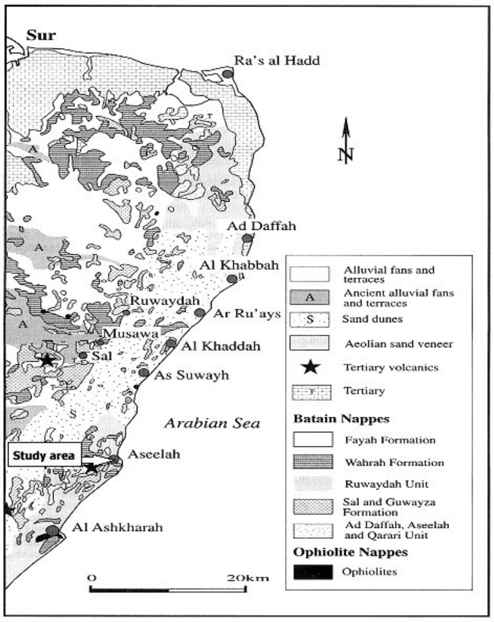
Evolved carbonatitic kimberlite from the Batain Nappes, eastern Oman continental margin

S. Nasir[(1)], S. Al-Khirbash[(1)], H. Rollinson[(1)], A. Al-Harthy[(1)], A. Al-Sayigh[(1)], A. Al-Lazki[(1)], E. Belousova[(2)], F. Kaminsky[(3)], T. Theye[(4)], H.-J. Massonne [(4)], S. Al-Busaidi[(5)]

[1]*Department of Earth Sciences, Sultan Qaboos University, Oman*
[2]*GEMOC ARC National Key Centre, Macquarie University, Australia*
[3] *KM Diamond Exploration Ltd, Vancouver, Canada*
[4]*Institut für Mineralogie und Kristallchemie, Universität Stuttgart, Germany*
[5]*Directorate General of Minerals, Oman*

The geology of northeastern Oman is dominated by the Batain nappes, which comprise an allochthonous sequence of Permian to uppermost Cretaceous marine sedimentary and volcanic rocks (Map below). At the Cretaceous-Paleogene transition (~65 Ma), oblique convergence between India and Afro-Arabia caused fragments of the early Indian Ocean to be thrust onto the Batain Basin, eastern Oman. The Lower Permian to Maastrichtian sediments and volcanic rocks of the Batain basin and fragments of the Indian Ocean floor (eastern ophiolite of Oman "Masirah ophiolite") were obducted northwestward onto the northeastern margin of Oman.

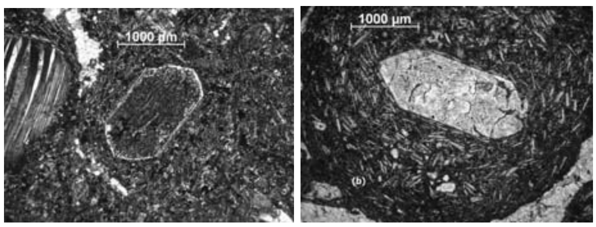


Field description and Petrography

The ultramafic lamprophyric rocks outcrop on the beach of the Asseelah village as a few, almost house-sized blocks. The diameter of the corresponding pipe is suggested to be 200-300 m. In general, the rocks are macrocrystic, spinel, and phlogopite bearing diatreme facies calcite ultramafic lamprophyres with globular segregationary textures. The lamprophyres intrude the cherts of the Late Jurassic-Cretaceous Wahra formation of the Batain Nappe with a sharp contact. The main body of the Asseelah pipe is comprised of two rock varieties with a sharp contact between them:

(1) Heterolithic breccia (HB)

The rocks are fine-grained, carbonate-rich, and porphyritic (Left figure below). They contain olivine microcryts and phenocrysts, which are completely pseudomorphed by chlorite, calcite, and saponite. Xenocrysts of phlogopite up to 2 cm in size, and rounded grains of chromite are common in a carbonate-phlogopite-rich matrix. The breccias have distinct autolithic structures, cemented into a carbonate matrix, and range in size from microscopic to as large as 15 cm. Large ovoidal carbonatitic xenoliths are common.



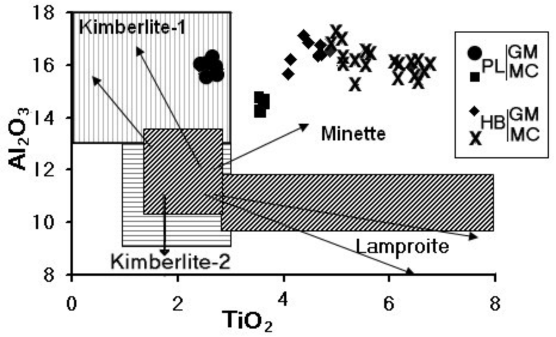
(2) Pelletal volcaniclastic lapilli tuff (PL)

The PL tuff consists of lapilli, 1-20 mm in sizes, which are composed of fine-grained aggregates of mica, magnetite, spinel, chlorite, and calcite, often with cores of mineral macrocrysts or phenocrysts (right figure above). The cored lapilli contain kernels of olivine pseudomorphs, and/or calcite which are surrounded by phlogopite-rich microlites. Xenoliths are common in the pipe of Asseelah. They comprise a suite ranging from carbonatite (up to 30 cm in diameter), discrete green chlorite xenoliths (1-8 cm) to high-alumina ultrabasic rocks (e.g., glimmerite). Abundant xenoliths of upper crustal wall rocks also occur in the pipe ranging from cherts and shales of the Wahra Formation to serpentinite.

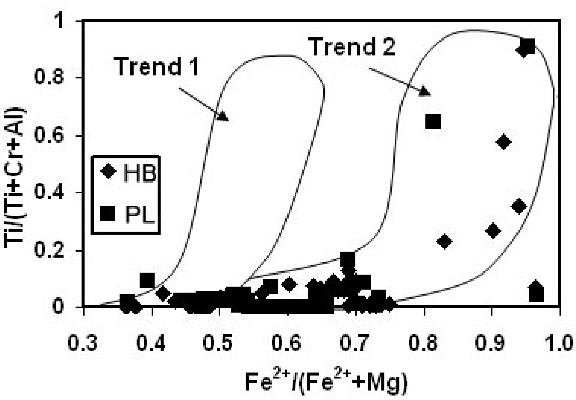
Mineralogy

Calcite is fairly pure with low SrO (up to 0.21 wt.%), MnO (up to 0.9 wt.%), MgO (up to 1.36 wt.%) and FeO (0.97 wt. %) contents.

Phlogopite grains exhibit a wide compositional range (Mg# = 0.69-0.86, Al_2O_3 = 14.2-17.4, TiO_2 =2.4-6.7 wt. %, Cr_2O_3 = 0.03-0.57, BaO=0.29-1.44 wt. %. The figure below demonstrates that the majority of PL groundmass phlogopite plot along a trend described for kimberlitic rocks (Mitchell, 1986) whereas phlogopite from the HB plots along a trend described for minette and ultramafic lamprophyres. Matrix phlogopite in HB exhibits zoning with cores having higher Ti but lower Al and Fe contents than the rim, whereas phlogopite macrocrysts show the opposite trend.



Spinels are mostly chrome spinels with up to 5 wt. % TiO_2, 0.6 wt. % ZnO and 0.8 wt. % MnO. Larger groundmass grains (0.04 to 0.1 mm) are zoned with titanomagnetite rims. Groundmass chromites in the PL plot on two different trends (Figure below). A small number of grains plot on the main kimberlite trend (magmatic trend 1 of Mitchell, 1986); these have higher TiO_2 contents and show Ti-enrichment as Fe^{3+} increases and the Cr# decreases.



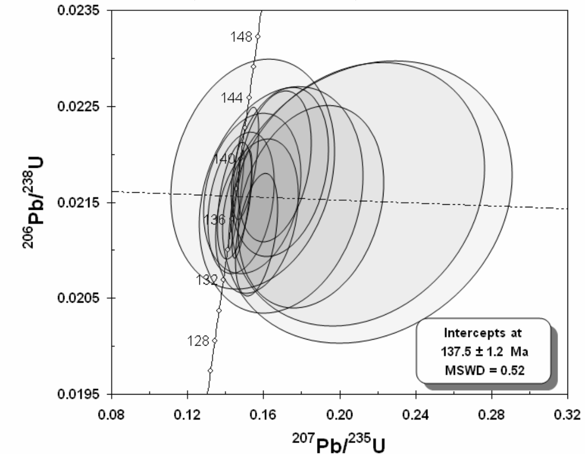
Ilmenite falls into the "Cr-poor" population, characterized by Cr_2O_3 contents of <1 wt. % with MgO contents ranging from 4.1 to 9.9 wt.

Zircon: Hafnium, Y, Yb, Lu, Th and U contents in the Asseelah zircons show that their trace-element composition is typical of zircons found in carbonatites and kimberlites (26 % of the zircon grains classified as carbonatitic, 26% kimberlitic, and 48% as carbonatitic/kimberlitic; Belousova et al., 2002).

Other minor minerals are G0 garnet, apatite, rutile, chlorite, vermiculite and serpentine.

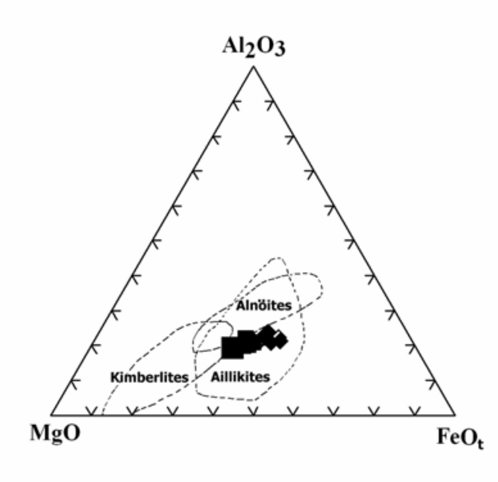
U-Pb LAM-ICPMS Geochronology

The U-Pb zircon data are plotted on a conventional concordia diagram below. All grains produced a weighted average $^{206}Pb/^{238}Pb$ age of 137.5 ± 1 Ma with 95 % confidence (MSWD = 0.49).



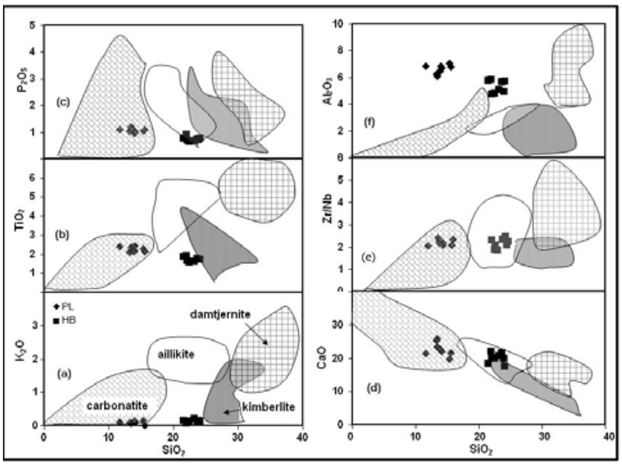
Whole Rock Geochemistry

The Asseelah rocks are characterized by low SiO_2 (11.6–24.1 wt%) and MgO contents (9.5-12.4 wt%). In the figure below, all the Asseelah rocks plot in the aillikite field.

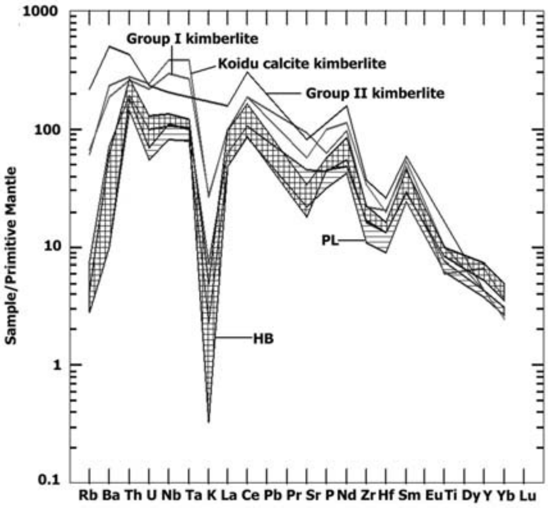


In a plot of K_2O vs. SiO_2 and TiO_2 vs SiO_2, the HB samples plot near the kimberlite field, whereas the PL samples plot within the carbonatite field. However, the HB samples plot within the aillikite field and the PL samples within the carbonatite field on P_2O_5, CaO and

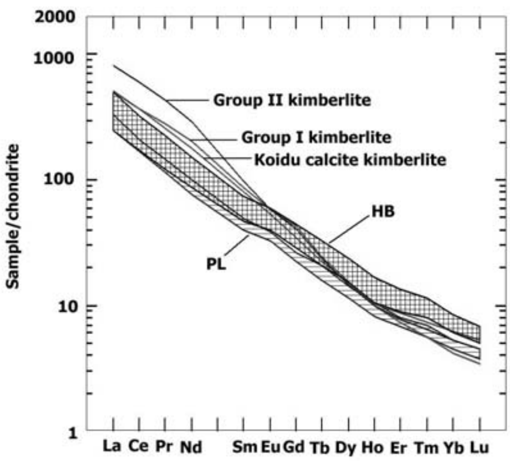
Zr/Nb vs. SiO_2 diagrams (Figure below). Both groups show K_2O depletion and Al_2O_3 enrichment (>4.75 wt.%) compared to other ultramafic rocks and carbonatite.



Trace element abundances (Figure below) show a strong enrichment in most LILE and Nb, Th, U and Pb, typical of Group-I kimberlites with small-degree partial melts.



All HB and PL samples exhibit smooth, sub-parallel patterns and steep slopes. with $(La/Sm)_N$ of 6-10. (Figure below).



Sr-Nd and Pb Isotopes

Initial $^{87}Sr/^{86}Sr$ ratios (at 137 Ma) vary from 0.70472 and 0.70625, whereas initial $^{143}Nd/^{144}Nd$ ratios vary between 0·512603 and 0·512696. The $^{208}Pb/^{204}Pb_i$ ratios are high relative to MORB and group I kimberlite, but are similar to the Reunion mantle plume rocks.

Hf-isotope

The $^{176}Hf/^{177}Hf$ ratio in all analysed zircon grains is identical within error (0.282862 ± 12). The mean εHf for the zircons is 6.18 ± 0.42. A minimum Depleted-Mantle model age, calculated using the measured Lu/Hf ratio is 0.54 Ga. A "crustal" model age of 0.8 Ga, that gives a maximum model age, is produced when assuming a Lu/Hf ratio corresponding to the average continental crust (0.015).

Discussion

Using the whole-rock chemistry as the primary classification criterion, the Asseelah rocks should be termed either aillikite and/or magnesio-carbonatite. From the similarity in mineralogy and texture to kimberlite, aillikite, and carbonatite, coupled with evidences from specific major, and trace elements, it is possible to infer that the Asseelah rocks before evolution represent a relatively cohesive group with a restricted compositional range intermediate between kimberlite, aillikite and/or carbonatite. The highly hybrid nature of the Asseelah rocks are not likely to represent a direct crystallization product from a mantle-derived magma. The composition of the Asseelah rocks may represent the late stage magmatic evolution of kimberlitic or more likely aillikitic melt in an oceanic environment.
The characteristic incompatible element enrichment and fractionated REE patterns of the Asseelah rocks are consistent with derivation by very low degrees of partial melting of metasomatically enriched sources. The enrichment of the Asseelah aillikite source region could be a consequence of upward percolation of alkaline melt from upwelling Mesozoic mantle plumes (e.g. Reunion) that impinged on the base of the sub-continental lithosphere just prior to Gondwana break-up. In a geodynamic context, the Reunion plume is inferred to have provided both material, in the form of metasomatizing alkaline fluids or melts, and heat to initiate melting to give rise to Batain magmatism.

References

Belousova, E.A., Walters, S., Griffin, W. L., O'Reilly, S. Y., and Fisher, N. I., 2002. Igneous zircon: trace element composition as an indicator of source rock type. Contributions to Mineralogy and Petrology, 143, 602-622.

Mitchell, R. H., 1986. Kimberlites: Mineralogy, Geochemistry and Petrology, Plenum, New York