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Formation of planar deformation features (PDFs) in zircon during coseismic faulting and an evaluation of potential effects on U–Pb systematics

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ABSTRACT

Zircons from pseudotachylyte and cataclasite veins in the Svarthumlevatnet metagabbro, SW Norway, are faulted, brecciated and display multiple sets of planar deformation features (PDFs) that we assign to coseismic deformation in the middle crust during Caledonian continent collision. The zircons give a U–Pb upper intercept age of 1507 ± 4 Ma, interpreted as a minimum age of the gabbro, and a lower intercept age of 968 ± 31 Ma, likely indicating the time of granulite-facies metamorphism, but they do not record the Caledonian coseismic faulting even when the fault planes are healed by thin veins of low-U zircon. The work indicates that PDFs are not exclusive to meteorite impacts, but may also develop during seismic faulting.

1. Introduction

Planar deformation features, or PDFs, are optically recognizable microscopic features in grains of silicate minerals consisting of very narrow planes arranged in parallel sets that have distinct orientations with respect to the grain's crystal structure. Shock pressure experiments on zircon at 20 to 40 GPa (Leroux et al., 1999) show the development of oriented micro-fractures by shear stress, accompanied by plastic deformation by gliding. PDFs form at 40 to 60 GPa, breaking down into an amorphous phase along specific planes. At the highest pressures zircon is then transformed into the high-density scheelite structure. Planar deformation features (PDFs) in zircon and quartz have been reported from a number of meteorite impact structures, notably the Vredefort and Sudbury craters (Bohor et al., 1993; Kamo et al., 1996; Grieve et al., 1996; Gibson et al., 1997; Moser, 1997), and are thought to be indicative of deformation at extreme strain rates. Deformation of zircon in mylonite zones at greenschist and amphibolite facies conditions, on the other hand, produces randomly oriented fractures (Wayne and Sinha, 1988, 1992a,b) and causes a grain size reduction down to an equilibrium size (Boullier, 1980). Seismic deformation occurs at high-strain rates between 0.1 and 2 m s^{-1}, intermediate between the rates of impact and deformation leading to mylonites (Spray, 1992). The behaviour of zircon during deformation at seismic strain rates is unknown. However, Austrheim et al. (1996) reported deformation features in garnet from eclogite facies pseudotachylytes and described sieved textured garnet developed from earlier granulite-facies garnets. Planar and curved fractures, brecciation and evidence of melting are found at successively smaller distances to the pseudotachylyte, and resemble deformation features described from the Ries crater (Wittmann et al., 2006). Deformation is known to enhance the re-equilibration of minerals such as garnet (Erambert and Austrheim, 1993; Straume and Austrheim, 1999; Røhr et al., 2007). An increased dislocation density that will increase volume diffusion may enhance the re-equilibration and, more importantly, fractures may allow fluids to interact with the strained crystal. Although the influence of deformation on re-equilibration of zircons, and thus on the recorded isotopic ages, is poorly understood it could be expected that deformation of this mineral will also enhance re-equilibration and influence the measured isotopic ages. Indeed, Reddy et al. (2006) demonstrate a relationship between crystal-plastic deformation and Rare Earth Elements variations in zircons while Timms et al. (2006) observe an increase in U and Th/U in deformation microstructures of a zircon crystal. Moser et al. (2007) also show that the degree of resetting of the U–Pb system is linked to the intensity of crystal-plastic deformation of zircon in lower crustal xenoliths subjected to sudden intense shearing. Rimsa et al. (2007) report hydrothermal brecciation of zircons and healing of the fractures by newly formed zircon in a migmatitic granite and consider hydraulic fracturing to have been the most likely mechanism for the brecciation.

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We report here on deformation textures, including PDFs, recorded by zircons deformed in centimetre thick zones of ultracataclasite/pseudotachylytes. Such features have generally only been observed in impact-related situations, but we believe that in our case they are the result of seismic deformation of the middle crust during collision and continental subduction.

2. Geological setting

The Western Gneiss Complex (WGC) of Norway is an area of more than 25 000 km^2 of dominantly middle Proterozoic gneissic rocks outcropping between Bergen and Trondheim (Fig. 1a). The WGC forms part of the Baltic Shield, which according to Gorbatschev and Gaal (1987) grew during four orogenies between 3.5 and 1.5 Ga, followed by reworking of the crust by metamorphism, deformation and melting during the Grenvillian and Caledonian events. The WGC is a Caledonian HP and UHP terrain separated from a series of overlying Caledonian Nappes by the Nordfjord-Sogn Detachment Zone, a composite, 2–6 km thick, top-W structure developed during exhumation of the WGC from mantle depths (Johnston et al., 2007a,b). The top-W shear fabrics of the detachment overprint a set of nappes representing the Lower and Middle Allochthon; these are themselves overlain, across a ductile to brittle detachment, by a lower grade nappe of the Upper Allochthon (Fig. 1b). The top of the succession is occupied by the Devonian Hornelen and Håsteinen basins, which formed during exhumation.

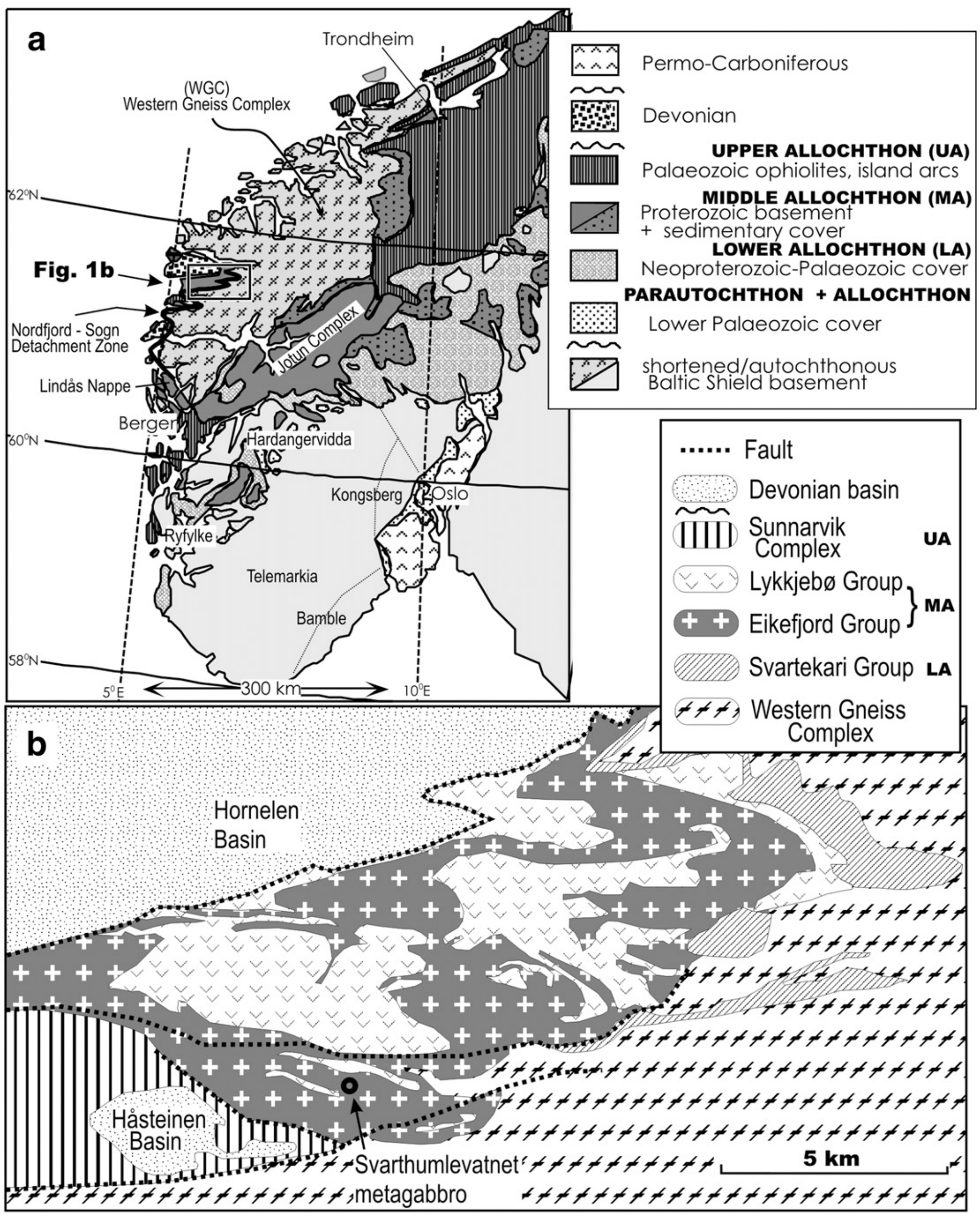

Fig. 1. (a) Tectonic map of south-central Norway showing the main subdivisions and location of the study area; (b) Geological map (modified from Johnston et al., 2007a) showing the location of the Svarthumlevatnet metagabbro within the Eikefjord Group, the likely equivalent of the Dalsfjord Nappe. The Svartekari, Eikefjord and Lykkiebø groups are all part of the Nordfjord-Sogn Detachment Zone in this area.