Topographical mineralogy of the Bamble sector, south Norway

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The Bamble sector of southern Norway is a classic high grade metamorphic gneiss region, which provided specimens to many mineralogical collections all over the world. The topographical mineralogy of this area is described and reviewed. All minerals known to occur in the area are listed according to Strunz' classification.

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Introduction

The Bamble sector is a high grade metamorphic gneiss terrain in southern Norway (Fig. 1), whose present day geological features mainly resulted from multiple metamorphism and deformation during the Gothian (1.75-1.5 Ga) and Sveconorwegian (1.25-0.9 Ga) orogenies (e.g. Bugge, 1943; Touret, 1968; Starmer, 1985, 1991; Nijland, 1993; Visser, 1993a). This area has since long attracted geological and mineralogical attention. In most systematic collections of mineralogy (e.g. at the National Natural History Museum, Leiden, and the École des Mines, Paris), localities from southern Norway (besides the Bamble sector also the surroundings of Brevik and the Langesundfjord) are among those most often mentioned, together with other classic areas like Langbàn (Sweden), Mont St Hilaire (Quebec) and Madagascar. The miner-
In the Bamble sector, two mining areas have been especially important, viz. those around Arendal and Kragerø. The skarns around Arendal represented one of the few places where large, idiomorphic crystals were readily available, because of iron-mining activities coinciding with the birth period of modern mineralogy. Among all these minerals, some have been of foremost importance because they have played major roles in the basic definition of mineral classes or have helped to precise their chemical
features. This holds, for example, for the pyroxenes, which group name was actually coined by Haüy (1799, p. 269) on a sample from Arendal, epidote (arendalite, delphinite), feldspars, scapolite (wernerite, gabbronite), and cordierite (iolite, aspasiolite, dichroite, polychroite), whose chemical composition was analysed by Scheerer (1848a).

A comprehensive topographical mineralogy of this area was, however, not available, although this was partly compensated for by Neumann’s (1985) overview of the mineralogy of entire Norway. The present paper aims to fill this gap, including both recent and old literature as well as unpublished data.

**Short history of mining, geological and mineralogical interests in the Bamble sector**

The Bamble sector, which is now a classic high grade gneiss terrane, has attracted geological and mineralogical attention since the early Middle Ages, when Viking sailors used gem quality cordierite crystals for navigation (Schlüter, 1994). This area is since long famous for its beautiful cordierite crystals, especially from the Tvedestrand area (e.g. Scheerer, 1848a; Lacroix, 1889; Hintze, 1897a), and is one of the most likely source areas for these navigation aids. In addition, Viking age utensils, made of kleberstein (talc) have been found near Vimme, south of Nelaug. These may have been derived from the small talc deposit in the same area (Moree & Nijland, 1996). Later, mining of both metallic and non-metallic ores became important. In 1860, the Ag-Pb-Zn deposit of Ettedalen (Espeland) was discovered, and Cu (at Bøylestad and Skytte-my) and Ni (at Messel) have also been mined, but Fe ores have been of foremost importance. The oldest iron works date back to about 1540 (Vogt, 1908). In 1806, when Arendal had c. 1700 inhabitants, most of them merchants and sailors, there were 22 iron mines in the surroundings, some of them property of the crown, most privately owned (Hausmann, 1812). The iron ores were derived from two areas, Arendal and Kragerø. In the Arendal area, magnetite deposits associated with skarns were exploited (Klådeborg, Solberg, Barbuadal, Langsev, Tornsbudalen, Raneklev, Mørefær, Lærestveit, and Vågsnes and Alvekilen on Tromøy), as well as mineralizations associated with the Holt granite. In the Kragerø area, Fe-ore deposits were associated with metagabbros, for example on the islands of Langoy and Gumøy. Production declined from c. 1850 onward, but around the last turn of century, an elaborate iron industry, mainly fed with local ores, was operative. Through the Danish owners of many of the mines, notably A. Hofman, mineral specimens found their way to the major mineralogical collections of western Europe. The latest iron mine, Bråstad, was closed in 1975. Nowadays, well preserved skarn sections can be visited at Lofstsad on Tromøy and Langsev-Barbudalen in Arendal.

Among the non-metallic ores, apatite was especially important. The large Ødegården Verk deposit was jointly exploited by the Compagnie Française de Mines de Bamle and Bamble AS. French mining activities in the area reflect the active scientific interest in the area by some of the great French geologists during the 19th century, among them Daubrée (1843), Michel-Lévy (1878a,b) and Lacroix (1889).

Granitic pegmatites have also been mined. One of the most prominent of these was the Narestø pegmatite, situated just above the shore of a small bay on Flota, thus guaranteeing easy transport. Pegmatite exploitation was done on a very local scale, by farmers who derived additional income from it during winter times. The
Pegmatites were quarried for feldspar, which was sent to the porcelain factories at Porsgrunn and in Scotland, while quartz was locally used (at Arendal Smelteverk in Eydehavn, and at Kristiansand) for the manufacturing of ceramics. Some of the radioactive minerals occurring in the pegmatites, notably the one at Auselmyra, were sold to Madame Curie at Paris.

Contemporaneously with Lacroix, W.C. Brøgger, who later in his life would write his famous monograph on the Fen area and become his country’s minister of education, actively studied the geology and petrology of the area; he continued his studies during the first decennia of the 20th century (e.g. Brøgger & Reusch, 1875; Brøgger & vom Rath, 1877; Brøgger, 1906a, 1934a, b). During the first half of this century, the Bamble sector was actively studied by, amongst others, four Norwegian geologists who made it one of the classical amphibolite to granulite facies transition zones, and whose names all start with the ‘B’ of Bamble. Besides Brøgger, already mentioned, these are Barth (1925, 1929), A. Bugge (1928, 1936) and J.A.W. Bugge (1940, 1943, 1945). In the same period, the first age estimates became available, based on lead abundances (Bakken & Gleditsch, 1938). Radiometric age determinations (on specimens from the Narestø pegmatite) were performed as early as the mid-fifties (Holmes et al., 1955). Later, the area became under investigation by several research groups and individuals.

Summary of regional geology

The Bamble sector is part of the Southwest Scandinavian Domain (Fig. 1), the relatively late accreted part of the Baltic Shield (Verschure, 1985; Gaál & Gorbatschev, 1987). The continuation of the Bamble sector below the Skagerrak is obscured by the Skagerrak Graben, a continuation of the Oslo Rift. Inland, the Porsgrunn-Kristiansand Fault (PKF; also denominated as Great Breccia, Great Friction Breccia, or Kristiansand-Bang Shear Zone) is traditionally considered to separate the Bamble sector from the neighbouring Telemark gneisses (Bugge, 1928, 1936; Starmer, 1985, 1990, 1993). However, both the style of deformation (Falkum & Petersen, 1980; Hagelia, 1989) and distribution of Bouguer anomalies (NGU, 1971) indicate some kind of continuity of the Bamble sector over the PKF. Elaborate descriptions of the lithological relationships in the area have been compiled by Starmer (1985, 1990, 1991, 1993). There is no point in duplicating this work. Here we will just introduce the reader to the central part of the Bamble sector.

The oldest rocks recognized in the area so far are clastic metasediments. In the Arendal-Froland-Nelaug part of the Bamble sector, at least three different suites of supracrustals may be identified, whose mutual stratigraphic and age relationships have still to be solved:
1) The Hisøy-Merdøy Supracrustal Suite (HMSS), which occurs on the islands of Hisøy and Merdøy, the western tip of Tromøy and several smaller islands. Characteristic are decimetre- to metre-scale alterations of quartzitic rocks, with the relatively frequent occurrence of millimetre- to centimetre-thick sillimanite-garnet-biotite seams. Deposition of these sediments occurred prior to at least 1.37 Ga (Knudsen et al., 1997).
2) The Nidelva Quartzite Complex (NQC), which is exposed between the post-tecton-
ic Herefoss granite and the Nidelva river, and is characterised by the occurrence of massive, relatively pure quartzites, with minor intercalations of metapelites, nodular gneisses, cordierite-orthoamphibole rocks, and monomict, intraformational conglomerates. The lithological association and locally preserved primary sedimentary structures, like large metre-scale cross-bedding, small-scale cross-bedding, ripple marks, and desiccation cracks indicate a continental depositional environment (Nijland et al., 1993a). The well known corundum-bearing gneisses occurring north of Froland (Oftedahl, 1963; Nijland et al., 1993b) have been interpreted as metamorphosed kaolinite-bauxite weathering crusts (Serdychenko, 1968). The NQC has been deposited prior to 1.47 Ga (Nijland and coworkers, unpubl. data), and is likely to be correlated with the Coastal Quartzite Complex (CQC) in the Kragerø area (Starmer, 1985).

3) The Selås Banded Gneisses (SBG), which are constituted by a series of banded, migmatitic, quartzofeldspathic gneisses, with abundant thin intercalations of amphibolites, and sulphurous horizons. The rocks likely represent metagreywackes, and have been interpreted as of turbiditic origin (Touret, 1966, 1968, 1969). They have most likely been deposited before 1.51 Ga (Moorbath & Vokes, 1963). The well-known Ettedal (Espeland) Pb-Zn-Ag-deposit occurs within these rocks (Naik, 1975; Naik et al., 1976; Krijgsman, 1991a, b).

Carbonaceous rocks are rare in the Bamble sector, but minor marbles and skarns occur throughout the area. Especially the skarns, with their associated magnetite mineralisations and salient minerals, have attracted a lot of attention (Barth, 1925; Bugge, 1945, 1951, 1954, 1960).

Cordierite-orthoamphibole rocks occur throughout the area as small lenses and boudins (Bugge, 1940, 1943; Beeson, 1976, 1988; Visser & Senior, 1990; Visser, 1993a). They are a minor lithology qua volume, intercalated in both the HMSS and NQC, but are important with respect to unravelling the metamorphic history and sedimentary environment. Different occurrences have been interpreted as either meta-evaporites (Touret, 1979; Visser et al., 1991; Nijland et al., 1993a), or as metamorphosed volcanics which underwent alteration prior to metamorphism (Visser, 1993a, 1995).

The supracrustals have been reworked, metamorphosed and intruded during the Gothian and Sveconorwegian orogenies. Prominent intrusive rocks are the so-called ‘hyperites’ (Bregger, 1934a), tholeiitic olivine-bearing gabbros that are often coronitic (de Haas et al., 1992a, 1993a, b). These intruded the area during both the Gothian and Sveconorwegian orogenies (de Haas et al., 1992b, 1993b). Some of these small gabbros show well developed primary igneous layering (Touret, 1968, 1969; de Haas et al., 1993a).

Several bodies of charnockitic to granitic augen gneiss have been emplaced during the Sveconorwegian orogeny (Hagelia, 1989; Andersen et al., 1994; Heaman & Smalley, 1994). These are surrounded by a few hundred metres wide granulite facies contact metamorphic aureoles (Hagelia, 1989; Nijland & Senior, 1991). Three of these, the Hovdefjell-Vegårshwei augen gneiss (HVAG), the Ubergsmoen augen gneiss (UAG) and the Gjerstad augen gneiss (GAG) occur in a zone featured by intense mylonitic deformation, bordering the PKF. A fourth body, the Gjeving augen gneiss (GVAG) occurs in the coastal area. The rocks are Fe-rich, containing orthopyroxene among the most Fe-rich natural ones known (UAG; Lieftink, 1992), rare pigeonite (HVAG; Krijgsman, 1991c) and fayalite (HVAG; P. Hagelia, pers. com., 1996). Large,
discordant NW-SE trending bodies of granitic gneisses, often rich in magnetite, occur, and postdate at least one generation of layered gabbros. They may be correlated with the augen gneisses, or, alternatively, with the Holt granite, which is in fact a gneissic granite (Nijland, 1993).

Large scale low to medium temperature alteration affected both metasediments and metababbros at a localised but regional scale, and involved the development of albite-actinolite-quartz (AAQ) assemblages (Brogger, 1934a; Elliott, 1966; Kloprogge, 1987; Nijland et al., 1993c). These rocks have also been termed albitites, and are often enriched in Ti-minerals (titanite, rutile), in which case they have been termed kragerörite (Johannsen, 1937; Force, 1991). They are similar to the albite-rich rocks from the Kongsberg sector (Jøsang, 1966; Munz et al., 1994, 1995), which have been dated at 1.09 Ga (Munz et al., 1994). Earlier hydrothermal activity involved the emplacement of hydrothermal dolomitic marbles in the Kragerø area (Bugge, 1965) at c. 1.18 Ga (Dahlgren et al., 1993).

Late, not to low-grade metamorphic granitic sheets intruded the area during the Late Sveconorwegian, and have been dated at 1.06 Ga (Field & Råheim, 1979). In addition, two types of pegmatites occur in the area:

1) Large irregular bodies, often featured with enrichment in rare elements and providing many of the mineral specimens for which the area is well known, like the Gløserhei pegmatite in the Froland area and the Tangen pegmatite in the Kragerø area (e.g. Brogger, 1906a; Åmli, 1975, 1977; Pl. 1, fig. a), and

2) Low angle pegmatites, which are much smaller, usually less than 2 m thick, that intruded along a joint system (Nijland, 1993). Type 1 pegmatites have been dated at c. 1.06 Ga (Baadsgaard et al., 1984). The post-tectonic Herefoss and Grimstad granites intruded the area at 0.93 (Andersen, 1997) and 0.99 Ga (Kullerud & Machado, 1991), respectively.

Late dykes (dolerites, lamprophyres, rhombporphyry dykes) which have intruded the Precambrian basement are prominent in the area. Most of these are related to Permian rifting in the Oslo region (Sundvoll & Larsen, 1991), whereas some intruded during the Tertiary (Støretvedt, 1968), and possibly Devonian and Eocambrian (Moree, 1994).

**Metamorphism**

A well developed regional amphibolite to granulite facies transition zone is situated in the area outlined above. This transition zone is characterized by the following, south facing, isograd sequence (Touret, 1971; Nijland & Maijer, 1993):

- **Ms** Muscovite-out in quartzitic rocks
- **Crd** Cordierite-in in metapelitic rocks
- **Opx(1)** Orthopyroxene-in in amphibolites
- **Opx(2)** Orthopyroxene-in in acidic gneisses
- **All** Allanite-out in gneisses, metapelites and amphibolites
- **Ttn** Titanite-out in gneisses, metapelites and amphibolites

The isograds are accompanied by increasing recrystallization of sillimanite from a fibrolitic habit to an euhedral prismatic habit. In addition, isopleths for Ti in hornblende and biotite from amphibolites increase with increasing metamorphic grade.
Fe²⁺/(Fe³⁺ + Fe²⁺) of both biotite and hornblende also varies with metamorphic grade (Nijland, 1993). Geothermobarometry indicates P,T conditions of c. 750°C and 7.1 kb in the amphibolite facies area (Nijland & Maijer, 1993) and c. 830°C, 7.4 kb in the granulite facies area (Nijland & Maijer, 1993; Knudsen, 1996). Peak metamorphism gave rise to the development of kornerupine-bearing assemblages in cordierite-orthoamphibole rocks (Visser & Senior, 1990; Visser, 1993a, 1995). Breakdown of cordierite in these rocks resulted in the development of lower temperature borosilicate assemblages, comprising dumortierite (Michel-Lévy & Lacroix, 1888; Visser & Senior, 1990, 1991) and rare grandidierite (Visser & Senior, 1990).

The (supposed) age of metamorphism in the Bamble sector became controversial during the eighties (e.g. Field & Råheim, 1979; Field et al., 1985). Since, detailed U-Pb zircon geochronology has demonstrated the presence of c. 1.1 Ga Sveconorwegian lower intercepts and overgrowths (Kullerud & Machado, 1991; Knudsen et al., 1997). This is corroborated by Sm-Nd mineral and mineral + whole rock isochron ages on granulite facies samples which ranges between 1.07 and 1.1 Ga (Kullerud & Dahlgren, 1993), although the closure temperatures of various minerals involved are not well constrained.

**Topographical and systematic mineralogy**

Minerals in the Bamble sector are largely confined to five modes of occurrence: 1) high grade metamorphic minerals, 2) minerals occurring in synorogenic intrusions and related ore deposits, 3) minerals in late orogenic granitic pegmatites, 4) minerals related to Late Sveconorwegian albitization, which resulted in albite-actinolite-quartz rocks and albities, and 5) mineral occurrences related to post-Sveconorwegian activity. Below, minerals from all these occurrences are listed according to Strunz (1982). Only minerals currently recognized by the IMA are considered; in a few cases, some old names and/or varieties are mentioned, and set in italics. The main localities in the central part of the Bamble sector are depicted in Fig. 2. Spelling of place names etc. is (as much as possible) according to the one currently used on the 1:50,000 topographical map sheets by Norges Geografiske Oppmåling.

**Elements**

**Metals**

A specimen of native copper, labeled Arendal, is present in the collections of the Nationaal Natuurhistorisch Museum, Leiden (Pl. 1, fig. b).

Silver has been reported from carbonate veins in metasediments that were intruded by late dolerite dykes at Stelsvik on Hisøy (Vogt, 1884, 1886), at Landviksvannet near Grimstad (Vogt, 1884), and at Nøddebro near Arendal (Scheerer, 1848b; Kjerulf & Dahl, 1861; Vogt, 1891). In addition, silver has been reported in samples from the Pb-Zn deposit at Tråk, in the eastern part of the Bamble sector, and from the old Cu-mine at Beylestad near Froland (Neumann, 1985).

Gold has been reported as an accessory mineral from some of the iron ore
deposits in the Arendal area, viz. Nedenes (Pontoppidan, 1752), Barbudalen (Pontoppidan, 1752; Scheerer, 1845a), and Langsev (Scheerer, 1845a). Daubrée (1843) also reported gold from the Arendal area. In addition, it has been reported from the silver-bearing carbonate veins at Stølsvik on Hisøy (Vogt, 1884), from a pegmatite near Ranevik, Risør (Brøgger, 1906a), and from quartz veins at Loftus near Lillesand and at Stabbestad on Skåtøy, off-shore from Kragerø (Neumann, 1985).

Metallic iron has been reported to occur in the ore zones associated with the Holt granite at Våland near Tvedestrand (Helland, 1904).

Metalloides and non-metals

**Bismuth** has been found in the ores from the Ettedal (= Espeland) Pb-deposit (Naik, 1975; Naik et al., 1976; Krijgsman, 1991a), and in the gold-bearing pegmatite at Ranevik near Risør (Brøgger, 1906a).

**Graphite** is a common accessory mineral in many rock types like marbles (Falkum, 1966; Touret, 1968), skarns (Kristiansand: Barth, 1925; Loddesol: Bugge, 1945), gneisses (Touret, 1968; Field & Rodwell, 1968; Alberti & Comin-Chiaramonti, 1974; Beeson, 1975; Field & Starmer, 1982; Broekmans et al., 1994), and metapelites (Starmer, 1972, 1976). In addition, it has been reported from the Skyttemyr and Boylestad Cu-deposits (Bugge, 1978). Coarse-grained hydrothermal graphite occurs in some quartz veins, especially in the Ubergsmoen area (Broekmans et al., 1994).

**Sulphur** has been reported from pegmatites at Tvedestrand (Andersen, 1926), Søndeled, Gjerstad, and Rosseland (Neumann, 1985).

Sulphides

**Sulphides with Me:S > 1:1**

**Chalcosite** has been reported from the skarns at Arendal (Bugge, 1954).

**Bornite** was reported from the surroundings of Arendal, Tvedestrand and Kragerø by Weibye (1847) who did not state its mode of occurrence. Bugge (1954) reported bornite from the skarns at Arendal, whereas Andersen (1931) mentioned it from the Hasalvik pegmatite in the Bamble community.

**Argentite** has been reported from silver-bearing carbonate veins associated with dolerites at Stølsvik on Hisøy (Vogt, 1884).

**Hessite** occurs as an accessory mineral in the ores from the Ettegdal Pb-deposit (Naik, 1975; Naik et al., 1976).

**Pentlandite** occurs as a major phase in the Messel (Brickwood, 1986) and Nystein (Kuiperus, 1986) Ni-deposits, both of which are associated with gabbroic intrusions. Besides normal pentlandite, cobaltian pentlandite (with up to 9.9 wt.% Co) also occurs in the Messel Ni-deposit (Brickwood, 1986).

Sulphides with Me:S = 1:1

**Sphalerite** has since long been known from the Bamble sector (Arendal: Weibye, 1847; Brevik: Weibye, 1849), although its specific occurrence was not reported. It is an important mineral in several ore deposits, viz. the Ettegdal Pb-deposit (Moorbath & Vokes, 1963; Naik, 1975; Naik et al., 1976; Krijgsman, 1991a), the Skyttemyr and Boylestad Cu-mines (Bugge, 1978), and the Tråk Zn-Pb-deposit (Røsholt, 1967). In addition, it sporadically occurs in the skarns around Arendal (Bugge, 1954).

**Chalcopyrite** is a common mineral in the Bamble sector. It occurs as an accessory phase in the skarns around Arendal (Weibye, 1847; Bugge, 1940, 1954; Broekmans et al., 1994) and at Loddesol (Bugge, 1945), in many amphibolites (Nijland et al., 1993d), and in Fe-rich felsic intrusions like the Ubergsmoen Augen Gneiss. It occurs also accessorially in several pegmatites, like those at Tangen (Andersen, 1931; Green,

1956), Lindtstøl, and Hella and Morefjær, both near Arendal (Andersen, 1931), in
apatite-enstatite-phlogopite veins at Ødegårdens Verk (Brøgger & Reusch, 1875; Sjö-
gren, 1883) and in apatite-hornblende veins at Noerestad near Risør (Solly, 1892). It is
an important mineral in the Ettedal Pb-deposit (Moorbath & Vokes, 1963; Naik, 1975;
Naik et al., 1976; Krijgsman, 1991a), the Messel (Brickwood, 1986) and Nystein
(Kuiperus, 1986) Ni-deposits, the Skyttemyr and Byøylestad Cu-deposits (Bugge,
1978), the Tråk Zn-Pb-deposit (Røsholt, 1967), and the ore-zone in the Blengsvatn
gabbro (van Linschoten, 1989). Chalcopyrite is also a common accessory in small
quartz mobilisates together with tourmaline, scapolite, and siderite/ankerite, for
example in the skarns at Lofstad and Arendal.

**Tetrahedrite** has been reported from the skarns around Arendal (Bugge, 1943).

**Freibergite** occurs as a minor phase in the ores from the Ettedal Pb-deposit (Naik,

**Galena** is a major mineral in the Ettedal Pb-deposit (Moorbath & Vokes, 1963;
Naik, 1975; Naik et al., 1976; Krijgsman, 1991a,b), the Tråk Zn-Pb-deposit (Oftedal,
1959; Røsholt, 1967). It also occurs in the Skyttemyr and Byøylestad Cu-mines (Bugge,
1978).

**Matildite** has been reported as an accessory phase in ores from the Ettedal Pb-
deposit (Oftedal, 1942).

**Pyrrhotite** has since long been known from the Bamble sector (e.g. Weibye, 1847).
It occurs as an accessory mineral in marbles (Falkum, 1966), the skarns at Kristiansand
(Barth, 1925, 1928), pegmatites (Hella near Arendal: Andersen, 1931), and amphibolites
(Nijland et al., 1993d). It is a major constituent of the Ettedal Pb-deposit (Moorbath &
Vokes, 1963; Naik, 1975; Naik et al., 1976; Krijgsman, 1991a,b), the Messel (Brickwood,
1986) and Nystein (Kuiperus, 1986) Ni-deposits, the Skyttemyr and Byøylestad Cu-
deposits (Bugge, 1978), the Tråk Zn-Pb-deposit (Røsholt, 1967), the ore-zone in the
Blengsvatn gabbro (van Linschoten, 1989), and the pyrrhotite deposit just west of
Imeneskilen, NW of Grimstad (M.A.T.M. Broekmans, pers. com., 1995). In addition, it
occurs in apatite-hornblende veins at Fogne and Hiåsen, both near Gjerstad, and Vale-
berg near Kragerø (Brøgger & Reusch, 1875), and at Noerestad near Risør (Solly, 1892).
Pyrrhotite is also a common accessory in sulphureous banded gneisses with graphite,
and in calcite ± scapolite ± biotite ± quartz alteration veins in gabbroic and amphi-
obolitic rocks, e.g. at the quarry in the Vestre Dale Gabbro in the Froland area.

**Millerite** occurs as an accessory phase in the Messel Ni-deposit (Brickwood,
1986).

**Nickeline** occurs in Ag-bearing carbonate veins associated with dolerites at
Stølsvik on Hisøy (Vogt, 1884; Oftedal, 1939) and Naudebro near Arendal (Scheerer,
1848b; Vogt, 1891). It also occurs in magnetite ores associated with gabbro on Langøy,
off-shore of Kragerø (Scheerer, 1845b; 1848a,b; Kjerulf & Dahl, 1861).

**Breithauptite** occurs as an accessory phase in the Ettedal Pb-deposit (Naik, 1975;
Naik et al., 1976).

Sulphides with Me:S < 1:1

**Violarite** has been reported as an accessory phase from the Messel (Brickwood,
1986) and Nystein (Kuiperus, 1986) Ni-deposits. **Cobaltian violarite** (5-19 wt.% Co)
occurs together with violarite in the Messel deposit (Brickwood, 1986).
**Bismuthinite** is a rare mineral in the magnetite ores associated with gabbro on Langøy, off-shore of Kragerø (Vogt, 1918).

**Pyrite** is a common accessory in gneisses (Falkum, 1966; Beeson, 1975; Starmer, 1976), amphibolites (Falkum, 1966; Starmer, 1969a; Nijland et al., 1993d), metapelites (Starmer, 1976), marbles (Falkum, 1966), and albitites (Green, 1956). It occurs in the skarns at Kristiansand (Barth, 1925, 1928), Arendal (Bugge, 1940, 1954), and Loddesol (Bugge, 1945). It is a constituent of the ores at the Messel (Brickwood, 1986) and Nyssstein (Kuiperus, 1986) Ni-deposits, the ore zone in the Blengsvatn gabbro (van Linschoten, 1989), the Skytemyr and Øyestad Cu-deposits (Bugge, 1978), and the Tråk Zn-Pb-deposit (Røsholt, 1967). It occurs in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Brøgger & Reusch, 1875) and in apatite-hornblende veins at Fugne near Gjerstad (Brøgger & Reusch, 1875). Pyrite also occurs in many pegmatites, like those at Kalstad and Lindvikskollen (Green, 1956), Tangen (Andersen, 1931; Green 1956), Hella and Møreø, both near Arendal, Lindstøl (Andersen, 1931), and Gloserhei (Åmli, 1975, 1977). **Nickeloox pyrite** occurs together with normal pyrite in the Messel Ni-deposit (up to 5.7 wt.% Ni: Brickwood, 1986).

**Vaesite** has been reported from a sulphide ore zone the Vissestad gabbro in the Bamble municipality (R. Morton, in Neumann, 1985).

**Cobaltite** occurs as an accessory mineral in the Messel Ni-deposit (Brickwood, 1986).

**Willyamite** has been found as an accessory mineral in the Ettedal Pb-deposit (Naik et al., 1976).

**Ullmannite** has been reported as an accessory phase from the Ettedal Pb-deposit, as is **cobaltian ullmannite** (Naik, 1975; Naik et al., 1976).

**Marcasite** occurs in the skarns at Loddesol (Bugge, 1945) and Arendal (Bugge, 1954), and from the sulphidic ore zone in the Blengsvatn gabbro (van Linschoten, 1989). It has also been reported from Ag-bearing carbonate veins on Hisøy (Vogt, 1884, 1886).

**Arsenopyrite** has since long been known from the Arendal, Tvedestrand and Kragerø areas (Weibye, 1847; type of occurrence not specified). It also occurs in the Ettedal Pb-deposit (Moorbath & Vokes, 1963; Naik, 1975; Naik et al., 1976; Krijgsman, 1991a), and the Øyestad and Skytemyr Cu-deposits (Bugge & Foslie, 1922).

**Gudmundite** occurs as an accessory phase in the Ettedal Pb-deposit (Naik, 1975; Naik et al., 1976).

**Molybdenite** has been reported from the Bamble sector as long ago as the eighteenth century (Brünnich, 1777; Schumacher, 1801). It occurs as an accessory mineral in marbles (Falkum, 1966), skarns at Kristiansand (Barth, 1925, 1928) and Arendal (Bugge, 1943), and pegmatites, for example at Skogstad (Andersen, 1931). Molybdenite seems to occur especially in those pegmatites which are in contact with amphibolites. It also occurs in apatite-hornblende veins at Noerestad near Risør (Solly, 1892).

**Skutterudite** (smaltite) has been reported from the skarns around Arendal (Bugge, 1943).

Sulphosalts

**Pyrargyrite** occurs in ores from the Ettedal Pb-deposit (Naik, 1975; Naik et al.,

Boulangerite occurs as a rare phase in ores from the Ettedal Pb-deposit (Naik et al., 1976), where it coexists with argentian boulangerite (Naik et al., 1976; Krijgsman, 1991a).

Halogenides

Halogenides with Me:X = 1:2

Fluorite occurs in the skarns at Kristiansand (Barth, 1925, 1928) and Arendal (Weibye, 1847; Buggle, 1954), with calcite, quartz and prehnite in late veins (Broekmans et al., 1994), along late fractures, for example in the Ubergsmoen area, and as retrograde lenses in biotites in late dykes on Tromøy. Light green REE-bearing fluorite occurs in late fissures near Hynnekleiv.

Oxides and hydroxides

Spinels

Spinels are already reported from Arendal by Weibye (1847). Spinels occur in the skarns at Kristiansand (Barth, 1925, 1928), Arendal (Buggle, 1940; Broekmans et al., 1994), and Loftsd on Tromøy (Broekmans et al., 1994). Spinels also occur in corona structures in many gabbros (Buggle, 1940; Frodesen, 1968a; Starmer, 1969a; de Haas et al., 2010), and in sapphirine-bearing rocks, like those at Hasleholm (Lamb, 1981; Kihle & Bucher-Nurminen, 1992), Rangleåsen, Gladstad and Snareund (Lamb, 1981), and in cordierite-orthoamphibole rocks (Visser, 1993a).

Gahnite occurs in skarns around Arendal (Scheerer, 1845a; Weibye, 1847).

Magnetite is a common accessory in gneisses (Buggle, 1940; Dietrich, 1960; Falkum, 1966; Comin-Chiaramonti, 1974), amphibolites (Falkum, 1966; Starmer, 1969a, 1976; Nijland et al., 1993d), marbles (Falkum, 1966), metapelites (Starmer, 1969b, 1972), gabbros (Barth, 1925, 1928; Arendal: Buggle, 1940; Broekmans et al., 1994; Løddesøl: Buggle, 1945), and in gabbros (Buggle, 1940; Frodesen, 1968b; Starmer, 1969a; Brickwood, 1986). V-bearing magnetite (up to 1.9 wt.% V₂O₃) occurs in the Messel Ni-deposit (Brickwood, 1986). Magnetite also occurs in the Tråk Zn-Pb-deposit (Rosholt, 1967), the Nystein Ni-deposit (Kuiperus, 1986), the sulphidic ore zone in the Blengsvatn gabbro (van Linschoten, 1989), and in veins on Langøy off-shore of Kragerø (Buggle, 1978). Large magnetite deposits are associated with the skarns around Arendal, and with the Holt granite. Several pegmatites, like those at Tangen (Bjørlykke, 1937; Green, 1956), Kalstad, Lindvikskollen, Sjåen (Green, 1956), Buøya (M.A.T.M. Broekmans, pers. com., 1995), and Gloserhei (Ämli, 1975, 1977) contain magnetite. Titanomagnetite occasionally occurs as an accessory phase in gabbros (Glaveris, 1970), amphibolites (Starmer, 1969a), and albitites (Green, 1956).
Ulvöspinel has been reported from one gabbro near Herre, in the Bamble community (Carstens, 1957). Magnetite in a granitic pegmatite on Buøya, near Tvedestrand, contains exsolution lamellae of ulvöspinel (M.A.T.M. Broekmans, pers. com., 1995).

Chrysoberyl has been found in the Lindtsøl pegmatite (Andersen, 1931).

Sesquioxides

Corundum is a major constituent of the corundum-bearing rocks at Kleggåsen, near Froland (Oftedahl, 1963; Nijland et al., 1993b; Pl. 2, fig. a). The beautifully red corundum crystals are too impure to be gem rubies, as they were designated by Oftedahl (1963). Large blue corundum crystals occur in partly molten metapelites at Maltemyra, south of Nelaug (Nijland, 1989). Corundum occurs as an accessory in albitites (Green, 1956), in sapphirine-bearing rocks at Hasleholmen (Lamb, 1981; Kihle & Bucher-Nurminen, 1992) and Rangleåsen (Lamb, 1981), and in cordierite-orthoamphibole rocks (Visser & Senior, 1990).

Hematite is a common (secondary) accessory in gneisses (Falkum, 1966), amphibolite (Falkum, 1966; Starmer, 1969a), quartzites (Starmer, 1976), and marbles (Falkum, 1966); it occurs more rarely in gabbros (Starmer, 1969a). Hematite also occurs in sapphirine-bearing rocks at Hasleholmen (Kihle & Bucher-Nurminen, 1992), the Tråk Zn-Pb-deposit (Rosholt, 1967), and in some pegmatites (Tangen: Green, 1956; Gloserhei: Æml, 1975, 1977). Mirrors of hematite occur on fracture planes in albite-actinolite-quartz rocks, e.g. around the Uvatn, NW of Jåmmås, and in retrograded clinopyroxene-garnet skarns, e.g. at Vågsnes on Tromøy.

Ilmenite is a common minor mineral in albitites (Force, 1991) and gabbros (Frodesehen, 1968b; Brickwood, 1986; de Haas et al., 1992a). Ilmenite occurs in the Nystein Nideposit (Kuiperus, 1986) and the Blengavåg gabbro ore-zone (van Linschoten, 1989). Large masses of ilmenite, of over 100 kg, occur in metagabbroic rocks near the Ødegårdens Verk apatite deposit (M.A.T.M. Broekmans, pers. com., 1995). It sporadically occurs in pegmatites, notably those at Kalstad, Lindvikskollen near Kragerø (Green, 1956) and at the Buøya peninsula near Tvedestrand (M.A.T.M. Broekmans, pers. com., 1995). Ilmenite is a common accessory in gneisses (Comin-Chiaramonti, 1974), amphibolite (Starmer, 1969a, 1976; Nijland et al., 1993d), metapelites (Starmer, 1969a), cordierite-orthoamphibole rocks (Visser & Senior, 1990; Visser, 1993a), and quartzites (Starmer, 1976). It also occurs in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Sjøgren, 1883; Neumann et al., 1960), and apatite-hornblende veins at Håsen near Gjerstad, Lykken and Valeberg, both near Kragerø, and Havredal in the Bamble community (Brøgger & Reusch, 1875). Hystatite, a species described from Arendal by Breithaupt (1830, p. 30), is a mixture of ilmenite with hematite and/or magnetite.

Högbomite occurs as a secondary phase in sapphirine-bearing rocks at Gladstad (Visser et al., 1992). A few crystals of högbomite have recently been identified as inclusions in ilmenite in a preiswerkite-biotite-tourmaline-scapolite rock from the Nidelva Quartzite Complex, in the Froland area.

Davidite has been reported from a pegmatite at Bringebærkastet on Langry, offshore of Kragerø (Neumann, 1885).

Betafite has been reported from the Tangen and Sjåen pegmatites (Green, 1956).
The variety *tangelite*, from the Tangen pegmatite (Gagarin & Cuomo, 1949, p. 10) represents a mixture, mainly composed by betafite.

**Microlite** has been found in the Mørkhøgda pegmatite, near Gjerstad (Bjørlykke, 1937).

**Pseudobrookite** was first mentioned from a pegmatite near Havredal in the Bamble community by Brøgger (1888), and subsequently reinvestigated by Smith (1969).

**Dioxides**

**Quartz** is a major rock forming mineral of most rocks in the Bamble sector. Several varieties, like smoky quartz etc., have been reported from many pegmatites. Small crystals occur in miarolitic voids in many pegmatites, e.g. at Moen near Tvedestrand. High purity quartz often occurs in association with albite-actinolite-quartz rocks. Rose quartz has been found in veins at the Solemsvatn in the Froland municipality.

**Chalcedony** has been found in the skarns around Arendal (Weibye, 1847).

**Rutile** is a common accessory in many rock types like quartzites (Bugge, 1940; Green, 1956; Starmer, 1976), amphibolite (Green, 1956; Frodesen, 1968b; Starmer, 1969a; Nijland et al., 1993d), cordierite-orthoamphibole rocks (Beeson, 1976; Starmer, 1976; Visser & Senior, 1990; Visser 1993a), the Froland corundum-rocks (Oftedahl, 1963; Nijland et al., 1993b), and skarns (Kristiansand: Barth, 1925, 1928; Løddesøl: Bugge, 1945). It also occurs as accessory mineral in some pegmatites, like the one at Gloserhei (Åmli, 1975, 1977). Rutile is present in some sulphidic ore zones associated with meta-gabbros, like those at Nystein (Kuiperus, 1986) and Blengsvatn (van Linschoten, 1989). It occurs in apatite-estatite-phlogopite veins at Ødegården's Verk (Brøgger & Reusch, 1875; Sjøgren, 1883; Neumann et al., 1960; Lieftink et al., 1993, 1994), and apatite-hornblende veins at many localities (Brogger & Reusch, 1875; Sjøgren, 1883; Solly, 1892). Relatively large rutiles occur associated with albites, e.g. at Lindvikskollen near Kragerø (Green, 1956; Bugge, 1978; Force, 1991) and in a small prospection pit northwest of Flaten. Dark purple-coloured oxygen-deficient rutiles rarely occur in graphitic gneisses, e.g. near Ubergsmoen, and altered meta-gabbro at Ødegården's Verk.

**Ilmenorutile** has been found in several granitic pegmatites, like those at Auselmyra (Brogger, 1906a; Neumann, 1961), Ramskjaer near Sondeled (Scheitelig, 1913; Andersen, 1931; Neumann, 1961), and Monbue on Tromøy (Scheitelig, 1913; Neumann, 1961).

**Anatase** occurs in the skarns around Arendal (Bugge, 1943). It has also been observed as retrograde breakdown product of titanite in apatite-hornblende veins near Kragerø (Hamberg, 1886), in hydrothermal dolomitic marbles near Kammerfoss, Kragerø (Schei, 1904), and in charno-enderbitic gneisses from the Arendal area.

**Columbite** has been reported from several pegmatites in the Bamble sector, like those at Tangen (Andersen, 1931; Bjørlykke, 1937; Green, 1956; Neumann, 1961), San-nikdal (Milch, 1900), Ramskjaer near Sondeled (Andersen, 1931), and Øvre Gjerstad (Neumann, 1961).

**Euxenite** has first been reported by Weibye (1847) from the Arendal area. It occurs in many pegmatites: Alve on Tromøy (Brogger, 1906a), Ranevik near Risør (Brøgger, 1906a), Kalstad, Lindvikskollen and Sjåen, all near Kragerø (Andersen, 1931; Green, 1956), Tangen, also near Kragerø, Lindtstøl (Andersen, 1931), Gloserhei
Aeschynite-Y, known in the old Bamble literature as blomstrandine, has been found in pegmatites near Arendal (Brøgger, 1906a) and at Mørefjær (Andersen, 1931). Crystals with a high metallic lustre occur in the pegmatite at Gloserhei.

Yttrotantalite-Y has been observed in the Hella pegmatite near Arendal (Brøgger, 1906a; Andersen, 1931).

Fergusonite occurs in many of the granitic pegmatites in the Bamble sector, like those at Hella near Arendal (Forbes & Dahll, 1855; Andersen, 1931), Narestø on Flosta, Alve and Hampemyr on Tromøy (Forbes & Dahll, 1855), Arendal (Brøgger, 1906a), Ranevik near Risør (Brøgger, 1906a), Gryting near Risør (Hauser, 1908; Barth, 1927), Merkhøgda near Gjerstad (Bjørlykke, 1937), Kalstad, Lindvikskollen near Kragerø (Green, 1956), and Rullandsdalen near Risør (Butler & Hall, 1960). The variety risorite (Hauser, 1908) was originally described as a separate mineral species from Gryting, near Risør, whereas bragite, now also discredited, was described from the Naresto pegmatite (Forbes & Dahll, 1855).

Samarskite has been found in granitic pegmatites at Ranevik near Risør (Brøgger, 1906a), Bjellåsen in the Froland community (Nilssen, 1970), Midtbø south of Ubergsmoen (D.J. Lieftink, pers. com., 1993), and at Lauvrak (M.A.T.M. Broekmans, pers. com., 1995).

Baddelyte has been found in the cores of zircons in metagabbros at Landvik, Grimstad, and Ravnberg near Risør (Dahlgren et al., 1990) and in the Jåmmåsknutene gabbro (C. Maijer, pers. com., 1992).

Uraninite, whose Y-bearing variety is known in the old Bamble literature as cleveite, occurs in several pegmatites: Garta near Arendal (Nordskiöld, 1878), Auselmyra (Bakken & Gleditsch, 1938), Gloserhei (Åmli, 1975, 1977), and in a pegmatite cutting across the skarns at Alvekilen on Tromøy (M.A.T.M. Broekmans, pers. com., 1995).

Thorianite has been found as accessory mineral in the Levang gneiss (Neumann, 1985).

Hydroxides

Goethite occurs as accessory mineral in the Gloserhei pegmatite (Åmli, 1975, 1977), the Tråk Zn-Pb-deposit (Rosholt, 1967), and in the sulphidic ore zone associated with the Blengsvatn gabbro (van Linschoten, 1989).

Groutite has been discovered in the Klådeborg skarns near Arendal (J.A.W. Bugge, in Neumann, 1985).

Uranylhydroxides

Clarkeite has been found in one pegmatite near Gjerstad (A.O. Larsen, in Neumann, 1985).

Curite has been reported in samples from a pegmatite at Fone near Gjerstad in the British Museum of Natural History (Neumann, 1985).

Fourmarierite occurs in the Gloserhei pegmatite (Åmli, 1977).
Carbonates

**Calcite** is a common mineral in marbles, skarns, and late calcite veins from the entire Bamble sector. It also occurs as retrograde breakdown product in several other rocks.

**Siderite** has been reported from the Tråk Zn-Pb-deposit (Vogt, 1907; Røsholt, 1967).

**Magnesite** occurs associated with actinolite at Vegårshei (M.A.T.M. Broekmans, pers. com., 1995).

**Dolomite** is the main constituent of hydrothermal marbles in the surroundings of Kragerø (Bugge, 1965; Dahlgren et al., 1993). It also occurs as a primary phase in skarns at Loftstad on Tromøy (Broekmans et al., 1994) and in marbles near Flaten, Nelaug (Nijland, 1989; Broekmans et al., 1994). In addition, it has been reported by Reitan (1959) from carbonate-quartz veins at Ryterholmen, Kragerø.

**Ankerite** occurs in late veins in gneisses and amphibolites west of Arendal (Broekmans et al., 1994) and in skarns at Loftstad on Tromøy (M.A.T.M. Broekmans, pers. com., 1995).

**Malachite** has been reported from the Arendal and Tvedestrand areas by (Weibye, 1847), who did not further specify its mode of occurrence. It occurs as secondary mineral in Tråk Zn-Pb-deposit (Røsholt, 1967), and as weathering crusts on chalcopyrite in skarns at Loftstad on Tromøy (M.A.T.M. Broekmans, pers. com., 1995).

**Parisite** has been found in the Tangen pegmatite (R. Kristiansen, in Neumann, 1985).

**Synchisite** has been discovered in a pegmatite at Gryting near Gjerstad (R. Kristiansen, in Neumann, 1985).

**Lokkaite** has been found in the Tangen pegmatite (R. Kristiansen, in Neumann, 1985).

A specimen of **hydrotalcite** labelled Kragerø occurs in the collections of the Mineralogical-Geological Museum, Delft University of Technology.

**Kamphaugite-(Y)** has recently been discovered as a new mineral species, and was also reported from the Tangen pegmatite near Kragerø, where it occurs in cracks in quartz and feldspar (Raade & Brastad, 1993).

**Borates**

**Cahnite** was reported from the Klådeborg skarns, near Arendal by Bugge (1951).

**Sulphates**

**Celestite** possibly occurs in the Tråk Zn-Pb-deposit (Røsholt, 1967).

**Baryte** has been mentioned by Weibye (1847, 1849) from the basement near Brevig, possibly meaning the Tråk Zn-Pb-deposit, from which it was reported by Vogt (1907), and by Røsholt (1967). In addition, it occurs in some dykes on Tromøy (S.H. Dahlgren, pers. com., 1991).

**Woodhouseite** occurs as rare mineral in the apatite-enstatite-phlogopite veins at Ødegårdens Verk (Morton, 1961).
Phosphates

Whitlockite occurs as a rare mineral in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Morton, 1961; Griffin et al., 1972).

Xenotime is present in many granitic pegmatites from the Bamble area, like those at Naresentø (Brøgger, 1883; Blomstrand, 1887; Andersen, 1931; Neumann, 1961), Gloserhei (Åmli, 1975, 1977), Gryting near Gjerstad (Neumann, 1961), Austre Moland, Arendal (Neumann, 1961), Ramskjær near Sondeled (Andersen, 1931), Tråk (Røsholt, 1957), Lofstad on Tromøy (Brøgger, 1883), Lyngrot in the Froland municipality (Andersen, 1931), as well as in unspecified pegmatites in the Kragør area (Betechtin, 1957). It also occurs in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Neumann et al., 1960; Lieftink et al., 1994).

Monazite from Arendal was originally described as a separate species, kryptolith, by Wöhler (1846), which was subsequently shown to be identical with monazite. It occurs in many granitic pegmatites, among them those at Midtbø south of Ubergsmoen (Mallard, 1887), Risør (Schei, 1905), Gloserhei (Åmli, 1975, 1977), Naresentø (Brøgger, 1906a; Andersen, 1931), Lyngrot (Andersen, 1931), Lauvland, Lauvvak, and Alvekilen (M.A.T.M. Broekmans, pers. com., 1995). In such granitic pegmatites, idiomorphic crystals of monazite are often associated with muscovite. Monazite also occurs as accessory mineral in gneisses and metapelites, in skarns at Vågsnes on Tromøy (Scheerer, 1848b), and in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Neumann et al., 1960; Lieftink et al., 1994).

Wagnerite occurs in several apatite-hornblende veins, like those near Havredal (Helland, 1874; Brøgger & Reusch, 1875) and Haukedal (Neumann, 1985) in the Bamble municipality, and in apatite-enstatite-phlogopite veins at Ødegårdens Verk (Brøgger & Reusch, 1875; Neumann et al., 1960). It has also been reported from a pegmatite near Havredal (Smith, 1969). The now discredited variety kjerulfine was originally described from Kjørrestad (von Kobell, 1873, p. 272).

Apatite has been mined at several localities in the Bamble sector (Bugge, 1922). These so-called apatite pegmatites are either apatite-enstatite-phlogopite veins, which occur at Ødegårdens Verk (Helland, 1874; Brøgger & Reusch, 1875; Sjögren, 1883; Neumann et al., 1960; Lieftink et al., 1994), or apatite-hornblende veins, which occur at Fogene and Hläsen near Gjerstad, at Ravneberg near Risør, in the obliterated Vuggens and Lykkens mines in Kragør, at Hauvedal and Kaleberg near Kragør (Brøgger & Reusch, 1875), at Landvik near Grimstad (Sjögren, 1883), at Noerestad, Risør (Solly, 1892), and Håvatn in the Froland municipality (Brøgger, 1934a). Apatite is also a common mineral in granitic pegmatites, like those at Kalstad-Lindvikskollen and Sjåen (Green, 1956), at Gloserhei (Åmli, 1975, 1977), where large euhedral green crystals occur, and at Hynnkelev. It is a common accessory in quartzites (Green, 1956; Starmer, 1976), gneisses (Bugge, 1940; Dietrich, 1960; Falkum, 1966; Alberti & Comin-Chiaramonti, 1974; Beeson, 1975; Starmer, 1972), amphibolites (Green, 1956; Falkum, 1966; Frodesen, 1968b; Starmer, 1969a, 1976; Nijland et al., 1993d), metapelites (Starmer, 1969b, 1972), metagabbros (Bugge, 1940; Green, 1956; Frodesen, 1968b; Starmer, 1969a; de Haas et al., 1992a), cordierite-orthoamphibole rocks (Visser & Senior, 1990; Visser, 1993a), marbles (Falkum, 1966), and skarns (Kristiansand: Barth, 1925, 1928; Arendal: Bugge, 1940; Løddesøl: Bugge, 1945). Apatite occurs in
veins together with chalcopyrite, titanite, rutile, and calcite at the contacts of gabbros with their country rocks, like at Ronningen (Broekmans et al. 1994), and in actinolite-albite-quartz rocks, for example at Uvatin NW of Jåmmås. Apatites are generally F-rich varieties, especially in amphibolites (Nijland et al., 1993d), pegmatites and apatite-hornblende veins, like those at Håvatn. However, primary apatites in the apatite-enstatite-phlogopite veins at Ødegårdens Verk are near Cl-end members (Morton & Catanzaro, 1964; Liefink et al., 1994); rarely, Cl-rich apatites also occur in amphibolites, for example near Ripåsen (Nijland et al., 1993d). The Cl-end member of apatite was first described from south Norway (Rammelsberg, 1860, p. 353). OH-dominated apatites tend to occur in alteration zones. The bluish-green variety moroxite was originally described from Arendal (Abilgaard, 1798, p. 349).

Carbonatehydroxylapatite, originally described as dahllite (Brøgger & Backstrøm, 1888), has been reported from the apatite-bearing veins at Ødegårdens Verk (Brøgger & Backstrøm, 1888; Neumann et al., 1960).

Bobierrite has been reported from the apatite-bearing veins at Ødegårdens Verk (Michel, 1893).

Vivianite occurs in the apatite-bearing veins at Ødegårdens Verk (Brøgger & Reusch, 1875) and in calc-silicate rocks from Froland (Beyer, 1992).

Silicates

Nesosilicates

Phenakite occurs in pegmatites from the surroundings of Kragerø, commonly as large prismatic crystals and twins together with quartz and albite. Large crystals have been found at Tangen (Hintze, 1897b; Backstrøm, 1898; Andersen, 1931) and Kalstad-Lindvikskollen (Brøgger, 1906a; Green, 1956).

Eucryptite possibly occurs as minute flakes on spodumene in a Li-paragenesis in a pegmatite near Lien, at the Kilsfjord (Beyer, 1992).

Olivine is a common mineral in the metagabbros (‘hyperites’) from the Bamble sector (Green, 1956; Frodesen, 1968a,b; Starmer, 1969a; Glaveris, 1970; Brickwood, 1986; de Haas et al., 1992a). The Mg-end member forsterite also occurs in the skarns at Tromøy (Broekmans, 1992a; Broekmans et al., 1994) and Leddesøl (Bugge, 1945). The Fe-end member fayalite has so far been identified in samples from the monzonitic Morkheia Complex (Touret, 1967a) as well as in a syenitic sample of the Hovdefjell augen gneiss (P. Hagelia, pers. com., 1996).

Zircon is a common accessory in quartzites (Bugge, 1940; Green, 1956; Starmer, 1976), gneisses (Dietrich, 1960; Falkum, 1966; Starmer, 1972; Alberti & Comin-Chiaramonti, 1974; Beeson, 1975; Gupta, 1986), amphibolites (Green, 1956; Falkum, 1966; Starmer, 1976), skarns (Barth, 1925, 1928; Bugge, 1945), cordierite-orthoamphibole rocks (Starmer, 1976; Visser & Senior, 1990; Visser, 1993a), and metapelites (Starmer, 1969b; 1972). Crystals of variable size are common in most granitic pegmatites, like those at Lindvikskollen (Bjørlykke, 1937), Sjåen (Andersen, 1931), Tangen (Andersen, 1931; Green, 1956), and Gloserhei (Åmli, 1975, 1977). In feldspathic parts of some pegmatites, like those at Lauvland, Alvekilen and Hynnekleiv, zircon occurs as intergrowths of several crystals up to several centimetres in size, with a so-called azonite-
habit (pseudo-octahedra). The zircons have occasionally been called alvite or malakon. The discredited species oerstedite (Forchhammer, 1835, p. 630) represents an altered, reddish brown variety of zircon.

**Thorite**, occasionally called orangite, occurs in several of the well-known granitic pegmatites of the Bamble sector, like those at Lindtstøl (Andersen, 1931), Kalstad (Andersen, 1931), Lindvikskollen (Bjrølykke, 1937), Tangen (Andersen, 1931; Green, 1956), Gloserhei (Åmli, 1975, 1977), Auselmyra, and Midtbø (M.A.T.M. Broekmans, pers. com., 1995). An U-rich variety, called uranothorite in the older literature, has been reported from a not specified pegmatite in the vicinity of Kragerø (Gleditsch & Qviller, 1932). In addition, thorite occurs together with allanite in aggregates of mica in gneiss from Arendal (sample in the collections of the École des Mines, Paris).

**Garnet** is a common mineral in most rock types from the Bamble sector. It occurs in felsic gneisses (Falkum, 1966; Starmer, 1972; Alberti & Comin-Chiaramonti, 1974; Beeson, 1975), in amphibolites (Green, 1956; Falkum, 1966; Starmer, 1969a; Nijland et al., 1993d), in metagabbros (Bugge, 1940; Green, 1956; Pl. 2, fig. b), in metapelites (Starmer, 1969b, 1972, 1976), skarns (Barth, 1925, 1928; Broekmans, 1992a; Broekmans et al., 1994), and in some granitic pegmatites. Garnet is also present in spinel-biotite-orthopyroxene-rich rocks (Lamb, 1981; Kihle & Bucher-Nurminen, 1992) and in cordierite-orthoamphibole rocks (Beeson, 1976; Visser & Senior, 1990; Visser 1993a). Garnet in the skarns have been described as colophonite (Kolophonit) in old literature, a term attributed to D.L.G. Karsten by Haüy (in Lucas, 1806). Although generally considered as a variety of andradite, early analyses (Simon, 1807) of colophonite from Nordic origin have already shown them to be mixtures of grossular and andradite (Al:Fe$_3^+$ ≈ 3:2). This is confirmed by modern analyses, although more spessartine-rich compositions also occur (with up to 11.5 wt.% MnO), for example at Skoletjern, just northwest of Arendal (Broekmans, 1992a). The latter garnets are both chemically and optically zoned, and have birefringent margins (Broekmans, 1992a), possibly due to a hydrgarnet-component, which is demonstrated to be present by IR-investigations (D. Visser, pers. com., 1997). In amphibolites and gneisses, garnets are generally almandine-pyrope mixtures, with minor amounts of grossular and spessartine components (Burrell, 1966; Nijland et al., 1993d).

**Hydrogarnet** occurs as small microscopic lenses and lamellae in biotite from various rock types (Visser, 1993b; Nijland et al., 1994), as well as in the skarns (see above). They are essentially hydrogrossulars with significant admixture of hydroandradite-component, and may contain considerable amounts of fluorine.

**Sillimanite** is well known from the entire Bamble sector (e.g. Weibye, 1847, 1849). Part was originally described as the separate species bamlite by Erdmann (1842, p. 19), on samples from the Bamble municipality. The mineral is common in metapelites (Macaudière & Touret, 1969; Starmer, 1972, 1976; Beeson, 1975) and quartzites (Bugge, 1940; Green, 1956; Starmer, 1976). In addition, it occurs in several rare rock types, like the Froland corundum-bearing rocks (Oftedahl, 1963; Nijland et al., 1993b) and spinel-biotite-orthopyroxene rocks at Hasleholmen (Lamb, 1981; Kihle & Bucher-Nurminen, 1992). In the Nelaug-Arendal area, its habit changes from fibrolitic to euhedral prismatic with increasing grade of metamorphism (Nijland & Maijer, 1993).

**Andalusite** only very rarely occurs in the Bamble sector. It has been reported from pegmatitic segregations at Fossingfjord, in the Bamble municipality proper.
(Ramsay & Morton, 1971). Hagelia (1989) reported andalusite overgrowing sillimanite and kyanite from a metapelitic near Eikås, NW of lake Nelaug. Rarely, it also occurs in cordierite-orthoamphibole rocks around the Blengsvatn (Visser & Senior, 1990) and biotite schists near Grandalstjern and Blakstad.

**Kyanite**, although generally considered scarce in the Bamble sector, has since long been known from the Kragerø (Weibye, 1847), Brevig (Weibye, 1847, 1849), and Risør areas (Forbes, 1857). It has now been identified in a range of cordierite-orthoamphibole rocks at Bøylefossbru, Blengsvatn, Åmdalsmoen, Haugsjå (Visser & Senior, 1990, 1991), at Bjordammen (Touret, 1979; Visser et al., 1990; Visser & Senior, 1991), Søndeled and Gjerstad (D. Visser, pers. com., 1990, 1992), and metapelitic gneisses near Kristiansand (A.C. Tobi, in Jansen et al., 1985) and Eikås, NE of lake Nelaug (Hagelia, 1989) and some aluminous gneisses in the Froland area (Nijland & Maijer, 1993). Kyanite also occurs in veins intersecting the Froland corundum-bearing rocks (Oftedahl, 1963; Nijland et al., 1993b), and in pegmatitic segregations at Fossingfjord, Bamble municipality (Ramsay & Morton, 1971).

**Staurolite** is a rare mineral in the Bamble sector. It is known to occur as a relictic phase in cordierite-orthoamphibole rocks at three localities (Bøylefossbru and Blengsvatn: Visser & Senior, 1990; Åmdalsmoen: this study), as well as in metapelites from the Hisøy-Torungen area (Knudsen, 1996) and in a biotite schist at Grandalstjern.

**Topaz** has been reported from the Tangen pegmatite, but the specimen has subsequently been identified as danburite (Neumann, 1985). Schneiderhohn (1961), however, mentions the occurrence of topaz as a common mineral in granitic pegmatites in the area.

**Chondrodite** occurs as an accessory mineral in marbles at Tveit (Falkum, 1966), and in the skarns at Kristiansand (Barth, 1925, 1928) and Arendal (Bugge, 1943).

**Clinohumite** has been reported from the Tveit marbles by Falkum (1966), the skarns at Barbuadalen (Broekmans et al., 1994), and probably at Lofstad (M.A.T.M. Broekmans, pers. com., 1995). It was also reported from the skarns at Kristiansand by Barth (1925), who called it *Ti-olivine*.

**Titanite** is one of the minerals for which the Bamble sector has since long been famous (e.g. Weibye, 1847; Pl. 3, fig. a). Large crystals occur in granitic pegmatites, like those at Kalstad and Lindvikskollen (Green, 1956), in albitites (Green, 1956; Force, 1991) and as aggregates or envelope-shaped crystals in albite-actinolite-quartz rocks and altered metagabbro (Kloprogge, 1987; Maijer & Nijland, 1991; Nijland et al., 1993c). Accessorial titanite occurs in amphibolites (Green, 1956; Falkum, 1966; Frodesen, 1968b; Starmer, 1969a, 1976; Nijland et al., 1993d), marbles (Falkum, 1966), skarns (Barth, 1925, 1928; Bugge, 1940), metagabbros (de Haas et al., 1992a), gneisses (Dietrich, 1960; Nijland & Maijer, 1993), and cordierite-orthoamphibole rocks (Starmer, 1976). Titanite is also present in the apatite-enstatite-phlogopite veins at Ødegårdens Verk (Brogger & Reusch, 1875; Sjögren, 1883) and in apatite-hornblende veins at Lykkens in Kragerø (Brogger & Reusch, 1875), Landvik near Grimstad (Sjögren, 1883), Noerestad near Risør (Solly, 1892), and Håvåtn in the Froland municipality. The Y-rich variety, *yttrotitanite*, has been reported from, among others, the granitic pegmatites at Kalstad (Andersen, 1931; Green, 1956), Lindvikskollen, Tangen, Sjåen (Green, 1956), Gloserhei (Åmli, 1975, 1977), and from the Arendal skarns (Oftedal, 1939). Bur was the type locality for the discredited variety *keilhautite* (Erdmann, 1844,
Titanite from Gjerstad and Arendal was used by Hawthorne et al. (1991) in their study of alpha-decay damage in titanite. The titanites vary in colour from light caramel brown to very dark brown. Well-developed envelope-shaped crystals occur at the Håvatn mine.

**Datolite** has been found at the various skarn mines around Arendal (Weibye, 1847; Kjerulf & Dahl, 1861; Betechtin, 1957; Pl. 3, fig. b), which is the type locality for this mineral (cf. Clark, 1993). At Lofstad on Tromøy, it occurs in late veins with axinite, epidote, actinolite, and calcite (Broekmans, 1992b; Broekmans et al., 1994).

**Gadolinite** occurs in many of the rare mineral-rich granitic pegmatites, like those at Haneholmen near Tvedestrand (Scheerer, 1845a) Ranevik near Risør (Brogger, 1906a), Lindvikskollen (Oftedal, 1972), and Lyngrot near Froland (Andersen, 1931). A large anhedral specimen has been collected from a granitic pegmatite that was intruded in the core of the layered gabbro at Flosta (M.A.T.M. Broekmans, pers. com., 1995).

**Kornerupine** is increasingly identified in cordierite-orthoamphibole rocks from the Bamble sector, both in the amphibolite and granulite facies areas. It occurs at Bjor-dammen (van de Wel, 1973), Hove on Tromøy (Hulzebos-Sijen et al., 1990), Bøylefosbru (Visser, 1993a, 1995), Rød (Hulzebos-Sijen et al., 1990; Visser & Senior, 1991; Visser, 1992a), and at Færvik on Tromøy (Visser et al., 1991).

**Dumortierite** has since long been known from cordierite-orthoamphibole rocks at Tvedestrand (Michel-Lévy & Lacroix, 1888) and Hasleholmen (Bugge, 1943). Recently, it has been found in alteration assemblages after cordierite at Bøylefosbru (Visser & Senior, 1990, 1991), Rød (Visser & Senior, 1991; Visser 1992b), Norum, Bjor-dammen, Haugsjå, Stutæsen, and Solbutjernane (Visser & Senior, 1991).

**Magnesiodumortierite** has recently been described as a new mineral species from the Italian Alps (Chopin et al., 1995); these authors note that one of the electron microprobe analyses of dumortierite presented by Visser & Senior (1991) qualifies it also as magnesiodumortierite. This specimen occurs in a sample from the Bøylefosbru cordierite-orthoamphibole rock locality.

**Grandidierite** has only been found once in the cordierite-orthoamphibole rocks at Bøylefosbru (Visser & Senior, 1990).

**Kasolite** has been identified in granitic pegmatites at Gløserhei (Åmli, 1975, 1977) and Gjerstad (Neumann, 1985).

**Uranophane** has been reported from a granitic pegmatite at Garta near Arendal (Nordenskiöld, 1884) and from the Gløserhei pegmatite, where **8-uranophane** also occurs (Åmli, 1975, 1977).

**Sorosilicates**

**Axinite** group minerals have been known from the skarns in and around Arendal for almost two centuries now (Schumacher, 1801; Hoffmann, 1811; Weibye, 1847). Recently, ferroan manganaxinite was found in late veins at the Lofstad skarn section on Tromøy, in which it occurs together with datolite and epidote (Broekmans, 1992b; Broekmans et al., 1994).

**Hellandite** occurs in granitic pegmatites. Besides from its type locality Lindvikskollen near Kragero (Brogger, 1903, 1906b; Green, 1956; Pl. 4, fig. a), it has been reported from the pegmatites at Tangen (Bjørlykke, 1939) and Auselmyra (Oftedal,
It occurs as tablets, together with tourmaline, thorite and allanite (Winchell, 1951, p. 452).

**Epidote** occurs as a retrograde, accessory mineral in almost all rock types in the area, including marbles (Falkum, 1966), skarns (Weibye, 1847; Barth, 1925, 1928; Bugge 1940, 1945, 1954; Broekmans, 1992a; Broekmans et al., 1994), amphibolites (Green, 1956; Falkum, 1966; Starmer, 1969a), gneisses (Dietrich, 1960; Field & Rodwell, 1968; Beeson, 1975; Nijland & Maijer, 1993), and albitite (Green, 1956). Epidote also occurs in the Cu-deposits at Skyytemyr and Boylestad in the Froland municipality (Bugge, 1978). The now discredited species *akanthicone* (d’Andrea, 1800) and *aren达尔ite* (Karsten, 1800) had Arendal as type locality.

The epidote-group mineral **clinozoisite** has been found as an accessory mineral in marbles (Falkum, 1966), skarns (Broekmans et al., 1994), gneisses (Dietrich, 1960), and amphibolites (Starmer, 1969a).

**Rare piemontite** has been reported from the surroundings of Vegårshøi (Touret, 1969).

**Allanite** is a common accessory in many rock types, like gneisses and amphibolites (Dietrich, 1960; Falkum, 1966; Beeson, 1975; Nijland & Maijer, 1993), but conspicuously absent in the most high grade part of the amphibolite-granulite facies transition zone at Arendal (Nijland & Maijer, 1993). It also occurs in many pegmatites, like those in the surroundings of Kragerø (Andersen, 1931; Bjørlykke, 1937), Gloserheia (Åmli, 1975, 1977), Lindstøl, Narestø, Hella, Lyngrot, and Morefjær (Andersen, 1931).

**Zoisite** occurs in some of the skarn localities near Kristiansand (Barth, 1925, 1928) and Arendal (Bugge, 1940) and occurs as an accessory mineral in some quartzites (Bugge, 1940).

**Pumpellyite** occurs as a late, retrograde mineral in the Arendal skarns (Bugge, 1954) as well as in many other rock types (Nijland & Maijer, 1993).

**Vesuvianite** was first reported by Weiss (1829, mentioned in Barth, 1963) from the skarns at Eg near Kristiansand (Vogel, 1887; Barth, 1963), and has subsequently been reported from the skarns near Arendal (Leonhard, 1841, p. 75; Weibye, 1847; Vogel, 1887; Bugge, 1940; Broekmans et al., 1994), from Kongsgårdskogen, Kristiansand (Barth, 1925, 1928, 1963), from Graslen in the Froland municipality, and Vegårshøi (Barth, 1963).

**Kainosite-(Y)** has been found in the Tangen pegmatite (G. Raade, in Neumann, 1985) and Gryting near Gjerstad (R. Kristiansen, in Neumann, 1985).

**Beryl** has since long been known from the Bamble sector. It was, for example, mentioned by Weibye (1847), who did not specify its mode of occurrence. It occurs in several pegmatites, like those of Ramskjaer near Søndeled (Andersen, 1931), Kragerø (Bjørlykke, 1937), Gloserheia (Åmli, 1975, 1977), and Skarpnes in the Øyestad municipality (Neumann, 1961). According to Oftedahl (1963), beryl also occurs in the well known corundum-bearing rocks from Froland.
Cordierite from the Bamble sector is famous for its often large idiomorphic and beautifully blue crystals, which occurs at many localities around Arenal (Holm, 1824), Tvedestrand, Kragerø, and Brevig (Weibye, 1847). The mineral has been reported under a variety of names like iolite, dichroite, aspasiolite, and polychroite. The latter name particularly alluded to an altered specimen, originally described from Kragerø (Weibye, 1846, p. 286). Kragerø was also the type locality for aspasiolite (Scheerer, 1846, p. 323). Cordierite occurs in peculiar cordierite-orthoamphibole rocks, which occur in many small exposures in the area (Frodesen, 1968b; Beeson, 1975, 1976; Starmer, 1976; Visser & Senior, 1990, 1991; Visser, 1992b, 1993a; Pl. 4, fig. b), in biotite-orthopyroxene-rich rocks which often also contain sapphirine (Lamb, 1981; Kihle & Bucher-Nurminen, 1992), and in some metapelites (Starmer, 1972; Visser et al., 1994; Knudsen, 1996). Cordierite from the Bamble sector has been used in studies of the incorporation of volatiles into its structure (Zimmerman, 1981; Vry et al., 1990; Visser et al., 1994).

Tourmaline (Pl. 5, fig. a) occurs as an accessory in amphibolites (e.g. Frodesen, 1968b; Starmer, 1969b), albitites (Green, 1956), gneisses (e.g. Beeson, 1975), quartzites (e.g. Bugge, 1940; Starmer, 1976; Nijland et al., 1993a), skarns (Bugge, 1940, 1945), in cordierite-orthoamphibole rocks (Visser & Senior, 1990, 1991; Visser, 1993a), in the apatite-ensatelite-orthopyroxene veins at Ødegårdens Verk (Brøgger & Reusch, 1875), and the apatite-hornblende veins at Hiåsen near Grimstad (Sjøgren, 1883). It also occurs in late, hydrothermally altered parts of the corundum-bearing rocks from Froland (Oftedahl, 1963; Nijland et al., 1993b). In addition, large crystals occur in many pegmatites, like those in the surroundings of Kragerø (Green, 1956), at Glosnerhei (Amli, 1975, 1977) and at Osdalen in the Froland area, where it has a triangular habit. Crystals in the pegmatite may be up to several decimetres across in size. Small pegmatites with extensively developed tourmaline-quartz symplectites occur just north of Übergsmoen. Aphrizite, now considered to be a black variety of tourmaline, was originally described from Kragerø by d’Andrea (1800). The Li-tourmaline elbaite is reported to occur in a granite pegmatite near Lien, at the Kilsfjord west of Kragerø (Beyer, 1992), together with other Li-minerals. Tourmalinites are locally present in the Nidelva Quartzite Complex (Nijland et al., 1993a), and in the ore-bearing sequence at Ettedalen (Krijgsman, 1991a,b).

Inosilicates

Pigeonite is scarce in gabbroic intrusions in the area, and has so far only been reported from the Selåsfjellet gabbro (A. Senior, in de Haas et al., 1992a), from a gabbro on Tromøy (Bugge, 1940), and as inverted pigeonite in one sample from the Vestre Dale gabbro (de Haas et al., 1992a). It also occurs as a primary magmatic phase in some Phanerozoic dolerite dykes in the area, for example at Norum, east of Übergsmoen.

Diopside to hedenbergite are the dominant end members in the composition of clinopyroxenes from calcsilicate rocks and skarns (Broekmans, 1992a). They have been described as augite in the old literature (e.g. Hintze, 1897a), but in fact, early analyses by Simon (1807) already confirm its diopsidic to hedenbergitic composition (SiO₂ 50.25, Al₂O₃ 3.50, Fe₂O₃ 10.50, MnO 2.02, MgO 7.00, CaO 25.50, H₂O 0.50, total...
99.37). Granular aggregates and masses from the skarns (Pl. 5, fig. b) have been termed *coccolite* (*Kokkolith*), following de Andrada e Silva (1800, p. 32). Hedenbergitic clinopyroxene also occurs in several of the albite-actinolite-quartz rocks (Kloprogge, 1987; Maijer & Nijland, 1991).

**Augite to ferro-augite** are the predominant end members in the composition of clinopyroxenes from both primary (magmatic) and secondary mineral assemblages in gabbroic rocks from the area (de Haas et al., 1992a; Dam, 1995), as well as in amphibolites and gneisses.

**Spodumene** is reported to occur as a prismatic crystals in a granitic pegmatite near Lien, at the Kilsfjord west of Kragerø (Beyer, 1992).

**Orthopyroxene** is wide-spread in both felsic and basic rocks in the granulite facies area. Orthopyroxene also occurs in the granitic to charnockitic augen gneiss bodies and their aureoles, like those at Hovdefjell-Vegårshei, Ubergsmoen, Gjerstad, and Gjeving (Touret, 1967b, 1968; Hagelia, 1989; Nijland & Senior, 1991). At Ødegårds Verk, large megacrysts occur in the apatite-bearing veins (Børger & Reusch, 1875; Lieftink et al., 1994) and other magmatic-deuteric veins. Orthopyroxenes in the Ubergsmoen augen gneiss are among the most Fe-rich varieties known, with 91% of ferrosilite component and up to 1.2 wt.% Al₂O₃ (Lieftink, 1992). In addition, magmatic orthopyroxene occurs in metagabbros throughout the Bamble sector. Orthopyroxenes from the Bamble community have been used in studies of mechanical behaviour of orthopyroxene (Riecker & Rooney, 1966), the presence of OH in orthopyroxene (Skogby et al., 1990, among others), and the terrestrial occurrence of orthopyroxenes with space group P2₁/a (Luo et al., 1992).

**Tremolite** has already been reported from the Kragerø area by Weibye (1847). It occurs as a rare accessory in marbles (Falkum, 1966; Broekmans et al., 1994), skarns at Loddesøl (Bugge, 1945), Lofstad and Arendal (Broekmans, 1992a; Broekmans et al., 1994), in cordierite-orthoamphibole rocks at Håsen (Fredesen, 1968b), and in amphibolites (Fredesen, 1968b; Starmer, 1969a). Tremolitic amphibole is also present in the talc deposits at Vestre Vimme in the Nelaug area (Nijland, 1989; Moree & Nijland, 1996). In the zone along the Porsgrunn-Kristiansand Fault, tremolite occurs in veins together with calcite, where it replaces the assemblage dolomite + quartz (J.L.R. Touret, pers. com., 1997).

**Actinolite** occurs commonly as a retrograde phase in both felsic gneisses and metabasites (Nijland & Maijer, 1993). In addition, it occurs in great abundance in the so-called albite-actinolite-quartz rocks (Kloprogge, 1987; Maijer & Nijland, 1991) and albitites. Among these lithologies are rocks with large, dark green, often radial actinolite crystals in transparent quartz (*strahlstein*; Pl. 5, fig. c). Such rocks occur at many gabbro-metasediment contacts in the Froland area, for example around the Uvatn and near Styggetjern, both a few kilometres NW of Jåmmås.

**Cummingtonite** occurs as a replacement of olivine in several gabbros and basic dykes, and as a late, relatively high temperature degradation product of orthopyroxene in both basic and felsic rocks. It also occurs as an accessory in some cordierite-orthoamphibole rocks (Starmer, 1976; Visser, 1993b), and as exsolution lamellae in hornblendes from amphibolites (Nijland et al., 1993d). Near the northern tip of the Blengsvatn in the Froland municipality, peculiar rocks occur, almost entirely consisting of garnet and cummingtonite.
Hornblende is a common constituent of all metabasites in the area; it also occurs in several felsic gneisses. In addition, some hornblendites occur. Compositions range from hornblende s.s. to more edenitic, pargasitic, or hastingsitic varieties (Nijland, 1993).

Arfvedsonite is rare in the Bamble sector, and has so far only been encountered in late veins cutting a small metagabbro body in the vicinity of the Gloserhei pegmatite.

Anthophyllite and gedrite occur as major minerals in cordierite-orthoamphibole rocks (Frodesen, 1968b; Beeson, 1976; Starmer, 1976; Visser & Senior, 1990, 1991; Visser, 1992b, 1993a, 1995; Pl. 6, fig. a) and in biotite-orthopyroxene-rich rocks which are often sapphire-bearing (Lamb, 1981; Kihle & Bucher-Nurminen, 1992). It occurs in some albitites and amphibolites (Green, 1956; this study).

Sapphirine occurs in biotite-orthopyroxene-rich rocks at Hasleholmen (Lamb, 1981; Kihle & Bucher-Nurminen, 1992), Snaresund (Touret & de la Roche, 1971; Lamb, 1981), Gladstad (Lamb, 1981), and Rangleåsen (Lamb, 1981). It also occurs in fine-grained symplectites in granulite facies migmatic metapelites at the Hauglandsvatn in the Ubergsmoen area (Nijland et al., 1997).

Rhodonite has been reported from the Arendal skarns by Vogt (1910) and Bugge (1940), as well as from the Kládeborg skarns (Neumann, 1985).

Babingtonite is known from the Arendal skarns since long (Møller, 1826; Weibye, 1847; Kjerulf & Dahl, 1861; Vogt, 1910; Bugge, 1940; Pl. 6, fig. b), and Arendal is the type locality for this mineral (Lévy, 1824b, p. 275). Babingtonite from the Arendal skarns was used by Burns & Dyar (1991) in their crystal chemical study of this mineral.

Prehnite has been known from several localities in the Bamble sector since the early 19th century (Schumacher, 1801; Holm, 1824; Weibye, 1847). It is a common accessory in most rock types, due to low grade alteration (Nijland & Majer, 1993), and also occurs in late calcite veins (Broekmans et al., 1994). Occasionally, it occurs as lenses parallel to the basal cleavage of biotite and graphite (Field & Rodwell, 1968).

Phyllosilicates

Apophyllite group minerals occur at several of the skarn exposures in the surroundings of Arendal (Schumacher, 1801; Weibye, 1847; Bugge, 1954).

Talc occurs as a secondary mineral in cordierite-orthoamphibole rocks (Visser et al., 1990) and in the apatite-enstatite-phlogopite veins at Ødegården Verk (Neumann et al., 1960; Liefink et al., 1994). Museum collections commonly contain pseudomorphs of talc after orthopyroxene from this locality. A small talc deposit occurs near Vestre Vimm, in the Nelaug area (Nijland, 1989; Moree & Nijland, 1996), whereas another small quarry used to be in the vicinity of Vegårshei (J.L.R. Touret, pers. com., 1996).

Muscovite is still present as a primary phase in the western and northern part of the Bamble sector (Touret, 1971). Elsewhere, it occurs as a retrograde phase which developed at expense of sillimanite and feldspars in metapelites and some gneisses. Late muscovite poikiloblasts occur in some of the Late Sveconorwegian granitic sheets on Tromøy (Nijland & Majer, 1993). Large muscovites are common in the granitic pegmatites (such as Lauvrak and Gloserhei); these muscovites occasionally
form large concave crystals, often with inclusions of monazite, xenotime, or zircon.

**Fuchsite** was reported from the Froland corundum-bearing rocks by Oftedahl (1963). However, reinvestigation by Nijland et al. (1993b) showed this mineral to be Cr-Fe-bearing muscovite.

**Biotite** is a common constituent of most rock types in the area. In most gneisses, granites and amphibolites, biotite crystals are a few millimetres in size, but pseudo-hexagonal crystals of over 1 m in diameter occur in several granitic pegmatites, for example at Moen, NW of Molandsvatnet. Biotite crystals elongate along one of the sides of the pseudo-hexagonal crystals, usually [100] (rarely [110]), the so-called **Riemen Glimmer** in German literature (Tröger, 1967, p. 503), are common in the granitic pegmatites, for example the Narestø pegmatite at Flosta. Biotite compositions in gneisses, metapelites and amphibolites vary from relatively Fe- to Mg-rich; occasionally, biotites may be Ti-rich, containing over 5 wt.% TiO₂ (Nijland, 1993).

**Phlogopite** occurs in some calcsilicate rocks and some ultramafics. It is also a major component of the apatite-enstatite-phlogopite veins at Ødegårdens Verk (Brogger & Reusch, 1875; Neumann et al., 1960; Lieftink et al., 1994). These phlogopites have relatively high Na/K ratios (Lieftink et al., 1994). The dark mica in the skarns on Tromøy and around Arendal is also a nearly pure phlogopite (Broekmans, 1992b).

**Zinnwaldite** is reported as small crystals in the granitic pegmatite near Lien, at the Kilsfjord west of Kragerø (Beyer, 1992) in the sole Li-paragenesis known from this area.

**Lepidolite** occurs as small crystals in the sole Li-paragenesis known from the Bamble sector, in a granitic pegmatite near Lien, at the Kilsfjord west of Kragerø (Beyer, 1992).

**Preiswerkite**, a rare Na-Al mica, has recently been discovered in a rock mainly consisting of biotite, tourmaline and scapolite from the Nidelva Quartzite Complex in the Froland area.

**Margarite** occurs as an alteration product of plagioclase, kyanite and corundum in the Froland corundum-bearing rocks. These margarites contain significant amounts of Na and K substituting for Ca (Nijland et al., 1993b).

**Volkonskoite** has been reported by Nilssen & Raade (1973) from the hydrothermally altered zone in the Froland corundum-bearing rocks.

**Chlorite** is a common retrograde phase in many rock types in the area.

**Serpentine**-group minerals occur as late accessory phases in basic rocks, viz. amphibolites and metagabbros (Green, 1956; Starmer, 1969a), and in skarns (Barth, 1925; Bugge, 1940, 1945).

**Chrysocolla** has been reported from the Arendal area by Schumacher (1801), who did not specify its mode of occurrence.

**Tectosilicates**

**Plagioclase** is a constituent of most rock types in the area. The lamellar variety **cleavelandite** occurs in the pegmatites in the surroundings of Kragerø (Andersen, 1926; Green, 1956). **Aventurine feldspar**, i.e. feldspar with interspersed mica flakes, and especially **solstein**, i.e. feldspar with interspersed hematite flakes, are well known from the Bamble sector, and occurs also in several pegmatites at Arendal (Weibye, 1847; Cop-
ley & Gay, 1978), Bamble (Copley & Gay, 1978), Bjordammen (Copley & Gay, 1979), Havredal (Copley & Gay, 1979), and Kragerø (Weibye, 1847). The species denominated tschermakite from Bamble (von Kobell, 1874, p. 411) is an oligoclase-albite.

**K-feldspar** is a common constituent of many felsic gneisses, quartzites and pegmatites in the area. Commonly, the K-feldspar is a **microcline**. Idiomorphic crystals, often with perthitic exsolution, occur in many of the pegmatites. Very large, metre-sized K-feldspar crystals occur in the granitic pegmatites at Gloserhei, Hynnekleiv and Lauvrak (Pl. 6, fig. c). Graphic intergrowths of K-feldspar and quartz are common; fair specimens may be found at the Lauvrak pegmatites.

**Danburite** has been found in the Tangen and Sjàen pegmatites near Kragerø (Oftedal, 1963).

**Scapolite** has since long been known from the Arendal skarns (Schumacher, 1801; Hausmann, 1812). It is also common as a replacement of plagioclase in gabbros in the Bamble sector (Judd, 1889). This replacement happened extensively in many metagabbros and their surrounding amphibolites (Green, 1956; Frodesen, 1968a,b; Starmer, 1969a; Glaveris, 1970; Nijland et al., 1993d). Occasionally, all plagioclase has been altered to scapolite; these rocks have been termed spotted gabbro (gefleckter Gabbro; Brøgger & Reusch, 1875) or ødegårdites (Brøgger, 1934a). Scapolite replacing plagioclase also occurs in apatite-hornblende veins at Hiåsen, near Gjerstad (Brøgger & Reusch, 1875) and Noerestad near Risør (Solly, 1892), and in the apatite-ensatellite-phlogopite veins at Ødegårdens Verk (Michel-Lévy, 1878a,b; Lacroix, 1889; Neumann et al., 1960; Liefthn et al., 1993, 1994). Associated with these veins is an odd rutile-phlogopite-scapolite rock, termed ‘sand rock’ by Brøgger (1934a); the scapolite in this rock is among the most Cl-rich varieties yet reported (Liefthn et al., 1993). Late replacing scapolite also occurs in the corundum-bearing rocks from Froland (Nijland et al., 1993b). Scapolite is a major component from some marbles (Falkum, 1966) and the skarns at Kristiansand (Barth, 1925, 1928), Arendal, Brastad (Bugge, 1940; Broekmans, 1992a; Broekmans et al., 1994), and Løddesøl (Bugge, 1945). Some pegmatites also contain large euhedral scapolite crystals, for example those at Garta, Bue, Hella, all in the Arendal area, Holt near Tvedestrand, Ramskjær near Risør, and Kragerø (Schetelig, 1915). Compositions vary from marialitic to meionitic. In addition, it occurs in veins with carbonates, tourmaline and sulphides cutting across a wide range of rock types. The species gabbronite, wernerite and paranthine, all originally described from Arendal by Schumacher (1801), d’Andrea (1800, p. 32) and Lucas (1806), respectively, have been discredited in favour of scapolite. The species atheria-site, described from Arendal by Weibye et al. (1850, p. 302), represents an altered scapolite.

**Natrolite** occurs in the skarns at Arendal (Bugge, 1943, 1954). It was also reported from the Kragerø area by Weibye (1847) who did not specify its mode of occurrence.

**Mesolite** has been reported from the skarns at Arendal (Hey, 1933; Bugge, 1954).

**Scolecite** occurs in the Raneklev skarns at Arendal (Bugge, 1954).

**Thomsonite** has been found in the skarns at Raneklev, Arendal (Bugge, 1954).

**Analcime** occurs in voids and late veins at many skarn localities in the Arendal area (Holm, 1824; Scheerer, 1845a; Weibye, 1847; Bugge, 1954).

**Laumontite** has been found in felsic gneisses at Østland near Kragerø (Sæbø &
Chabazite occurs in the skarns at Langsev and Raneklev, Arendal (Holm, 1824; Bugge, 1954).

Stilbit is known to occur in the Arendal skarns (Weibye, 1847; Bugge, 1954), and from late veins along road 407, where it is associated with epidote and other zeolites (M.A.T.M. Broekmans, pers. com., 1995).

The zeolite stellerite has been reported from the skarns at Arendal (Bugge, 1954). Small brown crystals of stellerite have been found at Lærestveit (M.A.T.M. Broekmans, pers. com., 1995).

Heulandite occurs at many skarn localities in the Arendal area (Weibye, 1847; Bugge, 1954). It has also been reported from gneisses near Kragerø (Sæbø & Reitan, 1959).

Acknowledgements

J.L.R. Touret, C. Maijer and M.A.T.M. Broekmans are thanked for their comments on an earlier version of the manuscript.

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Revised manuscript received 16 October 1997.
Table 1. List of specimens from the Bamble sector, present in the collections of the Nationaal Natuurhistorisch Museum (National Museum of Natural History), Leiden.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Metals</th>
<th>Copper 22 630 (Arendal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphides</td>
<td>Sulphides with ( \text{Me:S} &lt; 1:1 )</td>
<td>Pyrite 1543 (Arendal)</td>
</tr>
<tr>
<td>Oxides, hydroxides</td>
<td>Spinel</td>
<td>Magnetite 12 126, 12 954, 23 912, 23 951, 106 161, 106 194, 106 198 (all Arendal), 164 935 (Bråstad)</td>
</tr>
<tr>
<td>Sesquioxides</td>
<td>Ilmenite</td>
<td>163 624 (Arendal)</td>
</tr>
<tr>
<td>Dioxides</td>
<td>Quartz 2393 (rose quartz), 2483, 64 847, 69 373, 81 407, 105 158, 105 176, 105 391, 381 517 (all Arendal)</td>
<td>Rutile 2950, 105 185 (both Arendal)</td>
</tr>
<tr>
<td></td>
<td>Columbite 23 941 (Sannikdal)</td>
<td>Euxenite 164 637 (Arendal)</td>
</tr>
<tr>
<td></td>
<td>Aeschynite-(Y) 80 283 (Arendal)</td>
<td>Uranyl(hydr)oxides</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Calcite 24 110, 24 111, 24 325, 24 327, 24 342, 24 406, 24 462, 24 608, 64 847, 64 848, 64 852, 64 882, 69 391, 81 011 (all Arendal), 81 122 (Kragerø), 82 484, 105 138, 105 146, 105 148, 105 154, 105 162, 105 163 105 167, 106 194 (all Arendal)</td>
<td></td>
</tr>
<tr>
<td>Phosphates</td>
<td>Apatite 23 950, 23 951, 23 959, 105 138, 105 147, 105 164, 105 176, 105 445 (all Arendal)</td>
<td></td>
</tr>
<tr>
<td>Silicates</td>
<td>Nesosilicates</td>
<td>Zircon 80 279, 82 241 (both albite, Kragerø)</td>
</tr>
<tr>
<td></td>
<td>Garnet 12 979 (almandine), 23 493, 24 188, 24 315, 24 316, 24 323, 24 325, 24 327, 23 333, 23 334, 24 342, 24 839, 64 831, 64 869, 64 943, 64 950, 69 391, 105 148 (andradite), 105 154 (andradite), 105 162 (andradite), 105 164 (andradite), 105 163 (andradite), 164 230 (almandine) (all Arendal).</td>
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</tr>
<tr>
<td></td>
<td>Titanite 24 863, 64 823, 69 390, 69 391, 69 543 (keilhauite), 80 310 (keilhauite), 381 870 (all Arendal)</td>
<td>Datolite 24 110, 24 111, 64 833, 64 882, 105 167, 381 981 (all Arendal)</td>
</tr>
<tr>
<td></td>
<td>Sorosilicates</td>
<td>Hellandite 80 707 (Kragerø)</td>
</tr>
</tbody>
</table>
| | Epidote 18 654, 18 655, 24 178-24 183, 24 185-24 188, 24 662, 64 847, 64 848, 64 852, 64 853, 64 856, 64 867, 64 869, 69 380, 69 391, 81 011, 105 139, 105 166, 381 506, 381 511, 381
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vesuvianite</td>
<td>24 315, 24 316, 25 588, 64 943, 64 950, 81 257, 105 137, 105 172, 105 173, 105 180 (cyprine) (all Arendal)</td>
</tr>
<tr>
<td>Cordierite</td>
<td>24 561, 105 10, 105 158, 105 447 (all Arendal)</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>24 116-24 118, 64 786, 420 796 (all Arendal)</td>
</tr>
<tr>
<td><strong>Inosilicates</strong></td>
<td></td>
</tr>
<tr>
<td>Augite</td>
<td>12 126, 23 951, 64 823, 64 831, 64 833, 64 840, 412 151 (all Arendal)</td>
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<td>Actinolite</td>
<td>64 826 (Arendal), 411 764 (Åmdalsmoen)</td>
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<tr>
<td>Hornblende</td>
<td>18 659, 24 697, 24 699-24 703, 37 523, 69 380 (all Arendal), 81 122 (Kragerø), 105 175, 106 194, 381 517, 412 271 (all Arendal)</td>
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<tr>
<td>Babingtonite</td>
<td>24 662 (Arendal)</td>
</tr>
<tr>
<td><strong>Phyllosilicates</strong></td>
<td></td>
</tr>
<tr>
<td>Muscovite</td>
<td>10 158 (Arendal)</td>
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<tr>
<td>Biotite</td>
<td>24 402-24 404, 24 406, 24 410 (all Arendal)</td>
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<td><strong>Tectosilicates</strong></td>
<td></td>
</tr>
<tr>
<td>Plagioclase</td>
<td>24 816 (aventurine, Tvedestrand), 64 867 (oligoclase, Arendal), 69 380 (albite, Arendal), 105 199, 412 381 (both oligoclase, Arendal)</td>
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<td>K-feldspar</td>
<td>24 816 (orthoclase, Arendal), 64 901 (orthoclase, Kragerø), 69 373 (microcline, Arendal), 381 444 (orthoclase, Arendal)</td>
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<td>Scapolite</td>
<td>18 585, 24 830-24 834, 24 838, 24 839, 25 589 (all Arendal), 81 407 (wernerite, Arendal), 105 168, 105 391 (both Arendal), 105 548, 381 913 (both wernerite, Arendal)</td>
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</tbody>
</table>
Table 2. List of specimens from the Bamble sector, present in the collections of the Musée de Minéralogie, École des Mines, Paris.

<table>
<thead>
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<th>Oxides, hydroxides</th>
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<tr>
<td><strong>Spinels</strong></td>
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<td>Magnetite</td>
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<table>
<thead>
<tr>
<th>Sesquioxides</th>
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<tr>
<td>Cordundum</td>
<td>15 740, 15 755, 18 734 (Blakstad, Arendal)</td>
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<tr>
<td>Ilmenite</td>
<td>5744, 16 517, 17 742 (all Froland), 19 653 (Arendal)</td>
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<table>
<thead>
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<th>Dioxides</th>
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<td>Euxenite-(Y)</td>
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<tr>
<td>Aeschynite-(Y)</td>
<td>1371 (Arendal)</td>
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</table>

<table>
<thead>
<tr>
<th>Phosphates</th>
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<tbody>
<tr>
<td>Xenotime-(Y)</td>
<td>4855 (Narestø)</td>
</tr>
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<table>
<thead>
<tr>
<th>Silicates</th>
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</thead>
<tbody>
<tr>
<td><strong>Nesosilicates</strong></td>
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<tr>
<td>Phenakite</td>
<td>3300 (Kragro)</td>
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<td>Thorite</td>
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<td>Garnet</td>
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<table>
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<td>Hellandite</td>
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<td>Allanite</td>
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<td>Orthopyroxene</td>
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<td>Actinolite</td>
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<td>4101, 4103 (both Arendal), 4106 (solstein, Tvedestrand), 4110 (Arendal)</td>
</tr>
<tr>
<td>Stilbite</td>
<td>3969 (Arendal)</td>
</tr>
</tbody>
</table>
Plate 1

Fig. a. Granitic pegmatite at Ossedalen, near Blakstad.
Fig. b. Native copper, Arendal (Coll. NNM Leiden, RGM 22 630). Height is c. 4.5 cm.
Plate 2

Fig. a. Corundum, Blakstad (Coll. École des Mines, 15 790). Length of sample is 57 cm.
Fig. b. Large garnet porphyroblasts in metagabbro, Flatenskole, south of Nelaug.
Plate 3

Fig. a. Titanite and calcite in garnet-epidote rock, Arendal (RGM 69 390).
Fig. b. Colourless to white datolite and calcite, Arendal (RGM 24 111). Length of crystals is 6 to 8 mm.
Plate 4

Fig. a. Hellandite, Kragerø (RGM 80 707). Length of crystal: 5 cm.
Fig. b. Cordierite-garnet gneiss, Færvik on Tromøy (cf. Visser et al., 1991).
Plate 5

Fig. a. Dark green tourmaline with light green base, Arendal (RGM 420 796). Size 6.2 x 6 cm.
Fig. b. Clinopyroxene-garnet rocks within the skarns at Lofstad on Tromøy (cf. Broekmans et al., 1994).
Fig. c. Actinolite in quartz, small quarry near Uvatn (cf. Maijer & Nijland, 1991).
Plate 6

Fig. a. Anthophyllite rock, Bøylefossbru (cf. Visser & Senior, 1990; Visser, 1995).
Fig. b. Babingtonite, Arendal (RGM 24 662). Length of crystals is c. 3 mm.
Fig. c. Giant K-feldspar crystal, Lauvrak pegmatite.