NGU-rapport nr. 91.135.

Titanium in the eclogites from the western gneiss region. A compilation of published whole-rock data.

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RAPPORT

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Tittel:

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A compilation of published whole-rock data.

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Sammendrag:

Rapporten gir et sammendrag av en sammenstilling av hovedelement analysedata og annen geologisk og geografisk informasjon om eklogittbergarter på Vestlandet.
Hele materialet foreligger på diskett i form av 3 Lotus (wk 1) tabeller.

Emneord	hovedelement	
berggrunnsgeologi	titan	
eklogitt	rutil	

TITANIUM IN ECLOGITES FROM THE WESTERN GNEISS REGION.
A compilation of published whole-rock data.

A Report to Norges Geologiske Undersøkelse
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TITANIUM IN THE ECLOGITES FROM THE WESTERN GNEISS REGION

1. SCOPE OF THIS REPORT

This report presents the result of a bibliographic search for whole-rock chemical analyses on eclogites from the Western Gneiss Region (WGR) of Norway. This search included also the compilation of any relevant field, petrological and mineralogical data on these eclogites. The aim of the study was to evaluate whether some of these eclogites may represent a source of titanium of economical interest, in the form of rutile.

It should also be assessed whether any by-products of interest could be provided by the eclogites, such as garnet or olivine concentrates, or the rock itself used as building material.

2. SOURCE OF THE DATA USED IN THIS COMPILATION

The data come mostly from published articles and from some unpublished theses. This compilation does not pretend to be exhaustive; it is likely that at least many unpublished works (e.g. theses) have been missed. All the references checked for chemical data on eclogites are listed at the end of the report whether they contain relevant data or not. Two additional references (i.e.Schmitt 1960, Smith 1976) have been added, although they were not available, since they are known to contain unpublished valuable maps and chemical data.

During a first selection, all references dealing exclusively with isotopic work on eclogites or REE geochemistry have been a priori discarded. (A compilation of recent isotopic works on eclogites and other rocks in the WGR may be found in Kullerud et al, 1986. - REE data on eclogites may be found in Garmann et al 1975, Krogh and Brunfelt 1981, Brueckner and Griffin 1985, Gebauer et al 1985, Brastad unpubl.?, Erambert 1985, Mørk and Brunfelt 1987).

3. SELECTION OF THE DATA

In this compilation, the word "eclogite" has been given an enlarged meaning, to comprise all garnet-bearing rocks formed under high pressure, with mafic, ultramafic and anorthositic composition, at the exclusion of acidic rocks.

The first criterion for selection of an eclogitic occurrence on

which additional data was to be collected was the availability of whole-rock analyses (major elements). Some occurrences for which no bulk chemical data was found are also included in the compilation because the existence of detailed petrographical and modal descriptions or the mention of titanium concentrations (for ex: Furuviknipa, Gurskebotn, Festøy, Vindøldalen or Grøndalen).

Many recent works on eclogites are very detailed mineralogical investigations without any modal and bulk chemical studies. This is particularly true for the eclogites from the Stadtlandet-Måløy area (see Griffin and Mørk, 1981; Mørk and Krogh, 1987). These have been ignored here.

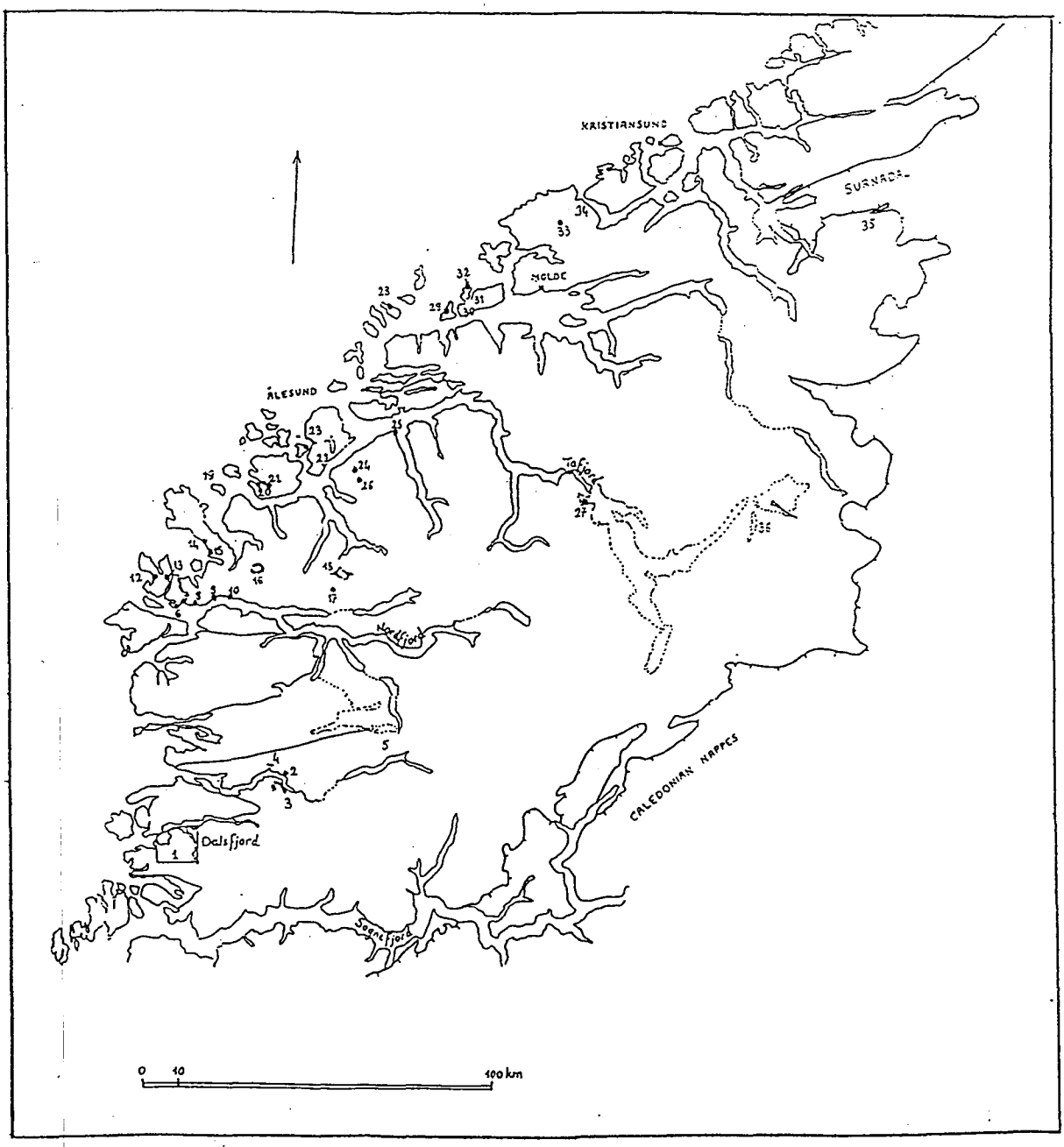

Fig.1: Eclogite localities: Dalsfjord (1), Kvineset (2), Fureviknipa (3) Nausdal (4), Årdalskupa (5), Verpeneset (6), Almenningen (7), Halvneset (8), Kvalneset (9), Maurstad (10), Lyngenes (11), Oppedal (12), Svartbottenvt. (13), Liset (14), Selje (15), Almklovdalen (16), Store Toren (17), Bjørkedalen (18), Kwamsøy (19), Sandvika (20), Gurskebotn (21), Eiksunddalen (22), Ulstein-Dimnøy (23), Essdalen (24), Festøy (25), Skorgedalen (26), Kalskaret (27), Flemsøy (28), Litledigerneset (29), Ugelvik (30), Raudhaugene (31), Raknestangen (32), Kolmannskog (33), Visnes (34), Vindøldalen (35), Grøndalen(36).

4. PRESENTATION OF THE DATA

The data are presented in three successive LOTUS 123 Worksheet files. A location map the eclogites described in these files is ajoined to this report (Fig.1). A description with comments on these files is given in Appendix B.

The first file gives a list of the eclogitic localities with their location and major characteristics. It is intented as a table of contents for the two other files. A print of the list of localities found in this file is given in Appendix C.

The second file presents the various lithologies present in each locality, with their general charasteristics.

The third file contains chemical data on rock samples. An extract of this file showing the major element compositions of eclogites in the WGR is given in Appendix C.

Diskettes containing these files are ajoined to the report.

5. RESULTS

Collected data

Nearly 300 whole-rock chemical analyses of eclogitic rocks have been collected over an area covering the whole coastal part of the WGR (see file WR3.wk1 and Appendix C). In the inner part of the WGR, the eclogites are generally strongly retrograded and have seldom been studied. The data comprise analyses on garnet peridotites, garnet pyroxenites as well as on true eclogites.

For many of these samples, modes and mineral compositions were also available. In contrast to the abundance of mineralogical data, appearance and physical properties of the rocks are rarely described.

Abundance of TiO_2 in the eclogites

Very few of the analyzed samples show a TiO_2 content higher than 5 wt% (see Appendix C and Table 1). These Ti-rich samples are:

- A sample from Nautsdal with 6.44 wt%. This sample is not representative of the Naustdal eclogite, being too enriched in Ti and P (Binns 1967).
- A sample from a dike in peridotite from Flekke, Dalsfjord with 5.05 wt% (sample D118, Cuthbert 1985). The total volume is likely to be small.
- (see also Fureviknipa, up to 6.80 wt% but with average TiO_2 below 5 wt%).

Few samples have TiO_2 concentrations higher than 2.5 wt%. Average concentrations for large eclogitic bodies like Ulstein-Dimnøy or Eiksunddalen (considering only the eclogite layers) are below 1.5

wt%.

Judging from the collected data, none of the described occurrences of eclogite appears to have high enough TiO_2 contents to be exploited economically for rutile alone.

Table 1: Titanium concentrations in eclogites from the western gneiss region.

Locality		Lithology	Range in bulk TiO_2 (wt%)	No of samples
Dalsfjord	Hellevik(Aurevågen)	Anorth. Ecl.	0.25-0.82	2
Dalsfjord	Sørdal	Metatroctolite	2.48-2.56	2
Dalsfjord	Gjørlanger-Tyssekwam	Ecl. in Webst.	1.34-2.65	5
Dalsfjord	Solvik	Ecl.(mafic)	0.37-3.70	4
Dalsfjord	Balsarvik-Andalsvik	Ecl.	0.76-0.91	2
Dalsfjord	Tyssedalvt.-Jyttevt.	Ecl.	0.17-0.83	2
Dalsfjord	Håheia+Jyttevt-Botnatj.	Ecl.	0.19-0.89	2
Dalsfjord	Flekke	Ecl. in Perid.	2.13-5.05	2
		Ecl. in gneiss	0.91	1
Dalsfjord	Flekke-Breidvt.	Ecl.	1.30-2.09	3
Dalsfjord	Breidvt.-Hovlandsvt.	Ecl.	1.24-2.86	3
Førdefjord	Kvineset	Ecl.	1.39-2.66	15
Førdefjord	Fureviknipa	Ecl.		
		Ecl.(Ti-rich)	1.50-6.80	
Førdefjord	Nausdal	Ecl.	6.44	1
Årdalskupa		Meta-Ecl.	1.88-3.74	6
Nordfjord	Verpeneset	Ecl. layer1	0.76-0.83	2
		Ecl. layer2	2.50	1
Nordfjord	Almenningen	Ecl.	0.54	1
Nordfjord	Halvneset	Ecl.	1.71	1
Nordfjord	Kvalneset	Ecl.	1.44-1.60	2
Nordfjord	Maurstad	Ecl.	0.15	1
Sørpollen	Lyngenes	GT-Perid.	1.36	1
Stadtlandet	Liset	Ecl.	0.40-4.58	20
Almklovdalen	Lien + Rødhaugen	GT-Perid.	0.06-0.28	4
	+ Raudkleivane	GT-Pyrox.+Ecl	tr.-0.55	10
	Raudkleivane	Ecl.(Fe-rich)	0.34-1.34	11
Bjørkedalen		Ecl.in Anorth.	0.28-1.13	3
		Ecl.in Perid.	0.89-1.25	3
		Ecl.in gneiss	0.37-1.00	6
Kwamsøy	N coast	Ecl.	0.11-0.17	2
		Amph. Ecl.?	2.33	1
Gurskøy	Sandvika	GT-Perid.	0.01-0.48	4
		GT-Pyrox.	0.23-0.25	2
Hareidlandet	Eiksunddal	OL-bearing rocks	0.53-1.14	14
		Webst.	0.70-0.96	4
		Ecl.	0.86-2.38	30
Hareidlandet	Ulstein-Dimnøy	Ecl.	0.31-2.45	36

Table 1 (continued):

Locality		Lithology	Range in bulk TiO_2 (wt%)	No of samples
Vartdal	Essdalen	Ecl.lens A	0.03-0.68	12
		Ecl. B	0.22-2.63	13
Vartdal	Skorgedalen	Ecl. + Pyrox.	0.50-0.60	2
Tafjord	Kalskaret	all GT rocks	0.04-0.64	14
Flemsøy	N.E. coast	Ecl. gabbro	1.37-4.63	3
		Ecl.	0.80-1.76	7
Midøy	Litledigerneset	Ecl.	1.3(Av)-2.45	5
Midøy/Otrøy	Av. given in	Ecl.(OL-thol.)		
	Carswell&Harvey85	OPX-Ecl.		
Otrøy	Ugelvik	GT-Perid.	tr.-0.07	4
		GT-Pyrox.	0.03	1
Otrøy	Raudhaugene	GT-Perid.	0.21	1
Otrøy	Raknestangen	GT-Perid.		
Eide	Kolmannskog	GT-Perid.	0.42	1
		Ecl.	0.90	1
Eide	Visnes (and around)	Ecl.-Amph.	0.36-2.52	20

Discussion

Representativity of the analyzed samples: Most data come from works whose main purpose was to study the eclogite facies mineral assemblages and the conditions of metamorphism. In such studies, Ti-rich samples are most likely to be avoided. Often also enriched in iron, they tend to be more easily amphibolitized (see for example Kvamsøy).

At the scale of the WGR, there is also a bias in the type of eclogitic rocks studied; emphasis is put on garnet peridotites and associated rocks, and on OPX-eclogites quite poor in TiO2. In comparison, common mafic eclogites have been rather neglected. In the present set of data, the eclogites with the higher Ti contents (around 2.5 wt% TiO2) seem to belong to three different settings:

(1) Metatroctolitic or metaanorthositic eclogites at Sørdal, Dalsfjord. Ilmenite concentrations are known nearby (Sørdal mine). A similar occurrence of metaanortositic rocks with Fe-Ti concentrations and eclogites is found in Grøndalen, Lesjaskog.

(2) Eclogites with gabbroic or doleritic protoliths (ex: Kvineset?, Fureviknipa, Nautsdal, Årdalskupa, Ulstein-Dimnøy, Flemsøy, Litledigerneset).

(3) Some Fe-Ti rich layers within the ultramafic-mafic layered bodies (Carswell et al 1983) are often GT-rich and Q-poor (see Essdalen, field report and composition of sample S6). GT-rich layers

similar to S6 are also found in Eiksunddalen.

If there is any possibility to find eclogites with higher concentrations of rutile, it is probably in one of these three settings (as indeed layers with very high concentration of Ti are known to occur locally in the cases 1 and 3).

By-products: Olivine-bearing rocks are rather poor in TiO_2. Where peridotites are dominant, associated mafic eclogites contain less than 1.5 wt% TiO_2, with the highest values found in Fe-rich eclogite pods which are presumed to be former dikes within the peridotite (Raudkleivane in Almklovdalen - see also Bjørkedalen) and are of minor abundance. In the Fe- and Ti-enriched ultramafic-mafic complexes, peridotites are present in minor amounts, often interlayered with the mafic rocks on the meter scale. (Olivine is also more ferrous: Fo 67-83 if this is of any importance?). Olivine does not appear as a potential by-product here.

If one considers the possibility of exploiting garnet, the Ti-rich layers from layered ultramafic-mafic complexes (type of occurrence 3 as listed above) contain often more than 75% GT and no quartz. The problem is the total volume of such rocks: at least in Essdalen, it is not large enough.

No data on the abundance of garnet is available for type 1 (although the compositions of the two metatroctolites from Sørdal D42 and D156, with low SiO_2, high Al_2O_3 and FeO point to GT-rich rocks). In the Dalsfjord area, many rocks are only partially eclogitized, and completely reacted eclogites often show a pseudomorphic texture with corona or atoll garnet; it is uncertain whether this is the case for these samples. The volume of these eclogites (?) is unknown.

Amongst the eclogites with gabbroic or doleritic protolith, GT abundances are given for Nausdal (40%) and Ulstein-Dimnøy (average 40%) both large bodies (1.5 by 1 km and 6 by 4 km respectively). These garnets contain numerous inclusions, mostly of amphibole but also of quartz at Ulstein-Dimnøy. (The eclogite at Kvalneset, Nordfjord contains 50% to 65% GT, but the two analysed samples have an average of only 1.50 wt% TiO_2. This eclogite outcrop is ca. 800 m by 300 m).

Use of the eclogites for building or decorative purposes: Further data are needed.

6. CONCLUSIONS

From the whole-rock chemical data compiled here, none of the eclogite occurrences appears to be a source of Ti of economic interest.

The possibility of exploiting conjointly rutile and garnet needs to be further studied. Three types of eclogitic occurrences which might contain rocks with higher Ti concentrations and which require

further field work have been outlined:

- Ti-concentrations (GT-rich layers) in meta-anorthositic/meta-troctolitic eclogites
- Layers enriched in Ti and Fe (GT-rich) in the ultramafic-mafic eclogite layered complexes (of Fe-Ti affinity according to Carswell et al 1983).
- Eclogites with gabbroic or doleritic protoliths (The best areas could be Sunnfjord or Nordfjord, owing to the large size and the abundance of eclogitic bodies, and the district of Ulstein-Dimnøy. Elsewhere, such eclogites are in small bodies, often only partially eclogitic.)

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Appendix A:

LIST OF ABBREVIATIONS

Minerals and mineral end-members:

AMPH: amphibole
AP: apatite
CARB: carbonate
CHL: chlorite
EP: epidote
    CZO: clinozoisite ZO: zoisite
GT: garnet
    PYR: pyrope ALM: almandine GRO: grossular
    SPE: spessartine AND: andradite UV: uvarovite
ILM: ilmenite
KY: kyanite
MAG: magnetite
MICA:
    BIOT: biotite PHLOG: phlogopite
    PHENG: phengite PARAG: paragonite
OL: olivine
    FO: forsterite
PL: plagioclase
PX: pyroxene
    CPX: clinopyroxene DI: diopside OMPH: omphacite
    OPX: orthopyroxene EN: enstatite
Q: quartz
RU: rutile
SP: spinel
SPH: sphene (titanite)
SULPH: sulphide

Rock types:

Amph.: Amphibolite
Anorth.: Anorthosite
Ecl.: Eclogite
Harz.: Harzburgite
Lherz.: Lherzolite
Perid.: Peridotite
Pyrox.: Pyroxenite
Webst.: Websterite

Other abbreviations and symbols used in the datafiles are described in Appendix B.

Appendix B:

DESCRIPTION OF THE DATA FILES

FIRST FILE: LOTUS 123 worksheet file LOC1.wk1

The first file gives the list of localities of eclogitic rocks on which whole-rock chemical data are available, and gives their major characteristics. Localities are listed from south to north in the WGR. Four main areas have been here distinguished in the WGR:

I - From Sognefjord to south of Nordfjord
II - From north of Nordfjord to south of Romdalsfjord
III - The Molde - Kristiansund area to north of the WGR (including the Nordøyane islands)
IV - Southeast or inner part of the WGR

This distinction is partly based on the difference in eclogitic assemblages found in the WGR from south to north (see Griffin et al 1985), from the "low-temperature" eclogites from the Sunnfjord (area I) to the high-temperature eclogites from the NW (area II and III). The distinction between areas II and III is somewhat more arbitrarily drawn. There seems however to be a difference in country-rock types, as well as in lithological associations of eclogites and in protoliths most commonly proposed for them, maybe also a difference in the P-T regime of metamorphism in the north of the WGR. In the area IV, the eclogites are consistently retrograded.

This file contains:

Columns A to D : Location data with names of the area, of the locality, of the map sheet (M711 topografisk kart, scale 1:50 000) and the reference grid coordinates.

Column E : Size of the eclogitic body.

Column F : Main lithological types forming the eclogitic body.

Column G : Surrounding country-rock types and/or unit.

Columns H to J : Field association of the eclogites and protolith proposed for the eclogitic rocks.

Column H: A crude classification of the eclogitic bodies is made, according to the lithological association and/or the protolith. The code used is:

UM: Ultramafic-mafic suite of eclogitic rocks, Mg- and Cr-rich.

UF: Ultramafic-mafic suite of eclogitic rocks, Fe- and Ti-rich (see Carswell et al 1983 for the main characteristics of UM and UF associations).

U: Ultramafic-mafic association, of unknown affinity

GD: Gabbroic or doleritic protolith

S: Sedimentary or volcano-sedimentary protolith

A: Anorthosite-dominated body

X: Unknown or not defined

Column K : Bibliographic references

Column L : Reference to publication(s) in which a detailed map may be found, and to Griffin and Mørk (1981; abbreviated G&M81) or Mørk and Krogh (1987; M&K87) if the map has been reprinted in one of these excursion guides.

Column M : Reference to the following files
LIT if complementary data on the occurrence are also stored in the second file; WR if whole-rock compositions are available.

SECOND FILE: LOTUS 123 worksheet file LIT2.wk1

The second file summarizes the data on the major lithologies forming a given eclogitic body. The average of, or the range in, characteristic features is given for each group of rocks. The localities are listed in the same order as in the previous file. The data include:

Columns A and B : Name of the eclogite occurrence

Column C : List of the main eclogitic lithologies
This list also includes rock types which do not show eclogitic mineral assemblages but are nevertheless an integral part of the body with eclogitic relicts, often as a major constituent (ex: SP-bearing peridotites, anorthosites, coronitic gabbros...). An estimate of their relative volume is then given but they will not be described further.

Columns D and E : Relative percentage of each rock-type in an eclogitic body and indications on their field occurrence (thickness of layers,...)

Column F : Mineral assemblage and range in modal content (in brackets after the mineral name).
Abbreviations are: m= minor - dom= dominant - tr.= traces

Columns G to L : Physical properties of the rocks, including color, hardness, texture, density, grain size and freshness of the eclogitic paragenesis.

Columns M and N : Range or average in bulk TiO_2 contents of the rocks, with the number of analyzed samples (in brackets), and nature of the Ti-rich minerals present in the rock-type.

Columns O to S : Mineral data on garnet and olivine, including composition and grain size as well as texture of the garnet and presence of inclusions ("+" if present, and nature of the inclusions in brackets).
Composition of the garnet is given in percentages of end-members PYR, ALM, SPE, GRO, AND, UV (although the Cr content is sometimes given in wt% Cr_2O_3, indicated by "%", instead of UV) unless otherwise indicated in the file. See additional comments on GT composition in the description of file WR3.wk1, columns AO to AT.

Column T : indicates (by "WR") if whole-rock chemical analyses are available for a given rock-type in the file WR3.wk1.

THIRD FILE: LOTUS 123 worksheet file WR3.wk1

The third file contains data on individual rock samples for which whole-rock analysis is available. The various localities are listed following the same order as in the first two files. Data stored here are the following:

Columns A and B : Location of the eclogite occurence

Column C : Reference in which the whole-rock analysis (at least the major element composition) may be found.

Columns D to F : Rock type, Comments, Sample number.

Column G : gives the analytical method used to determinate the major element composition of the sample: X: XRF - C: wet chemical methods, titration of Fe^{2+},... - N: neutron activation - EM: electron microprobe analysis (on glass pellets) - calcFe: Fe_2O_3 or FeO calculated from total Fe with a given Fe^{3+}/Fe^{2+} ratio. Symbol of a chemical element in brackets following an abbreviation for analytical method indicates that this method was used only to analyse this element.

Columns H to V : Major element composition of the sample.

Columns X to AM : Mineral assemblage of the sample.

When available, modal percentages are given. Otherwise, indications given in the original publications have been transfered into the file; for instance, major (M), minor(m), traces (tr.), rich, poor, dominant...; "+" indicates the presence of a mineral, although of unknown abundance; "0", the absence of this mineral; a blank, the lack of data.

Given modes were generally obtained by point-counting on thin sections; some others from the relative volume of fractions after mineral separation. Modes of the samples from Essdalen (Erambert 1985) were calculated from analyses of the W.R. and the eclogitic minerals; they reflect the eclogitic modes and not, if the rocks are fairly retrograded, the actual modes.

In many publications, no distinction is explicitly made between eclogitic and retrograde, sometimes post-eclogitic, minerals (see micas and amphiboles). However, when a mineral is known to be secondary (post-eclogitic), its abundance is given in brackets. For garnet and pyroxene, this should be read: % GT (+% kelyphite after GT) and % CPX (+% sympl. after CPX)

Columns AJ to AL are devoted to Ti-minerals: Abundance of rutile, its eventual alteration, and the presence of other Ti-rich minerals.

Column AM ("Other Minerals") is intented for sporadic minerals in eclogites which may be a major or minor constituent in some particular sample.

Column AN : Stage of retrogression of the sample.

Columns AO to AT : Data on minerals (Garnet and Olivine), including composition, grain size (or texture) and presence of inclusions.

GARNET: Composition: For consistency, the composition of garnet is generally given in percentages
of end-members PYR, ALM, SPE, GRO, AND, UV, although the chromium content may sometimes be given in wt% Cr_2O_3 instead of percentage of UV. For this purpose, many original analyses have been recast into end-members for this report; as a rule, Fe^{3+} has been assumed equal to 0 in the case of

microprobe analyses. Such recalculation is indicated by a star (*).

In the "low-temperature" eclogites (those from south of the WGR), strong chemical zoning of the garnet is the rule, core (C) and rim (R) compositions have thus been distinguished in the file, when microprobe analyses were available. Garnets in the "high-temperature" eclogites from the northwestern part are generally homogeneous, with the exception of a thin retrograded rim; core compositions are here representative, rim compositions being neglected in this report. Other abbreviations are: MS= mineral separate - AV= average - nz= not zoned - NA= not available or not determined.
Inclusions: "+" if inclusions are recorded; the nature of these inclusions is given in brackets.

Columns AV to BL : Trace element composition of the sample, including Ni, Cr, Co, Cu, V, Zn, Cs, Rb, Ba, Th, U, Nb, Sr, Zr, Y, Ti.

Column AV: method of analysis.

Column BM : Reference grid coordinates for the sampling locality is given when samples have been collected over a large area with various lithologies (ex: Dalsfjord).