Pergamon

PII: S0191-8141(97)00081-3

Journal of Structural Geology, Vol. 20, No. 2/3, pp. 229 to 242, 1998

0191-8141/98 $19.00 + 0.00

The role of strain localization in the segregation and ascent of anatectic melts, Namaqualand, South Africa

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(*Received* 19 *December* 1996; *accepted in revised form* 19 *September* 1997)

Abstract—Granulite-facies gneisses of the late-Proterozoic Okiep Copper District of the Namaqua Province in South Africa preserve evidence of a range of anatectic melt features that reflect the initial stages of segregation and ascent of crustally derived magmas during high-grade metamorphism. These melt bodies include both *in situ* and sharply transgressive, subvertical, pipe-like bodies, that show vertical dimensions of several hundreds of metres and horizontal dimensions of tens to hundreds of metres. Migmatite bodies are spatially closely linked with narrow, upright zones characterized by intense high-strain fabrics, locally referred to as 'steep structures'. They display a progressive textural development, from diktyonitic textures in *in situ* bodies, via schollen-and-raft textures to largely homogeneous intrusive granites that have migrated vertically for distances of several hundreds of metres or more. The intimate association of the migmatite bodies with the steep structures reflects strain-induced melt segregation, facilitated by increased permeabilities in these ductile deformation zones, and migration of melts into sites of strain incompatibility at the intersections between the regional subhorizontal gneissosity and the superimposed high-strain zones. Subsequent melt migration was focused along the network of subvertical structural anisotropies provided by the steep structures. Melt migration was controlled by a combination of buoyancy, shear-enhanced melt compaction during ongoing deformation, melt compaction due to the settling of wall-rock fragments from higher stratigraphic levels and subordinate brittle fracturing. The unusual geometry of the steep structures and the intensely heterogeneous nature of the strain, and the absence of similar strain features and voluminous melt bodies elsewhere in the granulite-facies terrane, suggest a positive feed-back mechanism between melt generation and strain localization in steep structures. The structural development of the migmatite bodies illustrates that the efficiency of melt segregation and migration in a mid-crustal segment is dependent not only on the fertility of its lithologies, but also on its deformational style. © 1998 Elsevier Science Ltd.

INTRODUCTION

One of the ongoing points of discussion about crustal anatexis during high-grade metamorphism concerns the mechanism(s) by which melts accumulate in their source regions and their migration to higher structural levels. The classical view of accumulation of melt to volumes exceeding the 'rheologically critical melt percentage', followed by buoyancy-induced diapiric ascent (e.g. Van der Molen and Paterson, 1979; Cruden, 1988; England, 1990; Weinberg, 1993), has been questioned in recent years (e.g. McLellan, 1988; Clemens and Mawer, 1992; Emerman and Marrett, 1990; Paterson and Fowler, 1993; Petford *et al.*, 1993; Sawyer, 1991, 1994; Petford, 1995). Most studies on magma transport have, in recent years, emphasized the role of deformation and strain localization for both melt generation and melt migration based on the close spatial and temporal relationship between deformation zones and granitic melts (e.g. Hollister and Crawford, 1986; Wickham, 1987; Allibone and Norris, 1992; McCaffrey, 1992; Brown, 1994 and references therein; Brown *et al.*, 1995; Rushmer, 1995). Numerous field and experimental studies have shown that the deformation of partially molten rocks provides pressure gradients and dilatant sites along which melts can migrate at considerably lower melt volumes than that of the experimentally determined critical melt fraction and current models favour tapping of anatectic crustal levels by brittle–ductile shear zones that provide conduits for subsequent melt ascent (e.g. Dell'Angelo and Tullis, 1988; Hutton, 1988; D'Lemos *et al.*, 1992; Hand and Dirks, 1992; Sawyer, 1994; Rutter and Neumann, 1995;

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