

## Eclogite facies fluids from the Caledonides of western Norway; compositions and implications for fluid-rock interactions

H. Svensen  
B. Jamtveit

Dept. of Geology, Univ. of Oslo, P.O.Box 1047 Blindern, N-0316  
Oslo, Norway

B. Yardley

School of Earth Sciences, University of Leeds, Leeds, LS2 9JT,  
UK

H. Austrheim

Mineralogical-Geological Museum, Univ. of Oslo, Sarsgt. 1, N-  
0562 Oslo, Norway

Abundant multiphase brine inclusions occur in omphacites from mafic eclogites in the Western Gneiss Region (WGR) and in the Bergen Arc Nappes, southern Norway. The eclogites formed during the Caledonian continent-continent collision *c.* 420 m.y. ago, as a result of prograde metamorphism of amphibolite facies rocks or hydration of granulites. Fluid inclusions are present both in matrix omphacites and in omphacites from eclogite facies veins. The fluid inclusion bearing omphacites are iron-rich, with an iron-content up to  $Fe/(Fe+Mg) = 0.53$ . The observed fluid inclusions are considered to be primary or pseudosecondary and all are elongated parallel to the *c*-axis in omphacite. They range in size up to *c.* 110  $\mu$ m. Inclusions from different localities show similar features; they are all brines and contain calcite crystals.

a minor component in the gas-phase. The presence of lead-daughter crystals (PbCl<sub>2</sub>, PbS) at one of the localities (Bårdsholmen) has been used to recalculate the concentrations of Pb (using volumes of the solids and the inclusions) in the original fluid, giving values ranging from *c.* 10,000 to 200,000 ppm Pb. Even though the errors are considerable, the lower limits still exceed known Pb analyses of fluids from e.g. Pb-Zn deposits. The fluid inclusions present in omphacites from the Bårdsholmen eclogites differ from the other fluid inclusions studied, in that they contain Pb-compounds and no sulphate (gypsum). The presence of calcite as solid phases in the inclusions has been used to calculate the mole percent of CO<sub>2</sub> in the fluid, giving values ranging from 2 to 12%. Omphacite crystals have been

### Multi-phase fluid inclusions and reconstructions of the fluid chemistry

All inclusions consist of liquid water and a Raman-inactive vapour bubble along with several solid phases. Methods used for reconstructing the fluid composition include microthermometry, crush-leach analyses, back-calculations based on volume-estimates and PIXE analyses (in progress). To reconstruct the metamorphic fluid composition it is crucial to determine if the solids are precipitates from a 'closed-system' fluid inclusion (i.e. daughter crystals) or if their formation is a result of retrograde fluid-mineral interactions (i.e. 'step-daughter' crystals). Solid phases in the fluid inclusions have been identified by SEM and Raman spectroscopy, and include carbonates, chlorides, sulphides, sulphates and silicates (Table 1). Microthermometric results indicate the presence of brines with salinities ranging from *c.* 19 wt.% NaCl eqv. to beyond salt saturation. Inclusions from one locality show evidence for N<sub>2</sub> as

TABLE 1

Phase/elements	Identification
Calcite	SEM, Raman
NaCl	SEM
Ca-K-Cl	SEM
Pb-Cl	SEM
Pb-Cl-Br	SEM
Pb-S	SEM
Zn-S	SEM
Fe-Ni-S	SEM
Fe-Cu-As-S	SEM
Cu-Fe-S	SEM, Raman
Gypsum	SEM, Raman
K-feldspar	SEM
Amphibole	SEM
Quartz	SEM, Raman
Albite	SEM
Fe-oxide	SEM
Rutile	SEM

analysed for halogens using the crush-leach method, giving Cl/Br concentration ratios from 40 to 850 (Fig. 1). The Br values are normalised to salinities to obtain the absolute concentrations in the fluids.

### Fluid rock interactions during metamorphism

The Bårdsholmen eclogites are formed by hydration of a Precambrian layered granulite complex (mafic and leucocratic layers), to produce a melange-type setting with eclogite lenses floating in felsic material (Engvik *et al.*, in prep.). Both the eclogites and the felsites are mica and amphibole bearing. The fluids that caused the eclogitization were externally derived. The halogen data (Fig. 1) suggest a Cl-Br fractionation trend for the fluids in the WGR and the Bergen Arc eclogites, with the Bårdsholmen eclogites having the lowest Cl/Br-ratio and the highest Br concentrations (compatible with the presence of a Br-bearing daughter crystal, table 1). An explanatory model includes: 1) influx and consumption of fluids during eclogitization; 2) enrichment of lead in the residual-fluid; and 3) partitioning of Cl into OH-minerals relative to Br, lowering the Cl/Br-ratio in the residual fluid. Evidence for this is supported by the presence of Cl-enriched micas and amphiboles in the felsites adjacent to the eclogite lenses (Engvik *et al.* in prep).

### Retrograde mineral-rock interactions

Calcite is observed within inclusions from all samples. It is however uncertain if the calcites are daughter crystals or products of retrograde fluid-pyroxene reactions (step-daughter crystal). Retrograde formation of calcite within inclusions in pyroxene and wollastonite are previously described by Andersen *et al.* (1984) and Heinrich and Gottschalk (1995). In addition to calcite, the presence of gypsum, iron-oxide, feldspars and quartz within the inclusions may be due to retrograde mineral-fluid interactions. A chlorine-bearing needle-shaped silicate has been identified by SEM, and is probably a

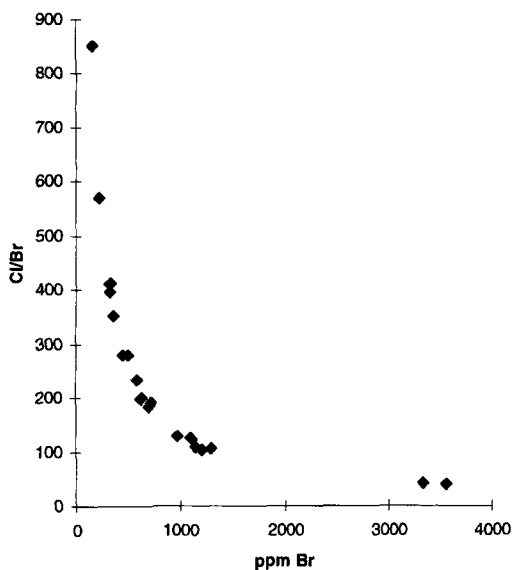


FIG. 1. Halogen data from fluid inclusions using the crush-leach method. The two samples with the highest Br concentration are from Bårdsholmen.

Na-Cl-rich amphibole. This may be a product of the reaction  $5\text{CaMgSi}_2\text{O}_6 + \text{H}_2\text{O} + \text{CO}_2 = \text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2 + 3\text{CaCO}_3 + 2\text{SiO}_2$ . No  $\text{CO}_2$  has been detected by Raman spectroscopy in the inclusions, suggesting that the  $\text{CO}_2$  availability controlled the progress of the calcite forming reaction. Additionally three Fe-bearing sulphur compounds are observed (Table 1); Cu-Fe-S, Fe-Ni-S and Fe-Cu-As-S, but it is not known if the iron-component is derived partly from the omphacite.

### References

- Andersen T, O'Reilly, S. Y. and Griffin, W. L. (1984) *Contrib. Mineral. Petrol.*, **88**, 72–85.  
 Heinrich, W. and Gottschalk, M. (1995) *Contrib. Mineral. Petrol.*, **122**, 51–61.