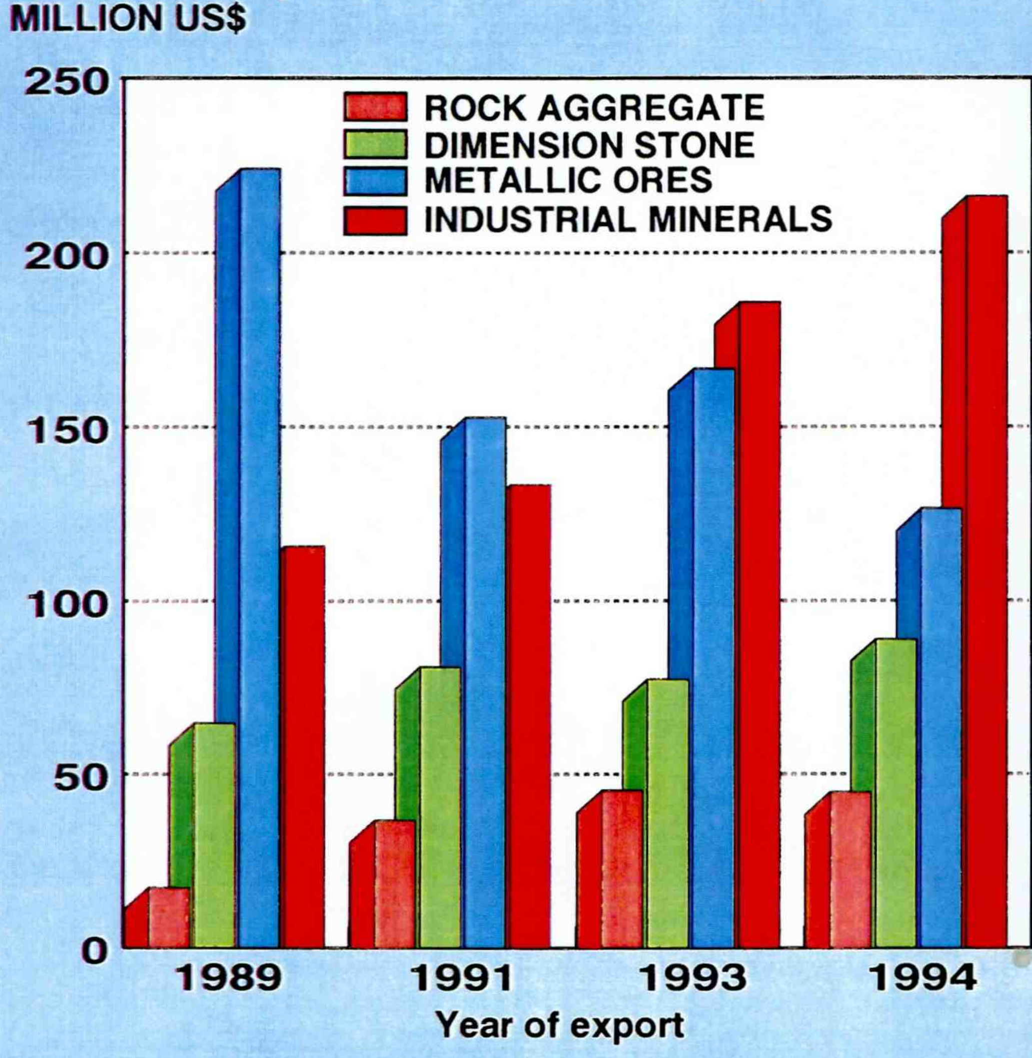


Fig. 4

EXPORT VALUE
MAIN MINERAL COMMODITIES
(Coal, Oil & Gas not included)



MINERAL COMMODITY EXPORT 1994
%-share of commodity groups
US$ 476.5 million

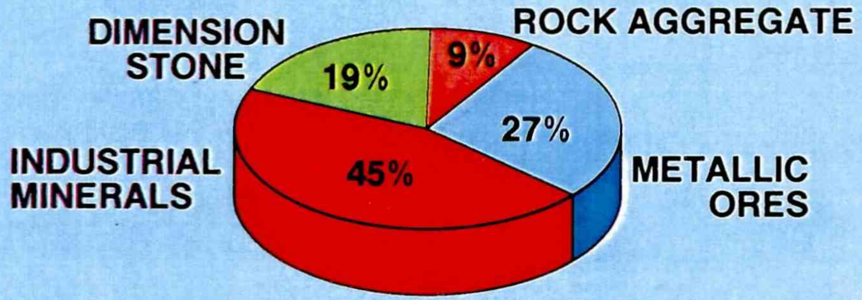


Fig. 5

2 DEVELOPMENT POSSIBILITIES FOR MINERAL RESOURCES IN NORWAY

Norway has a long tradition in scientific investigation, prospecting and mining/quarrying of its mineral resources. However, there are still large areas which are insufficiently surveyed in the detail required to adequately assess their mineral resource potential. In addition, the geological framework of Norway indicates a very interesting potential for finding new economic mineral/rock deposits. A considerable volume of information on the geology, geochemistry and geophysics of Norway and of known deposits is available in databases at the Geological Survey of Norway (NGU).

Prospecting for economically useful mineral deposits in Norway has, since 1945, been carried out by Norwegian companies, NGU and a number of international mining and oil companies. Prospecting activity increased considerably in the period 1970-85, based in part on cooperation agreements with international oil and mining companies. During this period approx. NOK 60 mill per annum was used in mineral prospecting. A significant number of new deposits was discovered in this period. Since 1992 only a small number of Norwegian and international companies has been involved in active prospecting. In addition to its regional surveying, NGU has also carried out a number of deposit investigations, but only as commissioned or cooperative projects together with other governmental agencies or with mining companies.

The above indicates that Norway has a favourable geological environment for mineral resource development. This together with a number of other factors - e.g. proximity to markets, favourable energy conditions and good transport possibilities gives a special potential for future developments in the mineral sector. The long coastline and proximity to the European market are particularly favourable for development of industrial mineral, natural stone and crushed rock aggregate deposits. The excellent facilities for shipping are an important contributory factor.

Norway is the world's largest producer of olivine and one of the largest for nepheline syenite. It is Europe's largest producer of ilmenite, and in a European perspective a significant producer of other minerals and products based on minerals. In addition, Norway produces natural stone which is unique on a global scale and international industrial companies are in the process of establishing aggregate super-quarries.

3 NORWEGIAN EXPERTISE

The Geological Survey of Norway (NGU) is the central institution for the investigation of the geology of mainland Norway, and the upper part of the continental shelf. NGU is a neutral and independent organization, with responsibility for accumulating and maintaining a strategic national geological databank. This databank should contain all available information on Norway's bedrock, surficial deposits and groundwater. NGU carries out regional geological mapping and mineral prospecting together with regional geophysical and geochemical surveys. These may be complemented by detailed geochemical, geophysical and mineral resource mapping often in form of cooperative or commissioned projects. The detailed investigation of a specific deposit is considered to be the responsibility of industry, though NGU may also do this as a commissioned project. NGU works continuously with the updating of the national mineral resource databases. NGU has extensive databases for both airborne and surface geophysical data.

The Norwegian Polar Institute (NPI) has a similar role in Norwegian territories in the Arctic and Antarctic, to that of NGU on mainland Norway. NPI, however, does not have responsibility for mineral resource investigations.

The Norwegian Petroleum Directorate (OD) has the responsibility for information on the subsurface geology of the continental shelf, as well as a range of responsiblities in relation to the oil industry.

The universities represent the largest groupings of geological expertise outside of the oil-industry, NGU and consultancy companies. In addition to teaching there is a considerable amount of geological and mining research including study of economically interesting deposits.

In cooperation with the Norwegian Institute of Technology (NTH) the research organization SINTEF is engaged in research in mining technology, beneficiation and metallurgy and carries out commissioned work for private companies. Various industrial companies and industrial associations carry out - partly in collaboration with SINTEF and other research institutes - development work on new products based on mineralogical raw materials.

The Norwegian Geotechnical Institute (NGI), the State Road Authorities and the Norwegian Railways partake in geotechnical surveys, and the Road Authorities also make sand, gravel and hardrock aggregate surveys. Individual county mapping authorities have carried out Quaternary geological mapping and also work with the national aggregates register.

Earlier several Norwegian industrial companies had their own prospecting groups and a number of international mining companies had branch offices in Norway. In the period 1985-1993 there was a marked reduction in the number of metal mining operations and a gradual reduction in the general expertise, much of which is now concentrated in a number of small independant consulting companies.

4 COMPARATIVE ADVANTAGES IN NORWAY

Proximity to the market is a very clear advantage for producers of industrial minerals, natural stone, and construction materials (especially aggregates) and Norway has a unique transport-economic situation in relation to the expanding European market. The industrial structure of Europe is strongly dependent on access to mineralogical raw-materials and products based on these. Norway is able to offer by reason of its excellent shipping connections easy access to the European and N. American markets.

This industry has a considerable growth potential, particularly in natural stone, construction materials and industrial minerals. This is well illustrated by the marked increase in production and export of such materials from 1975 to the present day.

Within the EU new environmental controls will lead to increasing restrictions for mineral exploitation in areas of high population concentration. Alternative sources of such mineral resources will become increasingly attractive. Norway with its special natural conditions, more sparsely distributed population and good transport facilities, is in a favourable position. This is particularly true in the case of Norwegian rock materials for construction purposes, and already this branch of the industry has seen the establishment of capital-intensive industrial companies which both produce, sell and use construction raw-materials in the international market.

The Norwegian authorities are very concerned that there should be a well planned and balanced development of mineral deposits and are aware of the considerable importance that the mineral industry has for employment prospects. There are favourable economic arrangements, for the establishment of industry in outlying parts of Norway. A highly qualified work-force and technical expertise to take part in all stages from initial prospecting, deposit evaluation, and industrial development of such deposits is available.

5 EXPLORATION OPPORTUNITIES

Exploration has been fairly intensive in areas of known mineral potential, mainly in regions related to both old and recent mining activities. However, substantial areas are under-explored, including extensive areas in nothern Norway, parts of central, western and southern Norway. The following metals have been the object of prospecting: gold, beryllium, rare earths, tungsten, and industrial minerals such as: high purity limestone, quartz, rutile, feldspar, wollastonite, graphite, garnet, fluorspar, kyanite/sillimanite and baryte. Until recently little attention was paid to the potential of Norwegian rocks, which can be exploited for dimension stone use and/or for large-scale production of rock aggregate. Quite recently international interest for diamond exploration in northern Norway arose due to promising kimberlite finds in Finland. In general the most promising prospects include gold, specialty metals, diamonds, industrial minerals, dimension stone and large-scale production of rock aggregate. On the basis of current geological knowledge and prospecting data, the following text presents some examples for exploration opportunities:

5.1 Gold

Occurrences of gold are found in a number of geological settings including Early Proterozoic greenstone belts, Late Proterezoic (Grenvillian) shear-belts, Caledonian batholiths, Permian palaeorift and Quaternary tills and glacifluvial deposits. In spite of the widespread occurrence of gold, prospecting and mining activity has been low and took place mainly at the end of the last century. Renewed interest for gold prospecting at the beginning of the last decade led to the reopening of the Biddjovagge Au-Cu mine in 1985. Up to its closure in 1991, it produced about 6,2 tonnes of gold delivered in Cu-concentrate.

The best known potential for economic gold deposits exceeding 1 Mt is in Au-Cu deposits related to mega-shear zones in the Palaeoproterozoic greenstone belts of northern Norway, including the Biddjovagge-type mineralization in fractured albite felsites. This type of deposit has also been mined elsewhere in the Fennoscandian Shield. Secondly, transpressive shear-zones in the Caledonian orogen may contain workable ores, especially where the shear zones intersect the contact between brittle deformed rocks and overlying ductile low-permeable cap rocks as in the Kolsvik Au-As deposit (Nordland) situated in the roof zone of the Bindal batholith. The Caledonian deposits of assumed Devonian age, are analogous to many mesothermal gold lodes in the Canadian Cordillera and the Sierra Nevada.

5.2 Copper-Zinc

The Grong district (N. Trøndelag, central Norway) is one of the most important areas for Caledonian volcanite-hosted massive sulphide (VMS) deposits in Norway. The Upper Allochton in the Grong district consists of several nappes, which comprise volcano-sedimentary sequences metamorphosed under low-grade conditions. Currently two copper-zinc mines are active, the Joma and Gjersvik mines (annual production: 600.000 metric tonnes). The now abandoned Skorovass deposit was in operation from 1952 to 1984.

The major VMS deposits, including Skorovass (7 Mt., 0.8 % Cu and 1.6 % Zn) and Gjersvik (1.6 Mt., 1.6 % Cu and 1 % Zn) deposits are closely related to a distinctive level of felsic volcanites within the mafic-dominated volcanites.

In addition to the potential for new discoveries of VMS deposits, the existence of small Ni-Cu-PGE mineralizations within ultramafic bodies and weak Cu-Mo mineralizations within felsic intrusions within the Gjersvik nappe should be noted.

The Geological Survey of Norway is running a prospecting campaign in the Grong area in close cooperation with the N. Trøndelag county administration. The investigations are based on modern sampling methods and sophisticated interpretation techniques. Prospecting models for the major VMS deposits have been developed. The whole area is covered by geological maps (1:50.000), modern airborne geophysical measurements (magnetic, electromagnetic, VLF and radiometric) with 100-200 m line spacing and totally about 15,000 profile km. More than 14,000 stream sediment samples were collected and analysed for the major base metals in the early 1970s. About 10% of these samples have recently been re-analysed for 30 trace and noble metals.

5.3 Calcite and dolomite

Demand for carbonates, particularly for high purity calcite fillers, is increasing in western Europe, and several national and international companies are showing increasing interest for developing carbonate deposits in Norway. Of greatest interest are the well developed carbonate sequences of the Caledonian orogen in central and northern Norway. They comprise both metamorphosed crystalline calcite and dolomite marble deposits with high brightness features and at many localities with favourable chemical and/or metallurgical properties.

The most interesting regions for high brightness calcite marbles are:

- White Precambrian marble in eclogite facies rocks in the Eide area (Møre og Romsdal, (west Norway).
- Caledonian marbles in the central part of Norway (Trøndelag) with a number of deposits with high brightness calcite marbles; some of these localities are also characterized by high chemical purity and good metallurgical properties.
- S.W. Helgeland, Skjerstad - Saltdalen and Ofoten regions in Nordland (northern Norway).

Sequences with well developed white and high purity dolomites are widespread in the Caledonides of nothern Norway and large quarries are found in Ballangen and around Fauske (both in Nordland). Production comprises metallurgical-, chemical-, agricultural- and filler qualities.

At Granåsen near Mosjøen (Nordland) a very large dolomite deposit was discovered during the 1970s. This dolomite is characterized by good metallurgical properties, low silica/silicate content and very attractive brightness values (90-95%). A special and interesting feature of this deposit is the average content of 15-20% brucite (Mg-hydroxide) in a thick and consistent outer contact rim with an intrusive gabbroic rock and its off-shoots. Fairly comprehensive investigations including diamond drilling (> 5,000 m) have been carried out.

5.4 Rutile

Rutile mineralizations are reported from several regions in Norway. Of special interest are the rutile-bearing eclogites of western Norway (Møre og Romsdal, Sogn og Fjordane, Hordaland). Several hundred eclogite lenses of varying size occur in the Precambrian basement gneisses in the coastal part of this region. So far, the eclogite bodies found to be richest in rutile are at Førdefjord and Dalsfjord on the west coast and on the island of Holsnøy near Bergen. The average rutile content is about 2 %, but the richest parts contain 3-3.5 % rutile. The possibilities for finding eclogites containing higher rutile grades seem favourable. The garnet content of eclogites - for abrasive use - has interesting commercial aspects. Furthermore, eclogite rock aggregate properties for road construction and "heavy" concrete and larger size rip-rap blocks are attractive.

In the Bamble area on the south-east coast (Telemark) a Precambrian altered gabbro consisting of hornblende and scapolite (intersected by hydrothermal apatite-rich dikes) contains 1-4 % rutile. This deposit which recently has been investigated by NGU, was previously mined for apatite.

5.5 Feldspar and quartz

Near Lillesand, on the south coast, feldspar (both K- and Ca-feldspar) and quartz are produced by flotation of a pegmatitic granite. The feldspar products are used in glass, porcelain, ceramics and filler products, while the quartz is used for silicon carbide and glass fibre manufacture. Some small scale mining of pegmatites in the Evje/Iveland area (southern Norway) produces lump feldspar (dental quality) and quartz for silicon production.

Large potential potassium feldspar resources (8-9 % K_2O) are known from the Precambrian basement gneises in the Tysfjord area and from Bø i Vesterålen (both northern Norway). One of the occurrences recently mapped contains 85 % microcline (10-11 % K_2O) with additional quarz, sodium-feldspar and mica. Occurrences of almost pure sodium-feldspar rock (albitites) are known from several areas in both northern and southern Norway.

Anorthosites, rocks consisting predominantly of Ca-Na-feldspar, occur widely in the Precambrian of southern Norway. Huge anorthosite complexes, with low sodium content and high in alumina (Al_2O_3) occur in the Gudvangen area. Due to favourable alumina-leaching properties, some of these deposits have been investigated in great detail and a potential industrial process was developed for production of alumina. Other scientific research has concentrated on production of silicon and aluminium in a continuous electrolytical process based on "feldspar" rocks.

Another huge anorthosite complex occur in Rogaland (south-west coast of Norway). Near Egersund around 300.000 tpa of white anorthosite is produced, mainly used as road aggregate, but a minor part is processed for abrasive fillers and ceramic products. Due to peculiar mineralogical properties, parts of this anorthosite complex, possess attractive features for dimension stone utilization.

Norway is a significant producer (approximately 900.00 tpa.) of ferro-silicon quality quartzite. Large quartzite deposits are located both in southern and northern Norway. The largest deposits are located in the Tana region (eastern Finnmark) and a large quarry in Late-Precambrian quartzites at Østre Tana, provides quartz raw material for the ferro-silicon industry in Norway with some export to Iceland. Silicon-metal quality quartz is mined from a Caledonian hydrothermal quartz deposit near Bodø in northern Norway. A quartz beneficiation plant for production of high purity quartz (electronic- and optical grades) based on local raw material from pegmatites was commissioned in the late 1980s but was closed down due to technical and economic problems. Exploration and development potential especially for hydrothermal and pegmatite quartz in Norway is quite favourable with a large domestic market for silicon-metal quality quartz.

5.6. Graphite

Several qualities of flake graphite are produced at the Skaland mine on the island of Senja in Troms, northern Norway. The carbon content of the commercial flake-graphite qualities produced varies from 85-95 %. Research and development work is being carried out on a beneficiation process to up-grade the quality to + 95 % and even to high purity niche products. The Precambrian geological environment on the island of Senja is favourable for future graphite prospecting and development. This applies also for parts of the Vesterålen region (with similar geological conditions), south-west of Skaland, where many older graphite workings are found. A recent airborne geophysical survey carried out by NGU has delineated many anomalies indicating that especially the Jennestad region is an interesting area for further graphite prospecting.

5.7 Beryllium

A Be-mineralization was discovered by NGU at Bordevedåga, NW of Mo i Rana, in 1984. The mineralization and the surrounding area has the potential of becoming an economic deposit. The Bordevedåga deposit has phenacite (Be2SiO4) as the dominating Be-mineral, and flotation-tests have produced a rich Be-concentrate. As yet, the drilled and tested reserves are too small for the deposit to be considered economic, and in addition there is a difficult market situation.

5.8 Rare Earth Elements (REE)

MEGON A/S was, during the 1950s and 1970s, responsible for the Norwegian production of REE's based on imported raw materials. Today Norsk Hydro produces REE-metals from apatite-ore imported from Kola. This production was started up in the last couple of years.

Several localities containing REE-bearing minerals, have been described in Norway, though prospecting specifically for REE has not been made in the past 20 years. Prospecting for uranium and other minerals has, however, given considerable information concerning associated enrichments in REE often of a not inconsiderable volume. The most important occurrences are in the Fen carbonatite complex, lavas and intrusive rocks in the Oslo region, e.g. Seteråsen, rhyolites in Caledonian rocks, e.g. at Skarvatnet, and in relation to certain Precambrian granitic gneisses, e.g. the Bordvedåga Be-mineralization in the Høgtuva-window, NW of Mo i Rana.

5.9 Dimension stone

Due to the nature of its geology, Norway has large and varied resources of attractive dimension stones such as "granites", gneiss, marbles, serpentinite, soapstone, quartzites and schists (Fig. 6). Many are worked and exported worldwide for a variety of decorative prestige architectural applications. The potential for a significant expansion of the dimension stone industry is considerable, both for block production and adding value through local stone processing.

The dominant stone type produced in Norway is larvikite (SE. Norway, near the town of Larvik), an attractive type of monzonite with a peculiar bluish play of colour. Some exclusive types of marble (especialy "Norwegian Rose") are exploited in northern Norway near the town of Fauske. In addition several other "granite" types, gneisses, serpentinite and soapstone are produced by smaller companies around the country. Internationally, Norway is also renowed for its production of high quality quartzite- and phyllite-slate. These rock types, which are found in a variety of colours are at present quarried at many localities both in the central- and northern part of the country.

In addition to the active quarries, a number of dimension stone occurrences might be further developed. These include easily-extractable deposits of pink and grey granite, multicoloured gneisses, marble, serpentinite, soapstone and slates. The Geological Survey of Norway (NGU) can provide more specific details about prospective areas, localities and quarries. Furthermore NGU provides consulting services in the fields of deposit evaluation, small block sampling, cutting/polishing and rock testing. NGU maintains a close cooperation with the Federation of Norwegian Stone Industries and with the Norwegian Centre for Natural Stone Research.

The Norwegian stone industry has witnessed a significant development during the last decade. From 1985 to 1990 dimension stone exports increased by more than 100 percent to a peak of USD 70 million and export figures for 1994 are expected to be around USD 88 million. Most of the Norwegian stone companies are very small, even in a Norwegian context (only 10 companies have more than 20 employees). Recent developments have stimulated new investment capital, introduction of sophisticated technology and a tendency towards fewer but larger enterprises. Still, only little dimension stone processing is carried out in Norway. This may well represent a very interesting potential development segment for the Norwegian dimension stone.

5.10 **Rock aggregate**

Due to favourable natural conditions Norway can play an important role in the supply of rock aggregate internationally. Coastal Norway with its easy access for bulk carriers and short transportation distances to to all major European sea-ports, has in addition a wide range of very large size rock occurrences suitable for production of high quality rock aggregate (Fig. 3).

Large deposits of anorthosite and other quartz-poor rock types are of special interest due to lower drilling-, blasting- and crushing costs (Fig. 7). A sparse coastal population and high coastal mountains intersected by deep fjords contribute to the comparative advantages for locating favourable super-quarry sites in parts of coastal Norway, in such a way that they need not give rise to serious environmental conflicts.

With the increasing demand for large scale import of rock aggregate in the northern part of continental Europe and south England, Norway offers attractive investment opportunities in this sector.

The Geological Survey of Norway (NGU) has proposed to embark on a 5-year investigation program to delineate the most suitable locations for super-quarries along the coast from V. Agder in the south to Troms in northern Norway. In this program NGU will cooperate closely with planning authorities on the county level, so that the most attractive locations can be reserved for future mining activities.

DIMENSION-STONE IN PRODUCTION

Fig. 6


FELDSPATHIC ROCKS IN NORWAY
MANGERITE
ANORTHOSITE
LARVIKITE
LOFOTEN
TRONDHEIM
Sunnmøre
SOGN
BERGEN
OSLO
STAVANGER
LARVIK
EGERSUND

Fig. 7

6 MINERAL BENEFICIATION; ADDING VALUE

Besides mining, Norway has also long traditions in mineral processing. After inexpensive hydroelectrical energy became readily available during the second half of the last century, many electro-metallurgical processeses were developed for industrial scale mineral refining and processing. The mineral processing industry is a very important part of Norwegian on-shore industry. It comprises also some specialty niche products such as very high purity yttrium and silicon. However, a substantial part of Norwegian mineral production is exported with relatively little value added through beneficiation.

As manufacturing processes involving the use of minerals become more and more sophisticated the number of natural mineral substances that can qualify as raw materials in their natural state will diminish in a relative sense. This applies especially for industrial minerals.

The following presents some examples of how raw materials can be given an "added value" through a beneficiation process to such an extent that they can reach a far greater part of the market than they could have done without any mineral processing.

For example, for coarser crystalline calcite-marbles physical mineral beneficiation techniques can be applied to enhance the ore brightness which makes the fine ground calcite product highly suitable for paper coating applications. Other crystalline calcite marbles - due to favourable chemistry - are highly suited as raw materials for precipitated calcium carbonate (PCC) processing, a chemical calcite processing application becoming more widespread for high quality paper coating usage in European paper mills.

Chemical leaching of certain anorthosite types can produce both amorphous silica and liquid aluminium coagulant. Amorphous silica can be used as a functional filler or as cement/ concrete additive; while liquid alumina coagulant is used for purification of industrial waste water.

Regarding dimension stone, most of the Norwegian production is exported as large blocks. There is a potential "investment opportunity" in the establishment of industrial plant, in Norway, for the processing of natural stone to provide a "value-added" effect. The same is true for a number of industrial minerals.

APPENDIX 1: GEOLOGY

The continental shelf off the coast of Norway contains large sedimentary basins of Late Palaeozoic, Mesozoic and Tertiary strata. These contain important oil and gas fields which form the basis for the Norwegian hydrocarbon industry. The bedrock geology of on-shore Norway (Fig. 8) is dominated by igneous and metamorphic rocks:

* Precambrian basement complexes which form part of the Fennoscandian Shield
* Nappe complexes, mainly metamorphic rocks, forming part of the Caledonian Mountain Belt
* Late Carboniferous-Permian igneous and sedimentary rocks of the Oslo Graben

1. The Precambrian Complexes

The bedrock geology of the Nordic countries (except Denmark) is dominated by a Precambrian basement complex, the Fennoscandian Shield. A succession of orogenic cycles (mountain building episodes) between 3500 and 900 Ma ago (Fig. 9), constructed this resistant shield, forming a single block which extends from the Atlantic to the Urals. In early Precambrian times this formed part of the Pangean supercontinent.

The Archean Complexes (> 2,500 million years old) consist of high-grade gneisses, developed from sedimentary, volcanic and plutonic protoliths (original rock types), which record a number of orogenic cycles, interspersed with stages of sedimentary basin formation. A number of plutons, of varying composition, were emplaced during the Archaean as a result of up-welling of mantle derived magmas. The Archaean Complexes are found in northeastern Norway (Finnmark) and in the Lofotens, (Fig. 10). The Archaean areas are now the focus of diamond prospecting by a number of international companies. The high metamorphic grade in these complexes has produced extremely pure magnetite mineralizations, opening the possibility for increasing use of the Kirkenes Fe ore for speciality products.

The Late Archean and early Palaeoproterozoic periods (2,750-2,000 million years ago) saw the development of the greenstone belts which are, as on many shield areas, the sites of major metallogenic provinces e.g. of Fe, Ni-Cu-PGE-Au. The latter part of the Palaeoproterozoic (2,000-1,600 million years ago) saw the first major development of oceanic crust, island arcs and collisional tectonics related to subduction driven systems. This activity was effectively terminated in the Svecofennian Orogeny (2000 - 1750 Ma). Many mineral deposits in Norway are related to Palaeoproterozoic sedimentary, volcanic and plutonic rock associations. These deposits include both metallic and non-metallic materials. The Svecofennian Orogeny was followed by emplacement of the Transcandinavian Belt of intrusive plutonic rocks.

A post-Svecofennian, sedimentary-volcanic suite (Telemark supracrustals) was deposited in the southern part of Norway from c. 1,500 million years ago. These were involved

BEDROCK MAP
OF NORWAY
LEGEND
MESOZOIC ROCKS
Sedimentary rocks
39 Claystone, siltstone, some sandstone, marl and limestone
Dark mudstone and claystone, siltstone with some layers of limestone
PALAEOZOIC ROCKS
Plutonic rocks
57 Volcanic rocks
64 Mainly sandstone and conglomerate
67 Mainly sandstone and conglomerate
PRECAMBRIAN AND PALAEOZOIC ROCKS
Rocks metamorphosed/overthrust in the Caledonian orogeny
Plutonic rocks
Granite to tonalite
72 Gabbro, diorite, ultramafic rocks
73 Amphibolite
Metamorphosed volcanic and sedimentary rocks
74 Phyllite, mica schist, mica gneiss, shale, metasandstone, amphibolite
75 Limestone, marble
Greenstone, greenschist, amphibolite, meta-andesite
77 Metarhyolite, metarhyodacite
78 Impact breccia (Gardnos breccia)
Metamorphosed, mainly sedimentary rocks
79 Tillite
80 Sandstone, conglomerate, locally slate, volcanic rocks
81 Limestone, slate, sandstone
82 Metasandstone, mainly meta-arkose, mica schist
PRECAMBRIAN ROCKS
Metamorphosed rocks overthrust in the Caledonian orogeny
85 Gneiss, migmatite, granite, metamorphosed volcanic and sedimentary rocks
Charnockitic to anorthositic rocks
Rocks locally metamorphosed/deformed in the Caledonian orogeny
Granite to tonalite
Gabbro, diorite, amphibolite, some anorthosite and mangerite
Ultramafic rocks
90 Metamorphosed sedimentary and volcanic rocks, gneiss
91 Gneiss, migmatite, foliated granite, amphibolite
Basement; autochthonous, metamorphosed rocks
Granite to tonalite
Charnockitic to anorthositic rocks
94 Gabbro, amphibolite, ultramafic rocks
95 Metasandstone, mica schist, conglomerate, supracrustal gneisses
96 Metabasalt, meta-andesite, amphibolite
97 Metarhyolite, metarhyodacite
98 Gneiss, migmatite, foliated granite
Granulite (plutonic rock metamorphosed under high-pressure conditions)
Basement; autochtonous, metamorphosed rocks
Granite
101 Monzonite
102 Mica gneiss, mica schist, amphibolite
103 Gneiss, migmatite
NGU
Reference to the map:
Sigmond, E. M. O. 1992: Bedrock map of Norway and adjacent ocean areas
Scale 1:2 million
Geological Survey of Norway
0
100
200 Km
Scale 1:2 mill.

Fig. 8

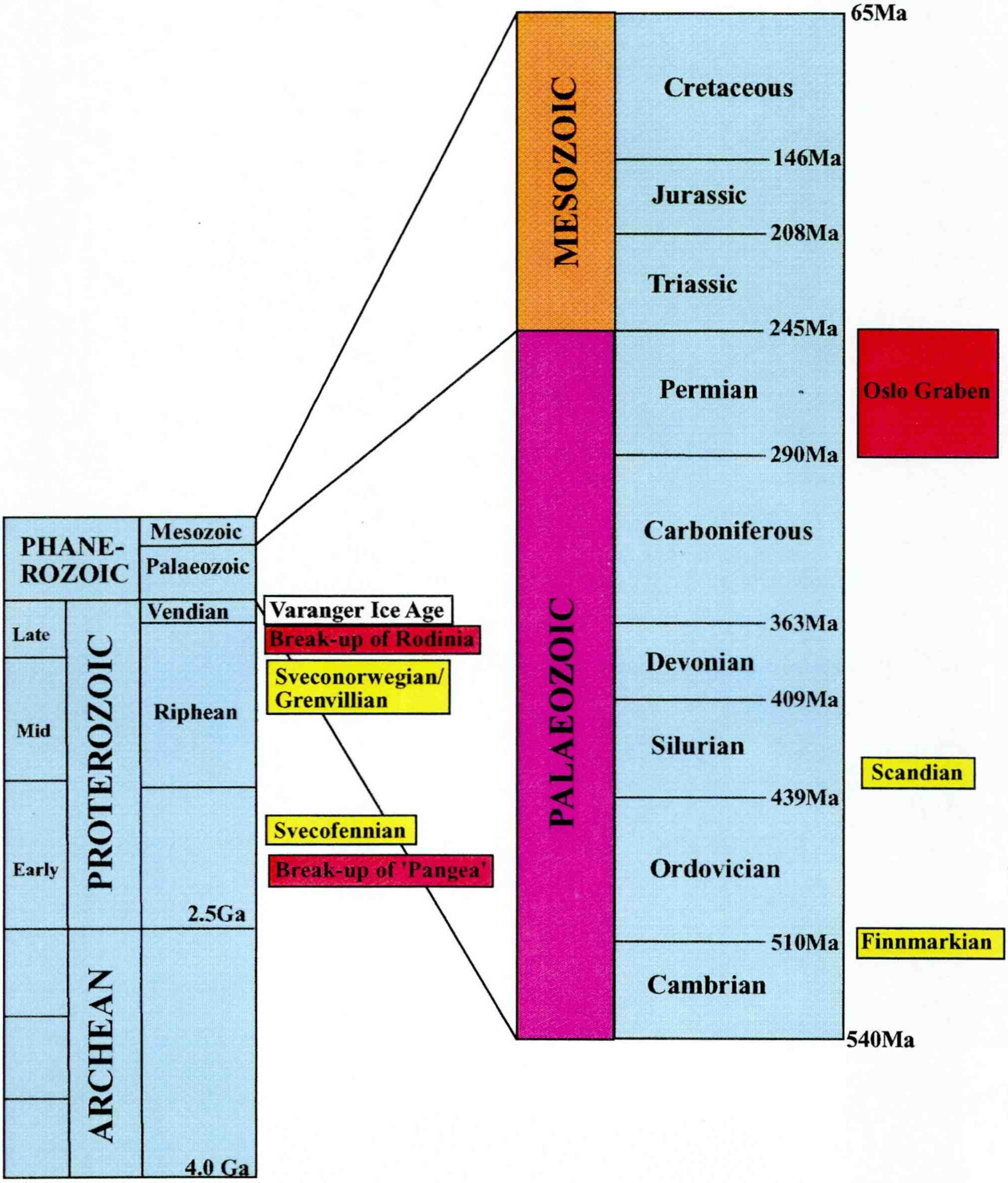


Fig. 9 Stratigraphic column (Archean - Mesozoic)

Fig. 10 Locations in Norway

in the Sveconorwegian (Grenville) Orogeny (1150-1000 Ma) and were penetrated by numerous syn-, post-tectonic granites. This region has had a long tradition in mining; at present the greatest interest in south Norway is in the large deposits of ilmenite, but the area must also be regarded as prospective for Mo.

2. Iapetus Ocean - Caledonides

Major intercontinental crustal rupture started in Middle to Late Riphean times and around 750 Ma the Rodinian supercontinent broke-up with the rifting off of great continental blocks such as Baltica. During Late Riphean and Vendian times (750-550 Ma) aulacogens, rift-basins and continental depressions formed within Baltica, from the Ukraine in the southeast to Norway in the west. Large alkaline intrusions in the Seiland province and the Fen carbonatite were emplaced in this period. The former are an important source of nepheline syenite and the latter is strongly enriched in REE.

During Cambrian times there was a rapid expansion of Iapetus, and on the Baltica margin a clear distinction between miogeoclinal (continental margin) and eugeoclinal (oceanic) regimes was established. The first sign of orogeny is an Early Ordovician island arc with coeval subduction of continental crust in which eclogite facies metamorphism (P>18 kb) occurred in part of the miogeoclinal assemblage, now part of the Seve Nappe. The rapid gravitational rebound of the continental slab was probably responsible for cratonwards propagating thrusts, and obduction of ophiolitic and island arc assemblages onto a westward extension of the continental miogeocline (Finnmarkian event). These thrust slabs which had been accreted onto the miogeocline were rapidly eroded and drowned by basinal assemblage of sedimentary and volcanic rocks during Early to Middle Ordovician times. The Ordovician history of the Caledonian Baltic margin was not unlike that of the SW Pacific today, with a series of island arcs, back-arc basins and periodic subduction. It was also during the Ordovician that the majority of the stratabound sulphide deposits so important historically to the Norwegian mining industry were formed. There is still a considerable potential for new discoveries in these formations.

The Caledonian orogeny culminated c. 420-430 million years ago, involving the eastwards emplacement of a complex sequence of nappes onto Baltica and the depression of the western part of the old continent. High-pressure metamorphism resulted in the transformation of many mineralizations of ilmenite to rutile. The Devonian Period also saw the development of major extensional tectonics and basin infill, and certain mineralizations e.g. Au.

3. Post Caledonian

In Late Palaeozoic times the continental rifts of the Oslo and the Central North Sea Grabens were initiated. The Oslo Graben is characterised by Permian volcanic and plutonic rocks of mainly alkaline to sub-alkaline character. This is a classical area for contact-metasomatic Pb-Zn deposits, though these do not appear to be of major economic interest today. The area was prospected, during the late 1970s for porphyry Mo deposits. The largest Mo-deposit in Europe was identified at Hurdal in the northern part of the area. The potential for Mo in this area is considerable. Many of the plutonic rocks of the Oslo Graben make attractive building stones, e.g. larvikite.

Norway is a country with a varied geology of volcanic, sedimentary and intrusive rocks, in which the possibilities for finding economic mineralizations are good. The generally high metamorphic grade is very favourable for the formation of pure mineral assemblages.