Downward infiltration of fluid into the high-grade basement of south Norway I: brines

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The migration of surface derived fluids into crystalline basement rocks has been recognised in a variety of structural settings and is particularly well documented in shield areas (e.g. Fritz and Frape, 1987), but the mechanisms and extent of such infiltration remains controversial. This paper reports results from basement rocks on the west flank of the Oslo graben, where there is evidence of infiltration by sedimentary fluids.

The Kongsberg Sector is a part of the high-grade Precambrian basement of South Norway, situated to the west of the Permian Oslo Graben. The Western Kongsberg Complex consists of granulite and amphibolite facies gneisses and metagabbros. Permian activity in this area resulted in dykes, cut by hydrothermal quartz, and base metal and silver mineralisation. The Modum Complex situated to the northeast, is dominated by metasediments and metagabbros, which exhibit high grade and retrograde hydrothermal effects (Munz *et al*, 1994) and have been intruded by diabase dykes, spatially related to the Oslo Rift. The final stage of hydrothermal activity in the region resulted in a suite of quartz veins, generally rimmed by fine albite. Previous work on fluid inclusions from these veins has identified hydrocarbon $\pm$ CO_2 and aqueous inclusions of variable salinities (Munz *et al.*, 1995) and cited these as evidence of penetration of basinal fluids into metamorphic basement rocks. This study has focused on aqueous inclusions from a larger sample suite of quartz veins from the Modum Complex and from previously unstudied material from the Western Kongsberg Complex.

Structural context and quartz textures

The Modum quartz veins have variable orientations, reflecting the structural complexity and lithological heterogeneity of their high grade basement hosts, and are cross-cut by N-S trending diabase dykes. In contrast, in the Kongsberg region to the south, superficially similar quartz veins post-date diabase dykes which trend E-W. It is not clear whether dykes and veins in the two areas are broadly synchronous and related to the Permian development of the Oslo rift, or whether the cross-cutting relationships observed in the field reflect fundamentally different veining eventsIn both areas the veins mainly consist of coarse prismatic quartz crystals up to 10 cm in length which are orientated at high angles from the wall-rock and display growth zones. Veins from the Modum area also contain a high density of small, crosscutting, healed fractures, some of which are easily distinguished by the presence of black carbonaceous? material. Samples from Kongsberg are less fractured and contain less discernible carbonaceous material on the macroscopic scale.

Fluid inclusion petrography

Two main types of inclusions have been found in this study. The first type, hydrocarbon $\pm$ CO_2 inclusions, have been described from the Modum area by Munz *et al.* (1995). These inclusions are most commonly found in secondary trails, cross-cutting growth zones, although some pseudosecondary hydrocarbon inclusions occur. The composition ranges from CH_4-dominated to those with liquid hydrocarbons (Munz *et al.*, this volume). Hydrocarbon-bearing inclusions occur only rarely in the quartz veins from Kongsberg.

Aqueous inclusions are abundant in samples from both area. The most common inclusion type in samples from both the Modum and Kongsberg areas are two phase liquid and vapour inclusions (Type 1). Type 1 inclusions vary in size from 3-70µm with a modal size around 20mm. These inclusions occur as primary, secondary and pseudosecondary inclusions in all samples. Additionally, in several samples from the Modum area, small (<10µm) aqueous inclusions containing halite cubes (Type 2) have been observed.

Microthermometric results

First melting of Type 1 inclusions from the Modum

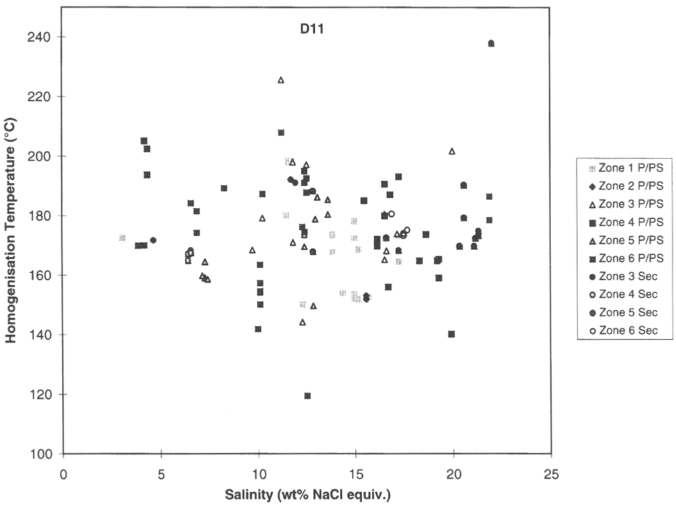

FIG. 1. Paired salinity-homogenisation temperature data from 6 zones of a single quartz crystal. P = primary, PS = Pseudosecondary, Sec. = Secondary.

area occurs at temperatures of −23 to −21°C, close to the eutectic in the system NaCl (± KCl)-H_2O. In some inclusions, a small amount of melting was observed at −55 to −38°C, suggesting a significant $CaCl_2$ component. Hydrohalite melting, when observed, always occurred before ice melting and in the range −27 to −12°C. Ice melting temperatures in NaCl rich inclusions occur over a very wide range (−0.5 to −20.1°C) and correspond to a salinity range of 0.8 to 22.4 wt.% NaCl equiv. Inclusions with significant $CaCl_2$ extend the salinity range to 26 wt.% NaCl equiv. The variation in salinity within each sample is high and there appears to be no consistent evolution of fluid composition with time (Fig. 1). Homogenisation of Type 1 inclusions is to liquid and occurs in the range 120 to 340°C.

Type 2 inclusions from Modum samples commonly show halite melting at about 50° below liquid-vapour homogenisation, although in one Type 2 population homogenisation occurred by halite dissolution. Modal homogenisation temperatures in this sample are higher than those of the Type 1 inclusions. These data suggest a range of salinities in Type 2 inclusions from 33 to 37 wt.% NaCl equiv.

Discussion

The high abundance of fluid inclusions in growth zoned crystals allow a detailed study to be made of changes in fluid density and composition in a given vein through time. Figure 1 presents data from Type 3 inclusions from one such banded crystal. Overall, the data show a broad range in salinity with no distinct evolution of fluid composition with time. This might suggest fluid mixing between a saline and a dilute end-member fluid, however the bulk of the data would correspond to intermediate compositions. This pattern is considered more likely to result from tapping of a range of reservoirs by the basement fracture system, than by simple mixing of end members. Along with a broad range of salinities, most zones (but particularly Zone 6, Fig. 1) also show a large spread in homogenisation temperatures at relatively constant salinity, for inclusions with no evidence of necking. We interpret these data to reflect primary variations in fluid density, and hence in pressure or temperature (or both) during crystal growth. In detail however, there are differences between quartz zones which may be significant. Data from Zone 4 is suggestive of mixing of a lower density, dilute fluid with a higher density saline one, although other zones show no such correlation. The migration of hydrocarbons and associated brines into crystalline rocks implies downward or lateral penetration of fluid from overlying sedimentary rocks during extension. The observed ranges in density has been interpreted previously (Munz *et al.*, 1995) as the result of fluctuations of fluid pressure between near hydrostatic values (fracture open for fluid penetration) to near lithostatic values (fluid-filled fracture effectively sealed in). The present data suggest that each zone in the quartz must represent at least one such cycle of fracturing, infiltration and sealing.