Geology of the Skrukkelia Molybdenite Deposit, Northwestern Margin of the Oslo Graben, Norway

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The Skrukkelia Mo-occurrence is situated in Precambrian gneisses along the northwestern margin of the igneous complex of the Oslo Region. Within the mineralized area a Permian granite suite (the Aurtjern granite) intrudes the gneisses 2km from the western border of the main igneous complex. The Aurtjern granite is a multistage intrusion of biotite granite. The gneisses are further cut by Permian dykes and hydrothermal breccias, the most important of the latter being the Glasberget breccia with a core of mainly pegmatitic quartz, and the Dalen breccias with a matrix mainly of rock flour.

Weak propylitic alteration and a weak stockwork of pyrite-bearing veinlets, defining a pyrite halo enclosing the mineralized area and the intrusives, are the most extensive alteration types in the area. Argillic alteration is observed in some drill-cores. Quartz-sericite-pyrite and K-silicate alteration and albitization are seen in subordinate amounts. A low-grade molybdenite mineralization is found over an area of more than 2km^2, occuring as a stockwork of thin ($<$2mm) veinlets in the gneisses and partly in granite porphyries. Quartz-molybdenite and quartz-pyrite-molybdenite are the main paragenetic types. The sulphide mineralizations and the alteration patterns in the area can be interpreted both as a porphyry molybdenum-like occurrence and as a roof zone mineralization of a granitic intrusion.

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Introduction

Little additional information has been published on the geology of the northern part of the Oslo Region and on the rock sequences in the Skrukkelia area since the publication of the bedrock map of the Oslo Region by Brøgger & Schetelig (1923). I. B .Ramberg & B. T. Larsen (1977, unpubl. results) made a detailed investigation of the Permian supracrustals in the Skrukkelia area while Nystuen (1970, 1975) has studied the Permian instrusions and sub-volcanic rocks in the neighbouring Hurdal area.

During the last years there has been an intense programme of prospecting for molybdenum in the Oslo Region which has led to the discovery of several occurrences of possible porphyry molybdenum type, e.g. at Bordvika by Glitrevann, NW of Drammen (Geyti & Schönwandt 1979) and at Nordli in Hurdal. Both prospects are under investigation by Norsk Hydro a.s. NGU's regional geochemical mapping programme with stream sediments resulted in the detection of Mo-anomalies in the Skrukkelia area in 1978 in the community of Hurdal (Volden 1979a). Investigations in the anomalous area led to the discovery of molybdenite-mineralized blocks over a large area that autumn. Intensive work during the summer of 1979 with geological mapping, block tracing, extended stream sediment sampling and soil sampling gave information on a large low-grade molybdenite mineralization in the Skrukkelia area (Volden 1979b, Olerud 1980a, Volden & Olerud 1980). The northern part of the mineralization was drilled in 1979 (Olerud 1980b). Norsk Hydro a.s. leased the claims from the Norwegian State in 1980 and financed the subsequent investigations. Sandstad (1981) did his undergraduate thesis on a genetic and mineralogical study of the southern part of the area, while Ihlen & Sandstad (1980) carried out further regional mapping. Ihlen has made a detailed investigation of the Dalen breccia reported in Olerud et al. (1982).

The present paper is a description of the Skrukkelia Mo-occurrence based on fieldwork in the period 1978–1980 and associated laboratory studies.

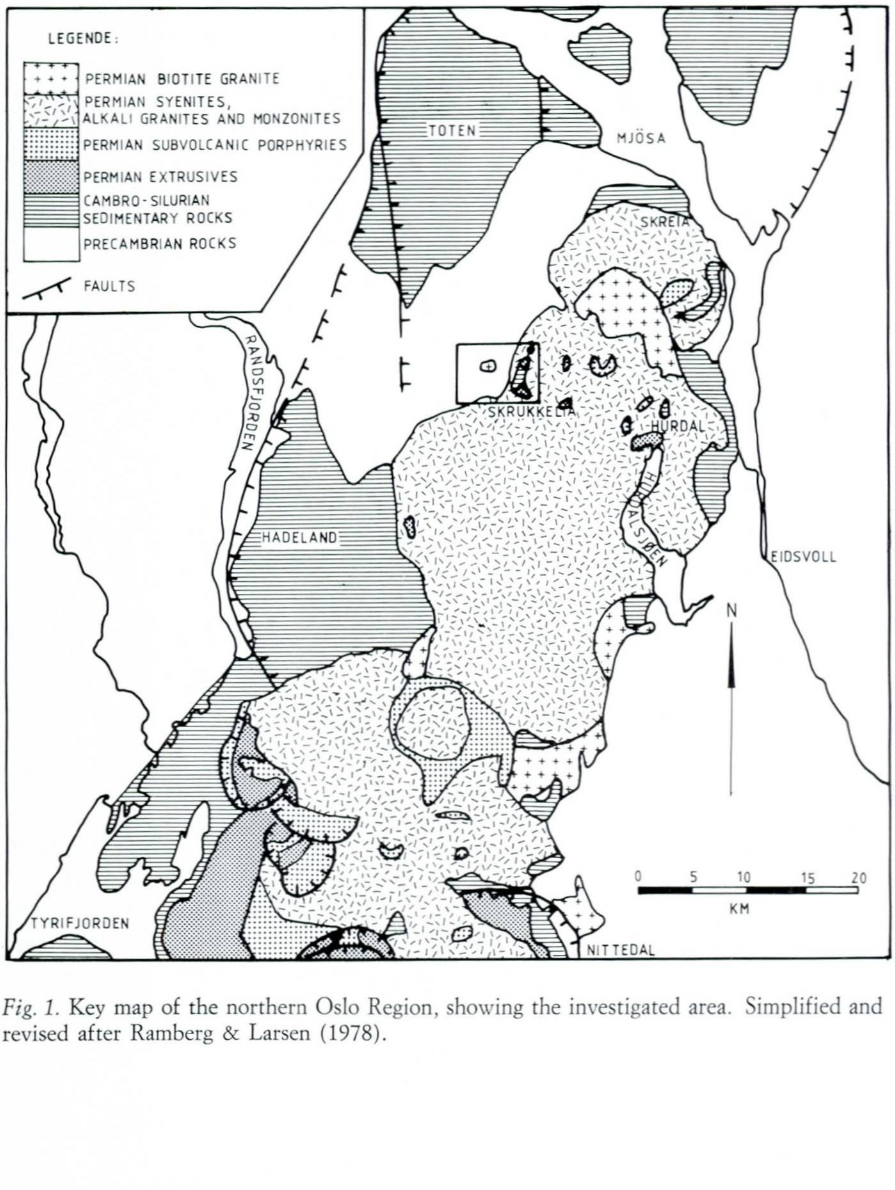

Fig. 1. Key map of the northern Oslo Region, showing the investigated area. Simplified and revised after Ramberg & Larsen (1978).

Geological setting

The investigated area is situated where the Oslo igneous province meets Precambrian gneisses along the northwestern margin of the Oslo Graben (Figs. 1 and 2). The Precambrian gneisses are intruded by Permian syenites and granites. Large isolated fragments of Cambro-Silurian and early Permian supracrustals occur in the intrusives. The gneisses are penetrated by a separate granite suite (the Aurtjern granite), and two breccias and dykes, all of supposed Permian age. The Glasberget breccia has quartz as its main matrix component, while the Dalen breccia mainly has rock flour as matrix. The intrusives are enclosed by a halo of pyrite-bearing veinlets. A low-grade molybdenite mineralization occurs in the central part of this pyrite halo as a spread stockwork in the gneisses and in the granite porphyries.

Both the aeromagnetic map (Norges geol. unders. 1967) and the gravimetric investigation by Ramberg (1976) are interpreted as indicating that the western border of the Oslo Region dips towards the west, and that the gneisses in the area covered by Fig. 2 are underlain by Permian plutonic rocks.

PRECAMBRIAN ROCKS

In the northern part of the area a 500 m wide breccia, the *Fiseko breccia* is bordering the Permian intrusives (Fig. 2). It is regarded as an intrusive breccia associated with a Precambrian intrusive complex consisting of granitic augen gneiss and the breccia. The groundmass of the breccia is coarse-grained with a granitic composition; texturally it is similar to the *granitic augen gneiss.* These two units both carry fragments of the adjacent *red granitic gneiss* and the undifferentiated gneiss units. The term *undifferentiated gneiss* is used for alternating, strongly foliated grey to greenish gneisses of variable composition and texture. The *microline augen gneiss* in the western part of the area has a granitic petrography. The petrology of these units has been described in detail by Olerud (1980a).

ORDOVICIAN-SILURIAN ROCKS

The Korpehaugen – Skurvekampen area consists of folded and steeply dripping contact-metamorphosed sediments of Upper Ordovician to Lower Silurian age (Fig. 2) (Ramberg & Larsen 1977, unpubl. results).

PERMIAN ROCKS

The plutonics are a part of a larger batholith occupying extensive areas in the northern part of the Oslo Region (Nystuen 1975) and consist mainly of coarse-grained and granular alkaline and peralkaline syenites and granites (Fig. 1).

Alkali feldspar syenite is the most common rock unit in this part of the Oslo Region (Fig. 2), and is equivalent to the Grefsen syenite (Oftedahl 1948). Smaller areas consist of the peralkaline variety nordmarkite. The contacts be-

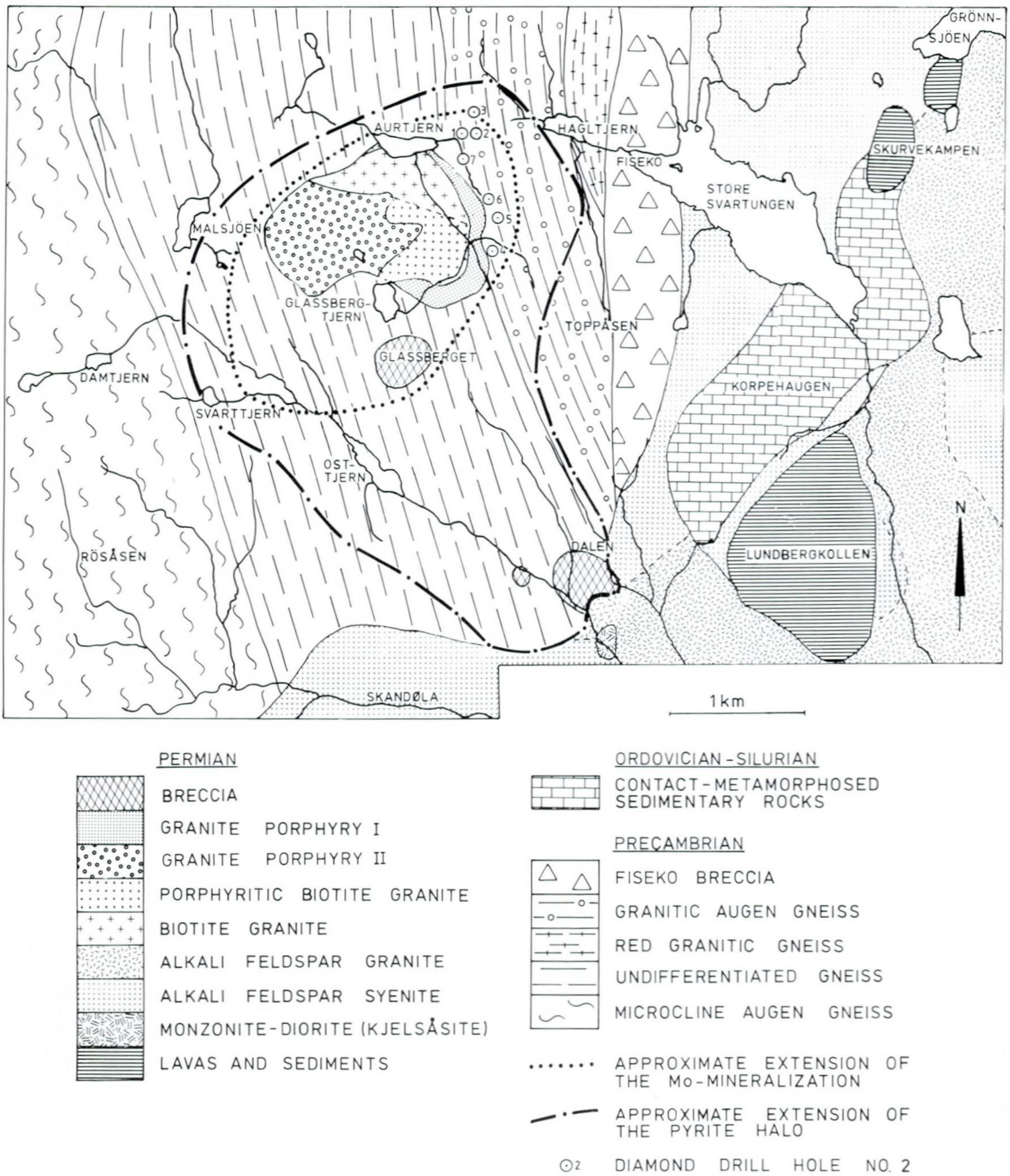

Fig. 2. Geological map of the Skrukkelia area compiled by S. Olerud based on work by the authors, P. M. Ihlen, B. T. Larsen and I. B. Ramberg.

tween the two types are transitional. A gradual change in the quartz content marks the transition to the *alkali feldspar granite* which includes granites of mostly alkaline composition, but small areas of the peralkaline variety ekerite are also found. A biotite granite body distinguished by Brøgger & Schetelig

(1923) in the southwestern part of Fig. 2 does not seem to exist as a separate unit, and as no petrological differences have been found it is here included in the alkali feldspar granite.

A small body of a dark monzonitic to monzodioritic rock (kjelsåsite) occurs in the southern part of the area.

The Permian supracrustal rocks at Lundbergkollen, Skurvekampen and Grønnsjøen have recently been studied by I. B. Ramberg and B. T. Larsen (1977, unpubl. results). The main occurrence at Lundbergkollen consists of various rhomb porphyries, felsite porphyries, syenite porphyries, basalts and thin layers of pyroclastic and epiclastic sediments with a total thickness of about 900 m. The Lundbergkollen area is separated from the Korpehaugen Ordovician-Silurian sediments by a syenitic dyke which according to Ramberg & Larsen (1977, unpubl. results) was originally part of a larger ring dyke associated with cauldron subsidence. The Skurvekampen lava area overlies the Ordovician-Silurian sediments, while the lavas at Grønnsjøen are surrounded by younger plutonic rocks (Fig. 2).

Permian intrusives enclosed by the pyrite halo

THE AURTJERN GRANITE

The Aurtjern granite occurs as a separate intrusion of supposed Permian age in the gneisses 2 km from the western border of the main igneous complex (Fig. 2). The granite is a multiple intrusion composed of four different granitic rock-types. Observations from the drill-cores from the Aurtjern area show that the eastern border of the granite is vertical or westward dipping. The vertical drill-holes nos. 4 and 6 which are about 100 m deep did not penetrate the granite suite although they were located in the gneisses less than 50 m from the contact to the granite. Field observations from the northwestern border also lead to the conclusion that the intrusion has nearly vertical contacts in the northern part. The contact relations to the south towards Glasberget are not known owing to overburden.

Petrological studies show that the suite is of biotite granite, resembling the biotite granite I described by Gaut (1981). They are mostly fresh and homogeneous rocks. Whole rock analyses and normative mineral assemblages of the fresh granite rock-types are presented in Table 1. Fig. 3 show the textures of the granite types.

Biotite granite occurs in the northernmost part of the complex. It consists of alkali feldspar, quartz and plagioclase in about equal amounts. The rock has a hypidiomorphic granular texture with a grain size of 1–4 mm (Fig. 3a). The alkali feldspar is a turbid microperthite. Plagioclase-mantled alkali feldspar is common. The plagioclase is calcic oligoclase to sodic andesine (An 25–33) with normal zoning. Quartz commonly occurs as aggregates of grains that give the rock a slight porphyritic appearance. Partly chloritized biotite, pyrite, iron

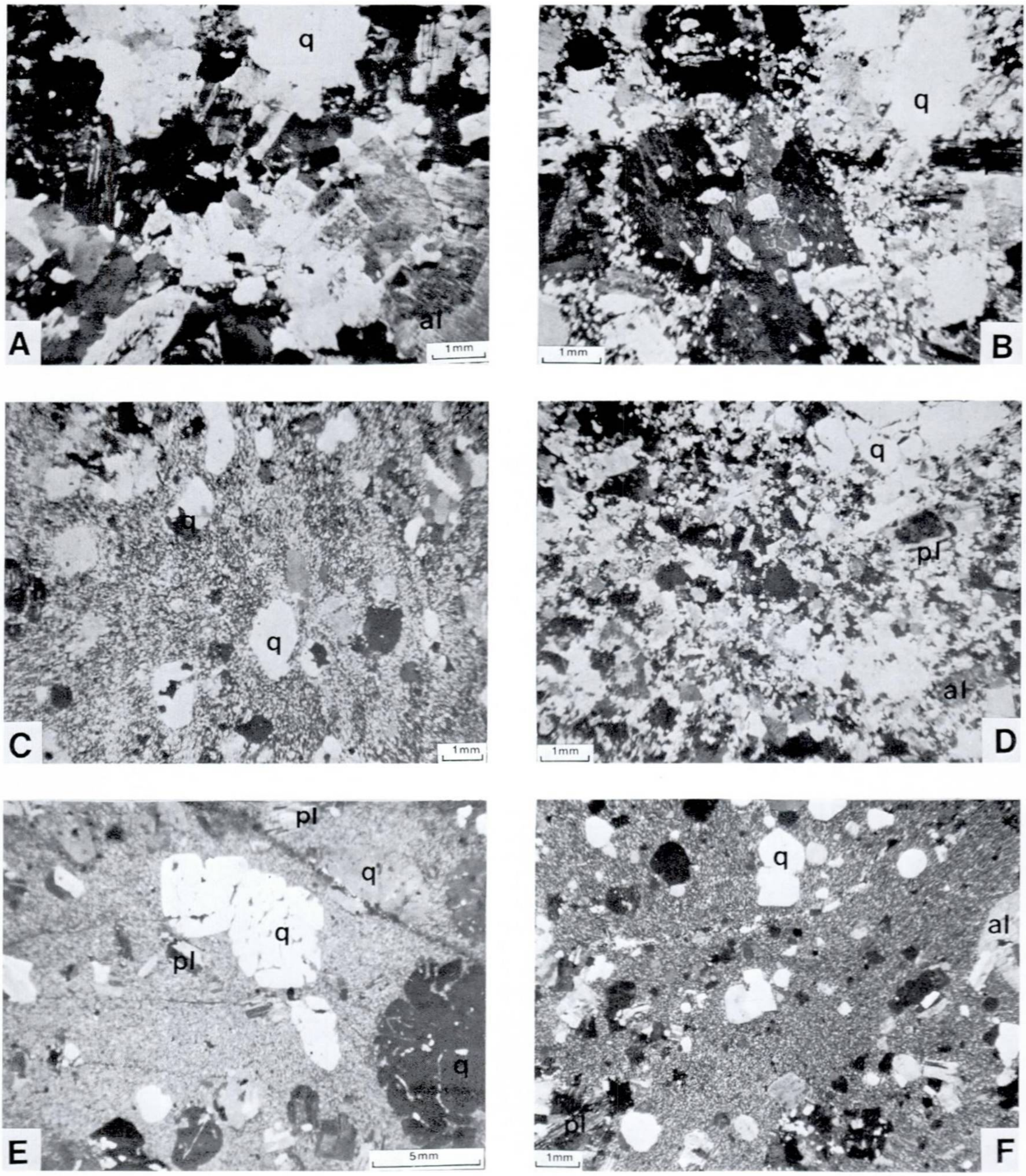

Fig. 3. Textures of the Permian granite varieties from the Aurtjern granite and the Glasberget breccia. al = alkali feldspar, pl = plagioclase, q = quartz. A. Biotite granite. B. Porhyritic biotite granite. C. Granite porphyry I. D. Granite porphyry II. E. Crowded porphyry. F. Quartz-feldspar porphyry.

oxides, zircon, sphene, sericite, fluorite and apatite are the most important accessory minerals and make up 2–3 % by volume.

Porphyritic biotite granite is found in the eastern part of the granitic suite. The rock seems to have transitional boundaries to the biotite granite as no intrusive contacts or sharp boundaries have been found. It consists of 50–70 % phenocrysts of quartz, perthitic alkali feldspar and plagioclase (An 24–36) with a grain size of 1–4 mm (Fig. 3b). The mineral content is nearly the same as that of the biotite granite. The matrix consists mainly of quartz and plagioclase of about 0.1 mm grain size.

Granite porphyry I occurs as a crescent-shaped intrusion in the main stock outcrop between the gneisses and the biotite granites (Fig. 2). The main body is up to 180 m wide. The porphyry forms a net of smaller veins and dykes in the surrounding biotite granites and gneisses, which indicates that the rock intruded later than the biotite granite. This granite porphyry consists of 15–35 % phenocrysts (1–3 mm) in a light pinkish groundmass (Fig. 3c). Partly rounded phenocrysts of quartz dominate over the content of hypidiomorphic perthitic alkali feldspar and plagioclase. The matrix is microcrystalline with an average grain size ranging from 0.04 to 0.1 mm. The main accessory minerals are sericite, biotite ad opaque minerals. The dark mineral content is less than in the other granitic rock-types.

Granite porphyry II makes up about half of the suite. Cross-cutting dykes indicate that the phase is later than the two types of biotite granite. Phenocrysts of 1–5 mm constitute about 25 % of the volume, and consist mainly of smoky quartz with small amounts of alkali feldspar and plagioclase (An 24–26) (Fig. 3d). The matrix comprises plagioclase, alkali feldspar and quartz with a grain size ranging from 0.05 to 0.4 mm. Biotite, opaque minerals, zircon, sphene, apatite and sericite are the main accessories.

THE GLASBERGET BRECCIA

The Glasberget breccia has an elliptical outcrop with axes 320 x 420 m and is located near the centre of the pyrite halo. It is a hydrothermal intrusive breccia with quartz as the main matrix component. The fragments include both Precambrian gneisses and several types of Permian porphyritic rocks. A single fragment is interpreted as Cambro-Silurian hornfels. The country rock consists of gneisses with the ordinary regional foliation. They are cut by widely separated quartz veinlets. The breccia is cut by diabases and by a syenite porphyry dyke in the north.

The breccia can be divided into three zones according to the amount of quartz matrix in exposures (Fig. 4) (Sandstad 1981). Especially in the inner zone, which has more than 90% quartz matrix in exposures, the quartz is milky and coarse grained with individual crystals up to 40 cm. Some pegmatitic alkali feldspar also occurs in the irregular core which has different Precambrian gneiss types as the dominant fragments. Vugs and cockade textures in the matrix indicate open-space filling.

The intermediate zone is most widespread and has also the greatest variety of rock fragments with both Precambrian gneisses (Fig. 5) and different porphyritic Permian rocks. The boundaries to the other zones are irregular. The

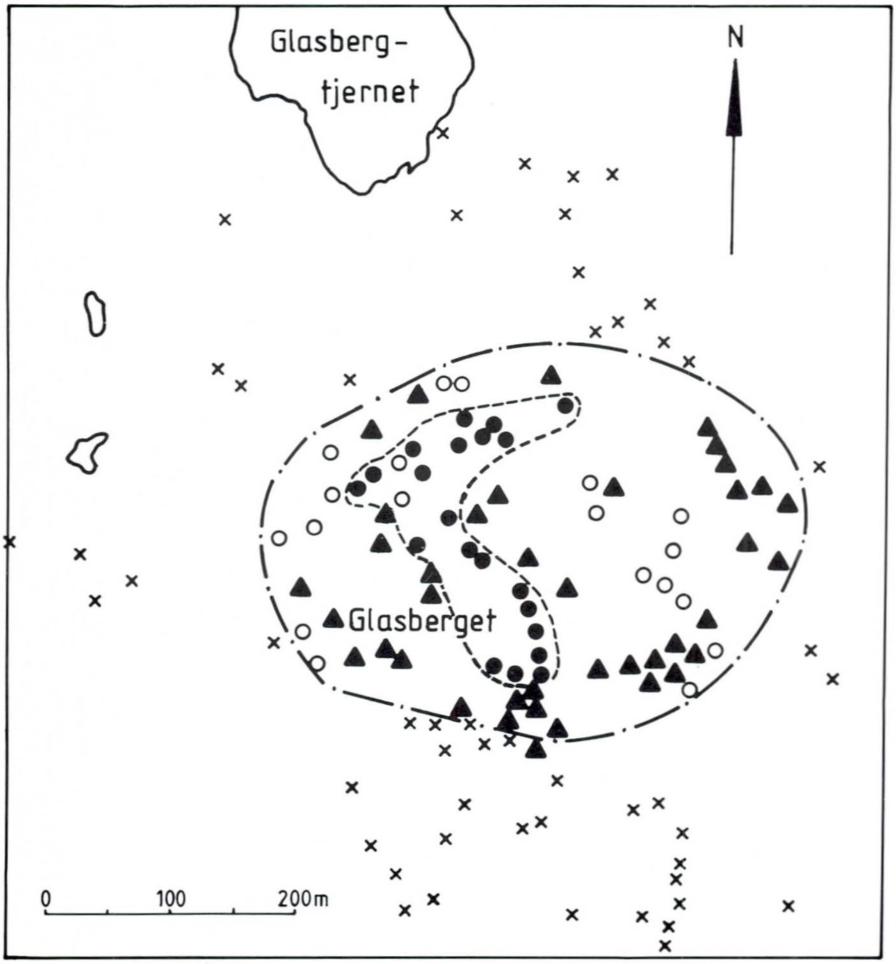

Fig. 4. The distribution of quartz matrix in exposures of the Glasberget breccia. Filled circles: the inner zone with more than 90% quartz matrix in exposures. Filled triangles: the intermediate zone with 10–90% quartz matrix in exposures. Open circles: the outer zone with less than 10% quartz matrix in exposures. Crosses: exposed gneiss with regional foliation.

matrix is composed mainly of quartz, which makes up 10–90% in exposures, but some magnetite is also found.

The outer zone is defined by exposures with less than 10% quartz in the matrix. This zone is made up of rotated gneiss fragments in a matrix of rock powder (Fig. 6) in addition to quartz, magnetite and other hydrothermal minerals. It is best exposed in the southernmost part of the breccia where a small iron claim is located. Magnetite occurs as breccia filling and in veins together with quartz, amphibole, epidote, feldspar, chlorite, phlogopite, garnet, fluorite, carbonates, pyrite and molybdenite in varying amounts. The magnetite is assumed to be altered hematite and occurs in tabular crystals with remnants of hematite. In the western and eastern parts of the breccia, large rotated blocks of gneiss and the absence of exposed matrix define this zone.

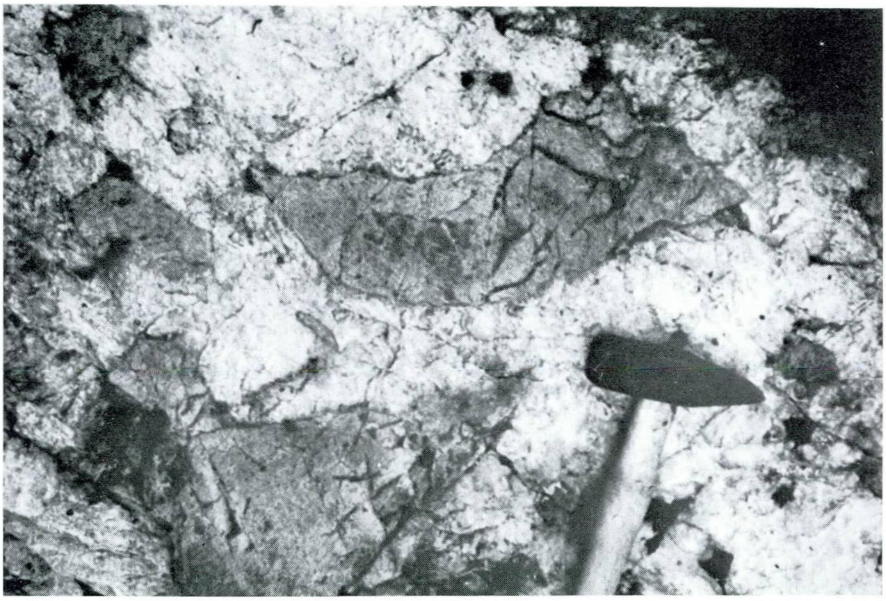

Fig. 5. Granitic gneiss fragments in coarse-grained, milky quartz matrix, from the central part of the Glasberget breccia, Skrukkelia.

Fig. 6. Roated gneiss fragments in a matrix of rock powder, from the southernmost part of the Glasberget breccia. The outlines of the largest fragments are marked.

The fragments are angular to rounded and range in size from a few mm up to 5 m. They usually have sharp contacts to the quartz matrix. The gneiss fragments resemble the surrounding gneisses. Some Permian rock fragments have petrography resembling the porphyritic rocks of the Aurtjern granite. The chemical differences will be discussed below.

THE DALEN BRECCIAS

The Dalen breccias constitute a system of different breccia bodies within an area of 0.3 km^2, situated on the border between the Permian plutonics and the Precambrian gneisses in the southeasternmost part of the pyrite halo. A detailed study of the breccias has been make by P. M. Ihlen (Olerud et al. 1982).

The following major types of fragmentation can be recognized:

1) Angular to subrounded fragments of gneisses and quartz- and feldspar porphyries dominantly cemented either by rock flour or quartz + pyrite or garnet + hornblende + epidote.
2) Megabreccia consisting of weakly rotated blocks ($>$ 2 m) of gneiss in the areas between and around bodies of type 1.
3) Pebbles and cobbles mainly of syenite and hornfelses set in a matrix of finely crushed syenite. Epidote alteration and pervasive pyritization are also common features.
4) A quartz breccia typified by the occurrence of strongly veined and silicified gneiss fragments scattered in a matrix of fine-grained quartz (80% volume).

The type 1 breccias both pre- and post-date the syenites of the main igneous complex of the Oslo region.

OTHER PERMIAN ROCKS

In the northern part of the area, *granite porphyry III* occurs as dykes in DDH 6 predating the molybdenite mineralization. It has a dark red matrix with grain size 0.01–0.05 mm. Phenocrysts with grain size 1–3 mm of quartz and alkalifeldspar make up about 25% of the rock.

Other Permian dykes in the area have been divided into six different types (Sandstad 1981). In addition to various porphyries some aplitic and felsitic dykes and diabases exist. The dykes strike mostly north to northwesterly, which corresponds with the youngest dykes of the Oslo Region (Huseby 1971). The aplitic dykes seem to be connected to the Aurtjern granite, while the others have a more erratic distribution. The most extensive dyke is exposed between the two breccias. It is a reddish feldspar porphyry with phenocrysts of grain size 1–2 mm in an aphanitic groundmass. Based on cross-cutting relationships a red-brown microcrystalline syenite porphyry and some diabases are assumed to be younger than the Glasberget breccia.

Some porphyries present as fragments in the Glasberget breccia have been studied in more detail. The dominant porphyry fragment type in the southeastern part of the breccia is a light reddish quartz-feldspar porphyry, called *crowded porphyry*. It has partly transitional boundaries to the quartz matrix and is not exposed anywhere else in the area. The phenocrysts, which comprise up to 50% of the rock, are coarse grained (5–10 mm), rounded and eroded quartz and some hypidiomorphic feldspars, mainly plagioclase with grain size 2 to 6 mm (Fig. 3e). The matrix has an average grain size of 0.05 mm and consists of quartz and feldspars with biotite, muscovite and epidote as accessories.

Other *quartz-feldspar porphyries* are white to light red with matrix about 0.01–0.08 mm. Phenocrysts of quartz, alkali feldspar and plagioclase (grain size 1–4 mm) constitute from 10 to 50% of the rock (Fig. 3f). Main accessories are micas, epidote and opaque minerals. A dark *feldspar porphyry* has also been analysed. The phenocrysts are plagioclase and pyrite, while the matrix consists mainly of plagioclase and biotite.

Chemistry of permian rocks

Whole-rock analyses of 20 samples were done at the Geological Survey of Norway by optical emission spectroscopy for the major elements and by an X-ray fluorescence method for the trace elements. The methods were described by Faye & Ødegård (1975). In addition the K_2O and Na_2O contents were determined by flame photometry, and some of the U and Th analyses by gamma spectrometry. The analysed chemical compositions and the calculated mineral contents (CIPW-norm) are listed in Table 1.

Table 1. Chemical composition of Permian intrusives from the Skrukkelia Mo-occurrence. BG: biotite granite. PBG: porphyritic biotite granite. GP I: granite porphyry I; sample 5074 is Mo-mineralized, 7934 is a post-mineral dyke, 7942 is a pre-mineral dyke. GP II: granite porphyry II. GP III: granite porphyry III. CP: crowded porphyry. FP: feldspar porphyry. QFP: quartz – feldspar porphyry. *: analysed by gamma spectrometry. **: total iron reported as Fe_2O_3.

	AURTJERN GRANITE														FRAGMENTS IN THE GLASBERGET BRECCIA					
Rock type	BG		PBG		GP I				GP II					GP III	CP		FP	QFP		
Sample no.	5076	5080	5077	5078	5074	5079	7934	7942	5075	2	3	4	5	5082	5081	375B	401C	420A	340C	401B
SiO_2	77.86	76.66	75.38	77.76	80.37	74.50	73.95	75.27	77.37	74.69	73.83	73.07	74.93	75.19	74.34	72.48	58.74	74.64	77.22	74.22
Al_2O_3	11.87	12.27	12.43	11.68	10.82	12.57	12.45	12.69	12.33	12.46	13.23	14.01	13.46	12.87	13.02	14.00	18.44	12.92	12.34	13.62
Fe_2O_3 **	0.63	0.91	0.69	0.73	0.36	0.95	0.64	0.67	1.27	1.26	1.65	1.78	1.62	0.72	1.05	1.49	3.49	2.22	0.68	0.72
TiO_2	0.07	0.09	0.07	0.09	0.08	0.07	0.07	0.07	0.14	0.22	0.31	0.26	0.23	0.11	0.17	0.21	1.30	0.07	0.09	0.06
MgO	0.06	0.13	0.12	0.13	0.14	0.17	0.05	0.07	0.11	0.20	0.19	0.17	0.17	0.24	0.33	0.17	1.70	0.01	0.02	0.09
CaO	0.35	0.59	0.40	0.39	0.19	0.34	1.12	0.76	0.60	0.66	0.56	0.90	0.73	0.84	0.54	0.56	2.25	0.17	0.30	0.25
Na_2O	3.61	3.76	3.91	3.63	2.86	4.04	4.28	4.04	3.63	3.37	3.91	4.03	3.59	2.61	4.61	5.02	6.00	3.45	3.55	3.92
K_2O	4.45	4.50	4.55	4.20	4.69	4.71	3.51	4.42	4.36	4.60	4.46	4.56	4.45	5.89	3.46	3.88	4.22	5.78	4.83	5.15
MnO	0.07	0.08	0.06	0.04	0.02	0.06	0.11	0.05	0.03	0.02	0.07	0.04	0.03	0.04	0.04	0.02	0.08	0.01	0.02	0.01
P_2O_5	0.02	0.02	0.03	0.03	0.02	0.03	0.01	0.01	0.04	0.05	0.08	0.06	0.04	0.03	0.08	0.09	0.39	0.02	0.02	0.02
L.o.ign.	0.39	0.43	0.44	0.86	0.61	0.33	1.32	0.83	0.60	0.58	0.62	0.82	0.59	0.49	0.71	0.85	1.61	0.26	0.29	0.43
Total	99.38	99.44	98.08	99.54	100.16	97.77	97.51	98.88	100.48	98.11	98.91	99.70	99.84	99.03	98.35	98.77	98.67	99.55	99.36	98.44
Q	39.0	36.2	34.3	39.6	45.2	32.1	33.4	33.2	38.2	35.9	32.8	30.2	35.3	35.4	32.9	27.2	1.4	32.1	37.5	31.1
Or	26.3	26.6	26.9	24.8	27.7	27.8	20.7	26.1	25.8	27.2	26.4	26.9	26.3	34.8	20.4	22.9	24.9	34.2	28.5	30.4
Ab	30.5	31.8	33.1	30.7	24.2	34.2	36.2	34.2	30.7	28.5	33.1	34.1	30.4	22.1	39.0	42.5	50.8	29.2	30.0	33.2
An	1.6	2.8	1.8	1.7	0.8	1.5	4.4	3.4	2.7	2.9	2.3	4.1	3.4	4.0	2.2	2.2	8.6	0.7	1.4	1.1
Other min.	1.3	1.6	1.6	1.7	1.4	1.9	1.4	1.1	2.4	3.4	4.2	4.2	4.3	2.2	3.0	2.8	10.0	2.9	1.5	2.1
Nb	85	126	120	133	255	242	250	240	30	74	96	118	74	241	120	162	125	211	105	286
Zr	66	100	75	86	491	102	99	107	40	146	264	261	160	167	141	173	493	86	84	171
Y	<5	6	<5	<5	12	40	51	41	5	10	17	20	13	36	12	20	42	35	10	25
Sr	49	46	33	52	9	12	57	42	19	134	198	185	146	52	158	221	423	150	115	104
Rb	362	258	308	276	259	266	221	277	31	225	213	251	260	261	168	226	360	306	225	322
Ba	120	76	93	124	74	18	128	103	21	176	357	505	244	182	639	705	766	531	360	461
Mo	<5	16	<5	<5	2100	7	<5	16	12	16	38	28	<5	300	93	36	7	6	<5	84
W	11	9	14	15	7	7	12	10	9	<10	<10	<10	<10	7	13					
Pb	22	19	29	12	79	13	54	22	299	<10	148	14	<10	21	17	25	24	15	<10	12
U	8*	9*	4*	4*	7*	13*	17*	12*	5*	13	<10	<10	<10	11	2*	8*	9*	9*	4*	3*
Th	8*	19*	27*	46*	10*	33*	15*	18*	31*	31	33	31	30	33	19*	4*	12*	35*	37*	12*

The analyses presented are of apparently fresh, unaltered samples from 4 units of the Aurtjern granite, the granite porphyry III dyke and three types of fragments from the Glasberget breccia. Metasomatic changes in the fragments and in the samples of the granite porphyry I,, however, cannot be excluded, but as no uniform changes in the alkali content have been found it is unlikely that any strong alteration has occurred.

MAJOR ELEMENTS

The analysed rocks are alkali-rich and low-calcium normative granites, except for the feldspar porphyry, sample 401C in Table 1. In a Q-Or-Ab ternary diagram (Fig. 7) based on the normative mineral assemblages, they plot near the centre in the area of granites (Tuttle & Bowen 1958). These results are in accordance with those obtained in the biotite granite varieties of the Drammen granite (Ihlen et al. 1982) and the Holterkollen granite (Neff & Khalil 1980), 20 km north of Oslo. The chemical differences can be observed in Table 1 and in Fig. 7. In the Q-Or-Ab diagram the biotite granite, porphyritic biotite granite and granite porphyry II units from the Aurtjern granite overlap, while the granite porphyry I has a more erratic distribution. The granite porphyry III dyke is recognized by high K_2O and low Na_2O contents. The three types of fragment analysed have a major element chemistry which distinguishes them from the Aurtjern granite types. The crowded porphyry is recognized by low K_2O and high Na_2O contents while the quartz-feldspar porphyry is recognized by its high K_2O content. The feldspar porphyry fragment shows a monzonitic composition.

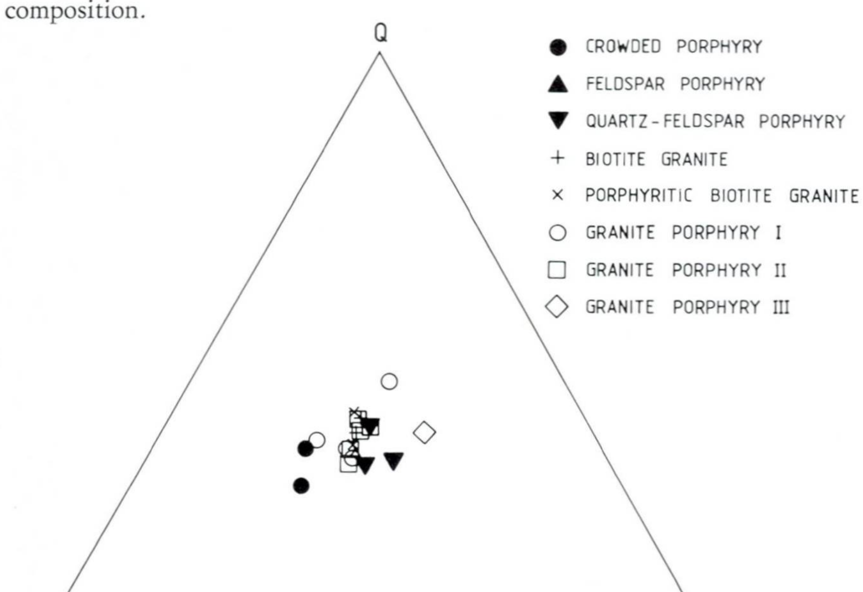

Fig. 7. Plots of the normative quartz (Q), orthoclase (Or) and albite (Ab) (CIPW norm) of Permian intrusive rock-types in the Skrukkelia molybdenite deposit. Filled symbols: fragments in the Glasberget breccia.

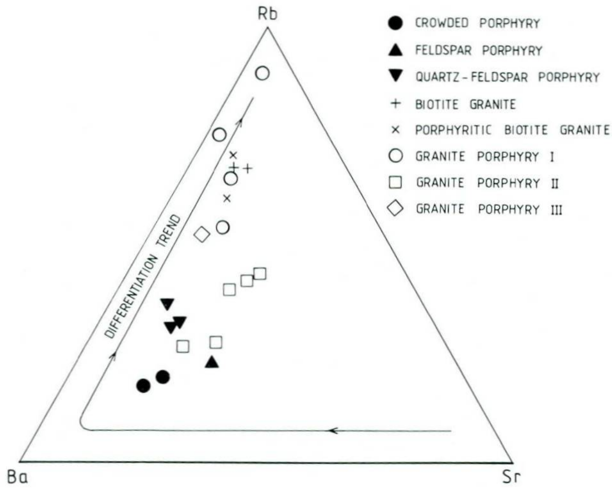

Fig. 8. The ternary relationship of Rb, Sr and Ba in Permian intrusives in the Skrukkelia molybdenite deposit (after El Bouseily & El Sokkary (1975).

TRACE ELEMENTS

The trace element contents of various granite suites can show the differentiation trend in magma evolution and the elements Rb, Sr and Ba have proved to be useful in this respect (El Bouseily & El Sokkary 1975). Khalil et al. (1978) reported that an increasing degree of differentiation in the Holterkollen pluton complex is accompanied by an enrichment of Rb and depletion of Sr and Ba. These trends correspond with the results from the Drammen granite (Ihlen et al. 1982).

Rb, Sr and Ba in rocks from Skrukkelia are plotted on a ternary diagram of El Bouseily & El Sokkary (1975) in Fig. 8. The samples show a relative enrichment of Sr compared to their results, but are in accordance with the results of Khalil et al. (1978) from Holterkollen. The diagram (Fig. 8) shows that the granitic rocks of the Aurtjern suite are more differentiated than the porphyritic fragments in the Glasberget breccia. Within the Aurtjern granite the granite porphyry I shows the strongest degree of differentiation.

Hydrothermal alterations

Propylitic alteration is the most extensive alteration type in the area investigated. It is weakly developed and occurs as a spread stockwork of narrow veinlets (< 2 mm thick). The main mineral assemblages of the veinlets are: quartz, pyrite, epidote, amphibole and chlorite with lesser amounts of microline, albite/oligoclase, calcite, fluorite, magnetite and molybdenite. Modal variations seem to be irregular and an attempted classification of veinlets dominated by specific minerals has not been successful. The rock enveloping the veinlets is only slightly altered. Pervasive propylitic alteration composed of calcite, albite, epidote, tremolite, quartz and chlorite together with galena and sphalerite is seen in only three small exposures.

It was difficult to distinguish weak propylitic alteration of rocks caused locally by the same hydrothermal system causing the molybdenite mineralization, from similar alteration effected by the regional influence from the Permian intrusives in the Oslo Graben. Both have low-grade metamorphic mineral assemblages. On account of these problems it has not been possible to delineate any definite propylitic alteration zone, but pyrite-bearing veinlets have been used to define a *pyrite halo* with an extension of 8 km^2 (Fig. 2) (Ihlen & Sandstad 1980). Pyrite is the most abundant sulphide in the area and is assumed to have a genetic relationship to the intrusives and the molybdenite mineralization. The amount of pyrite is small and seldom exceeds 1% in single exposures. The boundaries of the halo are transitional and are characterized by veinlets containing only rusty remnants of altered sulphides.

Variation in composition of mafic silicates within the veinlets and the adjacent gneisses has been examined by microprobe (Sandstad 1981). Hornblende in fresh country rock has been altered to actinolite and partly calcite. Biotite is partly chloritized towards the veinlets. This shows that alkalies have been removed. Epidote and actinolite indicate an enrichment of calcium and magnesium in the veinlets. Sulphur, $H+$ and CO_2 may have been added by the solutions indicated by pyrite, hydroxyl-bearing minerals and calcite in the veinlets. Iron from hornblende, chlorite and biotite has been involved in formation of epidote and pyrite.

It has to be pointed out that these alteration patterns are only visible microscopically. Further results from these investigations have been presented by Sandstad (1981).

Argillic alteration is found only in erratics and in the drill-cores. The alteration products are soft and easily weathered. In drill-cores this alteration is mostly pervasive, but veinlets occur peripherally. In drill-core No. 2 (Fig. 2) about 90 m out of 118 m has argillic alteration. The intensity of alteration varies widely: in the weakest alteration the plagioclase augen in the gneisses develop a slight green colour, while the most intense alteration results in the rock becoming a green or red, soft clayey mass. The weak alteration is a dusty replacement of the feldspars with clay and mica minerals. The most intense stage is characterized by a complete alteration of all minerals except some remaining quartz, the latter preserving the gneissic structure. The mineral associations have been investigated in thin-sections, with X-ray diffractometry and X-ray powder diffraction with a 9 cm Debye-Scherrer camera, and show that the dominant alteration products are illite-sericite with lesser amounts of carbonates, chlorite, a kaolinite group mineral (dickite) and traces of montmorillonite. The argillic alteration often cuts the quartz-molybdenite veinlets, and is regarded as a late, low-temperature stage of the hydrothermal activity.

Other alteration patterns are only observed locally and are of subordinate importance.

Quartz-sericite-pyrite alteration has been recognized in one exposure in the gneisses 200 m south of the Glasberget breccia and in a fragment of gneiss in the breccia. It occurs as grey to white, mm- to cm-wide zones enveloping veinlets containing quartz and pyrite. The feldspars are completely altered to quartz and sericite while remaining metamorphic quartz displays the gneissic texture. Pyrite exceeds 10% of the volume in the altered zones. In addition, X-ray powder diffraction reveals lesser amounts of montmorillonite and chlorite.

Potassium-silicate alteration is found in the matrix of the Glasberget breccia where hornblende has been altered to phlogopite in small amounts (Sandstad 1981). In addition, in drill-cores from the Aurtjern area Olerud (1980a) has recognized a few 0.5–2.0 cm-thick veinlets showing growth of fresh, anhedral, microperthitic alkali feldspars which replace the original feldspars and micas of the gneisses.

Albitization of alkali feldspar in the matrix of the Glasberget breccia occurs in mm-wide bleached zones along the contact between alkali feldspar and quartz. Alkali feldspar has been altered to untwinned plagioclase. Microprobe analysis has indicated the presence of pure albite (An1) (Sandstad 1981).

Mo-mineralizations

Low-grade molybdenite mineralization has been recorded in an area of approximately 2 km^2 (Fig. 2). The extent of this mineralization is based on observation of molybdenite in veinlets in outcrops and in locally transported blocks. Molybdenite occurs in a stockwork of varying intensity in different Precambrian gneisses (Fig. 9), in granite porphyries (Fig. 10) and in other Permian aplitic dykes. So far the investigation has shown that the richest mineralization is close to and partly within the granite porphyry I. The other units of the Aurtjern granite complex carry only minor Mo-mineralization as single or sev-

Fig. 9. Granitic augen gneiss with a stockwork of quartz-molydenite veinlets from the Aurtjern area in Skrukkelia. Scale in centimetres.

eral grains in coarse-grained quartz veinlets. In erratics from the area near DDH 4 (Fig. 2) and in drill-cores it can be seen that granite porphyry I dykes intruded both pre- and post-molybdenite mineralization (Fig. 10). The veinlets are usually less than 1 mm wide but can be up to 15 mm wide. The molybdenite grains are usually 0.05–0.5 mm across (Fig. 11), although more coarse-grained molybdenite is found in quartz-pyrite-bearing veinlets. The veinlets can be divided into four mineral assemblages:

1) Quartz-molybdenite veinlets occur mainly along the border of the Aurtjern granite, in the granite porphyries and in the southwesternmost part of the mineralized area.
2) Quartz-pyrite-molybdenite veinlets occur mainly west of the Glasberget breccia.
3) Molybdenite coatings in fissures with small amounts of quartz are found around Glasbergtjern.
4) Alkali feldspar-amphibole-epidote-molybdenite veinlets occur in the same area as type 2.

In addition, small amounts of the following minerals occur in the veinlets: sericite, carbonates, chlorite, fluorite, magnetite, hematite, pyrrhotite, and chalcopyrite. Unequivocal age relationships are difficult to establish among the different types of veinlets.

Molybdenite associated with the Glasberget breccia occurs as coarse-grained aggregates in the matrix and in quartz-bearing veinlets in fragments and in country rock. The molybdenite aggregates are found in vugs and as irregular stringers and patches in a matrix of quartz or rock powder. The aggregates have a preferred distribution along the boundaries of the fragments and on the surfaces of pegmatitic alkali-feldspar crystals. Quartz-bearing veinlets with fine-

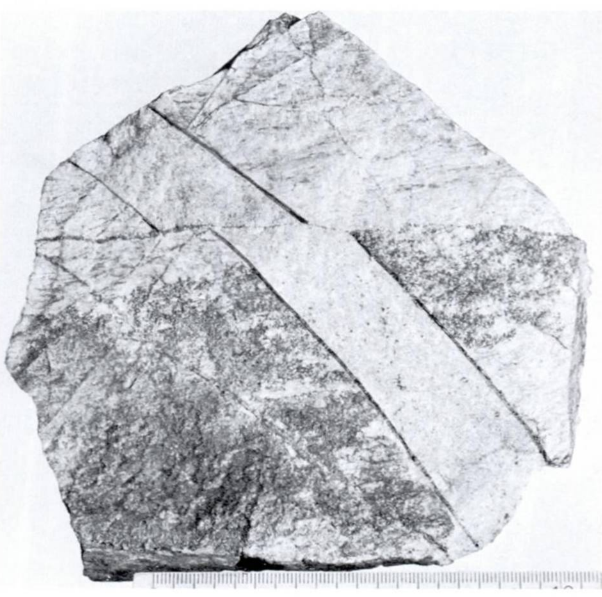

Fig. 10. Stockwork of quartz-molydenite veinlets in red granitic gneiss, cut by a faulted granitic porphyry dyke (the border is marked on the photo). Note that the dyke is both cut by and is cutting the mineralized veins. Scale in centimetres.

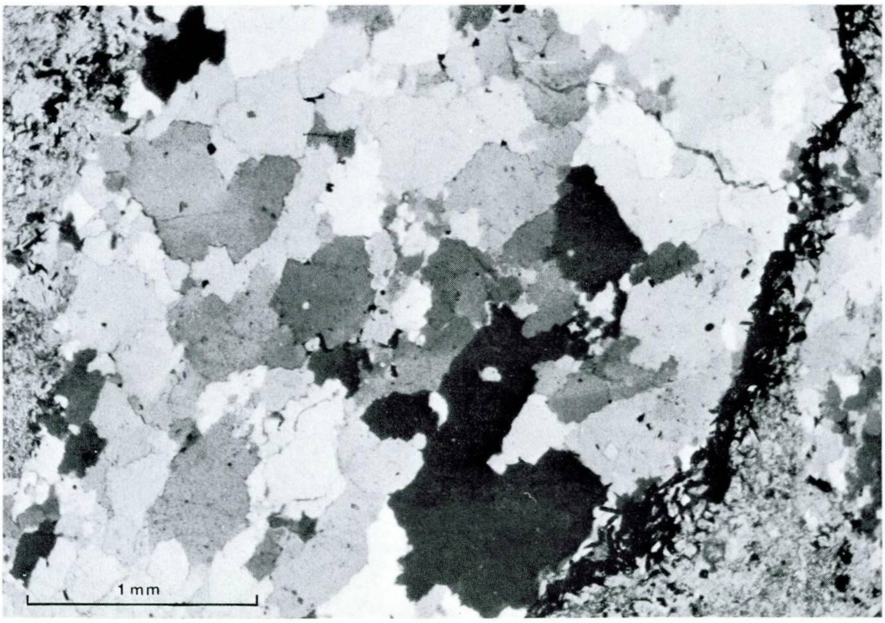

Fig. 11. Photomicrograph of a quartz-molybdenite veinlet with molybdenite (black rectangles) enriched along the border of the quartz. Sericite envelops the molybdenite grains. Crossed nicols.

grained molybdenite cut the boundaries between matrix and country rock and between matrix and fragments.

In the northern part of the mineralized area (Fig. 2) seven holes totalling 604 m with a maximum depth of 120 m were drilled during the autumn of 1979. The cores show that the mineralization seems to be nearly continuous in the drilled area. Molybdenite has been found down to the bottom of the deepest hole. The Mo grade of the core material was determined by atomic absorption spectrophotometry. Maximum grade over 3.0 m of core is 0.088% Mo and an average for the richest drill-hole is 0.037% Mo over 106.5 m of core. Elements typical for molybdenite deposits such as W and Sn are not above background value.

Discussion and conclusions

Several molybdenite mineralizations are known to be associated with the biotite granites of the Oslo Region. According to the classification of molybdenum deposits by White et al. (1981) three main types occur:

1. Quartz vein deposits. Intramagmatic molybdenite-bearing quartz veins are found within and apical to the main intrusive bodies of the Drammen biotite granite (Ihlen & Vokes 1978).
2. Porphyry molybdenum deposits. A possible porphyry molybdenum occur-

rence located in a subvolcanic environment is known from the Glitrevann cauldron (Geyti & Schönwandt 1979).

3. Skarn deposits. Molybdenite in skarn horizons in Cambro-Silurian hornfelses are found in exocontact position to the Drammen (Ihlen et al. 1982) and the Stor-Øyungen (Olerud 1980c) biotite granites.

The molybdenite mineralizations in Skrukkelia have features common to both type 1 and type 2.

Compared with the quartz vein type deposits both the biotite granite varieties and the sialic gneisses are mineralized in Skrukkelia, while the host rock of the Drammen mineralizations is exclusively biotite granite. The molybdenite-bearing veinlets in the Drammen granite have preferred orientations, while at Skrukkelia they occur in a stockwork. Alterations of the host rock are weakly developed in both the Drammen and the Skrukkelia mineralizations. A distinctive feature is a pyrite halo which has only been reported from the Skrukkelia deposit. From the geophysical and geological data on the Skrukkelia area it can be interpreted that the pyrite halo, the Aurtjern granite, and the Glasberget and Dalen breccias are surface expressions of a continuous underlying complex of granitic intrusives.

The Skrukkelia deposit also has features in common with North American Cordilleran porphyry molybdenum deposits, as summarized by Sutherland Brown (1976) and White et al. (1981). These include low-grade, stockwork sulphide mineralization of several stages in intrusive plutons and country rock, and molybdenite mineralizations of intrusive breccias. In addition the formation of a pyrite halo and widespread propylitic alteration spatially associated with breccias and felsic plutons with porphyritic texture are common characteristics. Important distinguishing features are the weak development of the high-temperature alteration patterns and the lack of alteration and mineralization zoning in Skrukkelia compared with the Cordilleran porphyry deposits. This can be explained by a relatively high level of exposure in a porphyry system with associated low-temperature formations. At the same time high-temperature formations are indicated by the Glassberget breccia, and a stronger development of e.g. K-silicate alteration would be expected in association with the breccia if a porphyry system was well developed (Sutherland Brown 1976). The discussed features of the Skrukkelia deposit might, however, indicate a failed or weakly developed porphyry molybdenum system.

As long as the term 'porphyry deposit' continues to be used for a wide variety of different low-grade deposits in modern literature, the authors feel uncertain as to whether the Skrukkelia deposit should be classified as a porphyry-like occurrence with similarities to the plutonic porphyry deposits described by Sutherland Brown (1976), or as a roof zone or contact phenomenon above the postulated granitic intrusives.

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