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OXYGEN FUGACTIY OF ABYSSAL PERIDOTITES ALONG THE GAKKEL RIDGE

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BACKGROUND

The Earth's oxygen budget is important in understanding how our planet evolved and how it continues to evolve chemically over time. Scientists study the deep Earth to understand the oxygen cycle of the Earth's interior, specifically the mantle, our planet's largest oxygen reservoir. At the bottom of the sea, at mid-ocean ridges, the Earth is splitting apart and generating new ocean crust, bringing to the surface rocks from the upper mantle called abyssal peridotites (Fig.1). As mantle rocks come to the surface, the lower pressure causes certain minerals in the rock to melt out preferentially to form magma; this is called partial melting. Geochemical differences among mantle rocks may be associated with varying degrees of partial melting and interaction with migrating melts as they travel to the surface.

The Gakkel Ridge, located in the Arctic between Russia and Greenland (Fig.2), is the slowest spreading mid-ocean ridge in the world (Hellebrand 2002), and exposes peridotites, similar to Fig.3, along its axis. Our sample set looks at two different types of melting systems - one that exhibits small degrees of partial melting and one that experiences larger degrees of partial melting, as well as interaction with migrating melts in the mantle. We used a thermodynamic property known as oxygen fugacity, which quantifies the ability for oxygen to react in a chemical system, in order to interpret how different types of melt processes affect the oxygen budget of the Earth's interior.

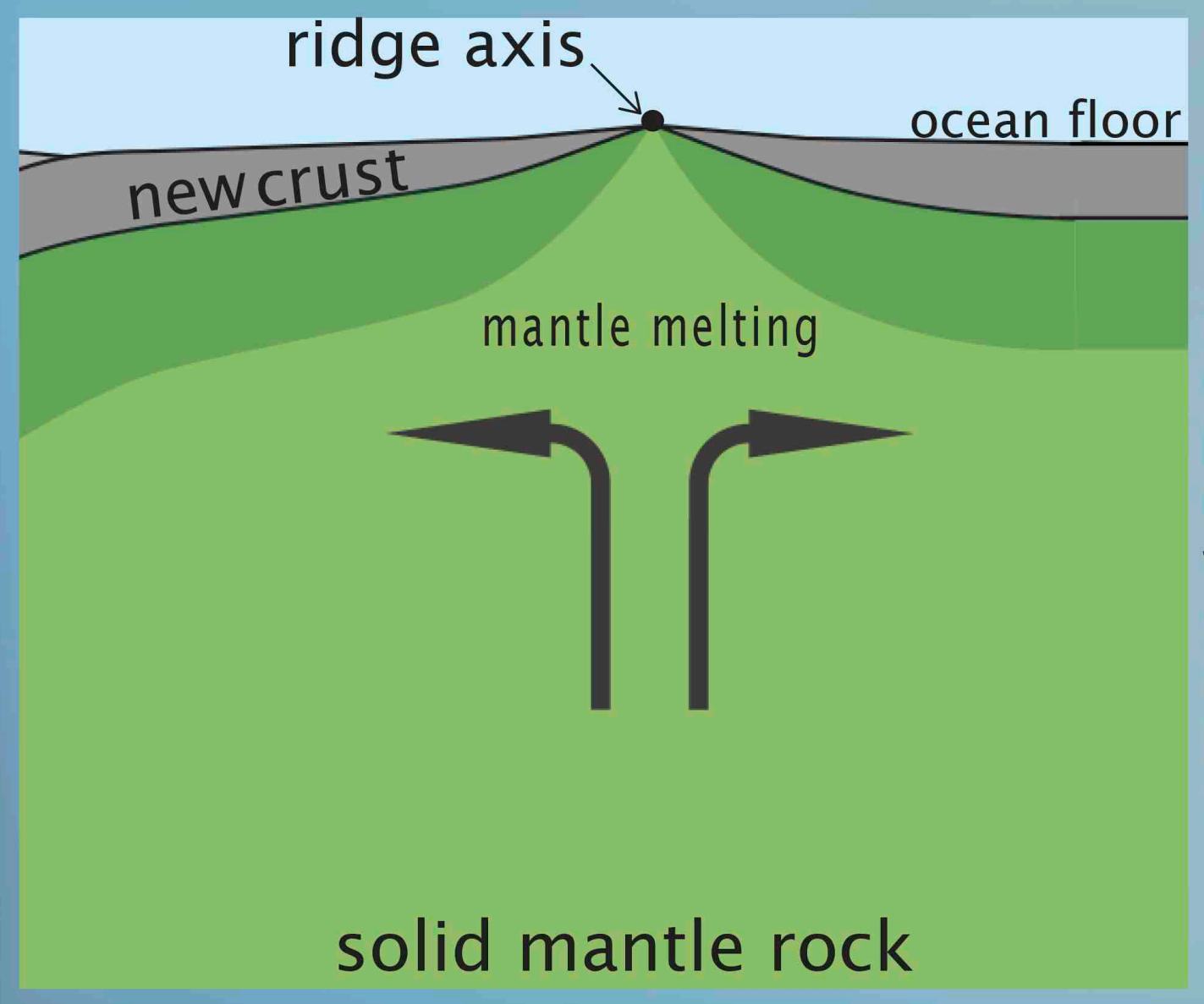


Figure 1: cross-section of a mid-ocean ridge; abyssal peridotites are represented with a black circle (modified from Kelley and Cottrell 2009).

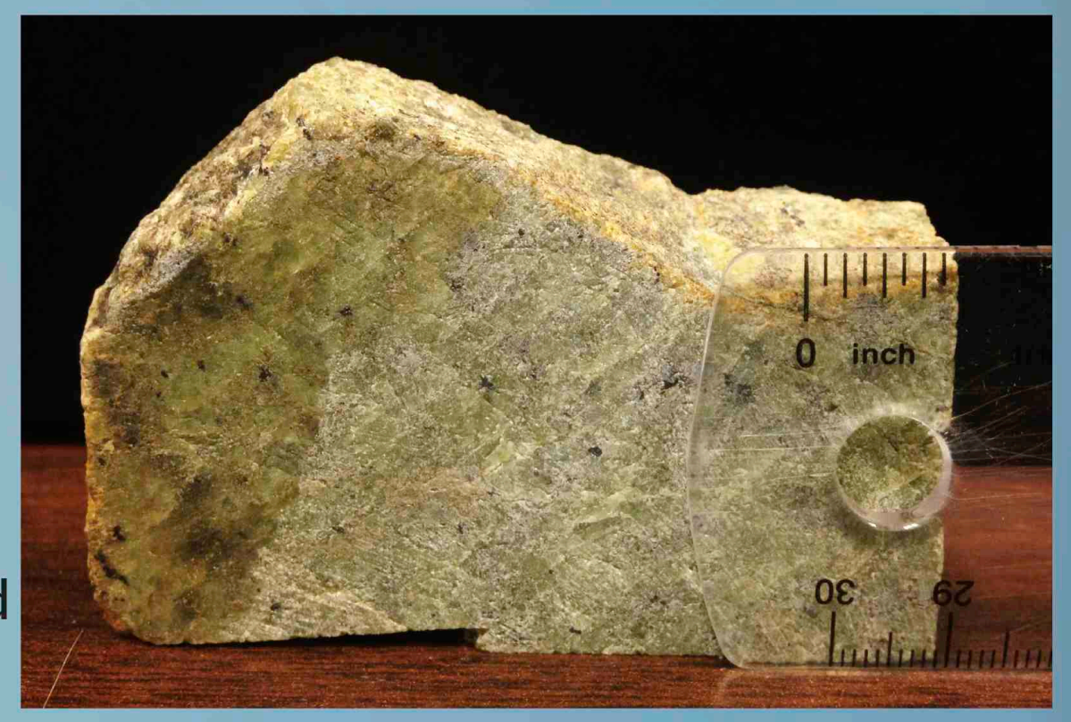


Figure 3: hand sample of a seafloor peridotite from Tonga, in the South Pacific.

SAMPLES

Ten thin sections of abyssal peridotite were mapped using a petrographic microscope. They were variably altered by serpentinization processes which can make minerals a challenge to identify, sometimes even unanalyzeable (Fig.4).

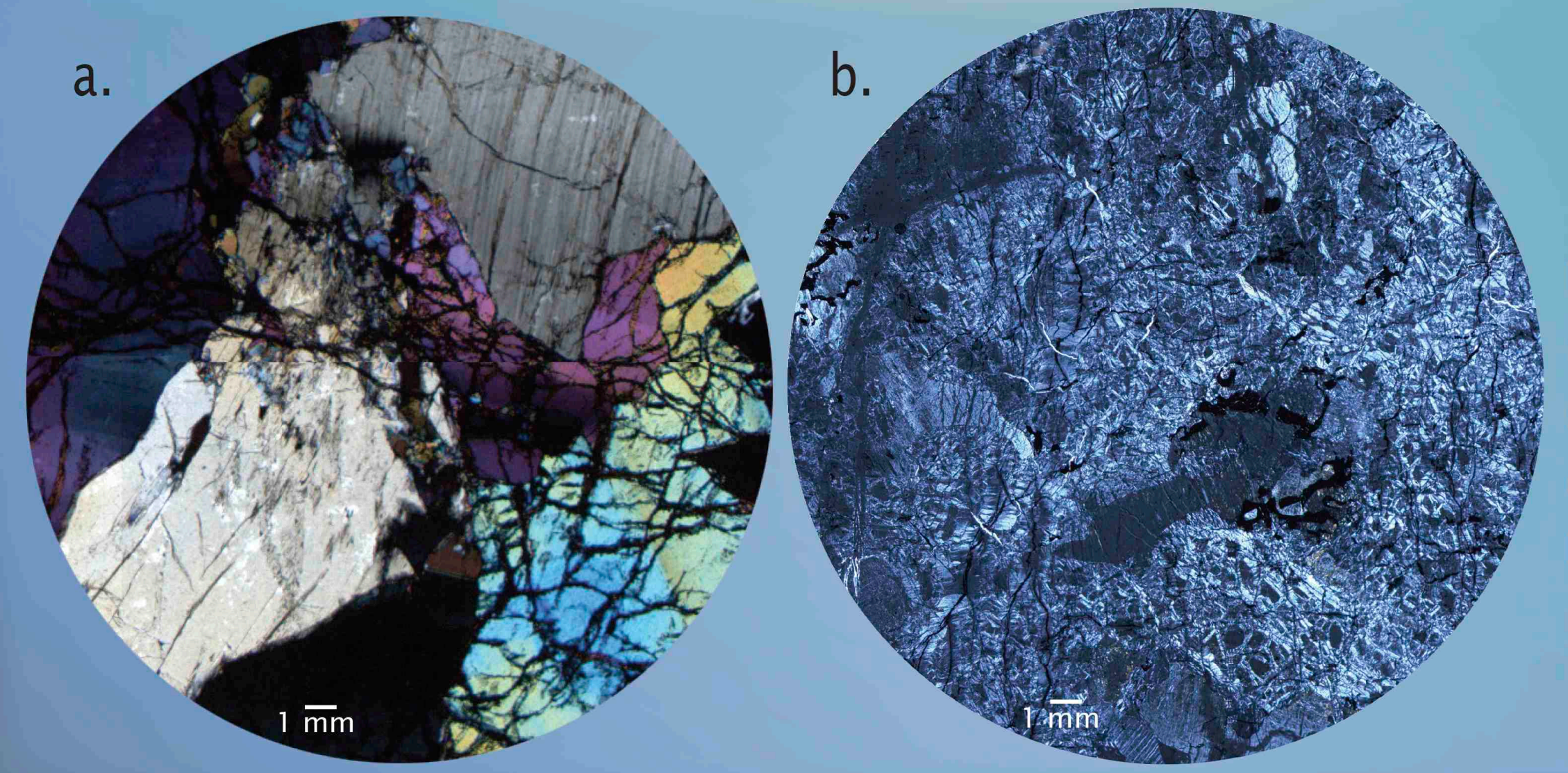


Figure 4: fresh, less altered sample (left) and highly serpentinized sample (right) displayed in cross-polarized light.

Samples were divided into categories based on both Chrome number and light rare earth element (LREE) enrichment. Chrome number is directly related to melt extraction and LREE enrichment may indicate melt-rock interaction.

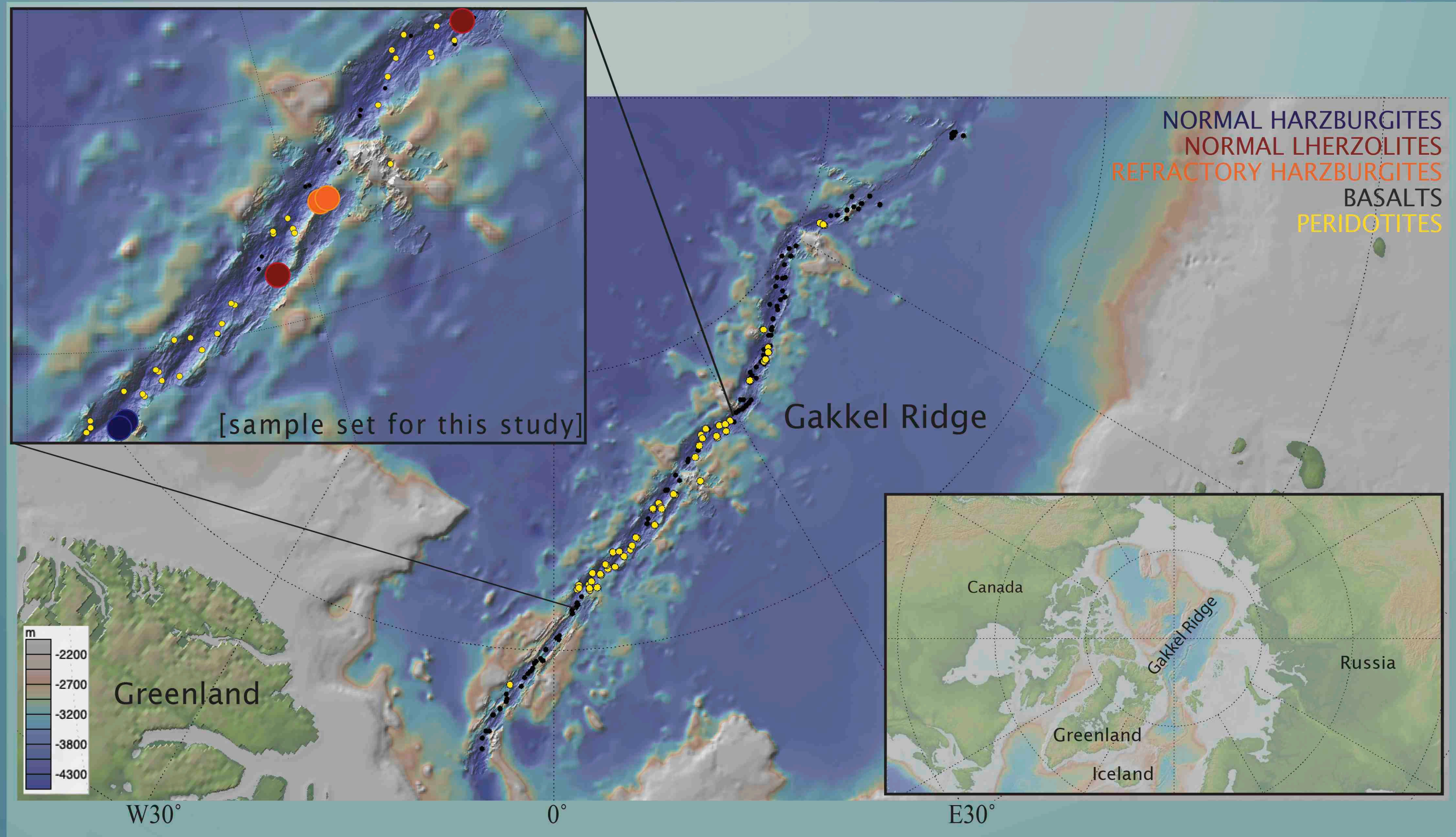


Figure 2: Gakkel Ridge, Arctic. Circles represent dredges. Created in GeoMap App (Basemap Ryan et al. 2009)

RESULTS

"Normal" or fertile peridotites refer to mantle rocks that have experienced little melt-rock interaction while refractory peridotites exhibit a larger degree of melt-rock interaction and melt extraction. Normal harzburgites and lherzolites fall in the range of previous abyssal peridotite measurements of fO_2, whereas refractory harzburgites show a trend of reduced fO_2 with increasing chrome number (Cr#=Cr/(Cr+Al)) . The normal lherzolites and normal harzburgites range from -0.1 to 0.6 log units relative to the QFM buffer (Fig.5). Chrome number is relatively low for the normal peridotites (0.13-0.17), indicating low degrees of melt extraction from the rock, as chromium is compatible relative to aluminum during partial melting. Refractory harzburgites have low fO_2 values, ranging from -0.7 to -2.7 log units relative to QFM. Chrome number in these samples is significantly higher (0.43-0.55), providing evidence of either large degrees of melt extraction or of melt-rock interaction.

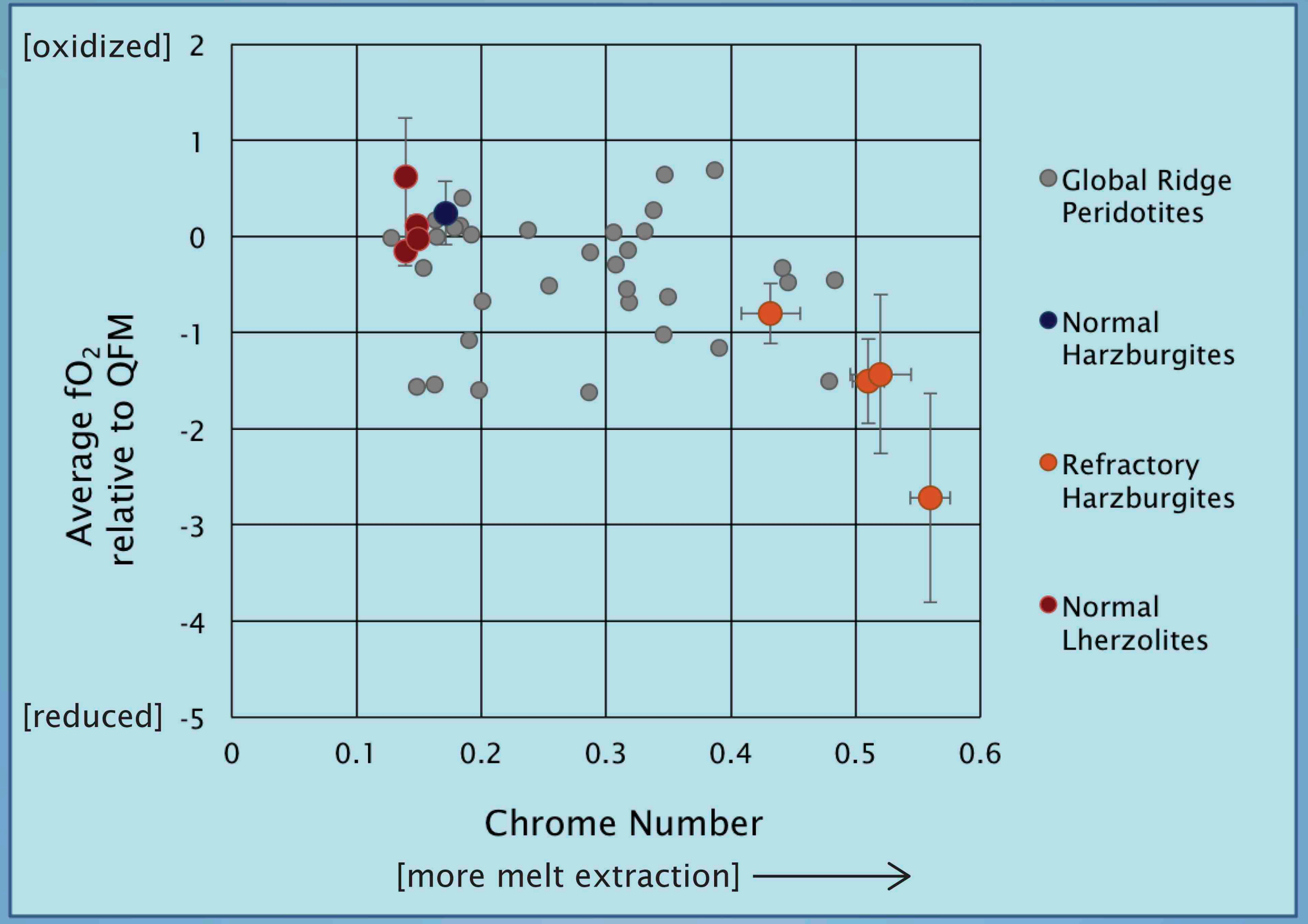


Figure 5: a normal harzburgite sample (Figure 4b) was too altered to gather olivine data - therefore, fO_2 results were inconclusive. This graph encompasses the other 9 thin sections that were sampled to completion as well as the global data set for abyssal peridotites along the Gakkel ridge.

METHODS

Oxybarometry requires compositional data from the minerals, temperature, and pressure (Bryndzia and Wood 1990). We used electron microprobe analysis with Mössbauer-calibrated spinels to obtain the compositional data in each sample in order to calculate fO_2 (Fig.6).

$$\underset{\text{olivine}}{6Fe_2SiO_4} + O_2 \rightleftharpoons \underset{\text{orthopyroxene}}{3Fe_2Si_2O_6} + \underset{\text{spinel}}{2Fe_3O_4}$$

The above redox reaction shows how Fe^{2+} turns into Fe^{3+} as oxygen is added to the system (as fO_2 increases), affecting the $Fe^{3+}/\Sigma Fe$ ratio in spinel, which we measure.

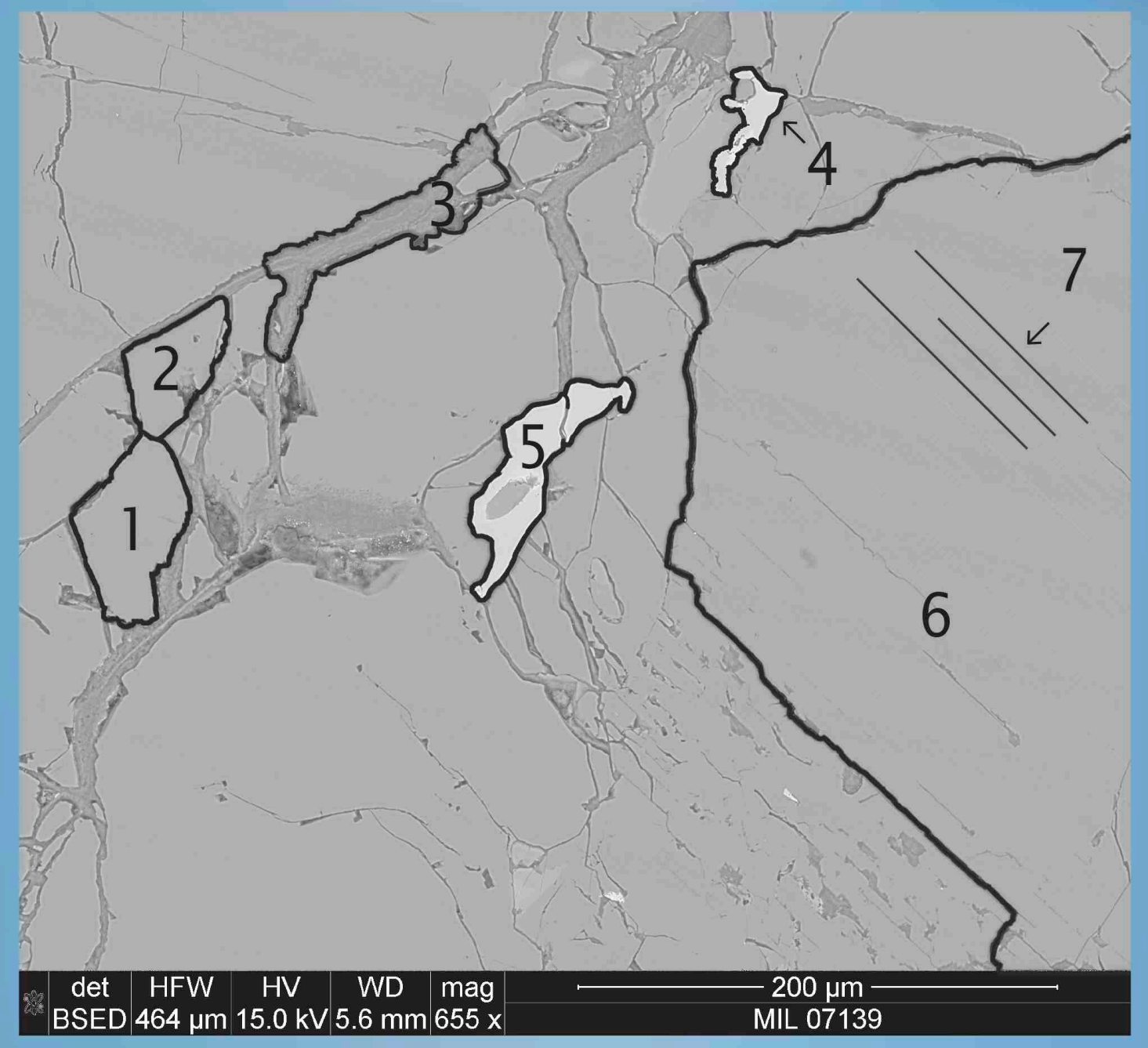


Figure 6: backscatter electron image of a refractory harzburgite. (1) and (2) are olivine grains, characterized by anhedral growth and fracture patterns. (3) is a large serpentinized vein. (4) and (5) are spinel grains. (6) is orthopyroxene, known for diagnostic exsollution lamellae (7).

DISCUSSION

We observe that the most refractory samples in our suite record lower fO_2s than any in the global peridotite array (Fig. 5). What is the timing and origin of such marked reducing conditions? D'Errico et al. (in prep) interprets the normal peridotites as recent melt extraction at the ridge, whereas the highly reduced refractory peridotites are believed to record a previous mantle melting event from the geologic past as well as recent melt interaction. Thus, the low fO_2 recorded by these refractory samples either reflects a past melting event, or was overprinted by recent melt interaction beneath the ridge. These rocks record LREE enrichment (Fig.7), which could arise from recent interaction with a mantle-derived melt; however, this hypothesis is not supported by the low Ti concentrations we measure in spinels (Fig.8). Therefore, both the timing and mechanism that could account for our observations are poorly constrained. Further research on additional refractory harzburgites may provide insight if similarly reduced samples are discovered.

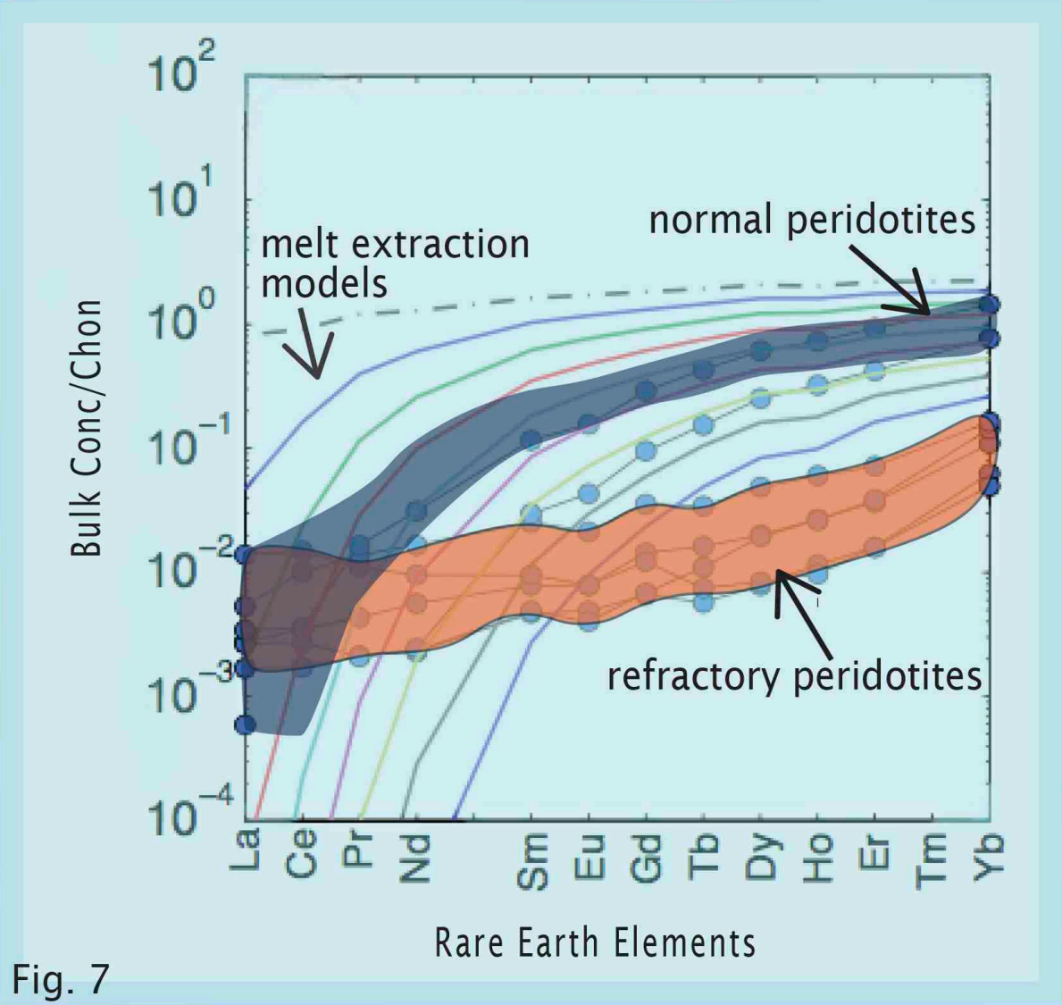
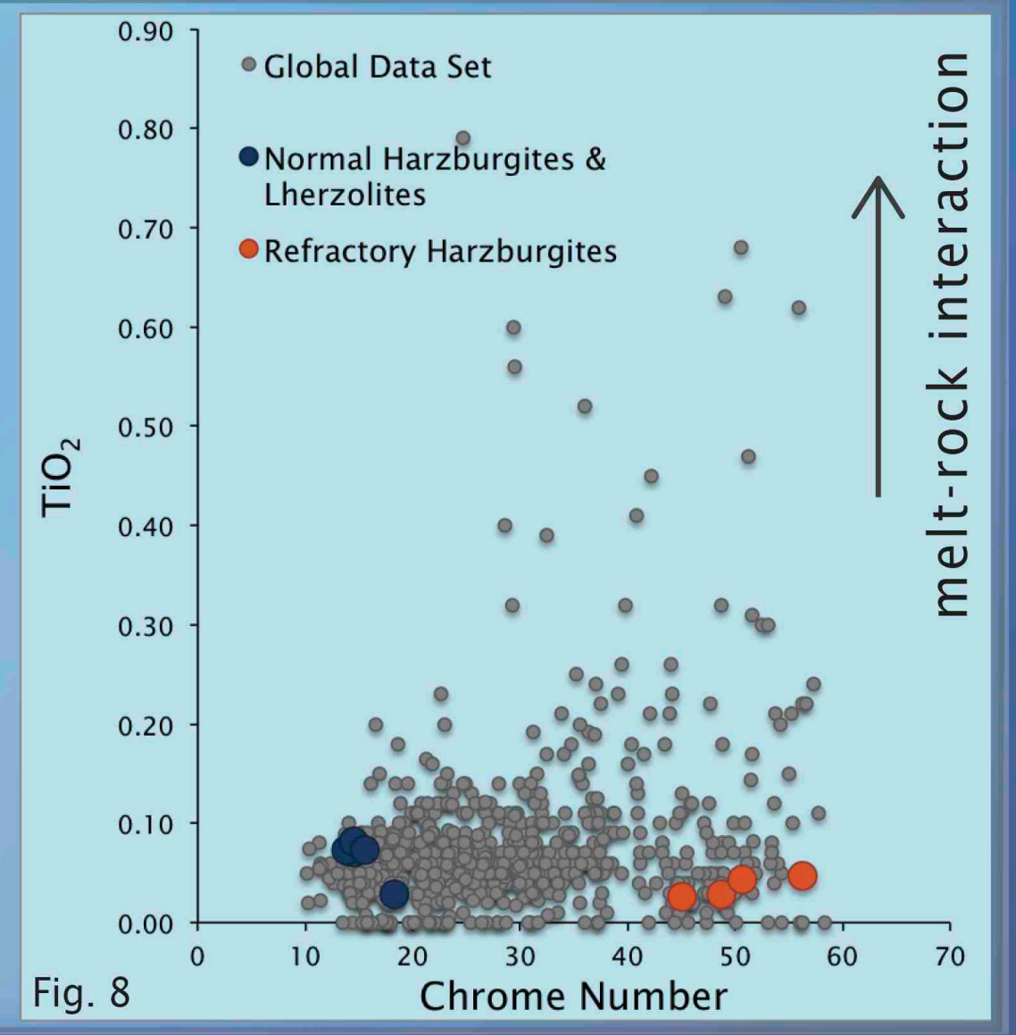


Figure 7: rare earth element (REE) patterns among abyssal peridotites as well as modeled rates of REE extraction (modified from D'Errico et al. submitted).

Figure 8: the concentration of weight percent TiO_2 in relation to chrome number, displaying intriguing results.



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