Lithos 132–133 (2012) 98–112

Contents lists available at SciVerse ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Lithospheric petrology of the eastern Arabian Plate: Constraints from Al-Ashkhara (Oman) xenoliths

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ARTICLE INFO

Article history:
Received 15 June 2011
Accepted 12 November 2011
Available online 29 November 2011

Keywords:
Arabian Plate
Oman
Xenoliths
Lherzolite
Lithosphere
Lower crust

ABSTRACT

Mafic granulite and spinel lherzolite xenoliths from Cenozoic alkaline basalts near Al-Ashkhara, eastern Oman, have been selected for a systematic mineralogical, geochemical and Sr–Nd–Pb isotopic study. This is the only place in E Arabia where samples of both lower crust and upper mantle can be examined. Lower crustal xenoliths consist of two mineralogically and chemically distinct groups: gabbronorite (subequal abundances of ortho- and clino-pyroxene and plagioclase) and plagioclase pyroxenite (dominant pyroxene and subordinate plagioclase). Temperature estimates for lower crustal xenoliths using the two pyroxene geothermometer (T-Wells) yield 810–865 °C. The mineral assemblage (spinel–pyroxene–plagioclase) and Al content in pyroxene indicate that plagioclase-bearing xenoliths equilibrated at 5–8 kbar (13 and 30 km depth) in the lower crust. εNd and $^{87}Sr/^{86}Sr$ calculated at 700 Ma for Al-Ashkhara lower crustal xenoliths (+6.4 to +6.6; $^{87}Sr/^{86}Sr = 0.7028$ to 0.7039) are consistent with the interpretation that juvenile, mafic melts were added to the lower crust during Neoproterozoic time and that there was no discernible contribution from pre-Neoproterozoic crust. Upper mantle xenoliths consist of both dry and hydrous (phlogopite-bearing) lherzolites. These peridotites are more Fe-rich than expected for primitive mantle or melt residues and probably formed by pervasive circulation of melts that have refertilized pre-existing mantle peridotites. Mineral equilibration temperatures range from 990 to 1070 °C. Isotopic compositions calculated at 700 Ma are εNd = +6.8 to +7.8 and $^{87}Sr/^{86}Sr = 0.7016$ to 0.7025, indicating depleted upper mantle. Pb isotopic compositions indicate that the metasomatism was relatively recent, perhaps related to Paleogene tectonics and basanite igneous activity. Nd model ages for the spinel peridotite xenoliths range between 0.59 and 0.65 Ga. The xenolith data suggest that eastern Arabian lower crust is of hotspot origin, in contrast to western Arabian lower crust, which mostly formed at a convergent plate margin. Geochemical and isotopic differences between lower crust and upper mantle indicate that these are unrelated, possibly because delamination replaced the E Arabian mantle root in Neoproterozoic time.

1. Introduction

We understand the principal aspects of how Earth's upper continental crust formed from studying rock exposures, but these samples represent a trivial fraction of Earth's mass. Deeper understanding of the silicate Earth depends on also understanding the lower continental crust and upper mantle. Because these last two silicate layers are mostly inaccessible, geoscientists must integrate information from large scale geophysical probing with petrologic investigations of lower crust and upper mantle samples. Petrologic investigations focus on samples obtained via two major approaches: exposures resulting from tectonic processes, such as ophiolitic peridotites or peridotite exposures at slow-spreading ridges and study of exhumed ancient granulite terrains (Kempton et al., 1995; Liu et al., 2001) and xenoliths brought to the surface by volcanic eruptions (Griffin and O'Reilly, 1987; Rudnick et al., 1986; Zhou et al., 2002).

Investigations of upper mantle xenoliths provide key constraints about mineral,, chemical and isotopic composition and thermal state of the upper mantle (e.g. Eggins et al., 1998; Griffin and O'Reilly, 1987; Griffin et al., 1999; Kempton et al., 1997; Rudnick, 1992). Similar information about the lower continental crust has also been obtained from xenoliths (Dostal et al., 1980; Downes et al., 1990; Griffin and O'Reilly, 1987; Griffin et al., 1987; Kay and Kay, 1981; Loock et al., 1990; Okrusch et al., 1979; Rudnick, 1992; Rudnick et al., 1986; Selverstone and Stern, 1983; Stosch et al., 1986; Taylor and McLennan, 1985). Such xenoliths which commonly occur in young volcanic areas that lack nearby outcrops of high-grade lower crustal rocks, permit comparisons to be made between petrological and chemical results of xenolith studies and models based on seismic data (Griffin and O'Reilly, 1987; Loock et al., 1990). Such xenoliths also preserve the fabric and mineral assemblages produced at the ambient pressure and temperature conditions at the site of their

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0024-4937/$ – see front matter
doi:10.1016/j.lithos.2011.11.011

formation in the lithosphere (Griffin and O'Reilly, 1987; Satsukawa et al., 2010).

The continental lithosphere of Arabia is a good place to reconstruct the processes that generated and/or modified continental crust and upper mantle during Neoproterozoic time. The nature of the upper mantle and lower continental crust of western Arabia is reasonably well known, because of some seismic refraction studies and an abundance of xenolith-bearing basaltic flows. Cenozoic alkali basaltic lavas in the northern, southern and western parts of the Arabian Plate contain a wide variety of crustal and mantle xenoliths (Abu-Aljarayesh et al., 1993; Coleman, 1993; Ghent et al., 1980; Grégoire et al., 2009; Henjes-Kunst et al., 1990; Kuo and Essene, 1986; McGuire, 1988a,b; McGuire and Stern, 1993; Nasir, 1990, 1994, 1995, 1996; Nasir and Al-Fuqha, 1988; Nasir and Safarjalani, 2000; Nasir et al., 1992, 1993; Nasir et al., 2006; Stern and Johnson, 2010; Stein and Katz, 1989; Stein et al., 1993). In contrast, there is little Cenozoic basalt in eastern Arabia and only few localities contain such xenoliths. However, peridotitic upper mantle xenoliths have been recently discovered in Cenozoic alkaline dykes and flows emplaced along the Oman passive margin facing the Owen Basin (Fig. 1A,B). These basalts and associate upper mantle xenoliths have been studied for their bulk rock and mineral trace element compositions (Gnos and Peters, 2003; Grégoire et al., 2009; Nasir et al., 2006). A recently-discovered Eocene basanite plug near Al-Ashkhara (Fig. 1A,B) contains abundant upper mantle and lower crustal xenoliths, which provide a unique opportunity to explore the composition and nature of eastern Arabian lithosphere to compare with the better-documented lithosphere beneath western and northern Arabia. The question addressed here concerns the nature and evolution of the lithosphere beneath eastern Arabia. We present new petrologic, geochemical, and isotopic data for xenoliths from the Al-Ashkhara plug and compare our results to those for mantle peridotite and lower crustal xenoliths from western Arabia.

2. Geologic setting

The continental Arabian Plate is dominated by Neoproterozoic (1000–543 Ma) crust, although small tracts of older crust are preserved

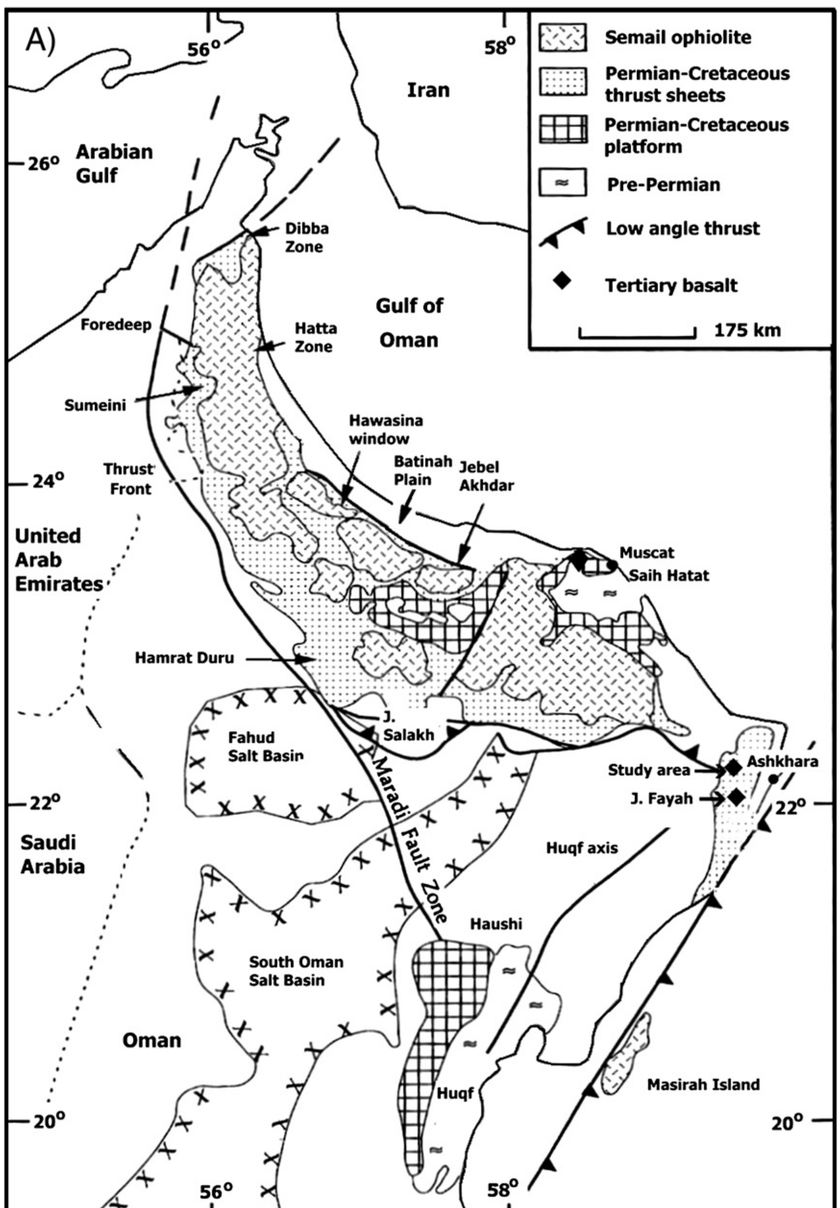

Fig. 1. (A) Locality map showing location of the studied Al-Ashkhara (Oman) xenoliths. (B) Xenolith location of studies by Gnos and Peters (2003), Grégoire et al. (2009) and Nasir et al. (2006).