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Mantle podiform chromitites do not form beneath mid-ocean ridges: A case study from the Moho transition zone of the Oman ophiolite

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A B S T R A C T

Podiform chromitites from the mantle transition zone at Maqsad in the Oman ophiolite have MORB-like cr# (0.48–0.59). However they show other features which are not in keeping with a MORB-origin: some parental melts have TiO_2 values lower than typical MORB, they have a higher $Fe^{3+}/\Sigma Fe$ ratio and a wider range of $Fe^{3+}/\Sigma Fe$ ratios than might be expected in MORB and their parental melts have a higher fO_2 than expected for MORB. The chromitites also contain silicate melt inclusions which are hydrous and atypical of MORB and inclusions of higher cr# chromites (cr# = 0.55–0.71). These inclusions are derived from a more depleted harzburgite source than that of the harzburgites which now host the Maqsad chromitites. In addition associated MORB-like lavas display geochemical traits which are atypical of MORB. It is proposed therefore that the Maqsad chromitites were derived by mixing from parental melts which were produced by the interaction of a MORB-like melt and depleted mantle. The MORB-like melt was produced by the hydrous melting of asthenospheric mantle above a subducting slab. The trigger for chromite to appear on the liquidus of the melt was the reaction between the primary melt and depleted harzburgite, illustrating the more general relationship in which chromite appears on the liquidus in mafic and ultramafic melts as a consequence of some form of mixing process.

Our preferred tectonic setting for the genesis of the Maqsad chromitites is in the context of subduction initiation in a forearc environment. We would argue on the basis of their geochemistry that they have not formed beneath a spreading ridge, despite the superficial similarity between their cr# and those of MORBs. In the absence of podiform chromitites in modern ridge environments and from 'truly MORB ophiolites' we propose that the very occurrence of podiform chromitites is a tectonic indicator of a subduction-related environment.

1. Introduction

Many recent geochemical studies of ophiolites have indicated that they formed in a supra-subduction zone setting, such that this is emerging as the consensus view (Whattam and Stern, 2011). Nevertheless there are ophiolite sequences where lavas of MORB-affinity are found, permitting the more conventional 'spreading ridge' model of ophiolites to persist. Studies of podiform chromitites from the mantle sequence of ophiolites also contribute to this debate. Early studies suggested that podiform chromitites formed in a mid-ocean ridge setting (Nicolas and Al-Azri, 1991) whereas now many scientists consider a suprasubduction zone setting a more suitable location for their formation (Zhou and Robinson, 1997).

In this paper we explore this problem by examining podiform mantle chromitites from the Moho transition area of the Oman ophiolite at Maqsad, in the southern part of the ophiolite outcrop. The Maqsad area was characterised during the structural mapping of the mantle harzburgites as a region of mantle 'upwelling' (a mantle diapir) and the locus of significant melt flux (Nicolas and Boudier, 2000). Almost all of the geochemical indications from previous studies have suggested that the melt in the region was MORB-like (Godard et al., 2006; Kelemen et al., 1997; Koga et al., 2001) leading to the inference that the chromitites also have a MORB affinity.

Here we provide evidence to challenge the view that MORB melts were parental to the Maqsad chromitite deposits and on this basis we seek to address the wider question of whether chromitites of true MORB affinity exist in any ophiolite sequence. Dilek and Furness (2011) classify ophiolites according to their tectonic setting and identify a number of occurrences which they suggest have formed at an oceanic ridge. Most notable are the Macquarie island 'ophiolite', an uplifted segment of the Macquarie ridge and the Taito ophiolite from southern Chile. However, in both of these no mantle podiform chromitites have been recorded to date (Paul Robinson, pers com.). In modern ocean ridge environments small chromitite pods have been recovered from the Hess Deep of the equatorial Pacific and the Mid Atlantic Ridge as a result of the ocean drilling programme (Abe, 2011; Arai and Matsukage, 1998). However, these are micropods, a few centimetres in diameter and not typical of the much larger ophiolitic podiform chromitites normally found in the mantle section of ophiolites. Whilst we recognise that there has been limited sampling of the modern

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ocean crust, to date there is no strong evidence to associate chromitites with a modern ocean ridge environment.

Kamenetsky et al. (2001) examined chromites from basaltic lavas from a variety of tectonic settings including mid-ocean ridge basalts and showed that basalts can be characterised using their spinel compositions on a $TiO_{2\text{-in spinel}}$ vs $Al_2O_{3\text{-in spinel}}$ plot. On this basis they showed that chromites from mid ocean ridge basalts are typified by high spinel-Al_2O_3. They also showed that some mantle podiform chromitites from ophiolites plot within this 'MORB' field, suggesting that these podiform chromitites have a MORB affinity. Here we shall argue that such 'MORB' chromitites show some significant differences from typical MORB and may not have formed at a mid-ocean ridge.

Our purpose in this study therefore is to examine chromitites from an area of the upper mantle which appears to have been a region of very high melt flux and was possibly located beneath a spreading centre. We use the petrology and geochemistry of the mantle chromitites to show that whilst they have MORB affinities they also show some important differences from MORB and could not therefore have formed beneath a spreading centre at a mid-ocean ridge.

2. Geological background

2.1. The Moho transition zone

The chromitites examined in this study come from the Moho transition zone (MTZ) of the Oman ophiolite and specifically from an area where this is particularly well developed close to the Maqsad diapir in the SE of the ophiolite (Fig. 1).

The Moho transition zone (also known as the crust–mantle transition zone) of the Oman ophiolite is a dunitic unit from a few tens to few hundred metres thick located just below the Moho, at the very top of the mantle sequence (Boudier and Nicolas, 1995). It is predominantly

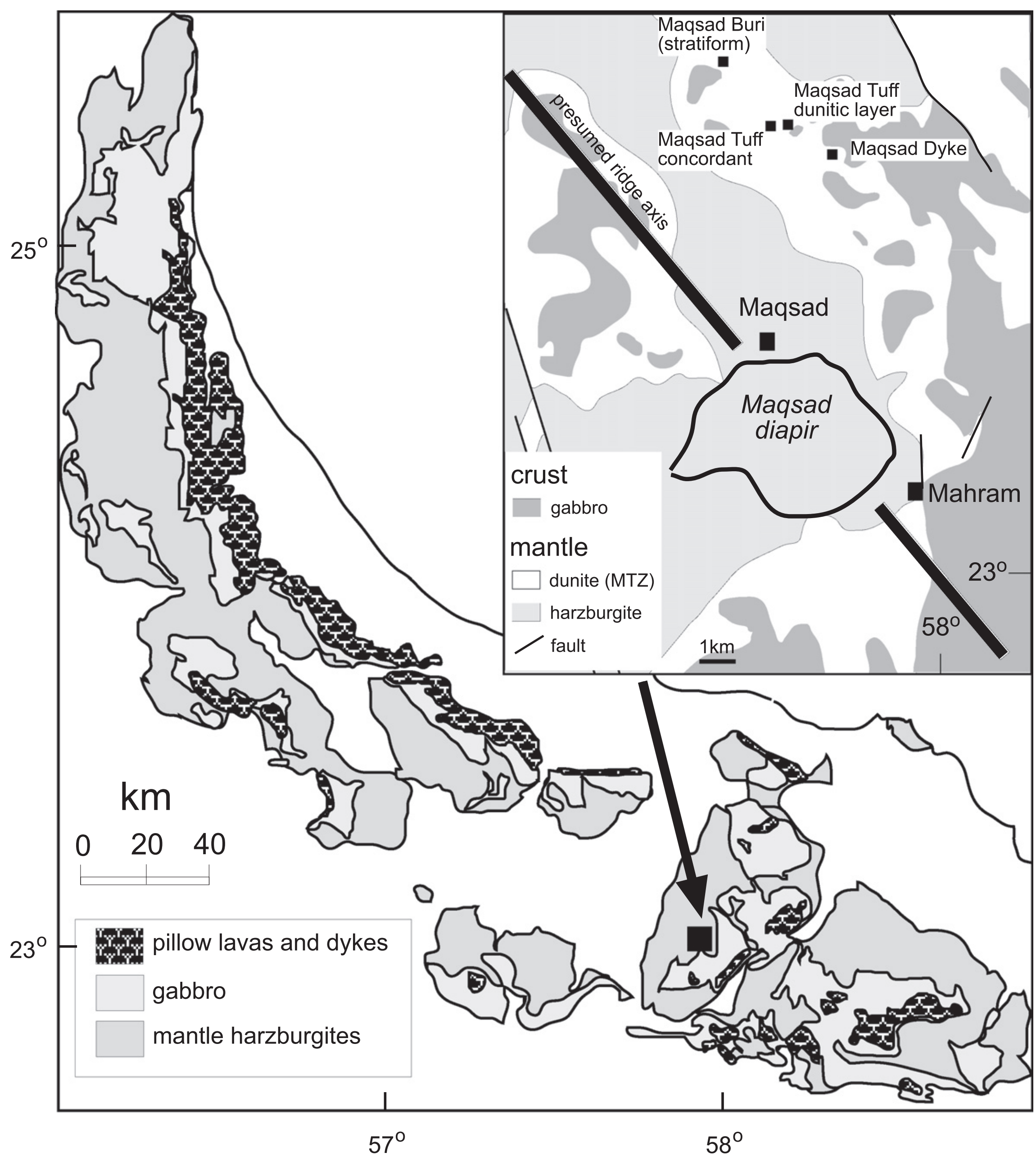

Fig. 1. Geological map of the Oman ophiolite and (inset) the Maqsad diapir showing the Moho transition zone and sample localities. After Boudier and Nicolas, 1995; Jousselin et al., 2012.