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The graphite schists in the Gjerstad-Kragerø area and their graphite potential, Southern Norway

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Title:
The graphite schists in the Gjerstad-Kragerø area and their graphite potential, Southern Norway

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Summary:

The purpose of this report is to present the available data regarding the graphitic schists in the Gjerstad-Kragerø area and to make the data available for explorers and municipal land use planners.

The graphite schists that occur southeast of Lake Vegård in the Gjerstad, Kragerø and Tvedestrand area have an average content of graphitic carbon of 2.77 %. Rocks from the abandoned Bjørnås mine have contents up to 33 %. The investigated area comprises a large area with low grade graphitic rocks and there is an almost complete airborne geophysical covererage with EM and MAG data.

In thin section the typical modal content of graphite is about 8 %

The graphite schist occur highly modified and dismembered by later migmatization and are usually found as small, some meters thick, lenses or patches within the migmatitic gneisses. At some localities (particularly near Kjølebrønn) the graphite schist can be followed continuously for several hundred meters.

When comparing the previous geological mapping (Touret 1968) with the airborne geophysical maps there seems to be an overlap of areas with an apparent resitivity of about 350 Ωm and the graphite bearing horizons. However, in the field this relationship is not everywhere obvious because the graphite schists always constitute the most weathered rocks in the area, occupying marshes and other low lying and overburdened areas.

Keywords: **Fagrapport**	Migmatite	Geophysics
Graphite	Mineral deposit	Geofysikk
Grafitt	Mine	

CONTENTS

Contents

FIGURES

TABLES

ATTACHMENT

Analytical data, C and S by Leco, main element by XRF

1. INTRODUCTION

The area between Gjerstad and Vegårshei in the northeast and Arendal in the southwest has been known for many years to contain areas with graphite schists and graphite bearing rocks. It was also the location of Norway's first graphite mine (1768-1775). The purpose of this report is to present a general description of the graphite bearing rocks, their areal extent and the range and variation of the graphite (carbon content). The main target group would be prospectors who might consider graphite exploration in this area and land use planners in different municipalities that should be aware of the graphite potential in the area. Field work was carried out in 2013. The descriptions and analytical results from the various occurrences have since 2013 been available in the Geological Surveys Mineral deposit database www.prospecting.no where all analytical details can be downloaded.
To keep this report concise, the use and markets for graphite will not be covered. Nor will any general geological descriptions be given, unless considered particular relevant to this report.

2. PREVIOUS INVESTIGATIONS RELATED TO GRAPHITE MINERALIZATIONS.

About 300 meter NE of the eastern end of Lake Bjørnåsvann the remains of Norway's first graphite producing mine can be found. The Englidahlske Blyants- og Isenfarve Værk (Englidahlske pencil and iron color works) was in operation from 1768 to 1792. The plant was located at the waterfall from lake Skorstølvatnet, 3 km east of the mine. The mine is described in chap. 4.2. Nothing is visible of the plant today.

The Bamble province, of which the investigated area is part of, is among the best studied geological provinces in Norway and it is also one of the most geological complex areas. Previous investigations cover almost all fields of geology, among other, metamorphic and magmatic evolution, metasomatic processes, mineralogy, economic geology, isotope geology and large scale geodynamic modeling. It is beyond the scope of this report to give a comprehensive review of all the previous geological work in the area.

The Geological Survey of Norway mineral resource database has four graphite prospects listed, but only one of these can be located with accuracy today (see chap 4.2).

2.1 Previous geophysical investigations

In 2006 Fugro Airbone Surveys performed an airborne geophysical survey, using a DIGHEM EM bird and magnetometer, carried out for AS Sulfidmalm over several properties located in south central Norway; near Ertelien, Bamble and Evje. Total coverage of the survey blocks amounted to 14559 km. The survey was flown from March 8th to April 18th, 2006. The purpose of the survey was to detect zones of conductive mineralization and to provide information that could be used to map the geology and structure of the survey areas. This was accomplished by using a DIGHEM multi-coil, multi-frequency electromagnetic system, supplemented with a horizontal magnetic gradiometer. The information from these sensors was processed to produce maps that display the magnetic and conductive properties of the survey areas. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base maps. The survey data were processed and compiled in the Fugro Airborne Surveys' Toronto office. Map products and digital data were provided in accordance with the scales and formats specified in the Survey Agreement. AS Sulfimalm was subsequently taken over by Blackstone Ventures. After Blackstone Ventures' liquidation the geophysical data was transferred to NGU and are available upon request from

www.ngu.no. Technical details regarding this geophysical survey is reported by Garrie (2006).

3. GEOLOGICAL SETTING

We limit the review of the regional geology and setting to what we consider relevant for this contribution.

The investigated area is part of the Late to Mesoproterosoic – Early Neoproterosoic Sveconorwegian mobile belt SMB (Andersen et al. 2004 and references therein). The rocks of the SMB comprise a volcanosedimentary sequence, which includes quartzites, garnet bearing paragneisses, graphite schists, cordierite bearing gneisses and a Kiruna type iron formation intruded by calc-alkaline granitoids (Andersen et al 2004, Slagstad et al. 2013). The present distribution of the rocks is the result of the Sveconorwegian orogeny, during which the crust was reworked and separated into different terranes or blocks, commonly separated by large shear zones (Andersen 2005, Bingen 2008, Slagstad et al. 2013). There appears to be a less than complete consensus among the scientists working with the regional geology of both this area, and the Norwegian Sveconorwegian domain in general, regarding the tectono-metamorphic and magmatic evolution, and the plate tectonic setting.

The first geological study that describes the areal extent of graphite bearing rocks in the investigated area is that of Touret (1968), which is still the most relevant general study showing the areal extent of the graphite bearing rocks. The graphite bearing rock units are also partly shown and described by Hagelia (1989) and Kihle (1989).

Touret (1968) regarded the graphite schists to be part of what he referred to as the "old group". In addition to graphite schists the old group comprises rock types such as quartzites and banded paragneisses, believed to represent greywackes, metacarbonates and acid metavolcanics. A modified version of the Touret (1968) map is shown in Fig. 1.

4. GRAPHITE BEARING ROCKS

4.1 Distribution and lithologies

Graphite bearing rocks are very abundant in an area extending from the Sunde bridge (at the southern end of lake Gjerstadvatn) and southwest towards Ubergsmoen and Tvedestrand (Fig.1). Another area with abundant graphite schists is near Kjølebrønn southwest of Kragerø (Gautneb 2013) where it extends in southwestern direction towards Dobbe and lake Mørlandstjerna (Fig.9). The graphite schists occur highly modified and dismembered by later migmatization, and are usually found as small, some meters thick, lenses or patches within the migmatitic gneisses. At some localities (particularly near Kjølebrønn), the graphite schist can be followed continuously for several hundred meters.

The graphite schists appear in the field as rusty brown to yellow, usually strongly weathered rocks (Fig. 2). They contain abundant iron sulphides, in addition to quartz, plagioclase (An 28-35), microcline, biotite, garnet, and at some localities also cordierite. The mineral compositions indicate that the graphite bearing schists represent organic rich clay or pelitic sediments. The graphite crystals occur most commonly as individual crystals; at some localities up to 1 mm in size (Fig. 3)

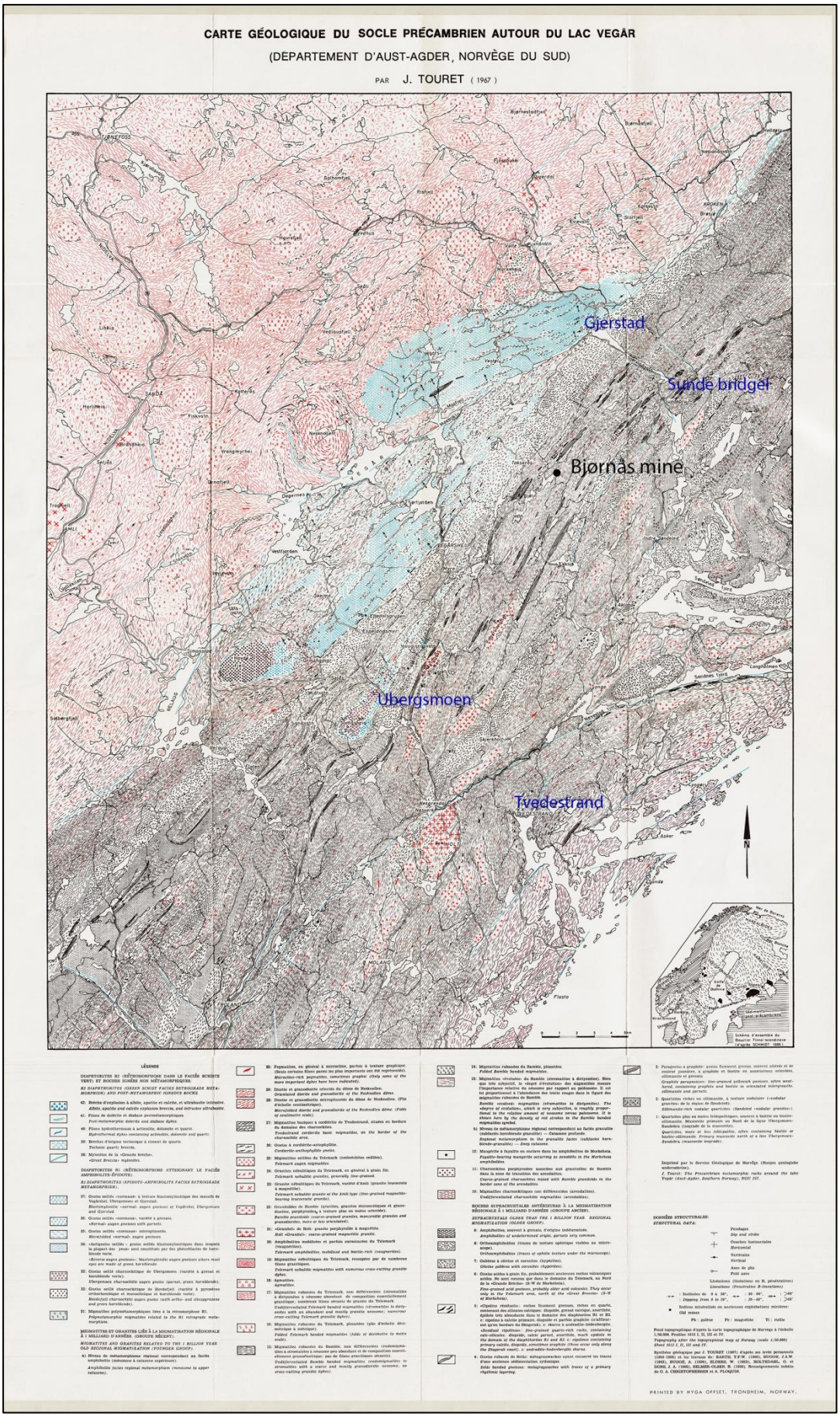


Figure 1 Geological map showing the locality of the Bjørnås mine and the distribution of the graphite bearing rocks (modified from Touret 1968)

Figure 2 Typical locality showing the rusty and strongly weathered graphitic schist.

Figure 3 Close up showing coarse grained graphite flakes in the rusty graphitic schist. This is the locality of sample hg38-13 in Tab. 1. at Stabbestad.

4.2 Bjørnås graphite mine

The Bjørnåsen graphite mine is situated about 300 meters NW of lake Bjørnåsvann, situated a few meters to the east of a forest road. The mine can be seen today as a 2-3 meters wide and 15 meters long water filled hole, with strike 075^{o} and dipping 70^{o} towards the east (Fig. 4). The forest road cut through and is partly constructed using the spoil heap from the former mine. In the spoil heap samples can be found which are very rich in flaky graphite (Fig. 5). The graphite ore seem to occur as one major compact lens, with thinner and more disseminated graphitic bands in the foot and hanging walls.

Reconnaissance with EM 31 handheld EM receiver along the strike of the ore body showed that the deposit is fairly constrained and cannot be followed for more than about 50 meters along strike.

Figure 4 Water filled mine workings at the Bjørnås graphite mine at Gjerstad.

Figure 5 Waste rock dump from the Bjørnås graphite mine at Gjerstad

4.3 Geophysical signature of graphite bearing rocks

The graphite bearing metasedimentary rocks give a medium but clear geophysical signature, indicated by bands with an apparent resistivity of about 350 Ωm (see Fig 9 or the geophysical raw data). It is reasonable to assume that the graphite-rich metasedimentary rocks are overlapping with the about 350 Ωm resistivity areas, in agreement with the map of Touret (1968). However, in the field this relationship is not everywhere obvious, because the graphite schists always constitute the most weathered rocks in the area, occupying marshes and other low lying and overburdened areas.

In areas near the coast the bedrock may be overburdened by marine salt bearing clays giving rise to a false geophysical anomaly of conducting (and graphite bearing) bedrock. In our area this is particularly the case southwest of Kragerø (near Kjølebrønn).

Readers interested in the spatial distribution of the graphite bearing metasedimentary rocks are referred to the geophysical data obtainable from the Geological Survey of Norway (www.ngu.no).

5. ANALYSES

5.1 Petrography of the graphite schists

The graphite schist are most commonly even- and medium grained rocks. They are strongly schistose, banded and foliated. In good exsposures they show evenly distributed sub-idiomorphic crystals of graphite with a typical grain size up to 1-2 mm. Typical associated minerals are quartz, k-feldspar, biotite and minor sillimanite and clino-pyroxene (Figs. 6, 7 and 8). The graphite crystals are most commonly arranged parallel to the general foliation of the rock (Fig. 6) but at the same time seem to overgrow many of the silicate minerals. This is particularly evident in Fig. 7 where the graphite crystals overgrow both the mica, quartz and

feldspar in the thin section. In the investigated thin sections the modal graphite content is about 8 %, measured using imaging analysis systems. (Zeiss axiovision).

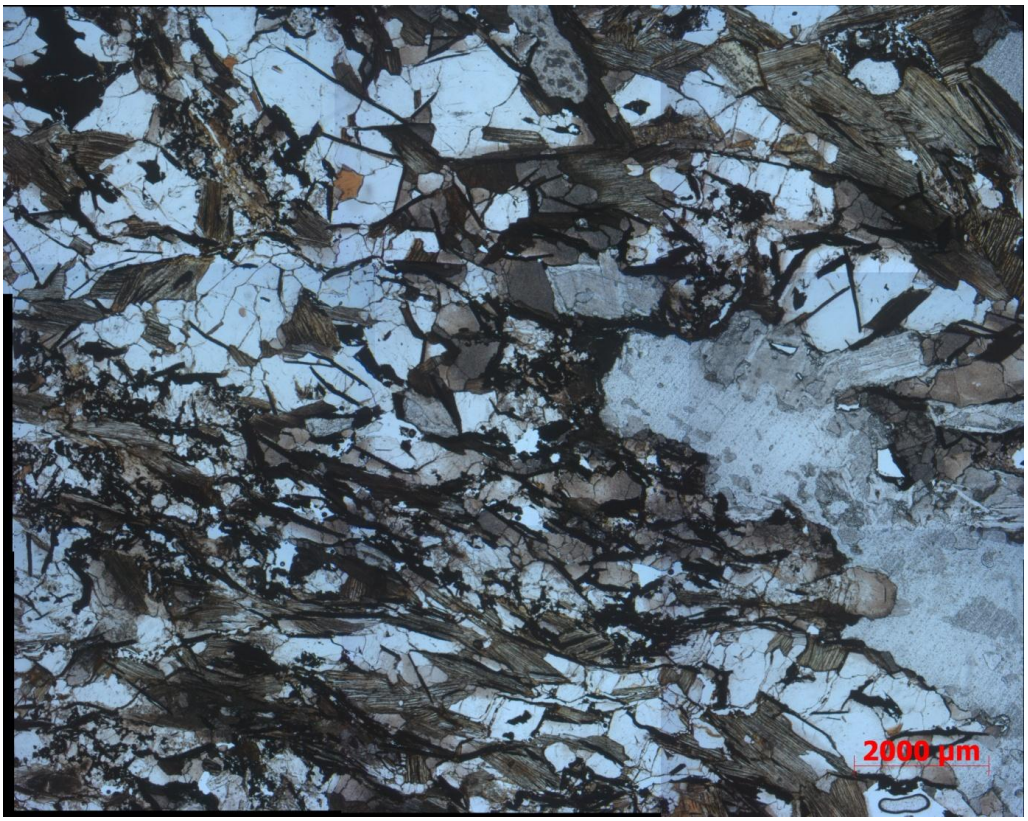


Figure 6 Large area (mosaic) thin section image of samples hg41-13 showing the size and orientation of graphite crystals.

Figure 7 Thin section image of sample hg41-13 showing the overgrowth of graphite over minerals like quartz feldspar and mica

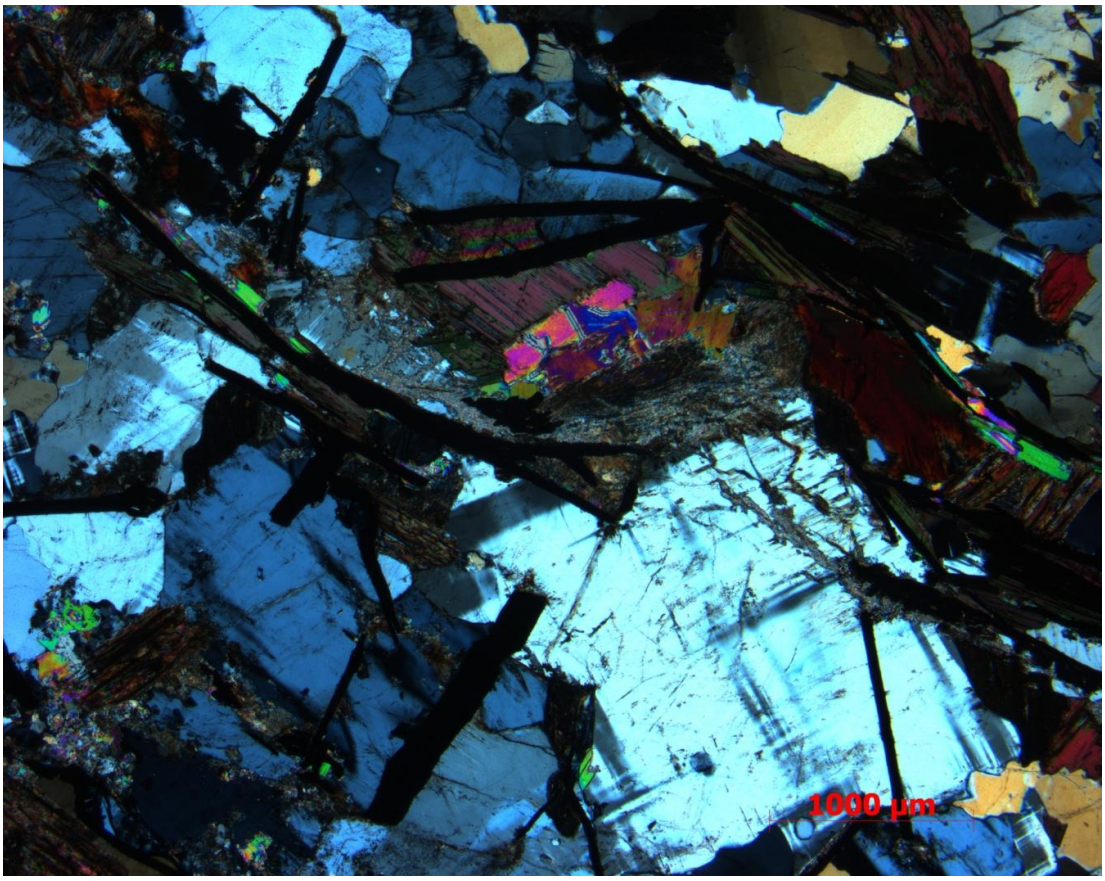


Figure 8 Thin section of Fig. 7 in crossed polars

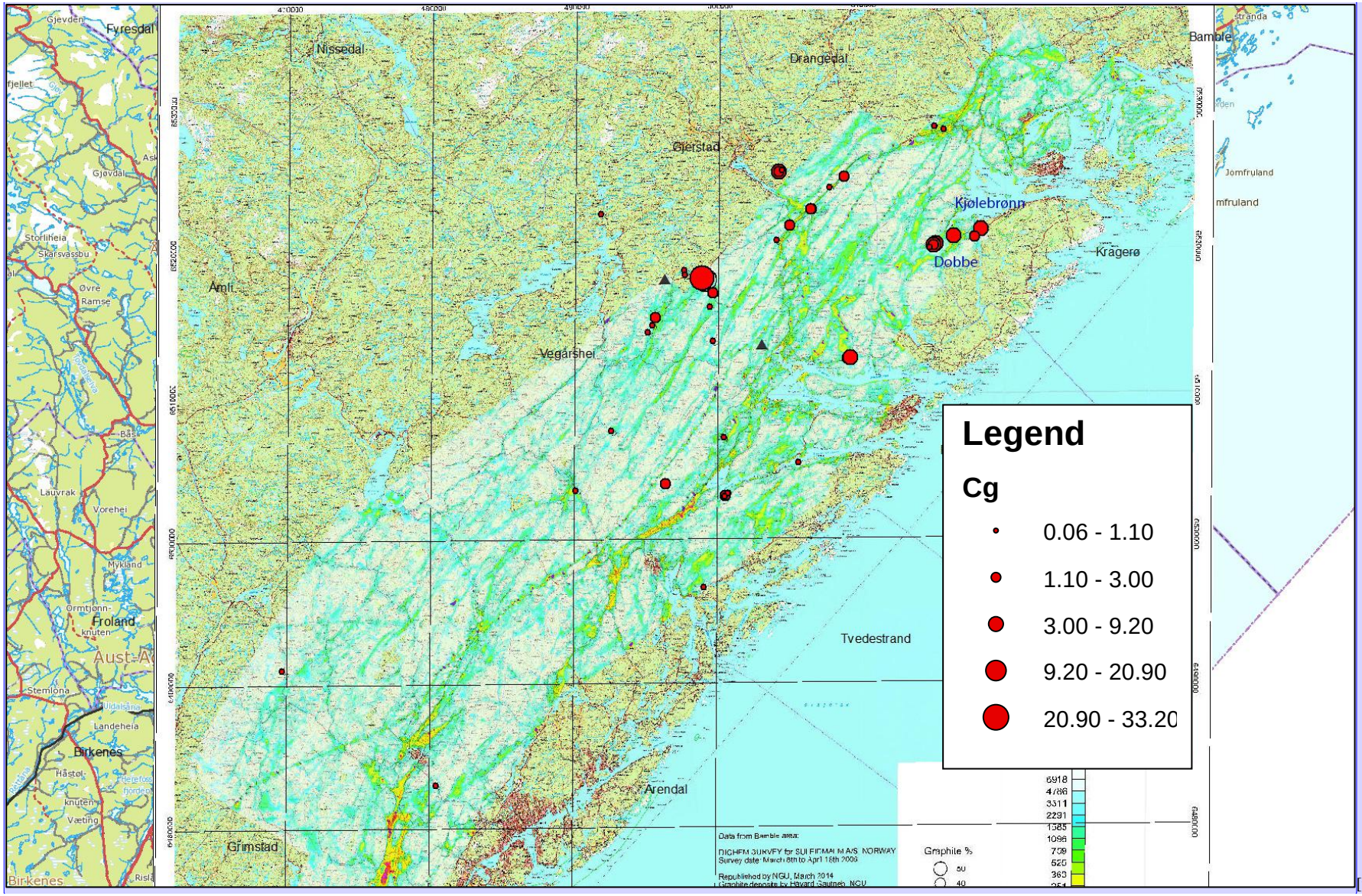
5.2 Chemical analysis

Samples of graphite bearing rocks where collected and analyzed with a Leco carbon analyzer and by XRF for main and trace elements using the analytical facilities of NGU lab. The results are shown in Table 1.

Complete analytical data are shown in the attachment.

Apart from the samples from the Bjørnåsen graphite mine which have a graphite content that varies from 13 to about 33 % Cg (total carbon in graphite form), most of the samples must be regarded as a low grade rock with a graphite content below 4 % Cg. A few samples can reach grades up to about 9 %. The measured grades are low compared to what is common in other parts of Norway (Gautneb, H. 2013) but comparable to what is in production in countries like Madagascar and Mozambique, and under exploration and development in Canada and the USA.

The spatial distribution of the samples is shown in Fig. 9 plotted on the geophysical EM map. Apart from the samples from the Bjørnås mine the samples with the highest graphite content occur in the area near Kjølebrønn SW of Kragerø.



[w1]

Figure 9 Spatial distribution of samples ranked by graphite content, superimposed on airborne geophysical map[w1]. Graphitic carbon (Cg) in percent..

Table 1 Analyses of graphitic carbon (%Cg) and total sulphur in the sampled rocks. See attachment for complete analytical data.

Sample No	E_UTM	N_UTM	Description	% Cg	%S
hg1-13	508831	6525013	Paragneiss with small lenses of graphite schist	1.70	0.06
hg2-13	499031	6517978	Graphite sample from Bjørnås mine	32.60	0.38
hg3-13	499031	6517978	Graphite sample from Bjørnås mine	20.87	0.03
hg4-13	499031	6517978	Graphite sample from Bjørnås mine	13.40	0.24
hg5-13	499031	6517978	Graphite sample from Bjørnås mine	33.27	0.05
hg6-13	497802	6518509	Low grade rust y graphite schist	0.20	1.33
hg7-13	497809	6518211	Low grade rust y graphite schist	0.50	0.54
hg8-13	500614	6502944	Coarse grained graphite hydrothermal type	2.94	0.02
hg9-13	500614	6502944	Coarse grained graphite hydrothermal type	1.32	0.02
hg10-13	500614	6502944	Coarse grained graphite hydrothermal type	2.32	0.03
hg13-13	500614	6502944	Low grade rust y graphite schist	0.92	0.01
hg15-13	500832	6503110	rusty fine grained graphite schist	0.58	0.11
hg16-13	500797	6503092	rusty fine grained graphite schist	0.56	0.05
hg17-13	505667	6505255	Low grade rust y graphite schist	0.76	0.16
hg18-13	505667	6505255	Low grade paragneiss	0.66	0.01
hg19-13	499131	6496587	Low grade paragneiss	0.44	0.05
hg20-13	504156	6520586	Low grade paragneiss	0.16	0.10
hg21-13	505104	6521601	low grade graphite shist	2.42	0.13
hg22-13	506570	6522777	low grade graphite shist	1.06	0.05
hg23-13	506561	6522774	low grade graphite shist	1.36	0.02
hg24-13	506559	6522763	low grade graphite shist	2.00	0.07
hg25-13	506549	6522758	low grade graphite shist	2.28	0.02
hg26-13	504318	6525334	Low grade paragneiss	5.50	0.13
hg27-13	504318	6525334	Low grade paragneiss	1.46	0.01
hg28-13	504309	6525324	Low grade paragneiss	2.14	0.10
hg29-13	504533	6525436	Low grade paragneiss	0.12	0.05
hg30-13	492019	6522368	Low grade paragneiss	0.74	0.88
hg31-13	492019	6522368	Low grade paragneiss	0.06	0.60
hg32-13	490255	6503287	Low grade paragneiss	0.18	0.01
hg33-13	492740	6507412	Low grade paragneiss	0.06	0.01
hg34-13	492746	6507421	Low grade paragneiss	0.12	0.01
hg35-13	495263	6514203	Paragneiss with small lenses of graphite schist	0.22	0.06
hg36-13	495551	6514714	Rusty fine grained graphite schist	0.84	0.27
hg37-13	495797	6515254	Rusty fine grained graphite schist	2.54	1.32
hg38-13	518265	6521380	Rusty graphite schist with coarse grained graphite	1.28	0.45
hg39-13	518289	6521383	Rusty graphite schist with coarse grained graphite	4.76	0.80
hg41-13	518305	6521396	Rusty graphite schist with coarse grained graphite	4.38	1.39
hg42-13	517842	6520890	Rusty graphite schist with coarse grained graphite	1.26	0.42
hg43-13	516481	6521103	Rusty graphite schist with coarse grained graphite	0.14	1.01
hg44-13	516432	6520900	Rusty graphite schist with coarse grained graphite	3.72	0.74
hg45-13	516432	6520900	Rusty graphite schist with coarse grained graphite	9.20	2.29
hg46-13	515152	6520400	Rusty graphite schist with coarse grained graphite	3.84	0.26
hg47-13	515152	6520400	Rusty graphite schist with coarse grained graphite	2.78	0.73
hg48-13	515028	6520303	Rusty graphite schist with coarse grained graphite	6.44	0.31
hg49-13	515004	6520260	Rusty graphite schist with coarse grained graphite	1.70	0.32
hg50-13	514743	6520105	Rusty graphite schist with coarse grained graphite	1.10	0.64
hg51-13	516192	6538055	Low grade paragneiss	0.14	1.89
hg52-13	516422	6538093	Low grade paragneiss	1.06	1.80
hg53-13	516638	6538182	Low grade paragneiss	2.00	3.38
hg54-13	516779	6538204	Low grade paragneiss	0.14	0.03
hg55-13	517264	6538270	Low grade paragneiss	4.32	0.21
hg56-13	517332	6538268	Low grade paragneiss	1.52	0.04
hg57-13	469986	6490735	Low grade paragneiss	0.16	0.01
hg58-13	480571	6482885	low grade graphite shist	0.80	1.29
hg59-13	500552	6502891	Paragneiss with small lenses of graphite schist	0.66	0.03
hg60-13	517669	6538245	Low grade graphite shist	0.10	0.02

hg61-13	517643	6538255	Low grade graphite shist	0.24	0.01
hg62-13	517630	6538256	Low grade graphite shist	0.10	0.01
hg63-13	517590	6538247	Low grade graphite shist	0.06	0.01
hg63b-13	517538	6538267	Low grade graphite shist	0.06	0.01
hg64-13	516960	6538269	Low grade graphite shist	2.14	0.16
hg65-13	517014	6538279	Low grade graphite shist	0.20	0.32
hg66-13	517340	6538267	Low grade graphite shist	0.22	0.01
hg67-13	515694	6528273	Low grade graphite shist	0.78	2.39
hg68-13	515042	6528514	Low grade graphite shist	0.24	0.04
hg69-13	500523	6506945	Low grade graphite shist	0.10	0.24
hg70-13	496470	6503719	Low grade graphite shist	1.44	1.20
hg71-13	509073	6512449	Graphite schist with thin bands containing graphite	3.00	1.00
hg72-13	509073	6512449	Graphite schist with thin bands containing graphite	2.32	0.79
hg73-13	509060	6512460	Graphite schist with thin bands containing graphite	2.06	0.59
hg74-13	509270	6512483	Graphite schist with thin bands containing graphite	4.34	1.50
hg75-13	507831	6524262	Graphite schist with thin bands containing graphite	0.54	0.34
hg76-13	499574	6515982	Graphite schist with thin bands containing graphite	0.78	0.55
hg76b-13	499813	6516916	Graphite schist with thin bands containing graphite	0.84	1.67
hg77-13	499777	6516937	Graphite schist with thin bands containing graphite	2.46	1.20
hg78-13	499780	6513619	Graphite schist with thin bands containing graphite	0.46	1.18

6. SUMMARY

The graphite shists that occur southeast of lake Vegård in the area of Gjerstad, Kragerø and Tvedestrand, have an average content of graphitic carbon of 2.77 %. Rocks from the abandoned Bjørnås mine have contents up to 33 %. The investigated area comprises a large area with low grade graphitic rocks and there is an almost complete airborne geophysical coverage with EM and MAG data.

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