ROLLINSON Hugh and ADETUNJI Jacob, 2015. Chromite in the Mantle Section of the Oman Ophiolite: Implications for the Tectonic Evolution of the Oman Ophiolite. *Acta Geologica Sinica* (English Edition), 89(supp. 2): 73-76.

Chromite in the Mantle Section of the Oman Ophiolite: Implications for the Tectonic Evolution of the Oman Ophiolite

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Chromite in the Oman ophiolite is located in the mantle section of the ophiolite sequence and forms abundant small podiformdeposits throughout the length of the ophiolite (Rollinson, 2005).The Oman ophiolite has an exposed mantle section of ca 10 000 km^2, and contains ca 200 chromitite bodies. Most are less than 10 000 tonnes and a only a few are >30 000 tonnes (Boudier and Al-Rajhi, 2014). We have examined these deposits in eight different areas of the ophiolite (Figure 1, Rollinson and Adetunji, 2013a), two of which we have studied in great detail – in WadiRajmi in the north of Oman (Rollinson, 2008) and atMaqsad in the south(Rollinson and Adetunji, 2013b).

1 Field Relationships

The chromitite bodies have a number of different forms – many are as concordant tabular bodies which in places are seen to be part of stratiformchromitite-dunite bodies several tens of metres thick. Elsewhere they may be thin stringers – bands of chromitite a few cm thick in a dunite host. Discordant chromititedykes are also present and deep in the mantle section there areirregular discordant pods and lenses of chromitite a few tens of cm thick. Ceuleneer andNicolas(1985)suggested that the concordant chromitites representdiscordant bodies which have been rotated intoparallelism with the mantle fabric during mantle flow.Whilst this may in part betrue for some chromitite pods it does not explain the field appearance of all the stratiform bodies. It is clear that there was more than one episode of chromitite formation for in WadiHiltiearly concordant podiform bodies are juxtaposed to later dykes. Most commonly the chromitites are massive, but some show nodular textures and form rounded nodules about 1 cm across with olivine between the nodules. Elsewhere there are antinodular textures where large elliptical olivine grains up to 2 cm across are studded with fine chromite grains and set in a matrix of chromitite. Typically olivine is the main phase present in association with the chromite and in many cases the chromitite is hosted within a dunitic sheath within a mantle harzburgite host.

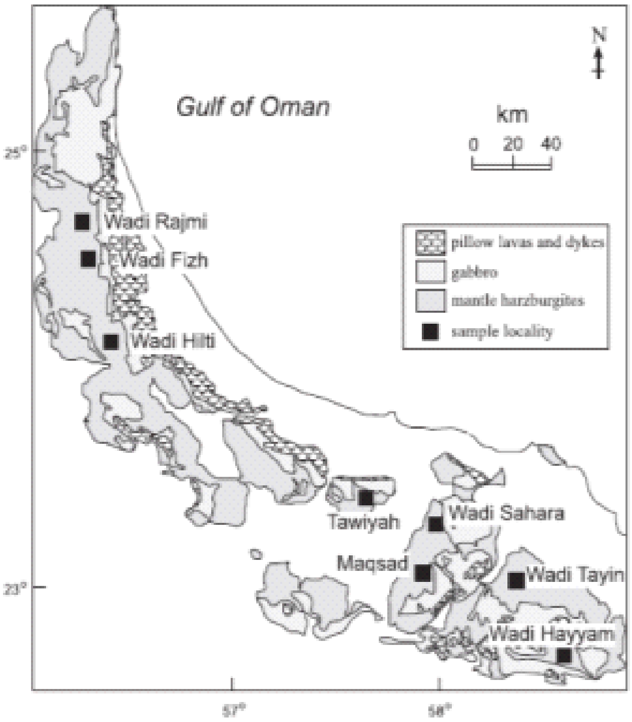

Fig. 1. Deposits in eight different areas of the ophiolite

2 Chromite Compositions

Chromite compositions are presented on a cr# vsfe# diagram in and their compositional variation is shown relative to the mantle harzburgite array. In a previous Figure 2 study Rollinson (2008) argued from a detailed study of asix-km traverse through WadiRajmi that the chromitites vary in composition with depth from the Moho. It was suggested that shallow chromitites had low cr# (0.5-0.6) whereas chromitites deeper in the mantle had higher cr#. The more recent study of Rollinson and Adetunji

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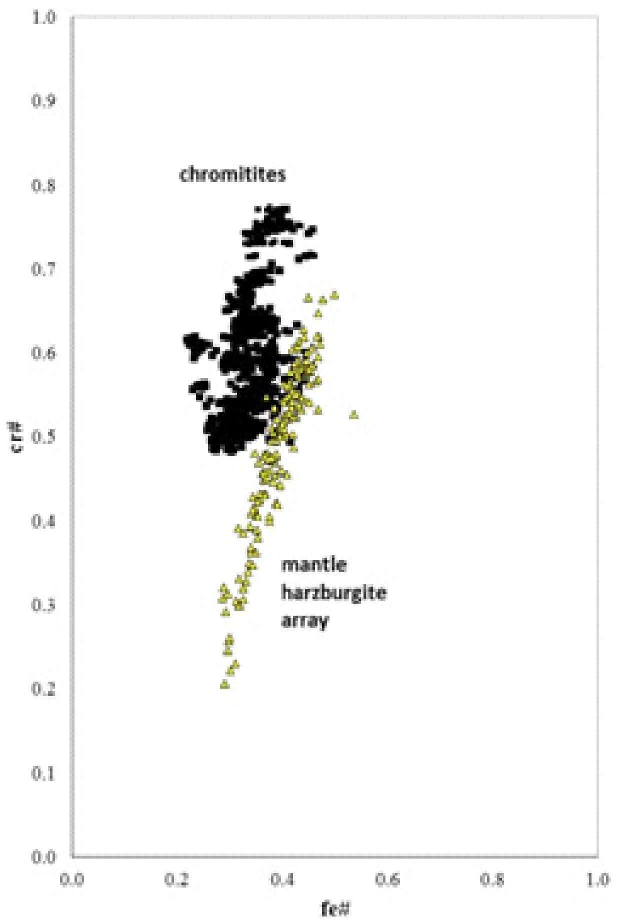

Fig. 2 A detailed study of asix-km traverse through WadiRajmi that the chromitites vary in composition with depth from the Moho

(2013a) over eight different localities in the ophiolite has shown that this finding cannot be sustained and that composition-depth relationships are more varied than previously supposed. There are important compositional variations, but they cannot be entirely related to depth. In WadiRajmi it is possible that the boundary between the low and high cr# chromitites is an oxidised shear zone (Michibayashiet al., 2006), which may have juxtaposed two different parts of the mantle section. However, Hanghoj et al (2010) suggested there is a north-south compositional gradient in the Oman mantle harzburgites reflecting a shift in magmatic processes. We concur, for we find similar evidence in the chromitites.

Melt compositions inferred from chromite chemistry Rollinson (2008) used the experimentally determined relationships between Ti and Al in chrome spinels and their host melt to calculate the composition of the melts from which the WadiRajmichromitites had been derived. These compositions were then compared with the composition of melts known in the lava sequence of the ophiolite. This work was extended by Rollinson and Adetunji (2013a, see Figure 3) to other localities in the ophiolite. Chromites with low Al and Ti concentrations have affinities with experimental compositions derived from depleted mantle and are thought to be of boninitic origin. Rarboninites arknown from the Oman succession. More aluminousand Ti-rich chromites crystallised from melts on a compositionalarray between true MORB-melts and those of depleted mantle. These melts are thought to be MORB-like melts which have interacted with the depleted mantle. Support for this view comes from high cr# chromite inclusions in chromites with a lowcr# at Maqsad, indicating that they have an inherited component (Rollinson and Adetunji, 2013b). MORB-like melts are known in the Geotimesunit of the lower Oman lava sequence, whereas those withlower Ti and Al are thought to equate to the Lasail andAlley lava units in the upper part of the lava sequence.

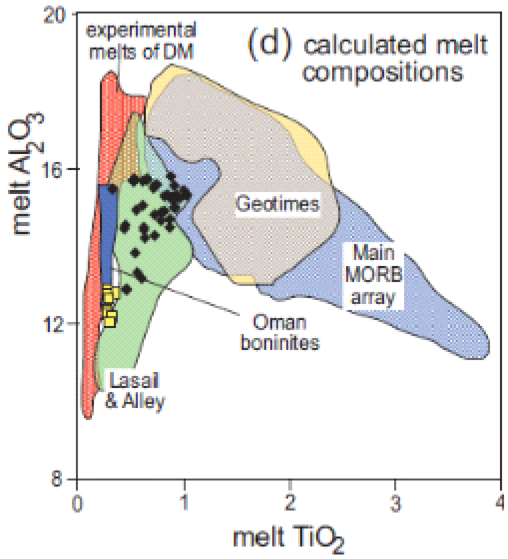

Fig. 3 Composition of the melts from which the WadiRajmichromitites compared with the composition of melts known in the lava sequence of the ophiolite

3 Melt Compositions Inferred from Melt Inclusion Studies

Chromitites in the Maqsad area in the southern part of the ophiolite contain abundant melt inclusions (Rollinson and Adetunji, 2013b). Chromitites in the Maqsad area are located in the Moho transition zone, a 300 m thick dunitic zone located below the Moho, representing an area of intense melt flux through the mantle. Melt inclusions were first described from this area by Schiano et al. (1997) and more recently by Borisova et al. (2012). The inclusions contain hydrous silicate phases – mostly Na-phlogopite, pargasite and chlorite indicating that the melt from which

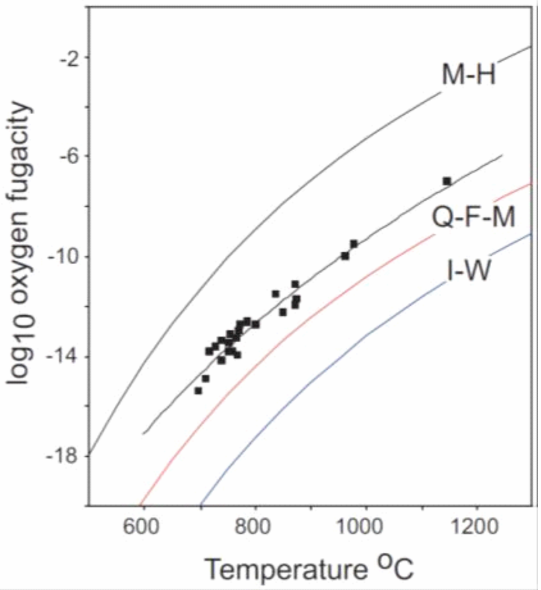

Fig. 4. These ratios are converted into oxygen fugacity values the Oman chromitites define a trend about 1.8 log units above the QFM buffer

they crystallised was hydrous. Homogenisation experiments suggest that the melts were primitive basalts with ca 47 wt% SiO_2, 10-12 wt% MgO, high FeO (11 wt %) and low CaO (7.6 wt%) (Schiano et al., 1997; Borisova et al., 2012).

4 Fe^{3+}/Fe Ratios in Oman Chromitites and the Oxidation State of Their Mantle Source

We have precisely determined Fe^{3+}/Fe ratios in Oman chromitites using Mossbauer spectroscopy (Rollinson and Adetunji, 2012; Rollinson and Adetunji 2013a) and a combination of Mossbauer spectroscopy and single crystal X-ray spectroscopy (Lenaz et al, 2014). The combined approach provides a robust and very precise means of estimating Fe^{3+}/Fe ratios without the uncertainties of line-fitting inherent in the Mossbauer method. Our work shows that the assumption of mineral stoichiometry-the basis for most Fe^{3+} estimates-is not commonly fulfilled and that in ophiolites many sampleare strongly oxidised and have vacancies in their structure. Whist this is bad for petrology,inasmuch as it obscures primary magmatic signals, it is good for the mining industry for the processing of these forms of chromite is less energy intensive (Adetunji et al., 2012). The most strongly oxidised chromitites are associated with high temperature shear zones in the mantle. Some of these samples also show brittle deformation (Lenaz et al., 2014). Primary magmatic Fe^{3+}/Fe ratios are between 0.164-0.270 and this range is thought to represent real compositional differences between the melts which were parental to the chromitites. If these ratios are converted into oxygen fugacity values the Oman chromitites define a trend about 1.8 log units above the QFM buffer(Figure 4), the conventional measure of oxygen fugacity in the suboceanic mantle.

5 Implications for Models of Ophiolite Formation

The Oman ophiolite has classically been interpreted as a slice of ocean crust formed at a fast-spreading ridge (Nicolas and Boudier, 2000), although there have been dissenting voices (eg. Pearce et al., 1981). However recent studies have shown that the parental melts to the Oman chromitites are not typical of MORB. Our work has shown that

- these melts are more oxidised than MORB melts and have equilibrated at a higher fO2 than is typical of a MORB source;
- the range of chromite compositions is greater than typical of chromites found in MORBs and includes chromites of boninitic parentage, ie of arc origin;
- some chromites contain chromite inclusions indicating that they have come from a more depleted source than that of typical MORB;
- the melts are hydrous-a point also made by Mateev and Ballhaus(2002) in relation to the nodular form of some chromitites and more recently by MacLoed et al. (2013) on the basis of the phenocryst assemblage in the Oman lavas.

These observations lead to a view that the Oman chromitites have not crystallised from conventional dry MORB melts and so require a different mode of origin from the ‘fast spreading ridge’ scenario conventionally accepted.

For many years it has been known that the Oman ophiolite contained an ‘arc component’ (see for example Pearce et al, 1981) and previous models had sought to accommodate this through a switch in processes during the life of the ophiolite. Increasingly however, we find that this does not satisfy the data – for example the continuum and range of chromite compositions observed. For this reason we have been strongly influenced by the Whattam and Stern (2011) model of ophiolite formation in a forearc settingand related to subduction initiation. This model accommodates early spreading, although in a forearc setting rather than at a ridge, followed by a gradually increasing subduction contribution to magmatic processes. At subduction initiation asthenospheric mantle rises and spreading commences – perhaps incorporating older deep subducted materials, now known to be present in some ophioliticchromites. We are persuaded that the forearc subduction intitation setting better explains the petrological and geochemical features of the Oman chromitites than the previously accepted fast spreading ocean ridge model.

Acknowledgements

This work was funded by Sultan Qaboos University, Sultanate of Oman and by the University of Derby, UK.

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