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Water in cratonic eclogites and pyroxenites from the Sask and Superior Cratons: impacts of tectonothermal events on mantle lithosphere evolution and dynamics

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Introduction

The mantle is dominated by nominally anhydrous minerals (NAMs) that contain trace amounts of structurally bonded hydrogen, or "water". Constraining how much water is stored in the mantle is important for understanding planetary evolution and dynamics. When sampled from Archean and Proterozoic cratons, NAMs can inform us about Earth's lithospheric mantle evolution including processes related to diamond genesis, preservation, and craton stability. Though a small component of the lithospheric mantle (up to 5%; Dawson and Stephens, 1975), mantle eclogites are critical to understanding the structure and evolution of continental lithosphere, because of their fertile composition, prominence as diamond host rocks, and as geodynamic indicators such as for the onset of plate tectonics (e.g. Shirey and Richardson 2011). In addition, because they consist of approximately 50% clinopyroxene, which can store more hydrogen than olivine, eclogites may control a disproportionate amount of the water content in the lithospheric mantle (Huang et al. 2014). Water in these rocks could originate from the protolith having undergone sea water alteration prior to subduction and metamorphism, or have been inherited from other lithologies upon subduction, or brought into the lithosphere during later hydrous metasomatism (e.g. Peslier et al. 2017). Despite their importance, to date there are few comprehensive studies of water in mantle eclogite minerals (Aulbach et al. 2023 and refs therein).

An investigation of NAMs in mantle eclogites and pyroxenites sampled from the Attawapiskat kimberlites (Victor pipe) from the Central Superior Craton, northern Ontario, and Fort à la Corne (FALC) kimberlites (Star and Orion pipes) from the Sask Craton, central Saskatchewan, provides a unique perspective because these cratons experienced younger tectonothermal events unrelated to craton formation. The Sask Craton underwent intense tectonothermal modification during the Trans Hudson Orogeny (1.9–1.8 Ga; Rayner et al. 2005), and the Superior Craton experienced rifting and thermal modification around 1.1 Ga related to the Midcontinental Rift event (Smit et al. 2014a,b; Czas et al. 2020). Studies of xenolithic material from the two cratons show a significantly modified mantle consisting of re-fertilized rocks and associated diamond deposits (Smit et al. 2014a,b, Czas et al. 2020, Stachel et al. 2018). Sask eclogitic diamonds also show unusual brecciation related to such events (Czas et al. 2018). The goal of this research is to measure the water contents in mantle eclogites from the Superior and Sask Cratons and interpret these results in the context of craton formation, modification, and stability in these understudied regions.

Methods

Double-polished grain mounts of garnet and clinopyroxene were measured using a Nicolet Nexus 670 Fourier Transform Infrared (FTIR) spectrometry system. Non-polarized transmission-spectra were acquired by averaging 256 scans between 400-4000 cm^{-1} wavenumbers at a spectral resolution of 4 cm^{-1}

using a cooled MCT detector and a 25 x 25µm aperture. A background averaging 16 scans was measured prior to each analyses. The effect of mineral orientation on water content was minimized by averaging water contents measured from up to 30 grains per mineral type and sample (Kovács et al. 2008). Grain thickness was measured by averaging 10 measurements using a Mitutoyo Digimatic Indicator ID-H0530/0560 micrometer (resolution to 0.5µm). Spectra were baselined and water contents were calculated using the absorption coefficients of Bell et al. (1995) and methods outlined in Aulbach et al. (2023). Reported C(H_2O) results have a 20% error.

Results and Discussion

Twelve FALC and 10 Attawapiskat (Victor) eclogites and pyroxenites in this study have MORB-like melt protoliths and, based on garnet compositions, are mostly high-Mg eclogites, while a small number of samples are classified as low-Mg, high-Ca, and pyroxenites (Smit et al. 2014a; Czas et al. 2020). C(H_2O wt.ppm) for clinopyroxene and garnet are mostly within the range of values from studies of eclogites from other cratons (Aulbach et al. 2023 and refs therein). In detail, C(H_2O) wt.ppm contents are the following: FALC cpx = 198 to 669 (av. 380) wt.ppm; FALC grt = 10 to 75 (av.43); Attawapiskat cpx = 189 to 649 (av. 488) wt.ppm; and Attawapiskat grt = <detection limit (~2 wt.ppm) and 80 (av.23) wt.ppm.

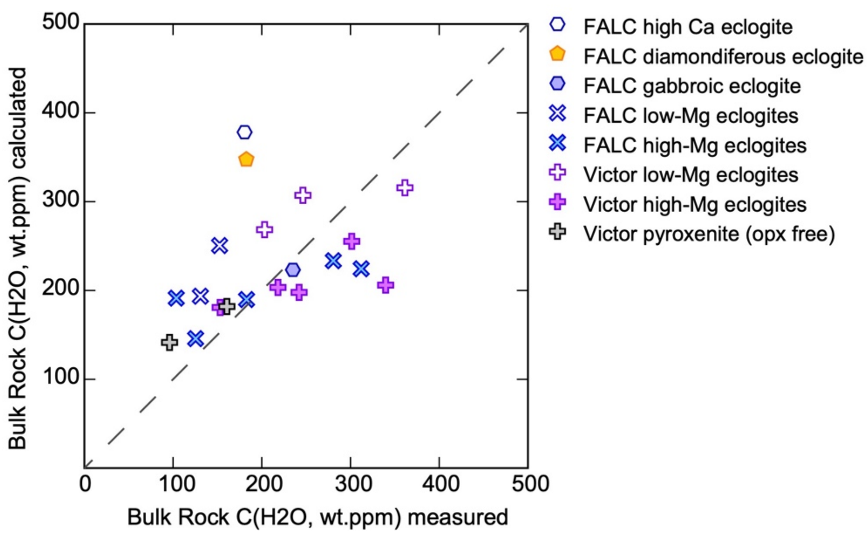

Figure 1. Bulk eclogite H_2O abundances reconstructed from measured abundances in garnet and clinopyroxene for FALC and Attawapiskat samples versus calculated bulk rock water contents in equlibrium with a kimberlite containing 3 wt.% H_2O (for explanation see Aulbach et al. 2023, based on Aubaud et al. 2008).

Reconstructed bulk rock water contents, based on modal abundances of 45 % cpx and 55 % garnet, range between 103 and 312 (av. 196) wt.ppm for FALC and 96 and 361 (av. 220) wt.ppm for Attawapiskat. Hypothetical H_2O abundances were calculated using mineral-melt distribution coefficients D(H_2O) as a function of Al_2O_3 in clinopyroxene and of TiO_2 in garnet (Aubaud et al. 2008) and assuming 3 wt.% H_2O in a melt similar to kimberlite. Most samples fall close to a 1:1 trend indicating interaction with a typical mantle metasomatic melt (Fig. 1), bearing in mind that CO_2 in the kimberlite may reduce the activity of H_2O. No relationship is found between C(H_2O) and temperature or depth of formation. For Attawapiskat clinopyroxenes Al_2O_3 and C(H_2O) are positively correlated, corresponding to H_2O uptake related to the stabilization of the omphacite component during high-pressure metamorphism (Aulbach et al. 2023), while for FALC garnets, a positive correlation between TiO_2 and C(H_2O) in garnet is observed, as in experiments (Aubaud et al. 2008). The average bulk H_2O content in eclogite xenoliths from the Superior craton is similar to that from the Sask craton, which suggests that rifting (Superior) vs. collisional tectonics (Sask) had no first-order control on $C(H_2O)$ in the mantle eclogite reservoir, which may reflect later mantle metasomatic interaction instead. The FALC diamondiferous and Ca-rich eclogite formed from intense melt metasomatism related to host kimberlite magmatism (Czas et al. 2020) and have the lowest water contents. This is consistent with $C(H_2O)$ findings for inclusions in diamond from Siberia, and may reflect low H_2O activity in deep carbonated protokimberlite melts (Novella et al. 2015).

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