

## Global Abyssal Peridotite Constraints on the Upper Mantle

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Abyssal peridotites are the residues of adiabatic decompression melting beneath ridges. A broad sampling of abyssal peridotites from all major ocean ridges reveals variations in composition that reflect both ridge processes (melting, refertilization) and pre-existing heterogeneity. I present a compilation of geochemical data for abyssal peridotites from 59 localities on 6 major ridge systems (EPR, MAR, SWIR, CIR, AAR, and Gakkel). While the majority of peridotites have been sampled at transform faults, sampling at slow and ultra-slow ridges in the past decade has recovered large suites of on-axis peridotites. Compositional data has now been published for ~1500 peridotites, permitting a detailed look at global variations in the oceanic upper mantle.

I classify peridotites into residual peridotites and four types of veined peridotite: (1) gabbro-veined & plagioclase-bearing peridotite, (2) pyroxenite-veined peridotite, (3) dunite, and (4) cryptically metasomatized peridotite. The veins are generally interpreted to represent incompletely extracted melt or melt-related features retained in peridotite after adiabatic decompression melting. Veined peridotites represent >30% of the dataset. The abundance of veined peridotite indicates that oceanic lithospheric mantle is less depleted than commonly assumed, resulting in recycling of relatively more enriched material at subduction zones.

Residual peridotites provide the best representation of mantle composition following melt depletion and extraction. However, these unveined, residual peridotites define a surprisingly large compositional range, particularly at some individual localities. Modal Cpx varies from 0 to 15%, while spinel Cr/[Cr+Al] varies from 0.1 to 0.6. Individual trace elements vary by one to three orders of magnitude, which corresponds to ~0-12% degree of nonmodal fractional melting. Such variation is at odds with theory, which predicts that the degree of melting beneath ridges should be relatively uniform, except at ultra-slow spreading rates. In addition, some sections of ridge contain highly depleted peridotite associated with thin or absent basaltic crust. Some local-scale variability can be explained by incipient melt-rock reaction to produce dunite, but the pervasive variability at all length-scales indicates that regions of the upper mantle must contain pre-existing heterogeneities. This agrees with isotopic data (available for <100 abyssal peridotites), which require long-term depletions and enrichments in the mantle.

## Long-term CO<sub>2</sub> induced reactivity, observations on natural CO<sub>2</sub> analogues and geochemical model predictions

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Predicting CO<sub>2</sub> trapping and containment over extended timescales asks for accurate models and well constrained input parameters. CO<sub>2</sub> natural analogues provide good opportunities to study the actual long-term effect of CO<sub>2</sub> on reservoir and caprock. This will provide valuable insight in long-term geochemical processes concerning CO<sub>2</sub> storage. Moreover, natural analogues can help calibrate simulations of the long-term chemical effects of CO<sub>2</sub> storage. Accurate simulations are essential for confirming whether the observed and modelled behaviour of injected CO<sub>2</sub> are in agreement, as required for EU regulations, thereby facilitating successful implementation of CCUS.

We present an integrated approach of petrography, basin modelling and geochemical modelling. Our study is focussed on the Werkendam natural analogue, a Dutch gas field containing > 70% CO<sub>2</sub>. The CO<sub>2</sub> was trapped millions of years ago and hence the reservoir has been reacting with CO<sub>2</sub> for prolonged periods of time. In addition to CO<sub>2</sub> induced reactions, reactions related to 'ordinary' diagenesis are expected to have occurred. To distinguish the effect of CO<sub>2</sub> from diagenesis, the Waalwijk methane field was selected as a CO<sub>2</sub> free reference of the same formation. Basin modelling showed that this field has a comparable burial history as Werkendam. Samples from both reservoirs are studied with SEM to assess the differences in the mineral relations. Comparison of the reactions observed in the CO<sub>2</sub> and the CH<sub>4</sub> fields points to differences in mineral dissolution and secondary carbonate formation. The presence of CO<sub>2</sub> appears to enhance feldspar dissolution while facilitating (additional) formation of carbonates such as siderite, dolomite and ankerite. Geochemical modelling with PHREEQC is performed to assess if these reactions associated with CO<sub>2</sub> correspond to the predicted mineral changes. Calibration of the model indicates that the selection of primary mineralogy, especially the minor iron-bearing minerals, has a large effect on predicted CO<sub>2</sub> mineralization.

Detailed mineralogical input and assessment of the burial history is required to calibrate geochemical models which will increase our knowledge on long-term geochemical processes considering CCUS.