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Relative strength of mafic and felsic rocks during amphibolite facies metamorphism and deformation

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ABSTRACT

Field observations of mafic dykes intruded into felsic rocks from the Lewisian Complex, NW Scotland, suggest that the mafic rocks are weaker than the felsic ones, contrary to experimental results. In order to resolve this conflict, samples were studied to constrain the deformation mechanisms active under amphibolite facies conditions. Crystallographic preferred orientation (CPO) in plagioclase is used to infer deformation by dislocation creep on the $(112)[1\bar{1}0]$, $(1\bar{1}2)[110]$, $(001)[1\bar{1}0]$, and $(001)[1\bar{1}0]$ slip systems. With increasing strain, this CPO became weaker due to grain-boundary sliding that accompanied diffusion creep. In rocks where grain size reduction of plagioclase occurred by chemically-dominated recrystallisation there is no CPO suggesting deformation was wholly accommodated by diffusion creep and grain-boundary sliding. In metamorphosed dykes, plagioclase grains have orientations that are not consistent with dislocation creep deformation. Amphibole has a CPO consistent with either dislocation creep on $\{100\}\langle 001\rangle$ or deformation by diffusion creep with anisotropic dissolution and precipitation rates. It is inferred that metamorphism of the dykes lead to the production of fine-grained amphibole and plagioclase, both of which deform by diffusion creep, but that anisotropic dissolution and precipitation in the amphibole produced a CPO. The mafic dykes are weaker than the felsic gneisses because grain size reduction is more extreme in the dykes even though both may be deforming primarily by grain size sensitive mechanisms. This work highlights the variation in processes active in polyphase rocks and how these can lead to variations in CPO of the same mineral among different rock types.

1. Introduction

Exhumed high-grade terranes are essential to understanding lower crustal processes. Deformation of key minerals such as plagioclase (e.g. Rybacki and Dresen, 2004), amphibole (Tatham et al., 2008), and quartz (Hirth and Tullis, 1992) controls the strength of rock over a wide range of bulk compositions. Varying modal proportions (e.g. Rybacki and Dresen, 2000) and grain sizes (Rutter and Brodie, 1988) control which deformation mechanisms are active in which minerals and therefore the relative strength of the rocks (Handy, 1990). Whilst mafic rocks are usually considered stronger than felsic ones (e.g. Wilks and Carter, 1990), activity of grain size sensitive mechanisms and the production of weak phases (strain weakening e.g. Imon et al., 2002) may result in a reversal of this rheological contrast.

The Lewisian complex, NW Scotland, consists of mafic and felsic rocks that were variably deformed and metamorphosed to granulite and amphibolite facies a number of times during the Archaean and Palaeoproterozoic (Park and Tarney, 1987). Tonalite–trondhjemite–granodiorite gneisses were intruded by mafic (Scourie) dykes, which were themselves metamorphosed to amphibolite facies. Therefore, these rocks provide an opportunity to study the effects of microstructure and bulk rock composition on mineral deformation mechanism whilst minimising variations in other variables such as temperature.

In this paper, we employ electron backscatter diffraction (EBSD) to measure the crystallographic orientations of minerals in deformed amphibolite facies gneisses and dykes as part of the first detailed microstructural study of the quartzo-feldspathic gneisses from the Lewisian Complex. Outcrop scale field maps constrain the age of the deformation relative to dyke intrusion. Plagioclase fabrics are presented for rocks of different strains from a single outcrop and for different ages of deformation from a single sample. Plagioclase and amphibole fabrics are presented from deformed Scourie dykes. The difference in fabric strength is interpreted to result from different deformation mechanisms being active in different minerals. These interpretations are discussed in terms of

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the effects of strain on grain size and the relative strength of the different rocks within the Lewisian Complex, and lower crustal rocks in general.

2. Geologic setting

The Lewisian Gneiss Complex is exposed in the foreland of the Scottish Caledonides (Fig. 1a – inset). It is broadly divided into three regions with a central granulite region flanked by more intensely deformed amphibolite facies regions to the north and south. The complex is dominated by felsic to intermediate metaplutonic rocks (tonalite–trondhjemite–granodiorite, TTG) but also includes more mafic to ultramafic, metasedimentary, and metaigneous components. A suite of dykes of varying composition (from mafic to ultramafic) intrude the gneisses of the complex. Separating the northern and central regions is the high strain Laxford front. North of this tectonic zone the gneisses exhibit a folded shape fabric with a horizontal enveloping surface (Coward, 1984). The southern boundary of the central region is more complex involving a number of shear zones around Gairloch which cut and fold the metasediments and metaigneous rocks of the Loch Maree Group. The southernmost of the high strain zones is a km-scale zone exposed on the north and south shores of Loch Torridon (Fig. 1a), the Torridon high strain zone. Following a short description of the terminology used in this study, the geometry of the high strain zone and relationship between Scourie dykes and gneissic fabrics are documented. Finally, two study areas within the high strain zone and samples collected from these areas are outlined along with field constraints on their deformation kinematics and relative ages.

2.1. Nomenclature

Events prior to and following the Scourie dyke intrusion were termed Scourian and Laxfordian respectively (Sutton and Watson, 1950). With the recognition of a pre-dyke amphibolite facies event (Evans, 1965) the Scourian was subdivided into Badcallian (granulite facies, NE–SW trending fabrics) and Inverian (amphibolite facies, NW–SE trending fabrics) events. Fabrics were identified using these criteria and correlated across the complex. However, a model based primarily on dating of zoned zircon suggests that the complex comprises a number of disparate terranes assembled throughout the latest Archaean and Proterozoic (Kinny et al., 2005). Therefore, correlation of metamorphic and deformation episodes across terrane boundaries is not necessarily valid. However, since the age of deformation does not alter the kinematics or dynamics of the event then it is not important whether post-dyke deformation occurred at the same time everywhere or not. In the absence of other well defined nomenclature the term Badcallian will be used to refer to N–S to NE–SW location fabrics, and the terms, Inverian and Laxfordian to pre- and post-dyke events which produce NW–SE striking shape fabrics respectively. Similar features may not be the same age everywhere in the Lewisian (Kinny and Friend, 1997).

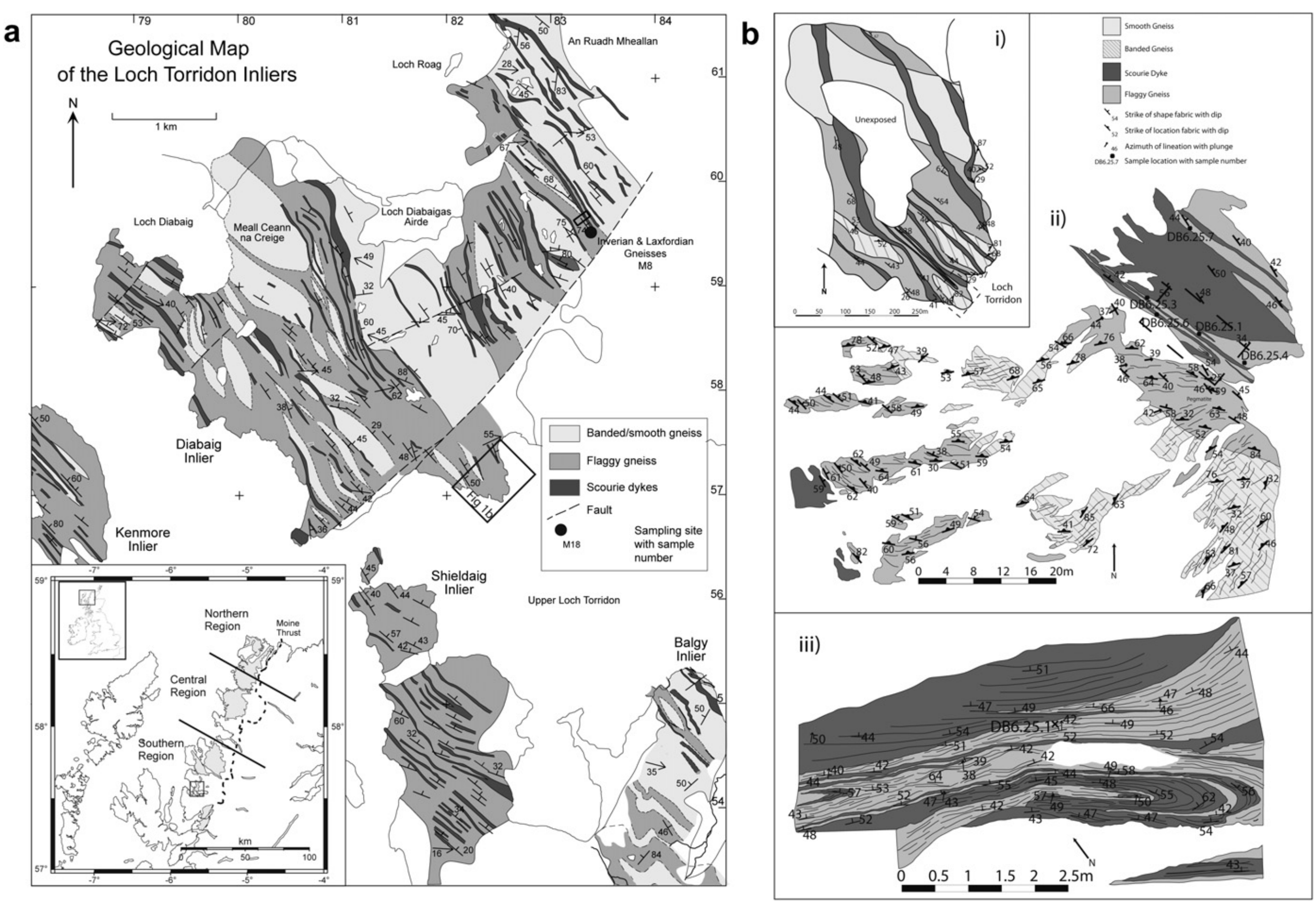

Fig. 1. Location map. a) Map of varying strain within Torridon high strain zone (from Wheeler, 2007). Torridon inliers are located in the Southern region of the Lewisian complex (grey shading, inset). b) i) Map of Alligin peninsula showing the relationship between dykes, high strain (flaggy) and low strain (banded, smooth) gneisses. ii) Outcrop map of the edge of a high strain zone exposed on the coast. iii) Detailed fabric map of the isoclinally folded Scourie dykes and interleaved gneisses. Form lines in ii) and iii) show location fabric which is parallel to shape fabric in high strain areas.