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On the rutile deposits Ramsgrønova, Orkheia, Ødegården and Lindvikkollen, S. Norway.

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REPORT

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Title:
On the rutile deposits Ramsgrønova, Orkheia, Ødegården and Lindvikkollen, S. Norway.

Authors: Korneliussen, Are and Furuhaug, Leif	Client: Rio Tinto Iron & Titanium
County: Norway	Commune: Hyllestad, Fjaler, Gulen, Bamble, Kragerø
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Deposit name and grid-reference: Orkheia (292800/6798200), Ramsgrønova (298400/6797200), Ødegården (532050/6535850), Lindvikkollen (521390/6525150)	Number of pages: 35 Price (NOK): -Kr. 290,- Map enclosures: 0

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Summary:

As a part of a joint project between the Canadian mining company Rio Tinto Iron & Titanium (RTIT) and NGU which is aimed at identifying rutile deposits in Norway with economic potential, a selection of rutile deposits have been sampled for further laboratory testing by RTIT.

The sampled deposits are the Ramsgrønova and Orkheia rutile-bearing eclogites in the Dalsfjord region of W. Norway and two metasomatic rutile deposits in the Bamble Sector of S. Norway, the Ødegårdens Verk scapolite-hornblende rock and the Lindvikkollen albitite, respectively.

All these deposits have favourable rutile mineralogy, including coarse grain-size and they have a dominant portion (> 90%) of the titanium as rutile.

The purpose of this report is to summarise available information on these deposits and discuss the possibilities for additional ore resources.

Keywords: Mineral resource	titanium	rutile
eclogite	scapolite rock	albitite
ødegårdite	kragerøite	

CONTENTS

Appendix 1: Kragerø geological map, scale 1 : 50.000, preliminary edition, NGU (Padget 1999).

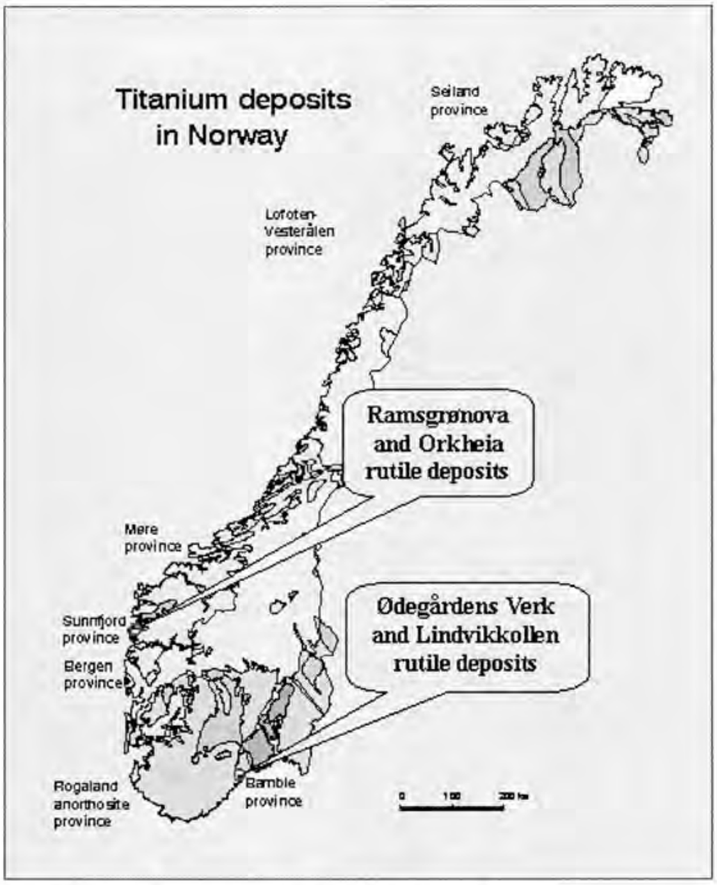


Fig. 1: Overview geological map of Norway.

1. INTRODUCTION

The present work is a follow-up of an overview report of rutile deposits in Norway (Korneliussen et al. 1999). The purpose is:

(1) Make a selection of rutile-bearing mineralisation types available for further studies by Rio Tinto Iron & Titanium (RTIT) in Canada.
(2) Summarise available information about the respective deposits.

50 kg samples from the two rutile/eclogite deposits Ramsgrønova and Orkheia in the Dalsfjord region (Sunnfjord) of West Norway, and the two metasomatic deposits Ødegården and Lindvikkollen in the Bamble region, were collected for beneficiation tests by RTIT.

The two rutile/eclogite deposits were chosen because (a) they are among the most coarse-grained rutile deposits known, (b) a dominant portion of the titanium occurs as rutile, and (c) the effects of retrograde alteration of the eclogite is relatively small. A high titanium and rutile recovery could be expected in the case of production. A disadvantage with Ramsgrønova and Orkheia is that the rutile-rich (> 3 % rutile) portions of these deposits would probably be too small to be mineable on its own, but might be of interest in combination with other deposits in the area. The surrounding areas have a significant potential for new deposits to be identified by exploration work in the future. A scenario for this part of the Dalsfjord region is a centrally positioned beneficiation plant obtaining ore from several deposits within a short distance from each other.

The two deposits in the Bamble region are also coarse-grained with a high proportion of the titanium as rutile, and a high recovery could be expected in the case of production. The Ødegården deposit is a large, relatively homogeneous, disseminated rutile-bearing scapolite-hornblende rock (ødegårdite) with a potential for large volumes of ore at depth. The ore potential might be as much as100-150 mill. tons or more with 2-4 % rutile. The Lindvikkollen deposit is a rutile-rich albitite (kragerøite) with grades ranging from 1-2 % to 10-20 %. Unfortunately this ore is highly irregular and the ore-tonnage probably relatively small, i.e. a few million tonnes. The dominant part of the surrounding albitite is probably too low-grade (1-2 % rutile or less) to be of economic interest unless a valuable albite product could be made as a coproduct.

2. THE RAMSGRØNOVA RUTILE DEPOSIT

The Ramsgrønova eclogite is situated in the western part of the ***The Dalsfjord region***. Another region name is Sunnfjord, which includes both the Dalsfjord region and the Førdefjord region. The Dalsfjord region contains a variety of gneisses, and basic (incl. anorthosites), ultrabasic and Fe-Ti oxide-rich rocks; the basic rocks are frequently eclogitized. Massive bands and impregnations of magnetite-ilmenite occur within gabbroic, partly eclogitized rocks. Some of these were mined for magnetite at the beginning of the 20th century. The largest of these deposits is at Saurdal where up to 0.5 m thick bands of massive magnetite-ilmenite occur along an E-W trending 800 m-long zone along the southern margin of an eclogitized gabbro. Investigations in 1993-94 by the DuPont/NGU project in the Dalsfjord region, mainly focused on rutile-bearing eclogites in the Gjølanger-Saurdal and Orkheia areas.

Rutile-bearing eclogites in the Dalsfjord region were also investigated by NGU in 1978-79 (Korneliussen 1980, 1981). The central part of this region, at Hellevik-Gjølanger-Flekke, is described in a doctoral thesis by Cuthbert (1985). This region contains a variety of gneisses, and basic, ultrabasic and Fe-Ti oxide-rich rocks; the basic rocks are frequently eclogitized. Many eclogites had demonstrably low-pressure igneous protoliths and/or show intrusive relationships with the gneisses, indicating a crustal, eclogite-facies metamorphism of all lithologies. Relics of early granulite-facies assemblages occur in most lithologies (Cuthbert 1985). Associated eclogites have been metasomatically altered but retain some tholeiitic characteristics. The Flekke unit rocks have affinities with some layered basic intrusions typical of mid-Proterozoic anorthosite suites. Mineral chemistry and parageneses of a variety of lithologies indicate an early (presumably Proterozoic) granulite-facies event at 7-13 kb, and 750-1000°C, followed by metamorphism to high-pressure eclogite-facies conditions at 597+/-30°C, and decompression during exhumation to below 6 kb. Such a P-T path is incorporated into a continental collision model for the Scandinavian Caledonides involving transient "subduction" of the Basal Gneiss Complex in a Himalayan-style collision zone (Cuthbert, 1985). Gabbro-eclogite relationships in the Gjørlanger area have recently been detailed studied in a doctoral thesis by Ane Engvik (2000).

The DuPont-NGU project paid significant attention to this area during 1992-94. In general, rutile from eclogites in the Dalsfjord region is relatively coarse-grained, which is a significant advantage in case of production. However, good indications of *large volumes* of rutile/eclogite ores with 3-5 % rutile was not found, and in the autumn of 1995 the focus was taken away from the Dalsfjord region in favour of the Engebøfjellet eclogite deposit on the northern side of Førdefjord. However, the Dalsfjord eclogite province might very well contain significant rutile/eclogite deposits yet to be identified.

The Ramsgrønova eclogite is a large, flat lying eclogite sheet covering the top and southern flank of the Ramsgrønova mountain. The photograph in Fig. 2 is of the Ramsgrønova mountain viewed from the southwest, while Fig. 3 shows a variety of photographs taken on the eclogite itself of landscape as well as of eclogite exposures. Microphotographs of reference samples K330A.00 and K330B.00 are shown in Figs. 4 and 5. These samples are representative for the 50 kg sample K330.00 taken at Ramsgrønova and sent to Rio Tinto Iron & Titanium in Canada for further testing. This larger sample was taken by sledge-hammer in garnet- and rutile-rich parts of the eclogite similar to the rock shown in photo no. (5) in Fig. 3, from several exposures within the areas indicated in Fig. 6.

In general, the effects of retrograde alteration of the eclogite is minor, although sample K330B.00 is distinctly retrograded along thin fractures in which omphacitic clinopyroxene is altered to fine-grained (symplectitic) aggregates of plagioclase and hornblende, and rutile to ilmenite.

Fig. 6 also shows drill-dust sampling profiles taken by the DuPont-NGU project in 1995. These samples were taken by a percussion drill-machine drilling 0.5-0.6 m long holes from which approx. 1 kg drill-dust were collected by a special sampling device. These samples are usually much more representative than samples taken by sledge-hammer, and experience has shown that analytical data derived from this kind of sampling are quite reliable. The Ramsgrønova drill-dust samples were analysed by the portable X-Met XRF machine (Table 1), which at that stage of the investigation was regarded as a "good enough" analytical method. Other analyses of Ramsgrønova eclogite also exist, but do not give significant additional information to the data given in Table 1, and is therefore not shown in this report.

When roughly considering that the outcropping eclogite cover 0.5 km^2, with an estimated average thickness is 75 m and a specific gravity of 3.2 t/m^3, then the total tonnage is approximately 100 million tons of eclogite. The rutile-rich (> 3 % rutile) portions of this eclogite mass would probably be ¼ or so, i.e. 20-30 million tons of potential rutile ore. A map showing the distribution of this ore-type eclogite is not available. However, scattered field observations of the distribution of the various eclogite types were done in 1995, but never compiled and reported.

The Ramsgrønova eclogite belong to a series of very similar, East-West trending eclogites laying in granitoid gneisses from Skifjord in the west, over Orkheia and Drøsdal to Ramsgrønova. Other similar eclogites are also found further to the east, outside the map shown in Fig. 2. These “within-gneiss eclogites” are all strongly deformed together with the surrounding gneisses under eclogite-facies conditions. The protolith rocks are presumably gabbroic to gabbro-anorthositic intrusions. Relics of massive, cumulate Fe-Ti oxide bands are found in the westernmost eclogites near Skifjord.

There is a tendency for a bimodality in the TiO_2-content in these eclogites; in volume most of the eclogite tend to belong to a low-grade type with 0.1-2.0 % TiO_2, while a minor part of the eclogite is of "ore-type" with 3-4 % TiO_2, locally up to 5-6 % TiO_2. In general, more than 90% of the TiO_2 occur as rutile, since the eclogitisation process have been complete and the effects of retrograde alteration is relatively minor.

Ore potential: There is probably not sufficient ore-type eclogite at Ramsgrønova to be of economic interest on its own, but the situation might be of more interest if several rutile/eclogite deposits were situated sufficiently close to each other. Then these deposits could represent the ore reserve for a beneficiation plant conveniently situated in the centre of the area. However, the presently known rutile deposits, such as Ramsgrønova and Orkheia, are probably not sufficient for this scenario, and additional ore would have to be identified by further exploration. It is possible that significant addition ores could be identified by a combination of a gravity survey identifying significant eclogite masses at depth, to be followed up core drilling to investigate the quality of the gravity anomalies.

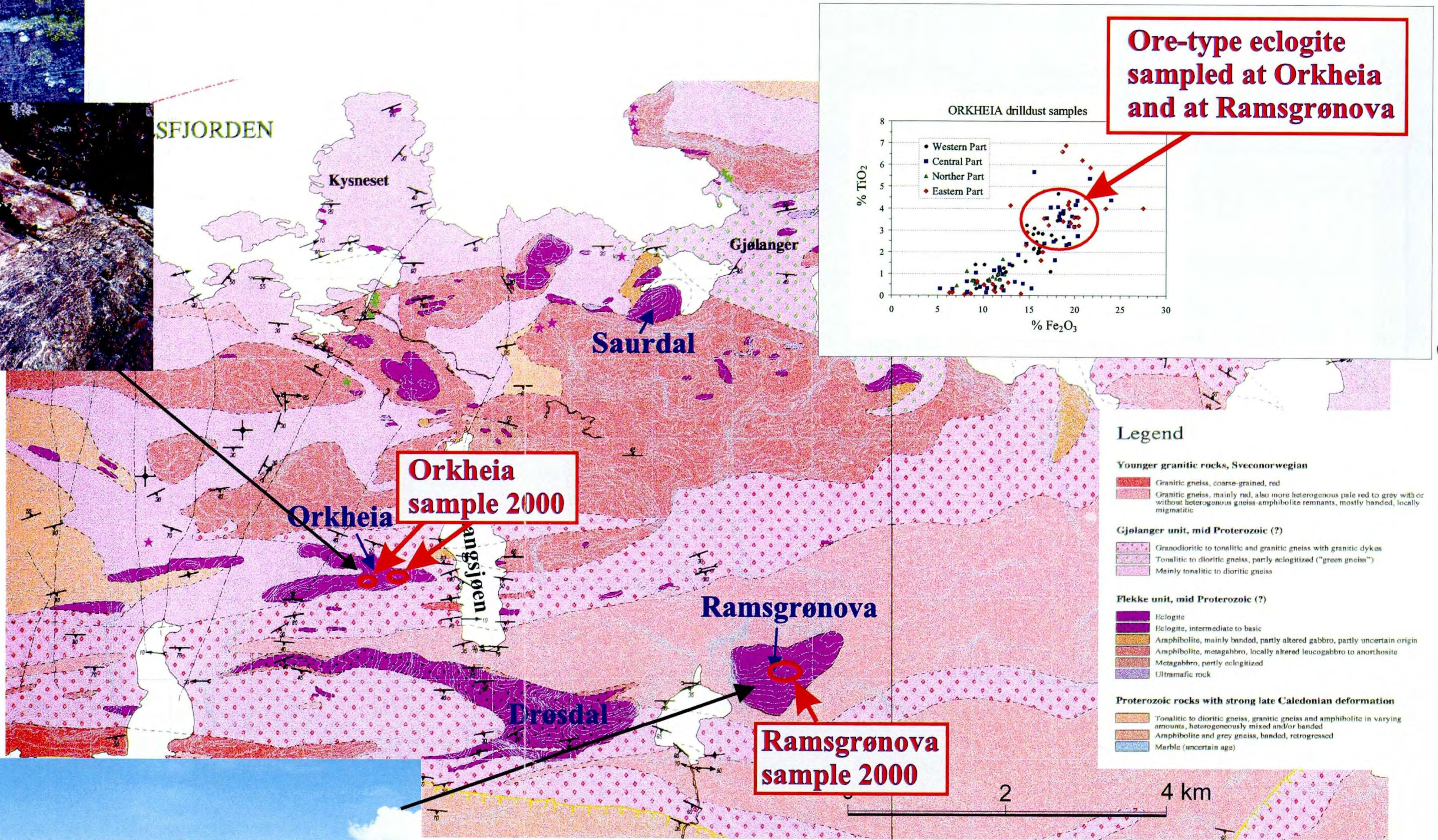
Geological map of the western part of the Dalsfjord region (Sunnfjord), W. Norway.

(2)

(3)

(2) Irregular bands and layers of dark, garnet-rich eclogite (dark) within an omphacite-rich eclogite (greenish), Orkheia.

(3) Dyke-like, dark, garnet- and Fe-Ti rich eclogite surrounded by a finely banded eclogite with relatively low Fe-Ti content, Orkheia.



(1)

(4)

Fig. 2: Geological map of the Western Dalsfjord region (after Ragnhildstveit & Nilsen 1998). The sample localities for the two samples taken in July 2000 at Ramsgrønova and Orkheia eclogite, respectively, are shown on the map. The Ramsgrønova sample was taken from within the area of the red circle, while the Orkheia sample was taken from within the two circled areas. Both samples represent selectively picked garnet- and rutile-rich eclogite (3-5 % rutile) that would plot approximately as indicated on the Fe_2O_3-TiO_2 plot of figure (1), and are therefore not representative for the respective deposits. Photographs (2) and (3) are from the Orkheia eclogite, while photograph (4) is of the Ramsgrønova mountain eclogite seen from the southwest.

Ramsgrønova eclogite

Dalsfjord region (Sunnfjord), W. Norway

(1)

(2)

(3)

(9)

(8)

(4)

(7)

(5)

(6)

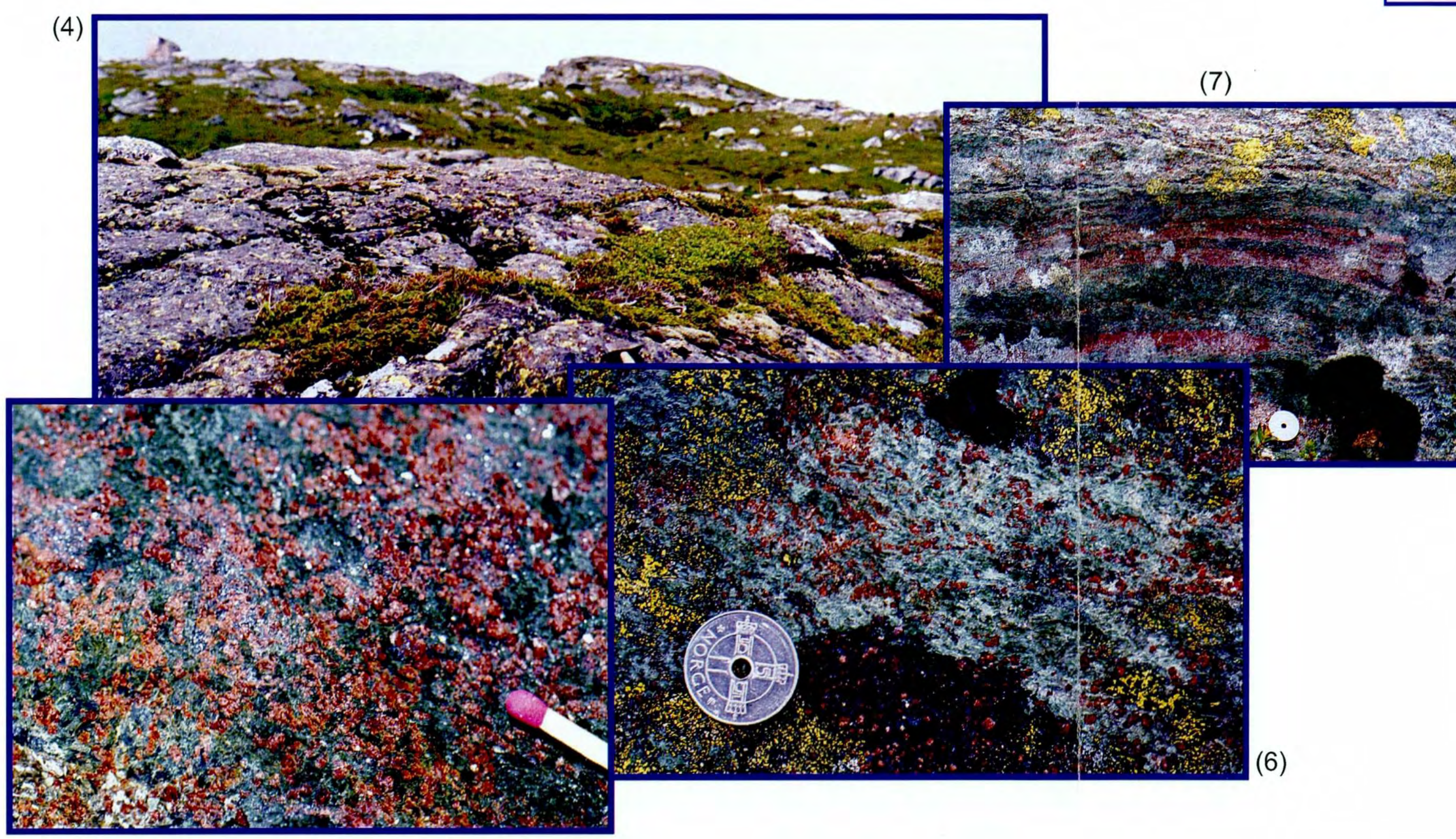


Fig. 3: Photographs, Ramsgrønova eclogite, Dalsfjord region. (1) Wide-angle photograph taken from the top of Ramsgrønova eclogite mountain northwards with Dalsfjord in the background. (2) Wide-angle photograph south-eastwards from Ramsgrønova. (3) Wide-angle photograph westwards from the top of Ramsgrønova. (4) Typical eclogite landscape from the upper parts of Ramsgrønova. (5) Close-up photograph of garnet- and rutil-rich eclogite. (6) Omphacite-rich eclogite with only minor amounts of rutile. (7) Banded eclogite. (8) and (9) Reference samples K330A.00 and K330B.00 of the 50 kg sample taken in July 2000.

Sample
K330A.00
Ramsgrønova

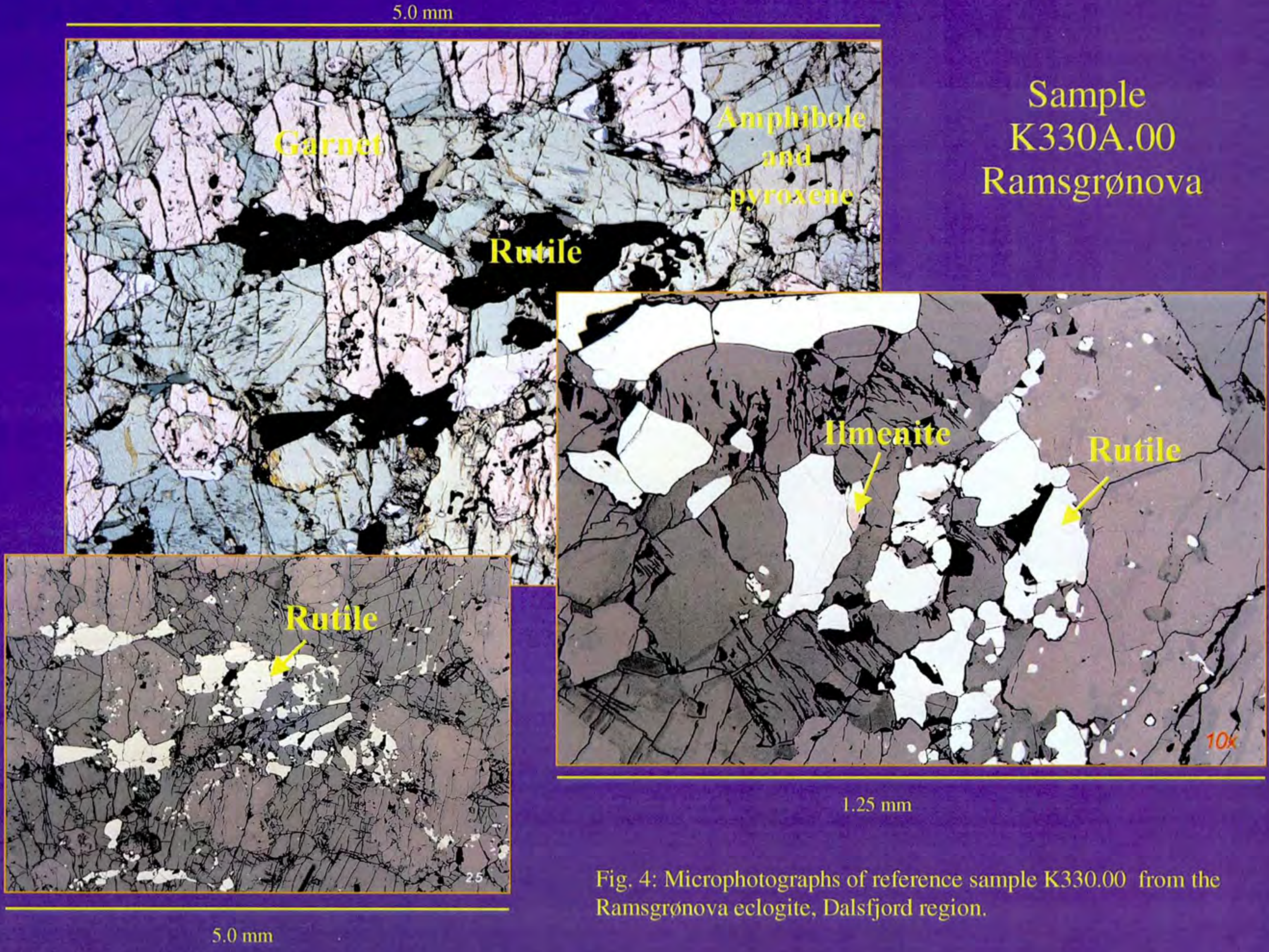


Fig. 4: Microphotographs of reference sample K330.00 from the Ramsgrønova eclogite, Dalsfjord region.

Sample K330B.00 Ramsgrønova

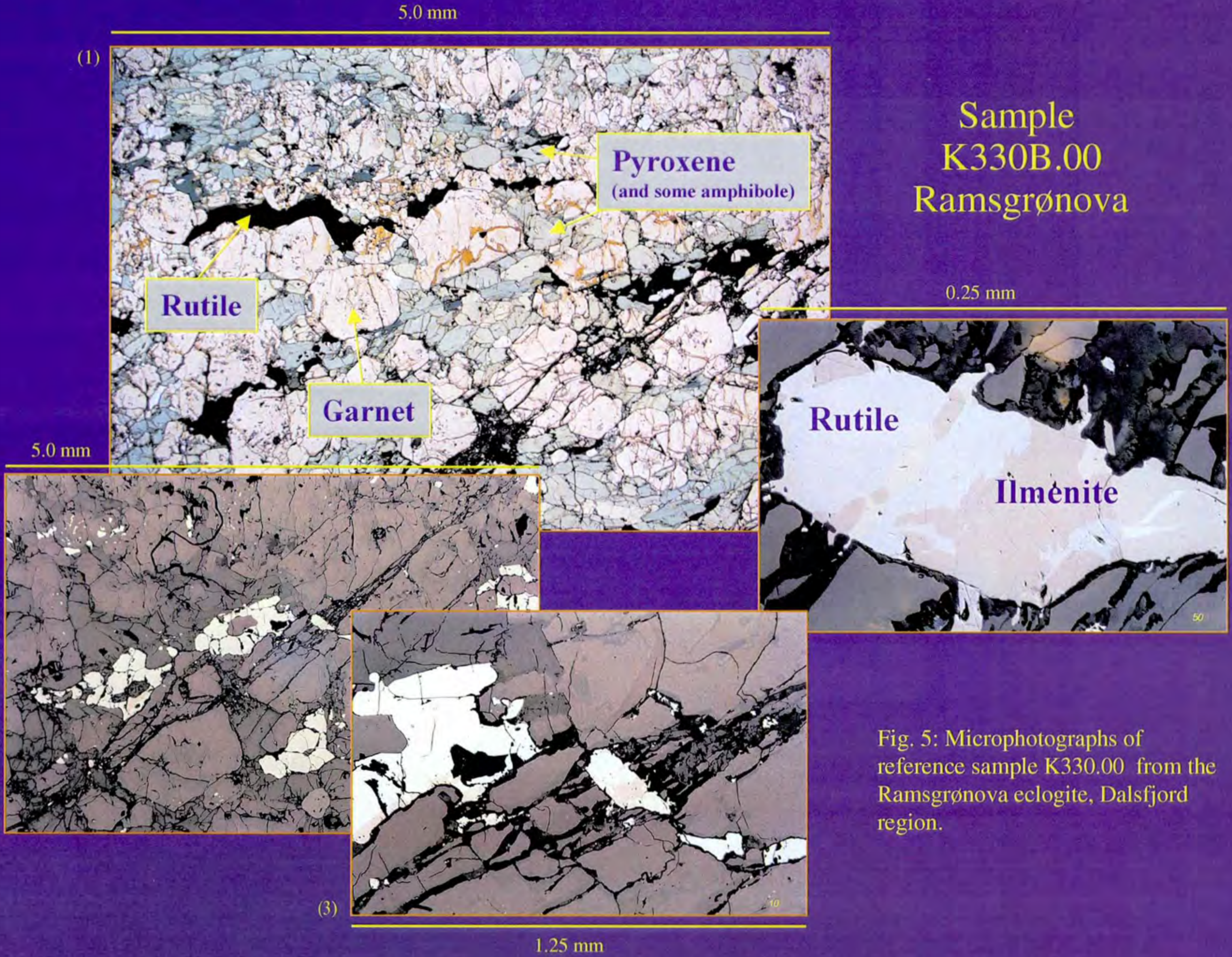
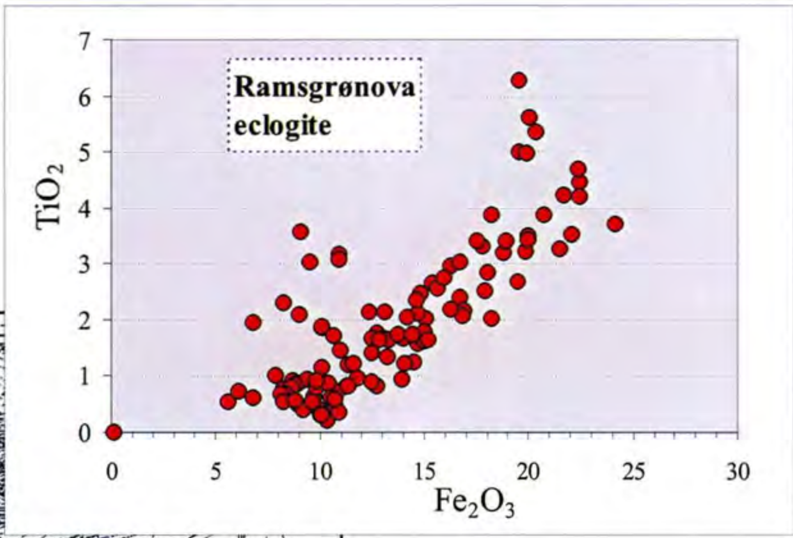
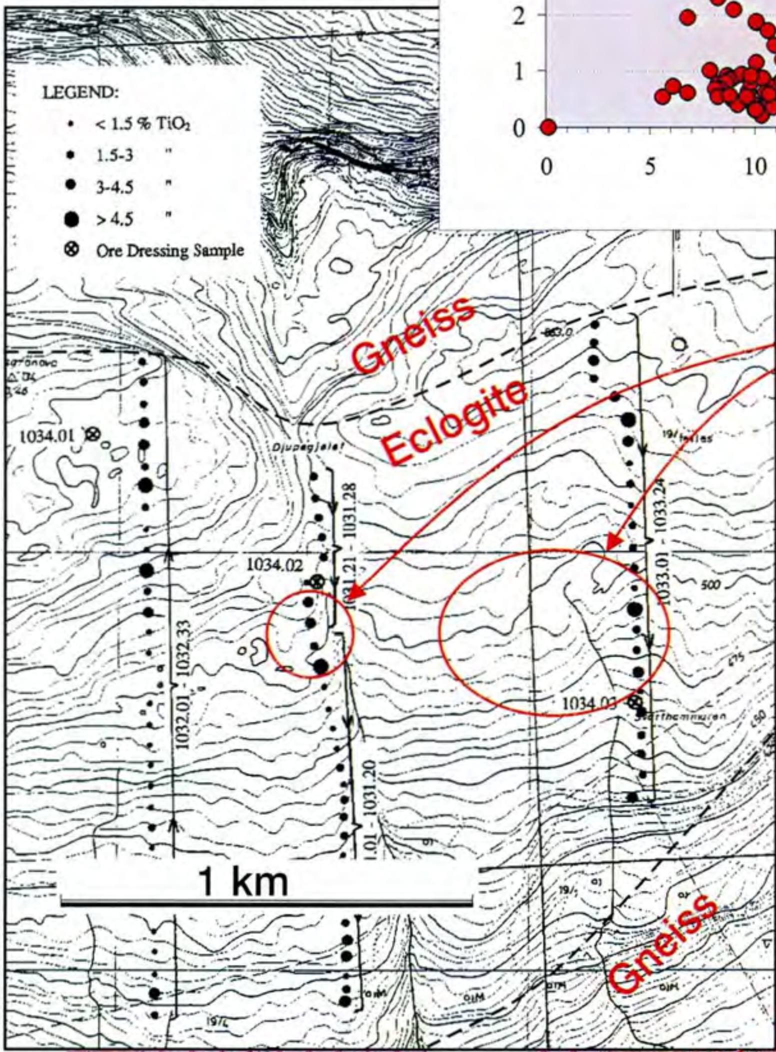


Fig. 5: Microphotographs of reference sample K330.00 from the Ramsgrønova eclogite, Dalsfjord region.

Ramsgrønova eclogite



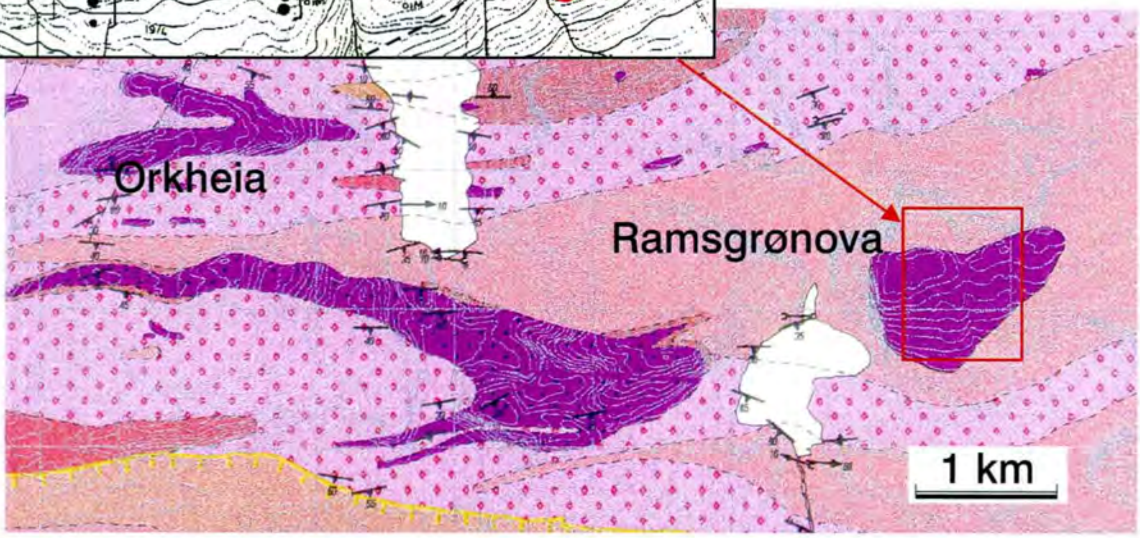
(2)



(1)

Sampling areas, sample K330.00

Fig. 6: Drill-dust sampling profiles (1) at Rramsgrønova eclogite, DuPont-NGU project 1995. A Fe_2O_3-TiO_2 scatter-diagram plot of X-met analyses of the drilldust samples is shown in (2). The geologic map (3) is from Ragnhildstveit & Nilsen (1998). See legend in Fig. 2. Analytical data are given in Table 1.



(3)

Table 1: X-Met analyses of drill-dust samples (DuPont-NGU project 1995), Ramsgrønova eclogite.

Sample	East coord.	North coord.	TiO_2	Fe_2O_3	Sample	East coord.	North coord.	TiO_2	Fe_2O_3	Sample	East coord.	North coord.	TiO_2	Fe_2O_3
Profile 1031					Profile 1032					Profile 1033				
1031,01	298735	6797275	2.66	15.36	1032,01	298535	6796840	2.95	16.28	1033,01	299090	6797650	1.67	13.05
1031,02	298740	6797250	5.35	20.35	1032,02	298535	6796865	3.20	18.79	1033,02	299090	6797625	1.64	13.29
1031,03	298745	6797225	0.87	8.92	1032,03	298535	6796890	1.35	13.22	1033,03	299090	6797600	3.22	19.85
1031,04	298750	6797200	0.93	9.38	1032,04	298535	6796915	0.64	9.68	1033,04	299090	6797575	2.76	15.96
1031,05	298755	6797175	0.97	11.78	1032,05	298535	6796940	0.84	8.83	1033,05	299105	6797550	4.20	22.44
1031,06	298760	6797150	0.85	9.86	1032,06	298535	6796965	0.95	13.92	1033,06	299120	6797525	5.00	19.51
1031,07	298765	6797130	3.88	18.21	1032,07	298535	6796990	0.83	12.72	1033,07	299120	6797500	3.52	22.04
1031,08	298765	6797110	0.78	8.25	1032,08	298535	6797015	1.24	14.51	1033,08	299120	6797475	0.83	11.32
1031,09	298765	6797090	2.03	18.21	1032,09	298535	6797040	1.21	14.04	1033,09	299120	6797450	1.85	10.10
1031,1	298765	6797070	2.30	8.25	1032,1	298535	6797065	2.14	13.09	1033,1	299120	6797425	0.68	8.16
1031,11	298765	6797050	1.57	14.67	1032,11	298535	6797090	0.81	8.62	1033,11	299120	6797400	1.65	12.84
1031,13	298765	6797000	1.19	11.35	1032,12	298535	6797115	0.79	9.83	1033,12	299120	6797375	1.74	13.75
1031,14	298765	6796970	1.67	14.01	1032,13	298535	6797140	0.50	8.95	1033,13	299120	6797350	1.73	14.43
1031,15	298765	6796945	1.62	15.01	1032,14	298535	6797165	0.54	5.60	1033,14	299120	6797325	0.00	0.11
1031,16	298765	6796925	3.27	21.50	1032,15	298535	6797190	0.72	6.09	1033,15	299120	6797300	5.62	20.02
1031,17	298765	6796905	3.88	20.74	1032,16	298535	6797215	0.62	6.79	1033,16	299120	6797275	1.65	15.20
1031,18	298765	6796885	0.82	11.31	1032,17	298550	6797245	1.01	7.90	1033,17	299120	6797250	2.11	14.66
1031,19	298765	6796870	2.47	14.79	1032,18	298550	6797265	0.72	10.87	1033,18	299120	6797225	3.03	16.68
1031,2	298765	6796850	4.47	22.41	1032,19	298535	6797285	0.47	10.74	1033,19	299120	6797200	2.04	14.16
1031,21	298745	6797475	1.77	12.72	1032,2	298535	6797305	0.69	8.36	1033,2	299120	6797175	3.49	20.00
1031,22	298745	6796450	2.67	19.46	1032,21	298535	6797330	3.40	17.54	1033,21	299120	6797150	2.06	16.84
1031,23	298745	6797425	2.40	16.73	1032,22	298535	6797355	1.79	14.97	1033,22	299120	6797125	2.35	14.64
1031,24	298750	6797400	2.03	15.05	1032,23	298535	6797380	6.28	19.51	1033,23	299120	6797100	2.19	16.28
1031,25	298750	6797375	2.16	16.86	1032,24	298535	6797407	1.15	10.10	1033,24	299120	6797075	3.43	19.97
1031,26	298730	6797350	1.46	10.96	1032,25	298535	6797430	0.90	12.46					
1031,27	298730	6797325	4.23	21.65	1032,26	298535	6797455	2.56	15.66					
1031,28	298730	6797300	3.31	17.79	1032,27	298535	6797480	4.70	22.36					
					1032,28	298500	6797505	2.85	18.03					
					1032,29	298500	6797530	3.70	24.16					
					1032,3	298500	6797555	3.41	18.93					
					1032,31	298500	6797580	1.66	12.49					
					1032,32	298500	6797605	2.51	17.89					
					1032,33	298500	6797630	2.14	12.38					

Table 2: X-Met analyses of drill-dust samples (DuPont-NGU project 1995), Orkheia eclogite.

Sample	East coord.	North coord.	TiO_2	Fe_2O_3	Sample	East coord.	North coord.	TiO_2	Fe_2O_3	Sample	East coord.	North coord.	TiO_2	Fe_2O_3
Profile 1035					Profile 1037					Profile 1040				
1035,01	293595	6798430	4.12	20.69	1037,01	293260	6798335	3.04	19.11	1040,01	292825	6798425	0.30	10.50
1035,02	293605	6798460	4.15	21.92	1037,02	293260	6798360	1.17	12.12	1040,02	292825	6798400	0.46	12.65
1035,03	293590	6798480	3.93	20.71	1037,03	293250	6798380	0.34	9.51	1040,03	292825	6798375	0.72	10.63
1035,04	293590	6798500	7.23	20.79	1037,04	293240	6798410	2.42	17.86	1040,04	292825	6798350	0.93	11.90
1035,05	293590	6798525	3.63	21.11	1037,06	293240	6798475	0.69	12.73	1040,05	292825	6798325	2.16	15.27
1035,06	293590	6798615	2.01	16.65	1037,07	293240	6798500	0.90	13.76	1040,06	292825	6798300	2.63	16.56
1035,07	293570	6798640	0.20	13.72	1037,08	293240	6798525	1.26	18.62	1040,07	292825	6798275	3.41	19.30
1035,08	293570	6798660	3.69	20.01	Profile 1038					1040,08	292815	6798255	0.61	9.26
1035,09	293565	6798675	3.39	19.39	1038,01	293160	6798490	3.28	19.04	Profile 1041				
Profile 1036					1038,02	293160	6798470	1.68	14.34	1041,01	292735	6798220	2.45	14.50
1036,01	293370	6798800	3.33	22.31	1038,03	293160	6798445	2.64	18.86	1041,02	292735	6798240	1.84	14.52
1036,02	293370	6798725	0.47	9.08	1038,04	293160	6798420	1.72	13.27	1041,03	292735	6798265	1.01	12.99
1036,03	293370	6798700	0.71	11.20	1038,05	293160	6798400	2.30	16.22	1041,04	292735	6798290	0.96	8.53
1036,04	293370	6798675	0.66	10.99	1038,06	293160	6798380	3.81	20.65	1041,05	292735	6798315	0.56	13.53
1036,05	293370	6798650	0.55	8.41	1038,07	293160	6798345	2.79	15.34	1041,06	292735	6798340	0.88	12.95
1036,06	293370	6798625	0.71	10.86	Profile 1039					1041,07	292735	6798360	0.06	12.32
1036,07	293370	6798600	0.64	10.20	1039,01	292970	6798315	0.29	17.72	Profile 1042				
1036,08	293370	6798575	0.67	11.34	1039,02	292980	6798335	2.33	16.89	1042,01	292635	6798310	0.29	12.22
1036,09	293370	6798515	0.04	12.81	1039,03	292970	6798355	3.88	17.84	1042,02	292635	6798285	0.27	10.09
1036,1	293370	6798435	4.34	21.94	1039,04	292970	6798380	1.57	11.84	1042,03	292635	6798260	0.80	11.55
1036,11	293370	6798410	8.18	21.18	1039,05	292970	6798405	2.00	13.60	1042,04	292635	6798235	1.15	12.32
1036,12	293370	6798385	3.70	21.37	1039,06	292970	6798430	0.87	13.49	1042,05	292635	6798210	0.30	9.23
1036,13	293370	6798360	3.69	20.89	1039,07	292970	6798455	0.16	2.87	1042,06	292610	6798235	0.64	13.52
1036,14	293370	6798335	4.10	21.38						1042,07	292585	6798230	0.29	12.04
										1042,08	292560	6798230	0.33	11.41

3. ORKHEIA RUTILE DEPOSIT

The Orkheia eclogite is an E-W trending, folded, sheet-like body laying on the top of the Orkheia mountain. The eclogite lies above the erosion plane at both ends. The mineralogical character of the Orkheia eclogite is similar to those for Ramsgrønova, and the general geological description given for Ramsgrønova is also valid for Orkheia.

The deposit was fragmentally sampled in 1993 and 1994, including samples taken with a small percussion drill-machine. In 1995 several drill-dust sampling profiles (Fig. 10) were carried out using a larger drill-machine, similar to the drill-dust sampling at Ramsgrønova the same year. A 200 core drill-hole was set down in 1993 to investigate the continuation at depth near the eastern end of the deposit, but only minor sections of rutile-rich eclogite was identified. The drilling was done by Stokke Industri in collaboration with DuPont and NGU (no report is available). The cores are stored at NGUs core storage at Løkken. The 1995-sampling was done by a Pionjär gasoline percussion drill machine, drilling 50-60 cm deep holes, and the drill-dust samples (0.5-1.0 kg) collected in a specially designed sample collector. The samples were analysed by the X-Met portable XRF. See the analyses in Table 2.

Photographs of landscape and field exposures on the Orkheia eclogite are shown in Fig. 7. Particularly the eastern part of the deposit has a banded character in which garnet- and rutile-rich layers alternate with fairly leucocratic eclogite layers with low rutile content (photograph (3) in Fig. 7). Microphotographs of the reference samples K331A.00 and K331B.00 are shown in Fig. 8 and 9. A characteristic feature is aggregates of rutile which is believed to mimic the occurrence of Fe-Ti oxides in the gabbroic protolith. Only traces of ilmenite is present. In Fig. 9 distinct retrograde alteration occur along fractures, which have a dark grey to black appearance in thin section (1), due to the fine-grained plagioclase + amphibole alteration products after omphacite.

The TiO_2 content of the eclogite shows a continous variation from 0 % to 8 % TiO_2, although the majority of samples plot in range 0.5 % to 4 % TiO_2 in the Fe_2O_3-TiO_2 scattergram diagram in Fig. 10. More than 90% of the TiO_2 is as rutile. The overall impression is that the TiO_2-content at Orkheia is slightly higher than at Ramsgrønova, and approx. 1/3 of the southern eclogite body is regarded to be of ore quality with at least 3 % TiO_2.

A rough ore reserve calculation is as follows: 1200 m (length) x 200 m (average width) x 100 m (estimated average depth) x 3.2 tons/m^3 (weight) would give approximately 80 million tons, of which 1/3, i.e. 25-30 million tons of eclogite might be of ore quality.

All the fragmented information available for the Orkheia eclogite have not been compiled and reported, and is therefore not given in this report. However, the drill-dust sampling done in 1995 (Fig. 10 and Table 2) is by far the most reliable sampling done and rule out much of the previous sampling.

Ore potential: Same as for Ramsgrønova.

Orkheia eclogite

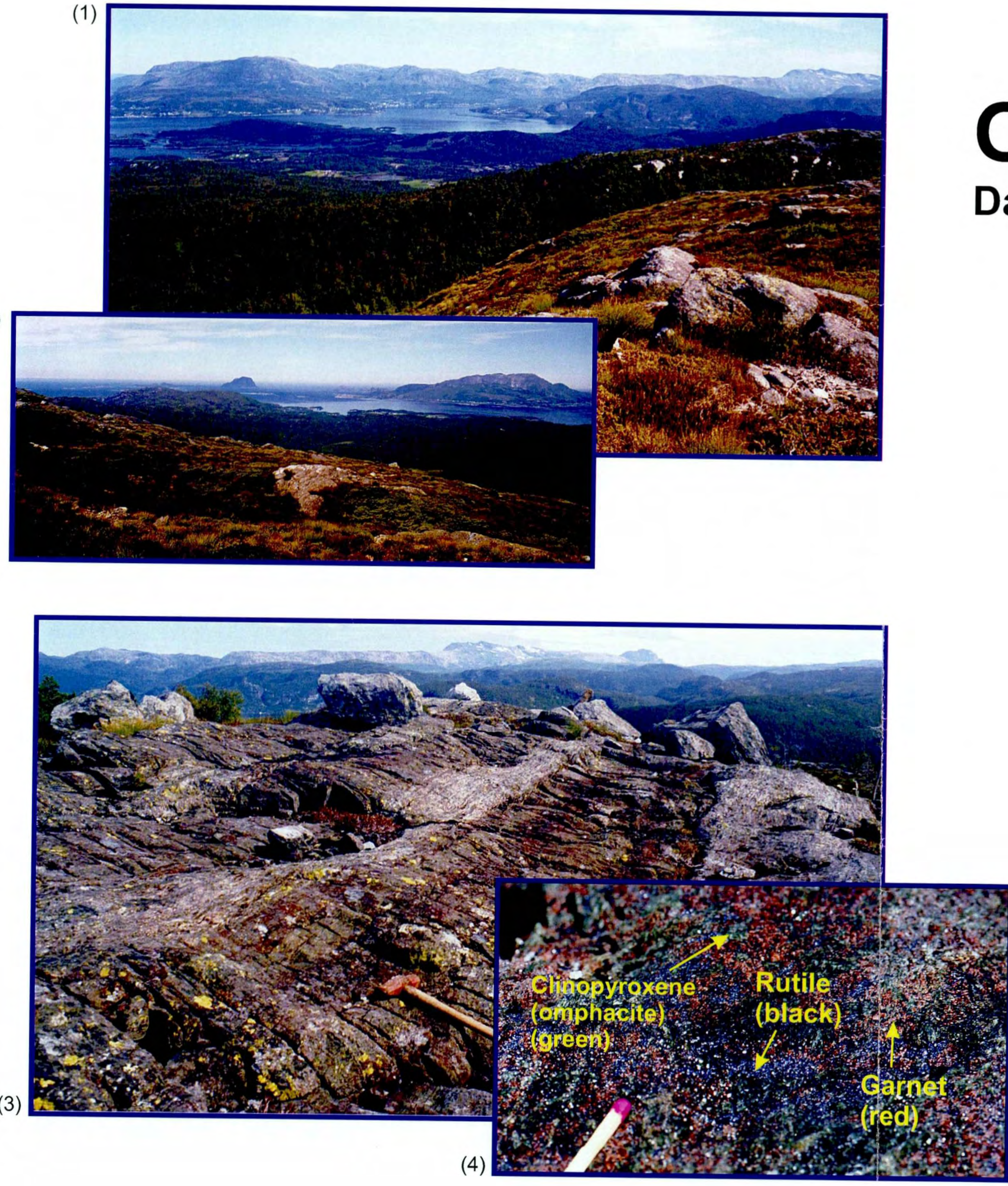
Dalsfjord region (Sunnfjord), W. Norway

(1)

(2)

(3)

(4)



(5)

(6)

Fig. 7: Photographs from the Orkheia eclogite, Dalsfjord region. (1) Wide-angle photograph from Orkheia viewed north-eastwards with the eastern part Dalsfjord in the background. (2) Wide-angle photograph from Orkheia viewed north-westwards with the outer (western) part of Dalsfjord and the open ocean in the background. (3) Layers of dark, garnet- and rutile rich eclogite (3-5 % rutile) alternating with felsic eclogite varieties with low rutile content (<2 % rutile). (4) Close-up photo of rutile-rich eclogite. (5) and (6) Reference samples K331A.00 and K331B.00.

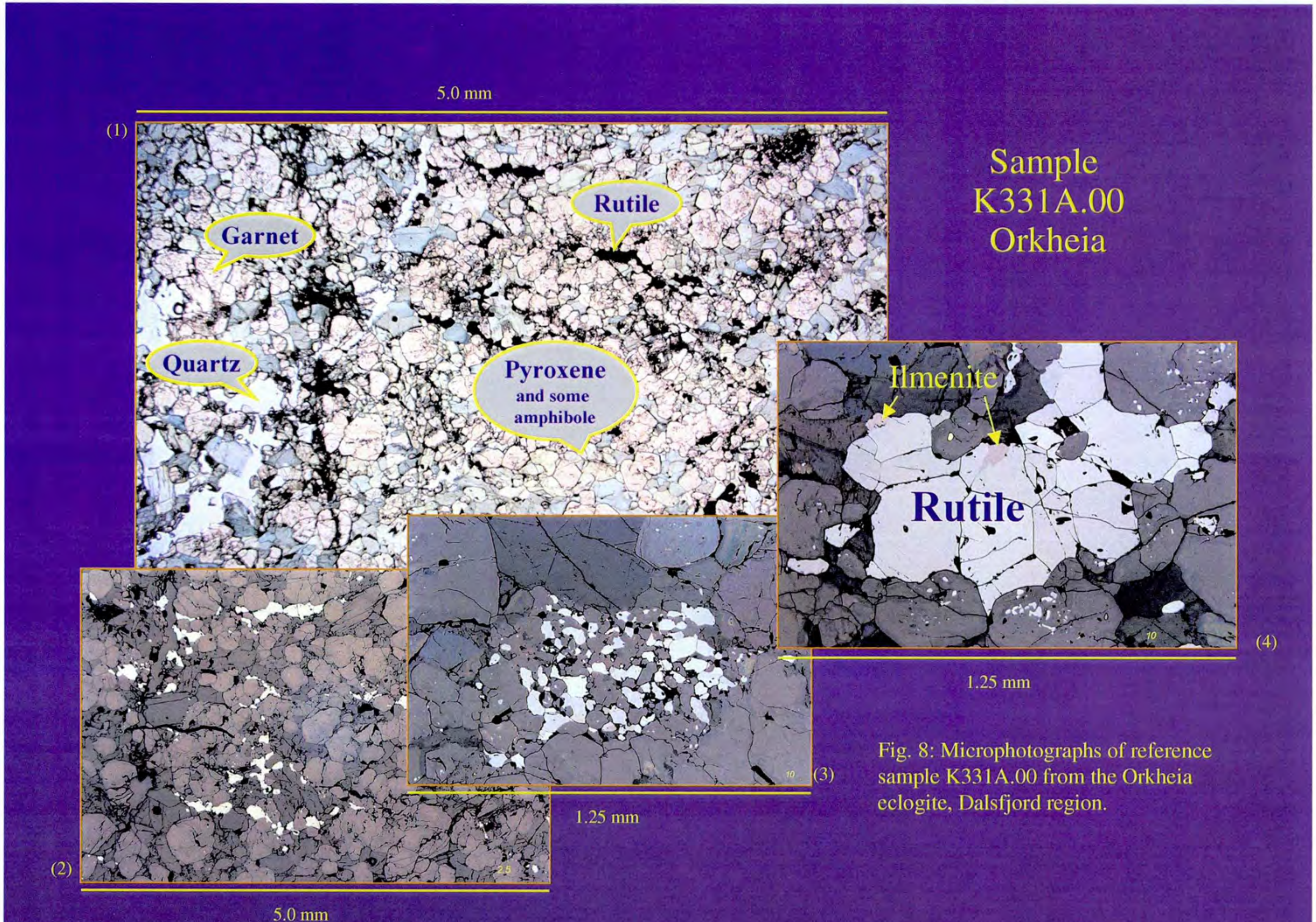
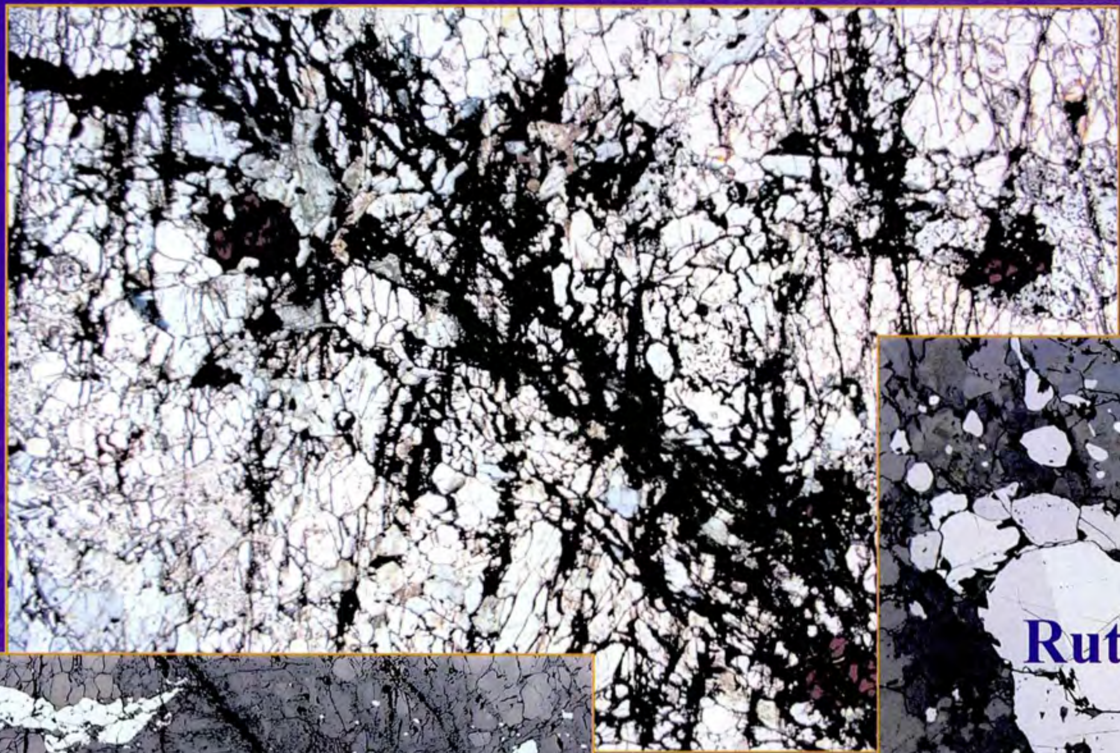


Fig. 8: Microphotographs of reference sample K331A.00 from the Orkheia eclogite, Dalsfjord region.

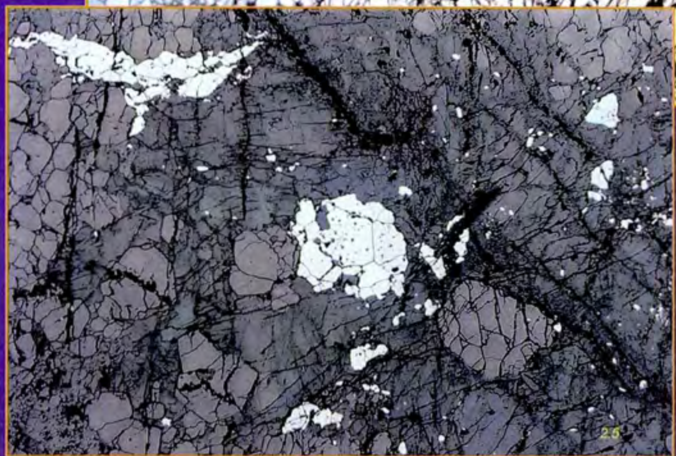
Sample K331B.00 Orkheia

5.0 mm

(1)

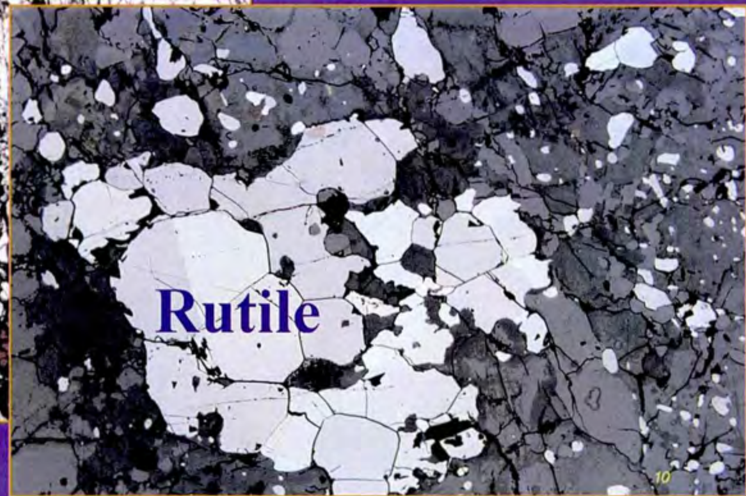


(2)



5.0 mm

(3)



1.25 mm

Fig. 9: Microphotographs of reference sample K331A.00 from the Orkheia eclogite, Dalsfjord region.

Orkheia eclogite

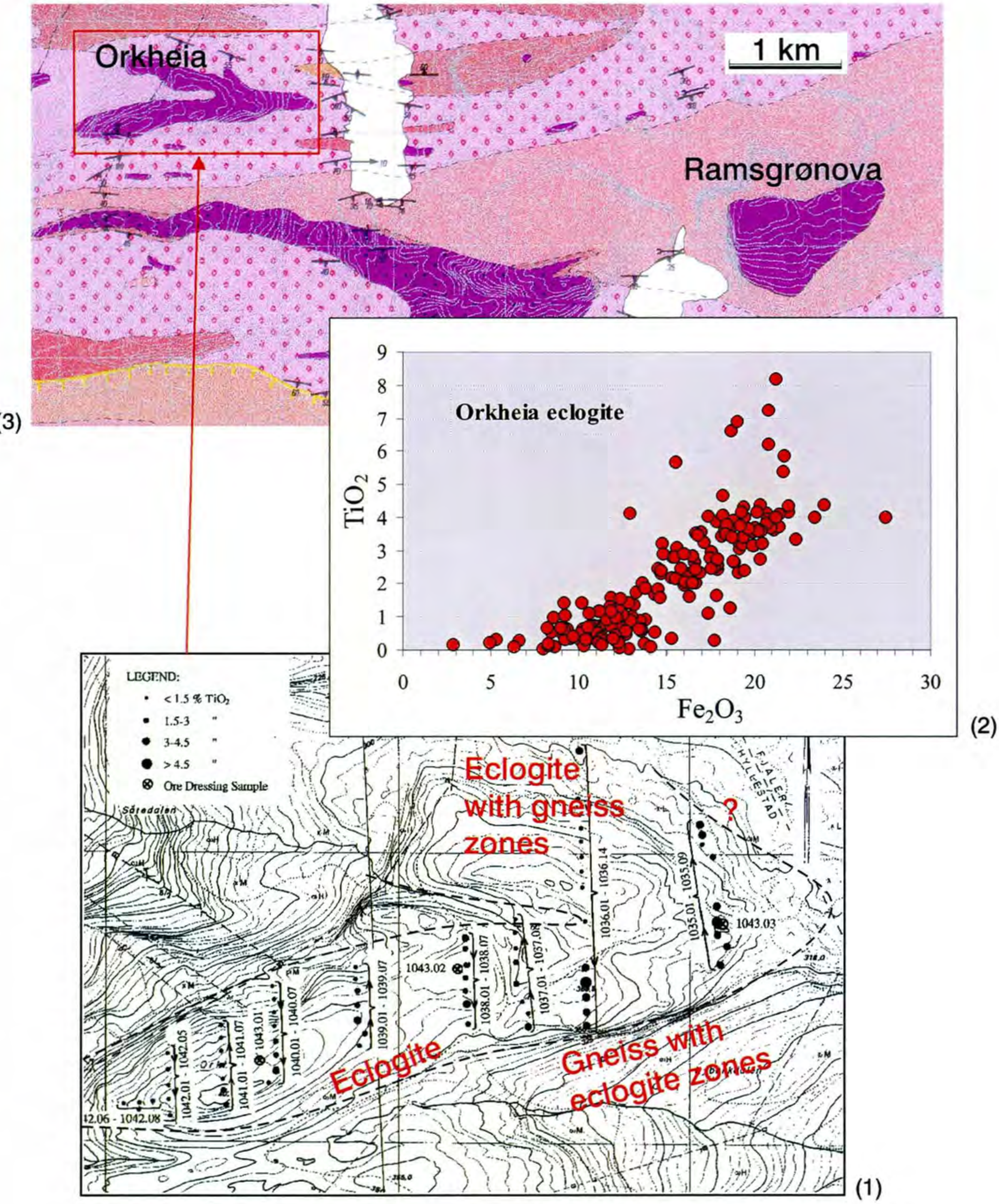


Fig.10: (1): Drill-dust sampling profiles at Orkheia eclogite. (2): Scattergram plot of X-met analyses of Orkheia drill-dust samples. See analyses in Table 2. (3): Geological map after Ragnhildstveit & Nilsen (1998). DuPont-NGU project 1995.

4. ØDEGÅRDEN RUTILE DEPOSIT

The Bamble-region (also "The Bamble-Arendal region" or "The Bamble Sector", Fig. 11) of the Baltic Shield is a geologic province anomalously rich in mineral deposits of various types, and one where mining has historically been important. The region's anomalous character, with respect to mineral deposits, may reflect unique, but poorly understood, circumstances in its geologic evolution.

The oldest rocks known in the region are supracrustals, intruded by several generations of basic and acidic intrusions. De Haas (1992) reports Sm-Nd ages of 1670 and 1640 Ma for two gabbroic intrusions in the Arendal area. This early period, The Gothian Orogen, in the region's geologic evolution lasted for approximately 250 m. y. (1500-1750 Ma; see references in de Haas 1992 and Starmer 1991). The maximum metamorphism in this period was at 700-800°C and 6-8 kb (granulite facies; see Lamb et al. 1986).

The region then experienced a fairly quiet geologic period until the Sveconorwegian Orogen (990-1250 Ma), characterized by significant basic magmatic activity followed by a period of upper amphibolite to granulite facies metamorphism. In certain parts of the region, for example at Ødegården, significant hydrothermal activity caused extensive metasomatic alteration of the basic rocks. This geologic period was terminated by the intrusion of large, post-tectonic granites (990 Ma; Kullerud and Machado 1991). According to Starmer (1991) basic magmatism was associated with an anorogenic early phase in the Sveconorwegian orogeny, and was associated with extensional tectonics followed by an orogenic phase with nappe tectonics. De Haas (1992) also supports an extensional model; according to de Haas the mantle from which the Sveconorwegian gabbros were derived, up-domed under a relatively thin crust. This mantle doming led to high temperature/-pressure-gradients and granulite facies metamorphism in the overlying crust. Smalley and Field (1991) have another opinion: based on trace element characteristics for the Sveconorwegian gabbros they claim that the gabbros formed at an active continental margin.

Regardless of which of these two models are preferred, the significant hydrothermal activity that was active in the region altered the basic intrusions that are believed to have formed during the first part of the orogen, and must, therefore, be younger than the intrusions. The hydrothermal activity is most likely related to the last part of the orogenic activity. Post-Sveconorwegian magmatism in the form of scattered carbonatitic dykes and alkaline basic dykes is associated with the Fen carbonatite complex (600 Ma.) and the Permian magmatism in the Oslo Graben (270 Ma).

Of the rutile-bearing rock-types, coordierite-bearing metasediments (?) and scapolitized and albitized gabbros occur in large volumes and may have an economic potential with respect to rutile.

The Ødegårdens Verk rutile deposit (Figs. 11-14) is a more than 1200 m long, roughly vertical zone (the end of the zone is not precisely defined due to overburden) of metasomatically altered gabbro/amphibolite. The dominant rock is a rutile-bearing scapolite-hornblende rock which was first called ødegårdite by Brøgger (1934). During transformation of gabbro to the ødegårdite, metasomatic fluids have leached a series of elements from the gabbro, to be carried away by the hydrothermal system. The major silicate minerals in the remaining rock is scapolite (after plagioclase) and a hornblende with low iron content (after mafic silicates in the original gabbro/amphibolite). The rutile is formed from the titanium remaining when iron from ilmenite was carried away by the fluids. The contact relations to the surrounding metagabbro/amphibolite are complex due to the interactions between the metasomatising fluids and the gabbro/amphibolite. Rafts of incompletely scapolitized gabbro/amphibolite occur within the main ødegårdite zone, see map (1) in Fig. 14.

An intermediate stage with pronounced Na-metasomatism caused extensive albitisation of the ødegårdite as well as of other rocks in the area, and late hydrothermal activity resulted in the formation of numerous phlogopite - enstatite - apatite veins along fractures in the ødegårdite. Apatite in these veins were the target for a significant mining activity from 1872 to 1945.

Comments on the previous investigations at Ødegårdens Verk:

(1) When *the apatite mines* were still operating the various rock types and varieties was detailed described by Brøgger (1934), who also pointed out the major element chemical variations associated with the scapolitisation process. Anyone who wants to study this deposit should carefully read Brøgger's extensive description from Ødegårdens Verk.

(2) *The scapolite and apatite* from Ødegårdens Verk have recently been described in two publications by Liefting et al. (1993) and Liefting & Nijland (1992), respectively.

(3) *Scapolite as a mineral resource.* NGU investigated the Ødegårdens Verk deposit during 1989-1992. Firstly, the late NGU geologist Jens Hysingjord did reconnaissance sampling of scapolite-bearing rocks in the Bamble region, including Ødegårdens Verk (Hysingjord 1990). Several possible product possibilities for the use of scapolite were considered, including potential usage of expanded scapolite in the form of a lightweight porous "scapolite glass" (S. Olerud, pers. comm..), see also Paulsen (1990, 1993). Hysingjord recognised that the rutile content of the scapolite-rich rock (the ødegårdite) could be of economic interest.

(4) *Drill-dust sampling* (same method as for Ramsgrønova and Orkheia) was done in 1990 to investigate the rutile-bearing rock in some more detail, and the relatively scattered exposures in the deposit area were sampled (Korneliussen & Furuhaug 1993). It was realised that this sampling did not give a sufficient overview of the situation since the rutile-bearing rock (ødegårdite) had a low resistance to erosion and tended to occur in depressions in the terrain. The gabbro/amphibolite, on the other hand, preferentially stood up as exposures due to higher resistance to erosion.

(5) *Magnetic survey.* In the metasomatic process leading to the formation of the ødegårdite, Fe-bearing minerals such as magnetite and ilmenite break down as iron is transported away by the hydrothermal fluids. Therefore, the rutile-bearing ødegårdite is a rock with very low magnetic susceptibility compared with the magnetite- and ilmenite-bearing protolith. Therefore, magnetics might be a powerful method to map the ødegårdite, and therefore a ground magnetic survey was done (Lauritsen 1992), and a revised map interpretation of the ødegårdite zone was made (map labelled (1) in Fig. 14).

(6) *Core drilling.* To be able to investigate the mineralogical and chemical character of the ødegårdite and the contact relations between the ødegårdite and the gabbro/amphibolite, two core boreholes were drilled (Korneliussen & Furuhaug 1993). The position of these boreholes and the rutile content along the holes are shown in Fig. 13. NGUs project was stopped shortly afterwards, and the focus for the continued rutile investigations shifted towards the rutile-bearing eclogites in W. Norway (the DuPont - NGU collaboration project).

(7) However, in 1995 Roar Sandøy wrote a diploma thesis at the Technical university of Trondheim, studying the details of the transition from metagabbro/amphibolite to ødegårdite (Sandøy 1995).

The maps in Fig. 11 gives a geological overview. The map labelled (2) is a section of the geological map Kragerø (Padget 1999); for further studies of this map see the original 1:50.000 scale geological map sheet Kragerø enclosed as Appendix 1. Various maps of the Ødegården Verk area have been made over the years. The map labelled (3) in Fig. 11 (by Ryan 1964-66) is the best overview map available, particularly when combined with Padgets map, while the map labelled (4) probably give the best update of the ødegårdite rutile ore zone itself.

Fig. 12 is a compilation of various pictures to give an impression of how the ore looks in core samples as well as in thin-section, while some details of the two boreholes are given in Fig. 13.

The ødegårdite zone is at least 1200m long, and continues into farm land north-eastwards where it has not been investigated. A rough tonnage calculation is as follows: 1200 m (length) x 150 m (average width) x 300 m (depth) x 2.8 (tons/m^3) will give a deposit of approximately 150 million tons. Due to the significant overburden drilling is necessary to give a precise definition of the size of the deposit.

Chip-samples of ødegårdite from mine tailings in the north-eastern (in the Dh1-area) and the central part of the deposit (approx. 500 m SW of Dh2) contains 3.5 - 4.0 % and 1.9 - 2.8 % rutile, respectively (Table 3), while the average rutile content (Table 4) in ødegårdite from Dh1 and Dh2 is 2.9 % and 1.7 % rutile, respectively. These data show that the rutile content in the ødegårdite varies roughly in the range 1.5-4.0 % rutile. Table 3 and Table 4 also show that the rutile portion of the TiO_2-content within the ødegårdite rock varies considerably, although in general it tend to be in the range 80-90 %.

Alteration of rutile to titanite, as shown in Fig. 12, is a common phenomena. Although a relative small portion of the rutile is altered to titanite, the presence of titanite might lead to high CaO-content in rutile concentrates made from this ore.

As pointed out by Korneliussen et al. (1999) rutile from Ødegården as well as from Lindvikkollen (see next chapter) is enriched in uranium (50-100 ppm U in rutile separates analysed by the neutron activation analytical method), while rutile from eclogites is practically free of this element (< 1 ppm U)

The 50 kg sample sent to Rio Tinto Iron & Titanium was taken from mine tailings near Dh1, and should give a reasonably good impression of rutile-bearing ødegårdite from the north-eastern part of the deposit.

REE-bearing apatite would be a by-product in case of rutile mining.

Ore potential: The rough estimations given above indicates a probable ore resource of 150 million tons with 1.5-4.0 % rutile. The end of the ore zone has not been defined in the north-east, and the tonnage might very well be even larger. Further drilling is needed to give more precise information of the situation. The potential for additional ores in neighbouring areas is probably significant.

Table 3: XRF- and rutile analyses of chip-samples from mine tailings at Ødegården (from Korneliussen & Furuhaug 1993).

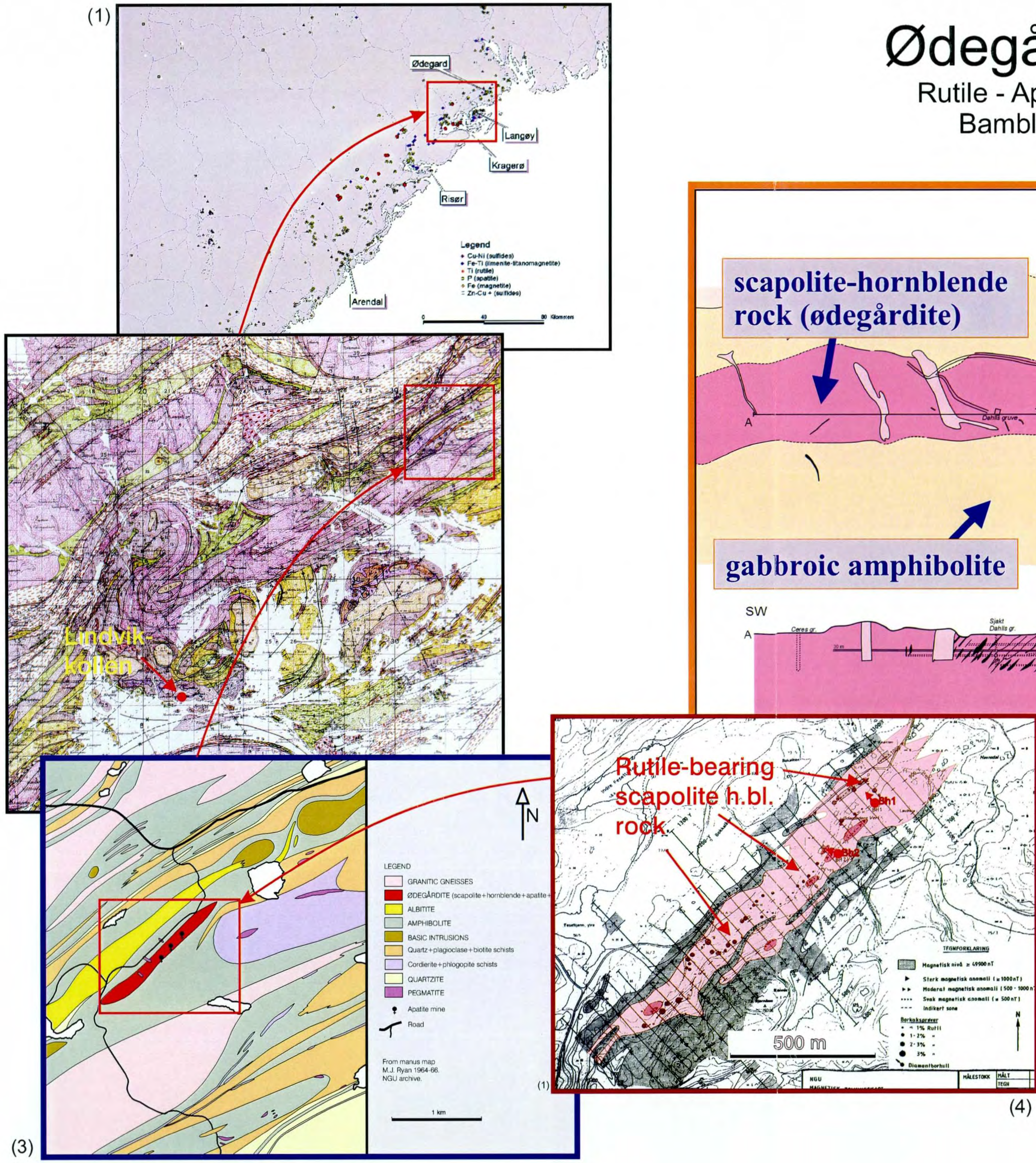
Sample no	KB51A.91	KB51B.91	KB51C.91	KB51D.91	KB52A.91	KB52B.91	KB52C.91	KB52D.91	KB52E.91
% SiO_2	52.33	52.44	53.14	52.01	50.07	49.98	49.92	49.88	56.37
% Al_2O_3	15.4	17.02	17.85	17.17	16.81	17.39	17.01	17.08	15.9
% Fe_2O_3	2.58	1.96	1.22	1.82	3.19	2.82	3.12	3.21	2.58
% TiO_2	3.98	4.08	3.92	4.19	3.05	3.01	3.14	3.11	2.05
% MgO	6.3	5.59	5.76	5.74	7.37	7.44	7.29	7.47	6.64
% CaO	7.06	6.7	4.66	6.8	8.53	7.62	8.18	7.79	5.92
% Na_2O	7.01	7.64	7.99	7.64	6.57	6.59	6.6	6.53	6.5
% K_2O	0.63	0.61	0.92	0.57	0.54	0.73	0.66	0.81	0.6
% MnO	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
% P_2O_5	0.73	0.51	0.4	0.35	0.39	0.43	0.43	0.45	0.34
% LOI	1.85	1.2	1.97	1.43	0.92	1.5	1.14	1.33	1.38
% SUM	97.89	97.75	97.83	97.73	97.46	97.52	97.49	97.67	98.29
% Rutile	3.51	3.82	3.62	3.95	2.53	2.61	2.83	2.68	1.85
Rel.%-rutile	88 %	94 %	92 %	94 %	83 %	87 %	90 %	86 %	90 %
Average rel.% rutile for KB51.91:			92 %		Average rel.% rutile for KB52.91:			87 %	

Table 4: Average major element composition in gabbro/amphibolite, ødegårdite and phlogopite-enstatite veins in Dh1 and Dh2 (based on Korneliussen & Furuhaug 1993).

	Average values, Bh1		Average values, Bh2		
Rock	Plogopite-enstatite rock	Ødegårdite	Avg. metag. Bh2	Plogopite-enstatite rock	Ødegårdite
n	7	71	23	14	84
% SiO_2	41.68	50.43	47.76	40.71	51.13
% Al_2O_3	11.78	15.89	13.54	11.44	15.77
% Fe_2O_3	3.14	3.36	15.12	4.59	4.88
TiO_2	2.78	3.56	2.88	2.61	2.81
MgO	18.30	8.10	4.36	18.98	7.42
CaO	6.41	6.69	8.05	7.05	6.94
Na_2O	2.10	6.01	4.37	1.85	6.04
K_2O	3.68	1.02	0.91	3.87	1.08
MnO	0.01	0.02	0.14	0.01	0.02
P_2O_5	3.52	0.60	0.94	3.16	0.55
Rutil	1.51	2.92	0.27	0.92	1.65
Rel.% rutile	49 %	82 %	9 %	32 %	54 %

Ødegårdens Verk

Rutile - Apatite - REE deposit,
Bamble, South Norway



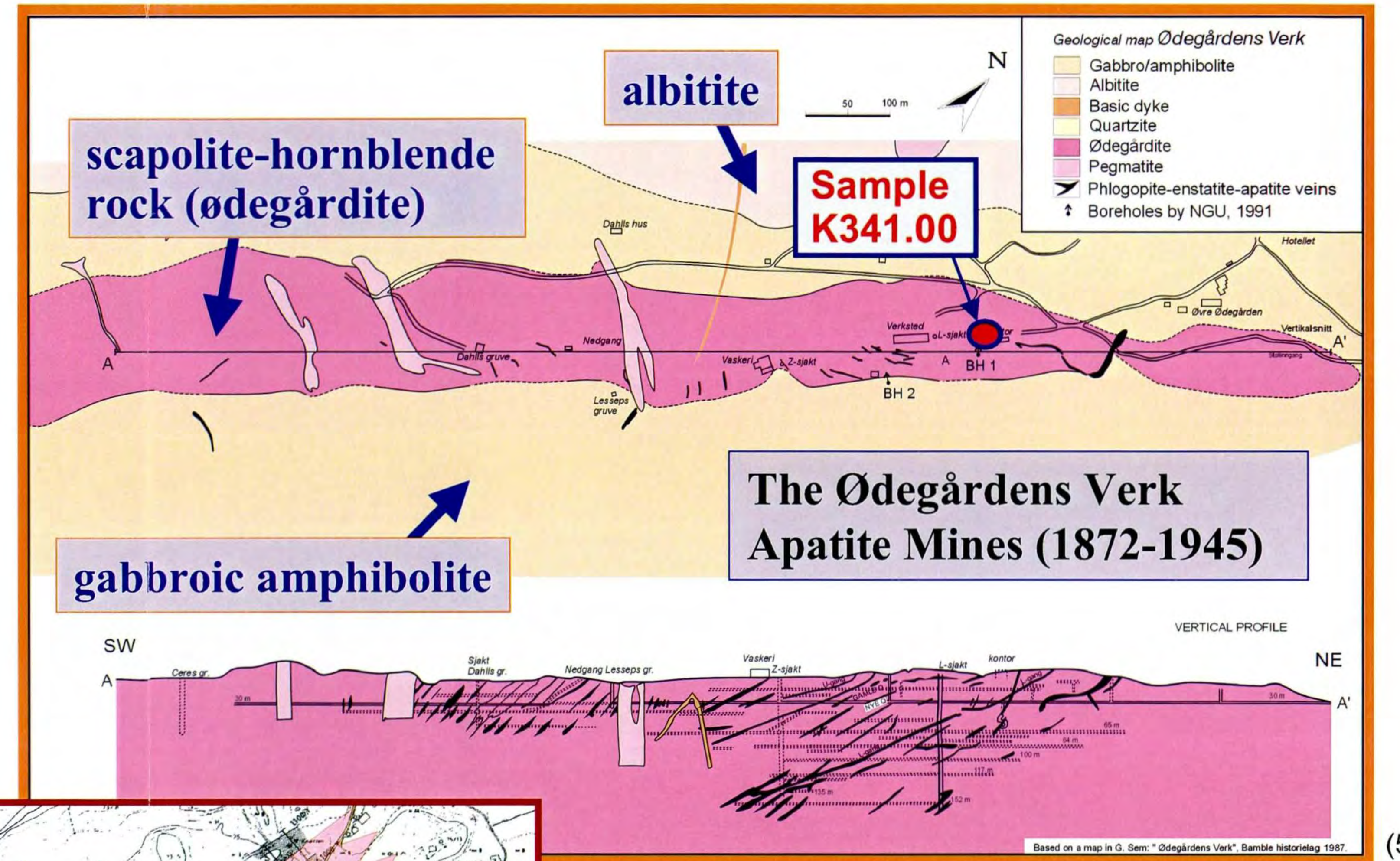
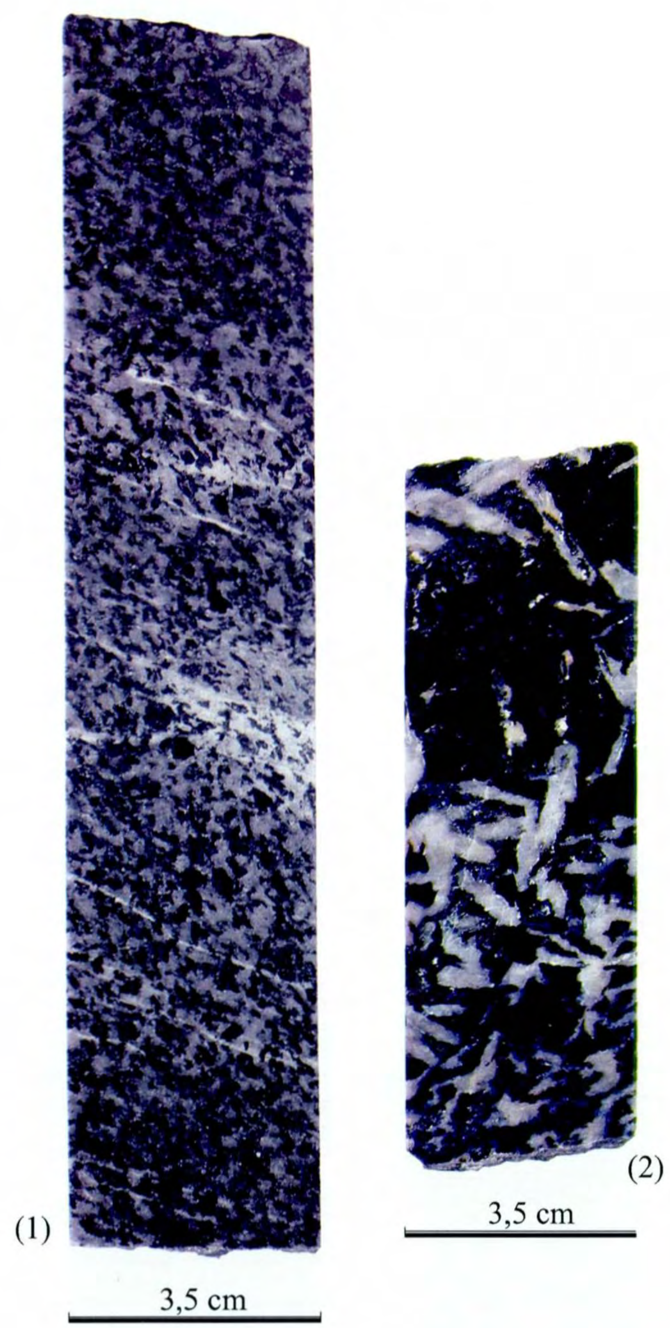


Fig. 11: Maps and photographs, Ødegårdens Verk, Bamble municipality. (1): Overview map of ore deposits in the Bamble - Arendal region (also called Bamble Shear Belt), S. Norway. (2): Part of the geological map Kragerø (Padget 1999), see Appendix 1. (3): Unpublished geological map of the Ødegården area after Ryan (1964-66). (4): An interpretation (Korneliussen 1993, unpublished) of the occurrence of the rutile-bearing scapolite-hornblende rock based on a combination of geology and ground magnetics (Lauritsen 1992). (5): Old map of the Ødegårdens Verk apatite mines available in NGUs Bergarkiv.

Ødegårdens Verk



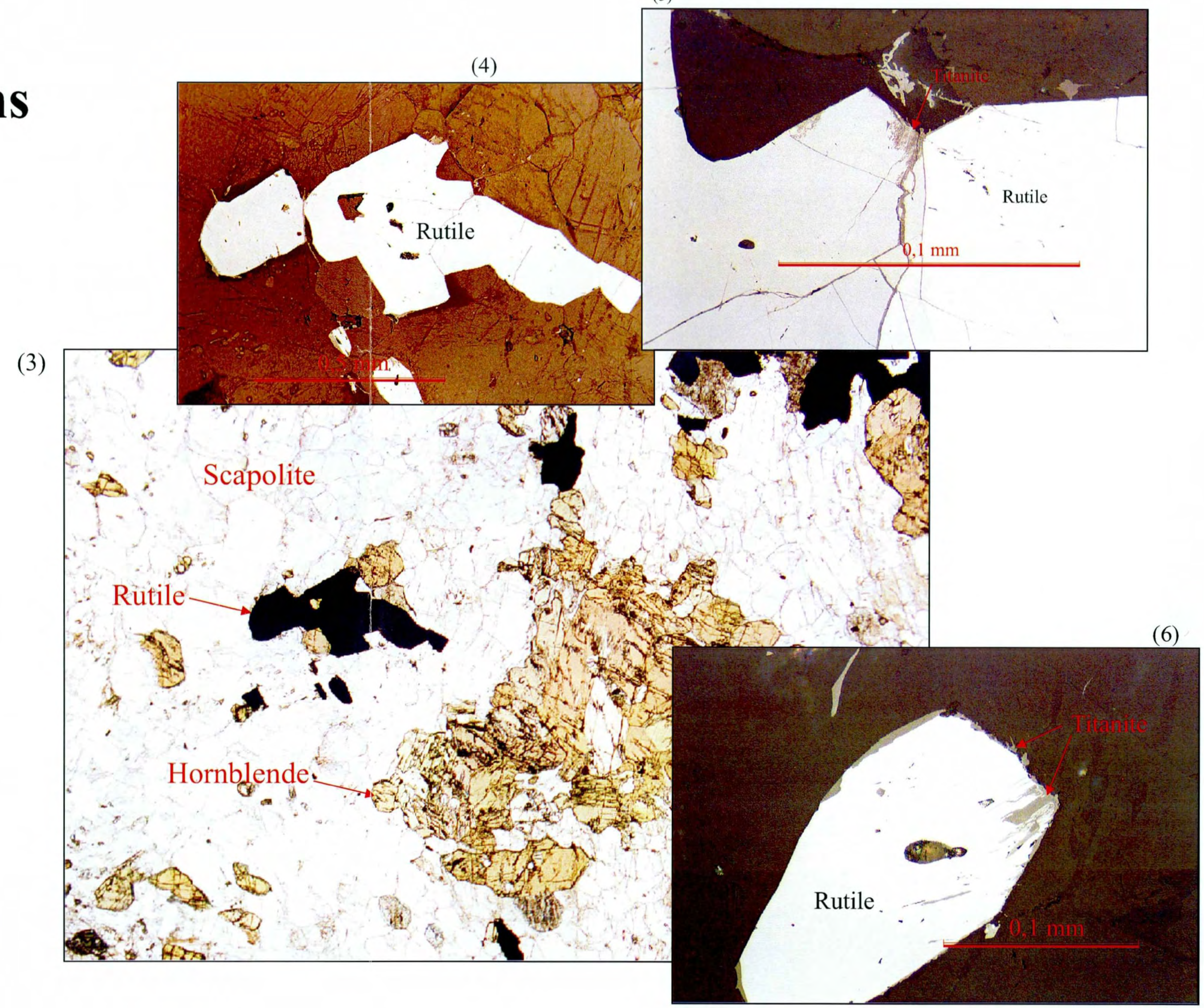
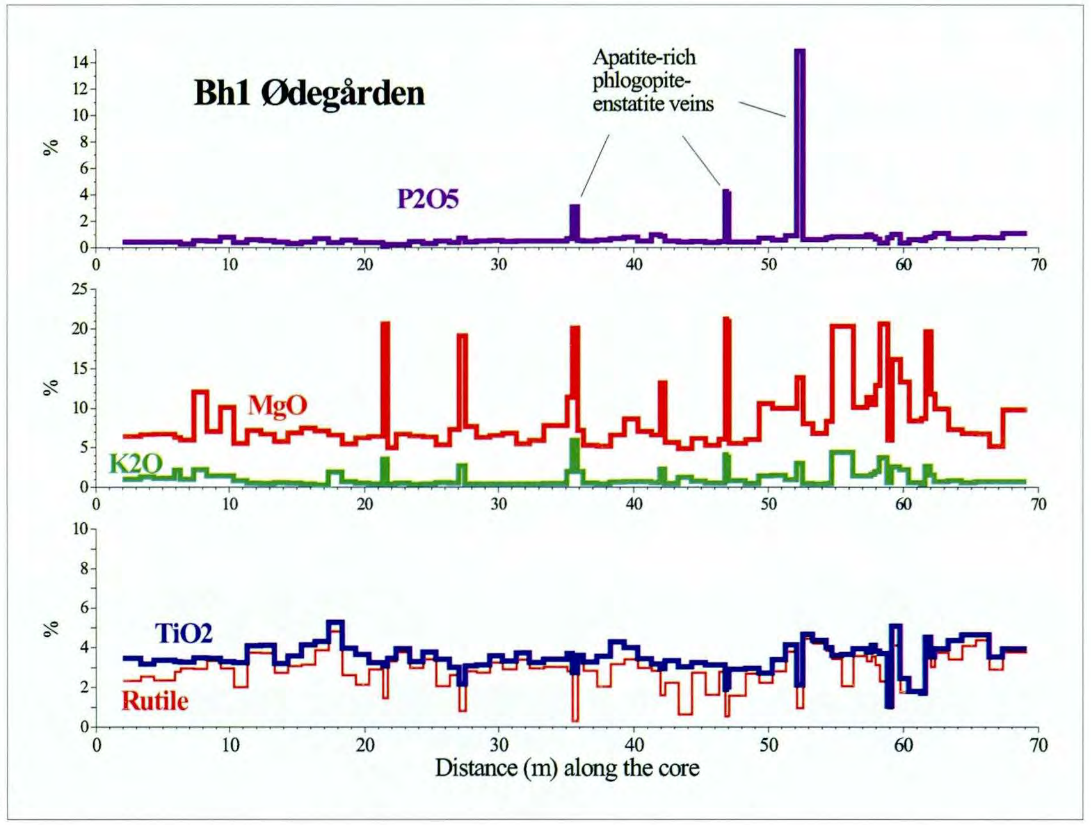


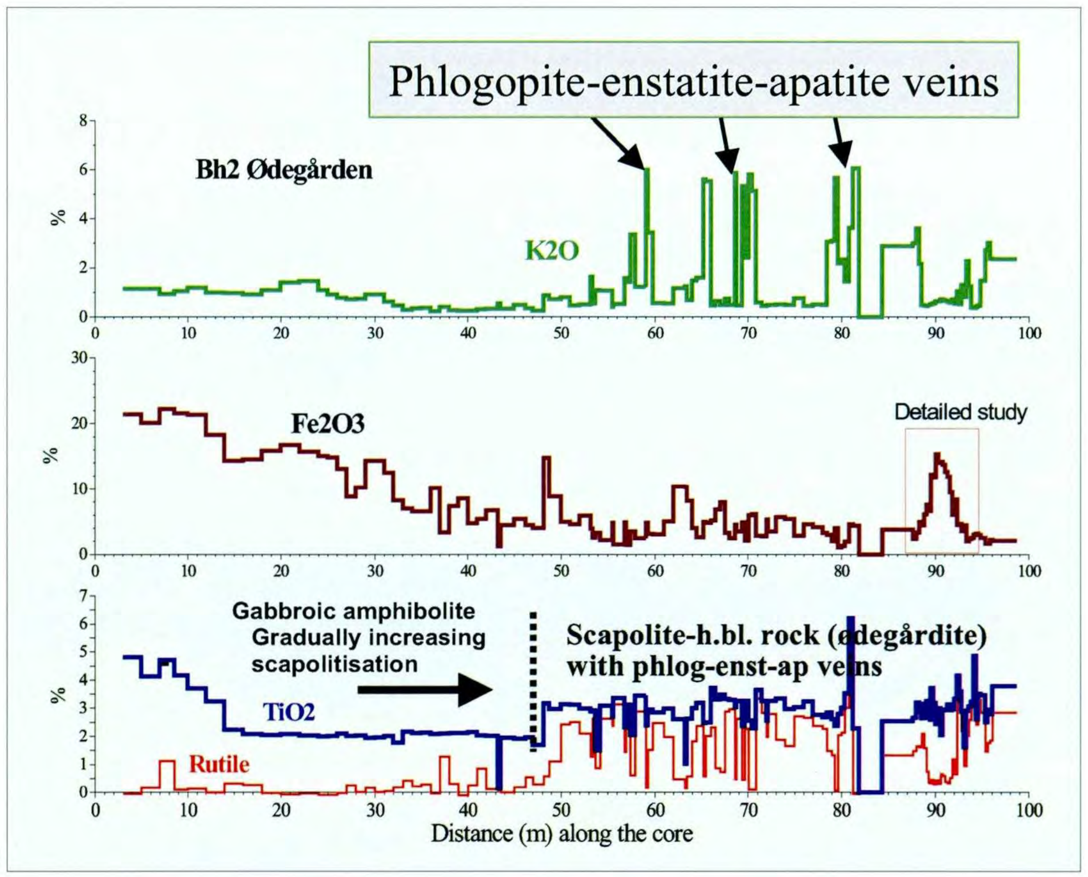
Fig. 12: Maps and photographs (continued), Ødegårdens verk, Bamble (based on Fig 19 in Korneliussen et al. 1999). The core samples (1) and (2) are showing two variations of scapolitised gabbro (ødegårdite) with the gabbroic texture well-preserved. The occurrence of rutile in the rock is shown by the microphotographs (3) to (6).

Borehole 1 and 2, Ødegårdens Verk

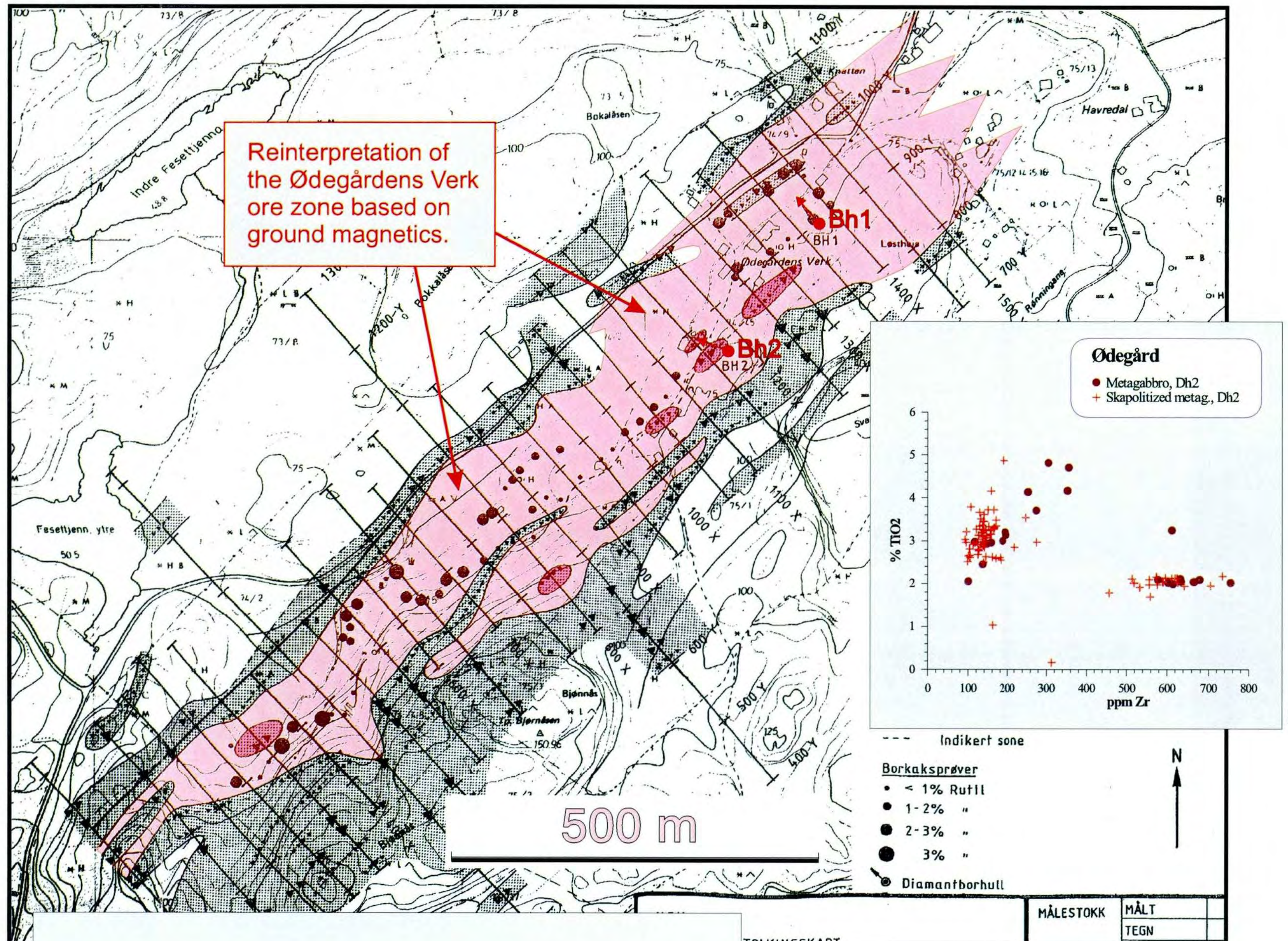
(based on Korneliussen and Furuhaug 1993)



(2)

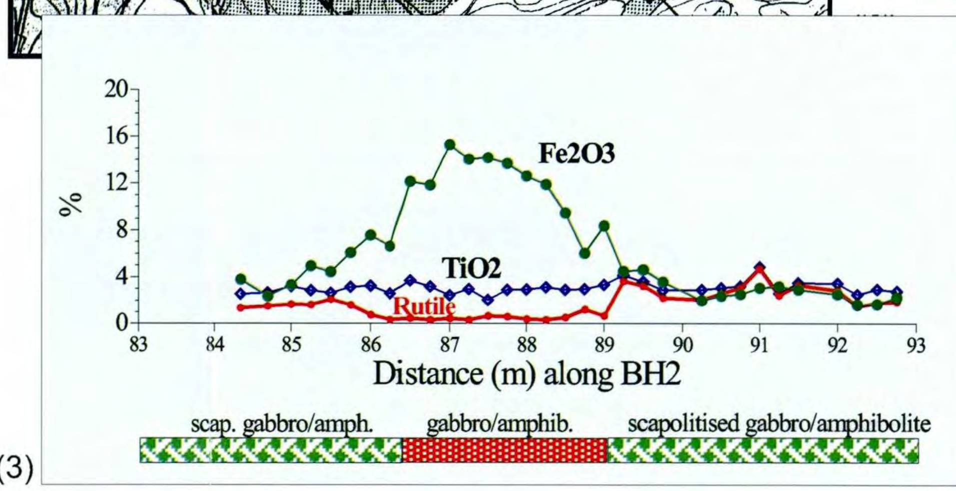


(3)



(1)

(4)



(3)

Fig. 13: Borehole 1 and 2, Ødegårdens Verk. (1): Interpretation of the ore-zone at Ødegården Verk based based on ground magnetics and the position of two boreholes (see Korneliussen and Furuhaug 1993). (2) Chemical variation along Bh1. (3): Chemical variation along Bh2. (4): Scattergram Xr-TiO_2 plot of samples of meta-gabbro/amphibolite and ødegårdite from Bh2.

Sample K341A.00, Ødegårdens Verk

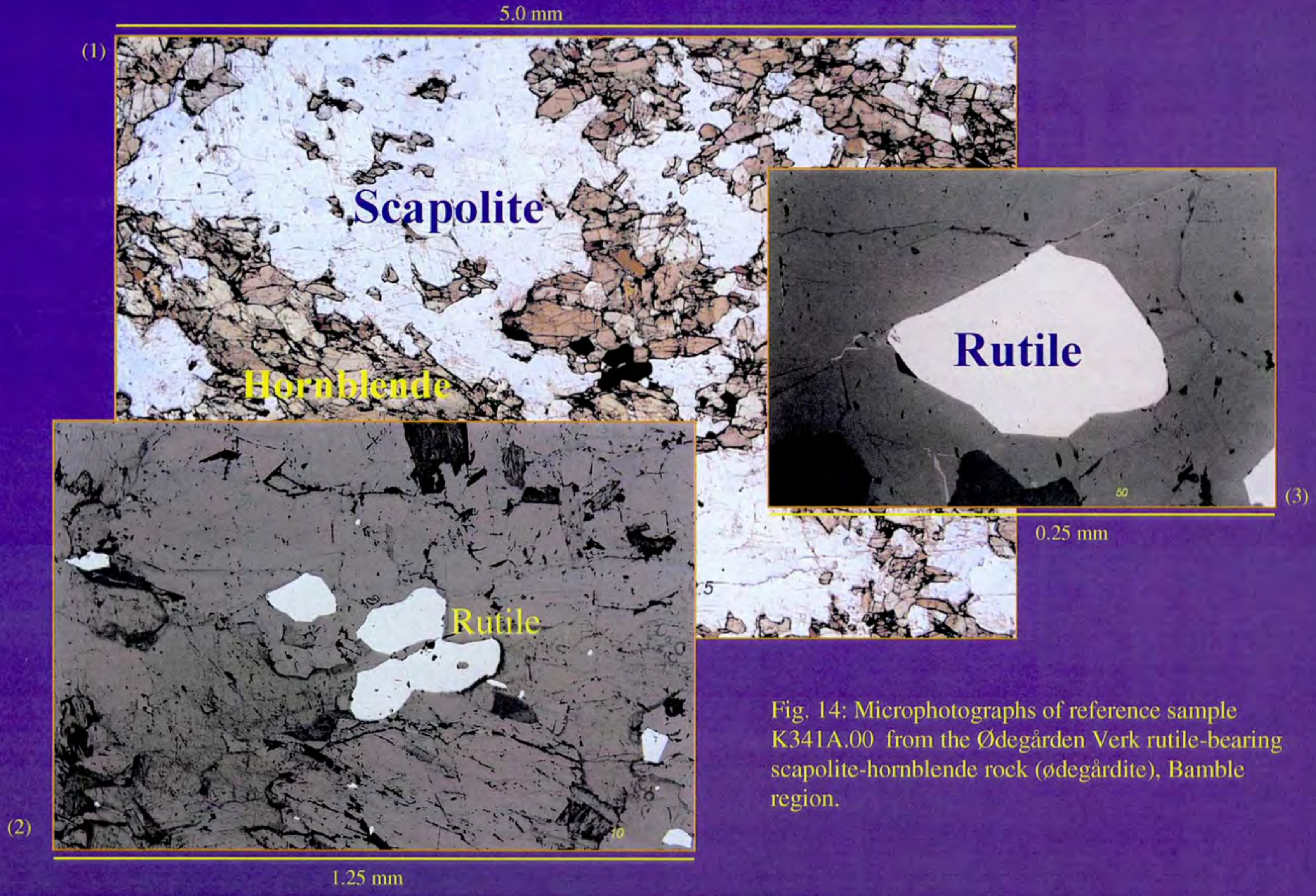


Fig. 14: Microphotographs of reference sample K341A.00 from the Ødegården Verk rutile-bearing scapolite-hornblende rock (ødegårdite), Bamble region.

Sample K341B.00
Ødegårdens Verk

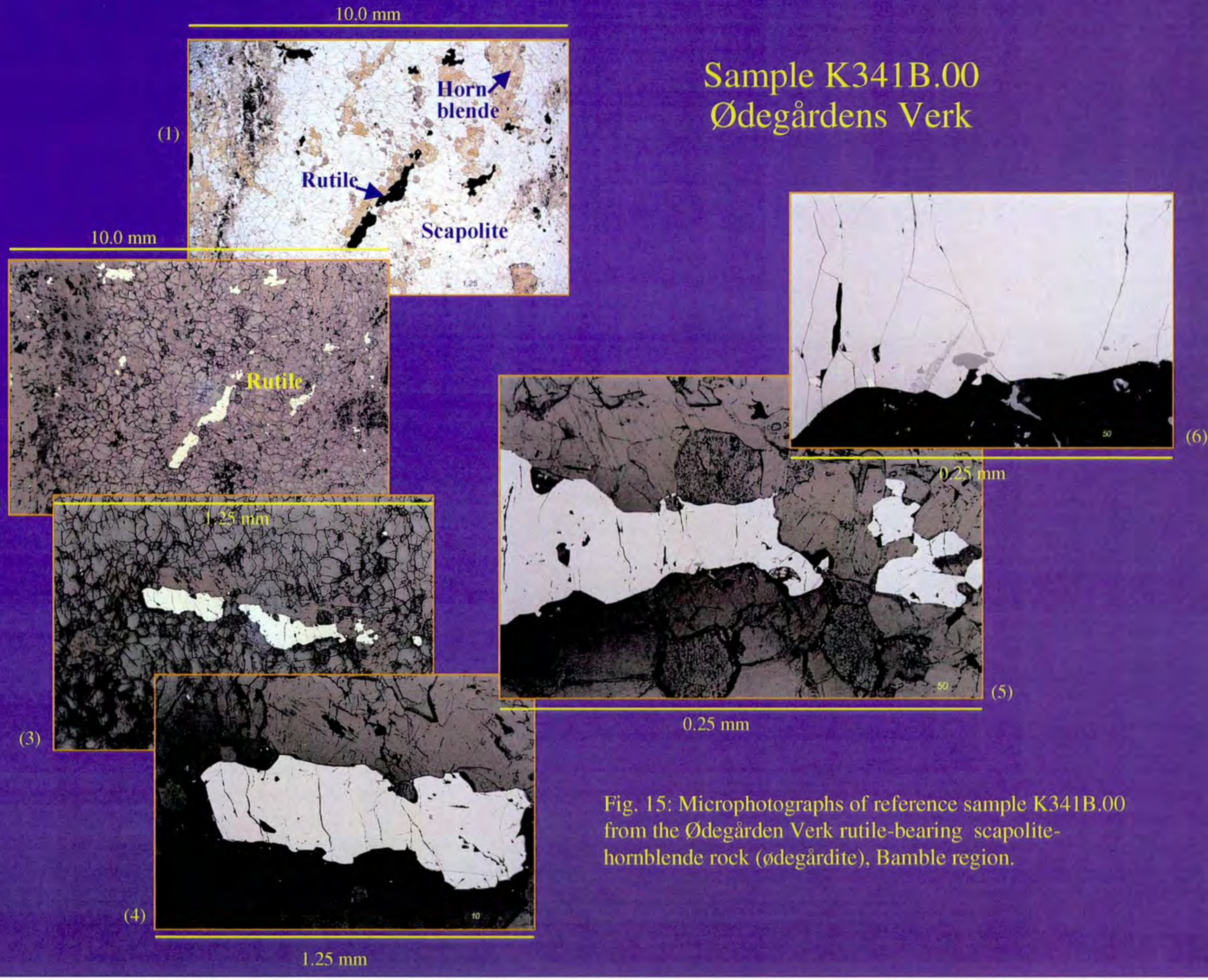


Fig. 15: Microphotographs of reference sample K341B.00 from the Ødegården Verk rutile-bearing scapolite-hornblende rock (ødegårdite), Bamble region.

5. LINDVIKKOLLEN RUTILE DEPOSIT, BAMBLE REGION

Rocks in the Lindvikkollen/Kragero area (after Green 1956):

Amphibolites: The amphibolites typically contains 50-60% of mafic minerals, mainly amphibole, and 40-50% plagioclase. Other common minerals are biotite, magnetite, ilmenite, pyrite, garnet, epidot, sericite, chlorite, calcite and apatite. Less common are quartz, rutile, scapolite, prehnite, titanite, serpentine and zircon. The amphibolites in the area are believed to represent highly-altered gabbros, while others might have a volcanic origin. Scapolite-hornblende rocks (presumably rutile-bearing) are found as alteration facies of gabbro and amphibolite. Hydrothermal iron ores have been formed along "fissures" in the scapolite-hornblende rocks.

Gabbros: The typical gabbro (hyperite) is a heavy, dark brownish-violet, medium-grained rock composed chiefly of clinopyroxene and plagioclase, with lesser amounts of olivine, biotite, orthopyroxene, magnetite, ilmenite, pyrite, apatite. Most of the gabbro bodies are partly altered to scapolite-hornblende rock (presumably rutile-bearing).

Albitite: Most albitite bodies are fine- to medium-grained leucocratic rocks characterised by sodic plagioclase (An 0 to 12) as the major constituent, with highly varying amounts of quartz and microcline, plus the accessory minerals biotite, rutile, titanite, hornblende, tourmaline and zircon.

The albitites occur as dike-like bodies from a few cm up to 400 m. Two major bodies are present in the Storkollen-Blankenberg area; the rutile-bearing albitite (kragerøite) of Lindvikkollen, approximately 350 x 60 m, and the great quartz-albitite mass which extends WNW from the west flank of Storkollen for 2.6 km, with an outcrop width ranging from 40m up to 400m. Many smaller dikes and smears of albitite are found, most of which have conformable but graduational contacts into the surrounding amphibolite.

The albitite at Lindvikkollen is a massive, granoblastic albite-rock with a grain size of about 1-3 mm, and having a grey to pink to white colour when fresh. The plagioclase is an albite (An 3-4), often slightly sericitized. The following occur: rutile, titanite, biotite, tourmaline, apatite, pyrite, actinolite, chlorite, zircon and calcite. Brøgger's name "kragerøite" refers to albitite with a considerable amount of rutile.

Some minerals other than albite make up fairly large volume-percentages in various parts of this body. Quartz make from 0 to 10-15% of the rock, as rounded interstitial grains. Microcline comprises up to 10%. It is, at least in part, replacing albite along grain boundaries and in patches within albite. Small grains of pyrite comprise up to 10% of certain zones of the kragerøite body, and a black tourmaline locally comprises up to 15% of the albitite.
Rutile attains the highest concentration of any mineral in the kragerøite, with the exception of albite. Although distributed throughout the body in amounts of at least 0.5 %, it is found in the easternmost part to form black streaks and concentrations which in the richest zones almost completely exclude all other minerals. These rutile "schlieren" are oriented parallel to the north wall of the body, and thus dip steeply south. The surrounding kragerøite contains roughly 5-8% rutile. This deposit has been mined sporadically since 1901. There is a string of pits and quarries near the northern contact, and two large underground workings exist towards the top of the hill which connect with surface holes. A single-span aerial bucket system took the ore down to a loading pier at the sea level.

The rutile occurs as 0.5-2.0 mm sized, generally equidimensional grains, black in hand specimen but of a deep red colour in thin sections. The grains commonly occur grouped in small streaks, giving a weak gneissic structure to the otherwise massive rock.

Small pegmatite areas in the kragerøite body are made up of the same minerals as the surrounding kragerøite; thus, large grains of albite (An 5-6), rutile, quartz, biotite, pyrite, apatite and titanite.

A large volume of rock lying between the two mines is of a peculiar veined or patchy appearance. The white "patches" are typical medium-grained kragerøite, while the darker patches are a finer-grained, rock consisting of albite, biotite (15 %), tourmaline (4 %), rutile (3 %) and muscovite (12 %) and corundum (1 %, as tiny grains in muscovite).
The main body of kragerøite extends from the top of Lindvikkollen westwards until it reaches a pegmatite striking N on the south-western corner of the hill. Approximately at this pegmatite the kragerøite proper ends, but it reappears at a narrow, conformable dike or sill above the houses west of Rekevik, and from there continues westwards into the fjord. Towards its western terminus this body divides into at least three branches, the northwestermost showing the greatest resemblance to the kragerøite of Lindvikkollen. This branch has also been mined for rutile, but seems to be considerably poorer ore than the main deposit.

The western kragerøite body lies conformably within biotite schists. At the northeastern corner, the large kragerøite body on Lindvikkollen wedges out abruptly, but a thin, rutile-bearing albitite dike can be traced around the end of the hill to a prospect pit on the northern edge of a large pegmatite. The rock prospected here is a heavily rutile- and titanite-bearing albitite also containing considerable biotite, penetrated by veins of a pure white oligoclase rock (An 13) which contains isolated crystals of green actinolite.

The large kragerøite body lies in amphibolite, and where its contact is not faulted or obscured by ground cover or later pegmatites, it is seen to be of transitional nature. The change from amphibolite to albitite is characterised by a gradual decrease in amount of femic minerals (biotite, amphibole, chlorite, tourmaline, apatite) and a parallel decrease in the An content of the plagioclase, while the amount of albite increases and the Mg/Fe ratio in amphibole increases. This transition zone is so wide in most places that an actual contact cannot be pointed out in the field; it is usually a matter of some metres.

Pegmatites: A large number of dikes, pods and more irregular bodies of pegmatite occur in the area. In general, they can be divided into microcline-pegmatites and plagioclase-pegmatites.

Schists: Variations between amphibolites and quartz-mica schists, with such intermediate types as gedrite-biotite-andesine schist, biotite-hornblende-oligiclase-scapolite schist and biotite- tourmaline-quartz-oligoclase schist. See descriptions by Green (1956) and Brøgger (1933, 1934).

Quartzites: Commonly impure quartzites, relative pure varieties have been mined in the past.

The rutile-bearing albitite at Lindvikkollen was mined for rutile during the period 1901-50 and produced about 3000 tonnes of rutile concentrate (Bugge 1978). The deposit was investigated by the company A/S Sydvaranger in the middle 1970'ies. This investigation included geological mapping and the core-drilling of 5 holes, 838 m in total. 120 m of these cores are stored at NGUs core storage-facilities at Løkken. The reports from A/S Sydvaranger are not available, but according to Bugge (1978) A/S Sydvaranger calculated the deposit to be 3 million tons of kragerøite with 2 % rutile.

Ore potential: The Lindvikkollen deposit is probably too small to be of economic interest. Albitites in neighbouring areas do contain rutile mineralisations here and there, but good information of the size of these deposits is not available. The potential for large tonnage of rutile/albitite ores is probably much less than for the rutile-bearing scapolite rocks.

Table 5: Major element XRF- and rutile analyses of rutile-bearing albitite from Lindvikkollen (after Korneliussen & Furuhaug 1993).

Sample no	KB11A.91	KB11B.91	KB11C.91	KB11D.91	KB11E.91
% SiO_2	62.99	65.76	63.70	64.93	62.78
% Al_2O_3	18.82	18.53	18.24	20.13	20.03
% Fe_2O_3	0.24	0.28	0.40	0.53	0.90
% TiO_2	2.98	2.97	4.15	1.20	3.22
% MgO	0.08	0.07	0.25	0.44	0.81
% CaO	1.08	1.26	1.28	1.18	1.15
% Na_2O	7.13	9.83	9.73	10.23	10.18
% K_2O	5.26	0.88	0.90	0.69	0.24
% MnO	0.01	0.01	0.01	0.01	0.01
% P_2O_5	0.16	0.23	0.21	0.06	0.15
% LOI	0.39	0.21	0.21	0.57	0.48
% SUM	99.14	100.03	99.08	99.97	99.95
% Rutile	2.88	2.72	3.87	1.17	3.17
Rel.% rutile	97 %	92 %	93 %	98 %	98 %
Average rel. % rutile:		95 %			

6. DISCUSSION AND CONSCLUSION

The Ramsgrønova and Orkheia eclogites are representative for rutile-bearing eclogites lying within granitoid gneisses in the Dalsfjord region, but they are quite different from eclogites within large masses of mafic rocks such as the Saurdal eclogite (Fig. 2). The main difference is that eclogitisation of the "within gneiss" eclogites has been 100 % efficient and no relics of previous mineral assemblages are found. Consequently, transformation of titanium into rutile has been almost 100 %. Any traces of ilmenite intergrown with rutile are probably effects of retrogression.

However, the 50 kg samples sent to RTIT (K330.00 and K331.00) belong to the Ti-rich parts the respective deposits, and must not be considered as average eclogite.

A rough estimate is that 1/4 of the total volume of the Ramsgrønova and 1/3 of the Orkheia deposit is eclogite of ore quality (i.e. > 3 % rutile). Then each of these deposits might contain 20-30 million tons of ore-type eclogite.

All these deposits have coarse-grained rutile with 90% or so of the titanium in the rock within rutile larger than 100 μm, which is significantly coarser than at Engebøfjellet (Korneliussen et al 1999). However, the overall rutile grade, when considering a large volume of rock, is relatively low (2-3 %), and distinctly lower than Engebøfjellet.

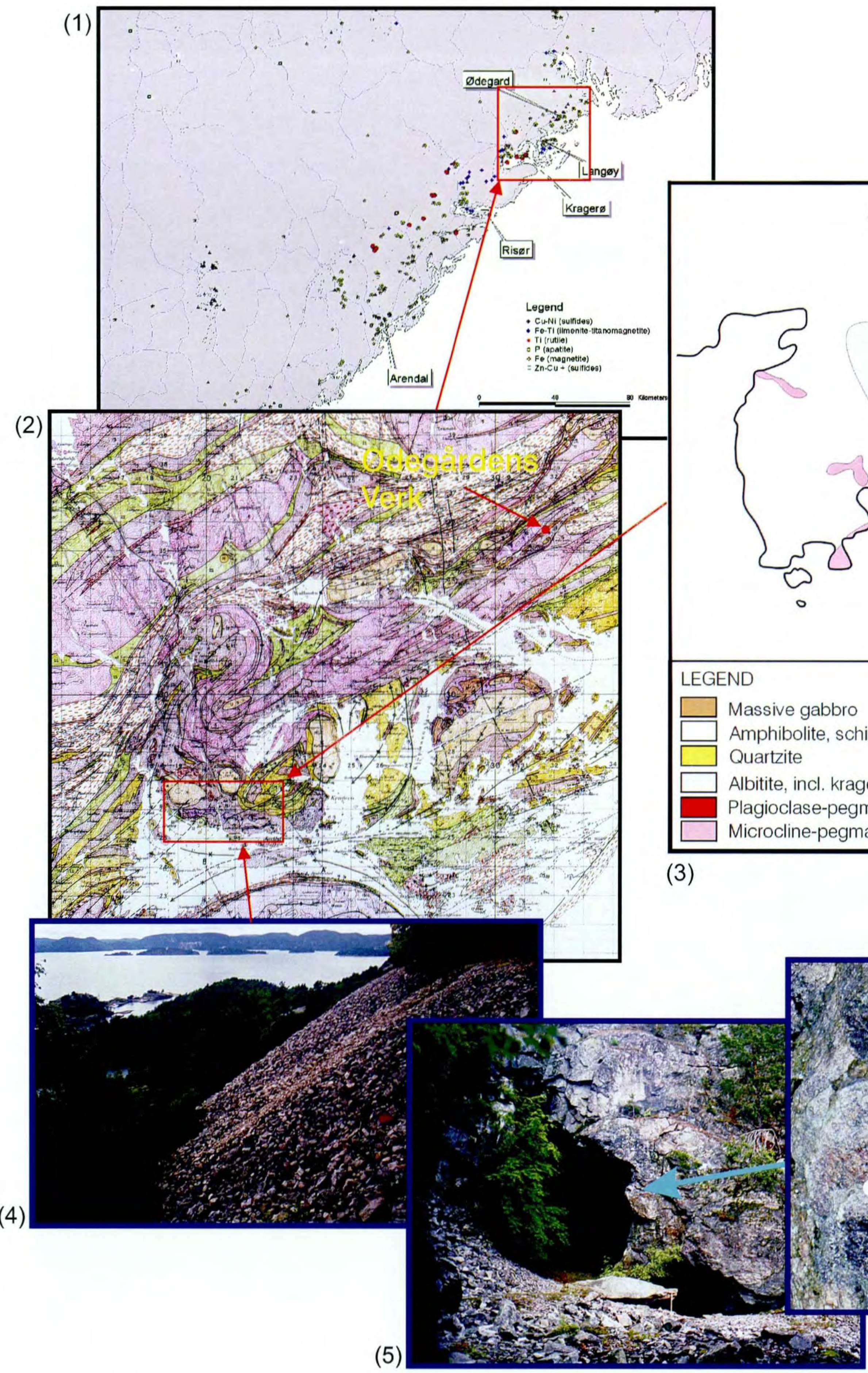
In the case of Ramsgrønova and Orkheia there is a significant potential for new deposits to be identified by continued exploration (gravimetrics followed up by drilling).

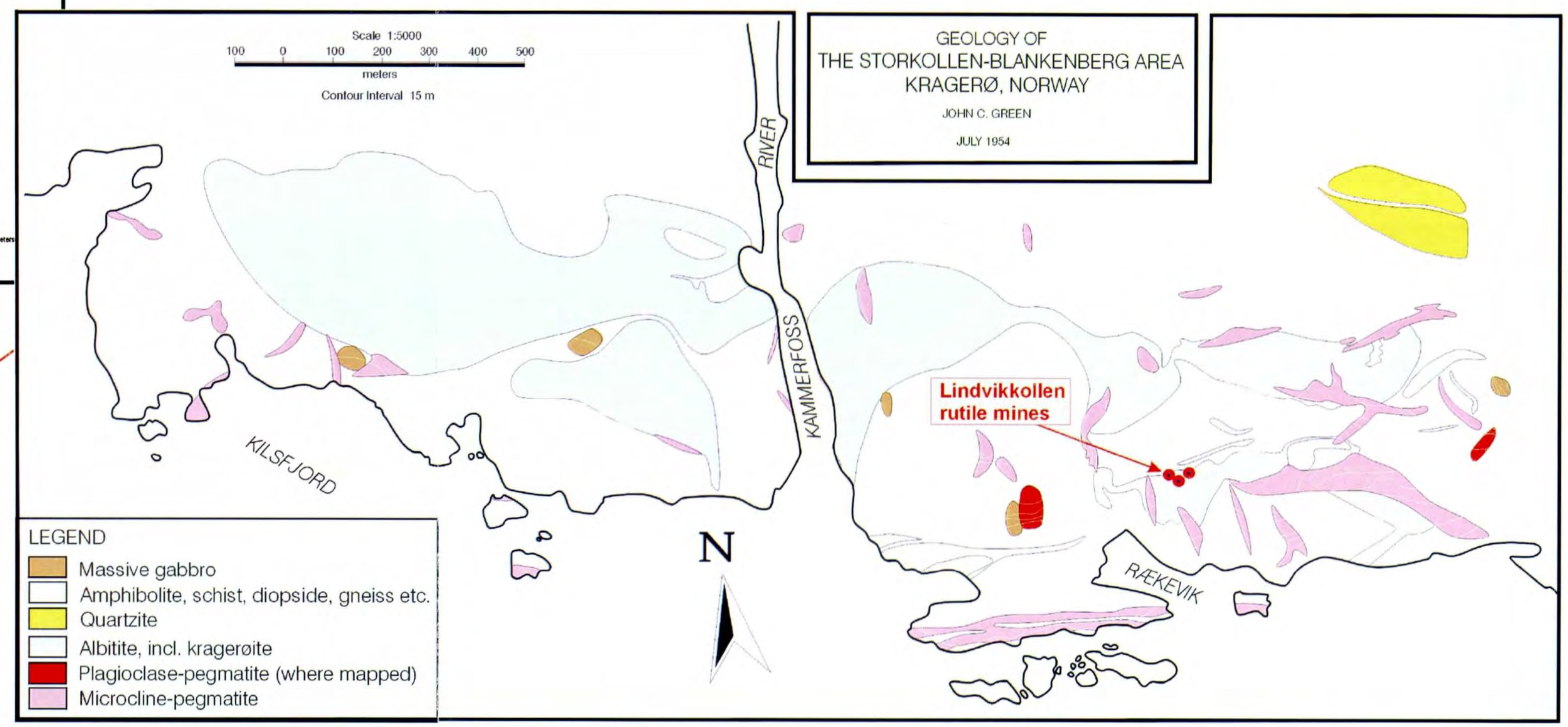
Lindvikkollen

Rutile-bearing albitite (kragerøite),
Kragerø, South Norway

(1)

(2)

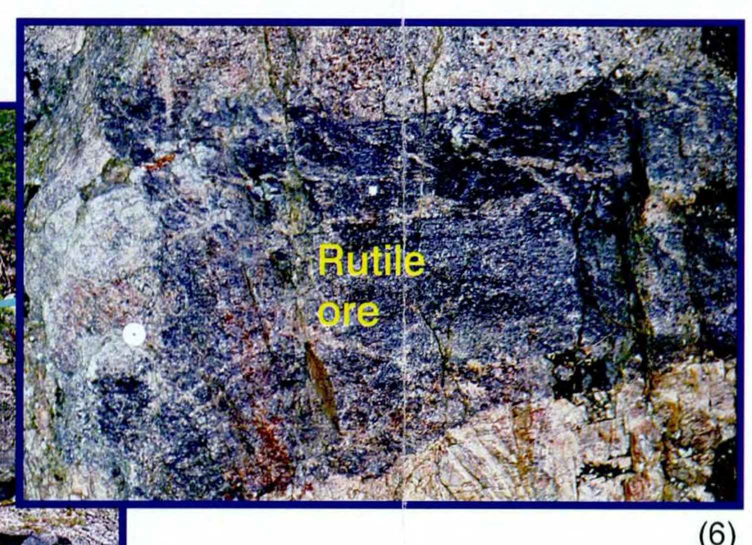




(3)

(4)

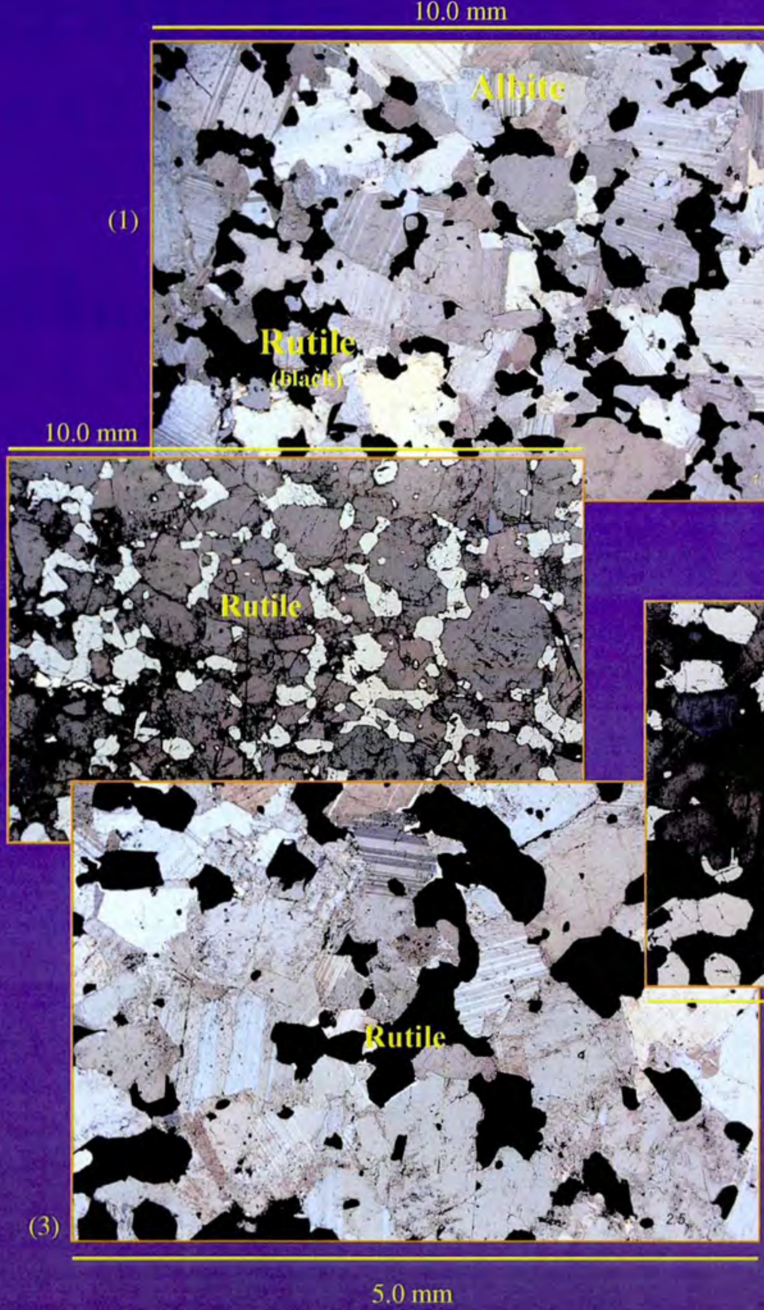
(5)



(6)

Fig. 16: The Lindvikkollen rutile-albitite deposit, Kragerø municipal, S. Norway. (1): Overview map of ore deposits in the Bamble-Arendal region (also called Bamble Shear Belt), S. Norway. (2): Geological map of the Kragerø area (after Padget 1999). (3): Geological map of the Lindvikkollen-Rekevik area, simplified from Green (1956). (4): Photograph of ore tailings from the old Lindvikkolen rutile mine. (5): Photograph of one of the old mine openings at Lindvikkollen. (6): Photograph of rutile ore (dark) in albitite on the rock wall of the mine opening shown in (5).

Sample K342A.00
Lindvikkollen



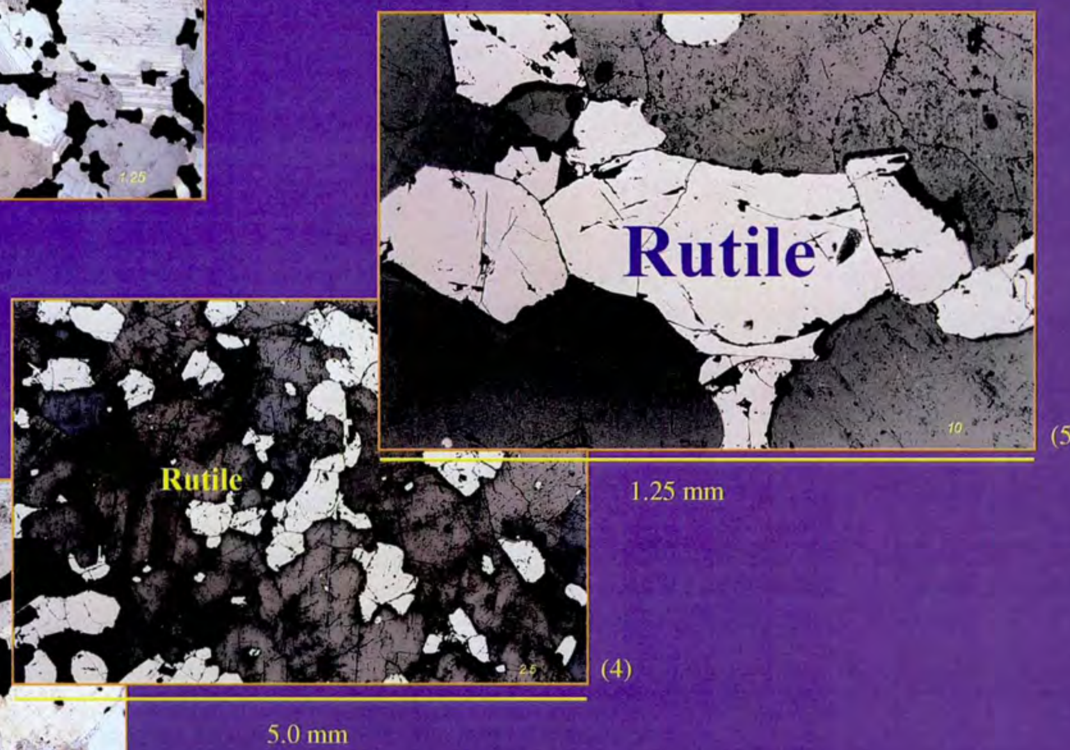


Fig. 17: Microphotographs of reference sample K342A.00 from the Lindvikkollen rutile-bearing albitite (kragerøite), Kragerø, Bamble region.

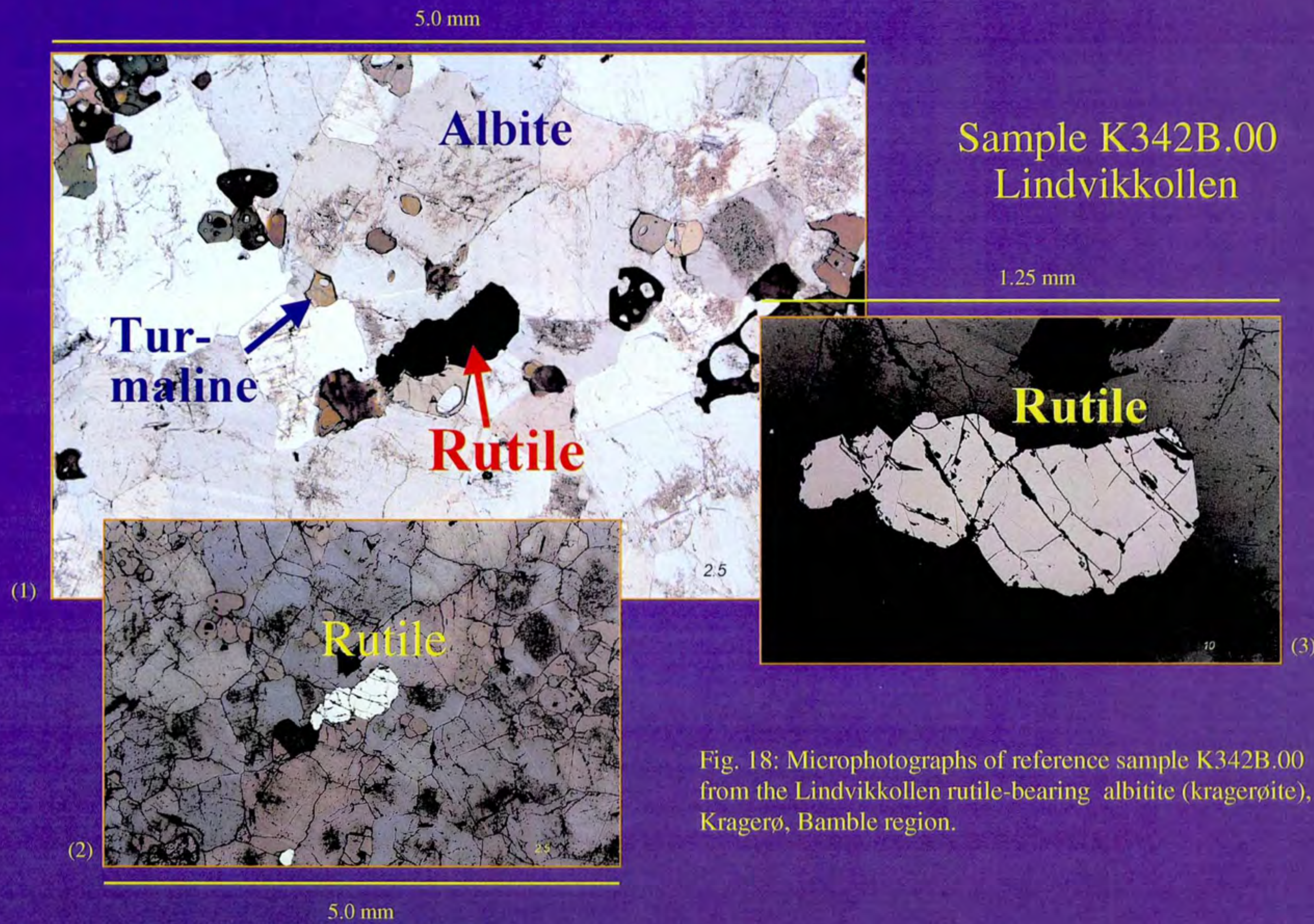


Fig. 18: Microphotographs of reference sample K342B.00 from the Lindvikkollen rutile-bearing albitite (kragerøite), Kragerø, Bamble region.

The Bamble region eclogites are very different from eclogite deposits elsewhere in Norway. The Ødegårdens Verk rutile-bearing scapolite-hornblende rock is the most distinct of this type of deposits in the region. It is relatively large and homogeneous over an area of more than 150,000 m^2 with a significant potential for continuation at depth, but it is low grade (1.5-4.0 % rutile). The Lindvikkollen deposit, on the other hand, is heterogeneous in its rutile grade varying from 1-2 % to more than 10% rutile.

The Ødegården deposit was formed by metasomatic and hydrothermal alteration of a relatively homogeneous ilmenite-disseminated gabbro and the present rutile mineralisation is a reflection of the ilmenite-dissemination in the protolith. The Lindvikkollen might have formed from a much more heterogeneous protolith, presumably a gabbro with cumulate enrichment of Fe-Ti oxides, now present as rutile-rich layers and "fragments" in the albitite. It may also be that titanium has been significantly mobile during the albitisation process at Lindvikkollen, leading to enrichment in some parts of the albitite and depletion in other parts.

Recommendations for continued investigations.

(1) *Rutile-bearing eclogites in the Dalsfjord region.* The possibilities for an ore reserve of 100 million tons or so of eclogite with at least 3 % rutile, either as a single individual deposit or as a combination of several closely spaced deposits such as Ramsgrønova and Orkheia, are probably relatively good. However, continued exploration will require a series of gravity profiles to be followed up by detailed interpretation work and geologic field work in the anomaly areas. The next stage after that will be core drilling. In practise, a gravity survey with interpretation/model work could be carried out in May/June 2001, and core drilling of favourable gravity anomalies can then be done in the autumn 2001.

(2) *Metasomatic rutile deposits in the Bamble region.* Continued investigations should be done at Ødegårdens Verk if the beneficiation test by RTIT gives positive result. If so, a series of relatively short drillholes, either core drilling or percussion drilling, should be done in order to cover a large part of the deposit area. Due to easy access, such drilling can be done at any time of the year. Further investigations elsewhere in the Bamble region should not be done until the results of the stream sediment sampling (see separate report) done in October 2000 have been evaluated.

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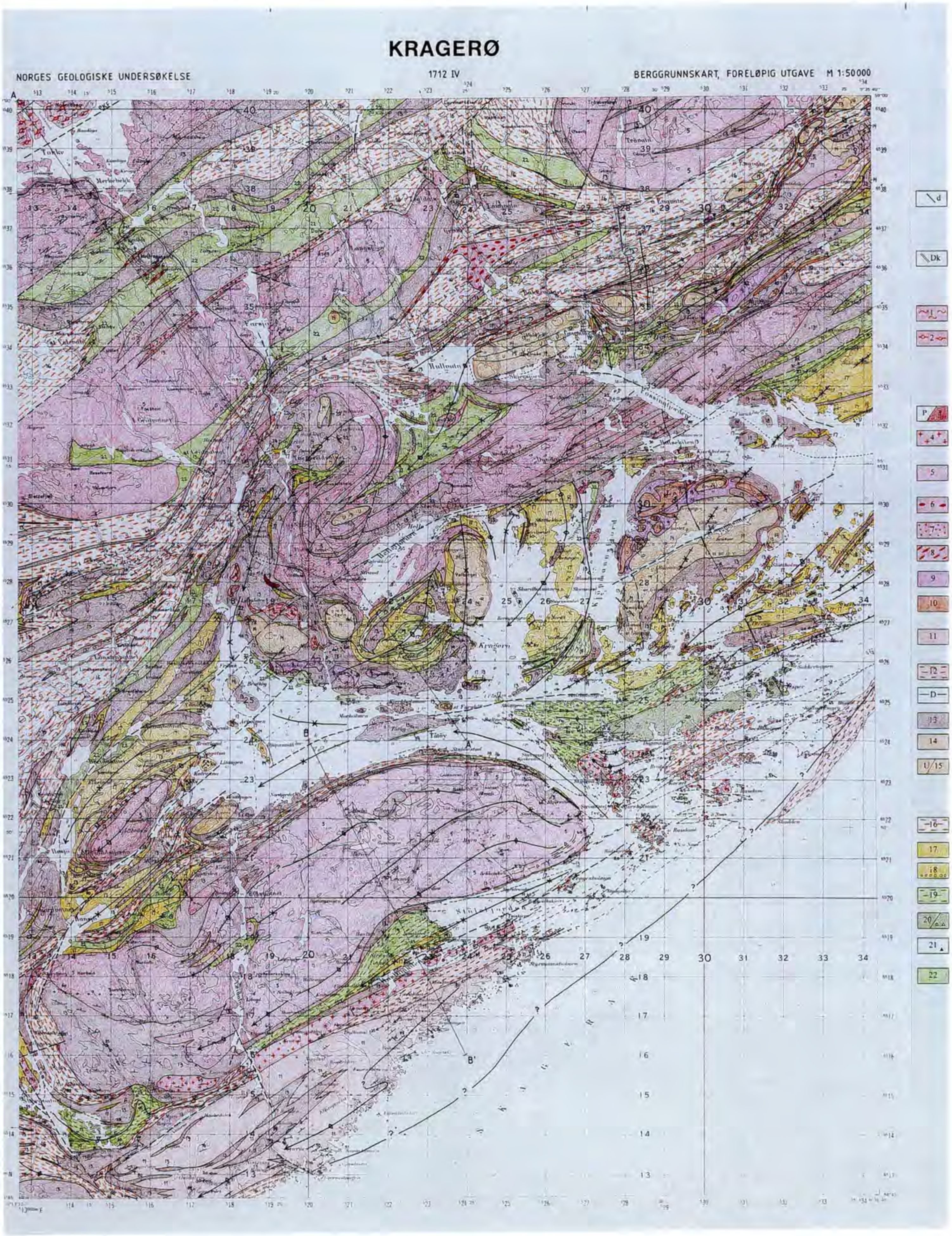
Appendix 1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