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METAMORPHOSED ULTRAMAFIC ROCKS IN EAST GREENLAND: M.A. Kays, and M. J. Dorais*, Department of Geology, University of Oregon, Eugene, OR 97403 (*University of Georgia, Athens, GA 30602)

Introduction: Ultramafic rocks have widespread distribution as elongate pod-like bodies in association with supracrustal belt rocks and granitoid basement gneisses older than ca. 2900 Ma (Fig. 1) in east Labrador [1,2], west Greenland [3,4,5], east Greenland [6,7], and northwest Scotland [8,9]. The bodies have locally preserved discordant contacts with the supracrustal belt rocks [5,6,7], and have strong compositional banding with cm thick layers enriched in chrome-iron oxides, olivine, pyroxene, or some combination of these minerals. Some ultramafic bodies also contain layers of gabbro [7,8]. The ultramafic rocks are not uncommon as xenoliths in Archean gneisses with age of ca. 2900 Ma or younger; the xenoliths occur with size ranging from a few cm diameter to large rafts more than 100 m long. Analyzed suites of the pod-like Archean ultramafic bodies have compositional characteristics similar to komatiite-tholeiite suites of Archean greenstone belts [8,10,11], or to the basal parts of layered intrusions and constructional sequences of similar character [12]. In the indexed localities of Fig. 1 the major period of emplacement of the ultramafic rocks was earlier than the voluminous generation of calc alkaline magma at ca. 2700-2900 Ma [13,14]. Thus, the occurrence of the ultramafic rocks may be an important marker in documenting the distribution of Archean rocks older than ca. 2900 Ma in the craton of the North Atlantic region.

This paper summarizes compositional and mineralogical characteristics of Archean ultramafic rocks in Kangerdlugssuaq Fjord (Fig. 1): the first provide information important to understanding the primary character of the rock suite, whereas the latter provide data necessary to determine conditions of their equilibration during the latest metamorphism. Field characteristics and documentation for the occurrence and probable emplacement history of the ultramafic rocks are given in a companion paper [7]. The two kinds of information will be of value in determining the affinity of the suite to similar Archean rocks in other areas of the North Atlantic craton.

Whole Rock Compositional Characteristics: Major element oxides of the ultramafic rocks have decreasing abundance with respect to increasing MgO contents, but Ni shows strong positive variation rising to nearly 1800 ppm in MgO-enriched rocks (Fig. 2). Cr contents in samples that don't have oxide segregation are variable and only a crude pattern is recognizable with respect to MgO. The highest Cr content measured is about 5500 ppm in a rock with the highest measured MgO content (34 wt.%); otherwise, Cr contents range from about 1600 to 3500 ppm rising to the higher value in rocks of intermediate MgO content (ca. 25 wt.%). Analyses of amphibolites associated with the ultramafic rocks in the supracrustal belts are plotted in Fig. 2, but the relationship of amphibolites and ultramafic rocks is not clear in Kangerdlugssuaq Fjord. REE contents of three ultramafic rocks from Kangerdlugssuaq Fjord have chondrite normalized plots showing enrichment in these trace elements similar to komatiites [11], but are in strong contrast to the patterns of depletion recognized in alpine peridotites (refractory mantle lherzolites, harzburgites, and dunites) [15] shown for comparison (Fig. 2).

To test the hypothesis that the regular major oxide compositional variations and the locally preserved surface of compositional layering Suml [7] are consistent with crystal fractionation of basic magma, plots of TiO_2 (wt. %) and Y (ppm) vs Zr (ppm) in ultramafic-mafic rocks were reproduced by calculated Rayleigh fractionation of olivine, pyroxenes, hornblende, and plagioclase.

clase (Fig. 3). In the calculations, distribution coefficients (K_D = mineral/liquid) were used consistent with crystallization of minerals from basaltic or picritic liquids [16]. The trend lines, when viewed in comparison with the major element contents of the ultramafic rocks, are consistent with olivine fractionation (\pm pyroxenes). Irvine [17] has also demonstrated that in basic or picritic melts crystallization follows a predictable path depending on mineral/melt K_D values and magma f_{O_2} . Thus, if olivine crystal fractionation was the mechanism responsible for forming the variety of Kangerdlugssuaq Fjord ultramafic rocks, Al would have been effectively excluded to the melt during the process. During such crystallization and exclusion, Al/Mg+Fe²⁺ changes gradually, the fractionation path changing little with additional separation of the pyroxenes. Ultimately, Al exclusion is drastically altered by separation of the feldspars. The path of Kangerdlugssuaq Fjord ultramafic rocks seems consistent with such a model (Fig. 3), although it seems doubtful that the stage of feldspar separation occurred during fractionation of the ultramafic sequences.

Metamorphism and Mineral Chemistry of the Ultramafic Rocks: Diagnostic assemblages in the polymetamorphic ultramafic rocks at the highest grade are the previously described Surs assemblages [7] containing olivine+orthopyroxene+green spinel+chlorite+amphibole. Textural evidence in the field and in thin section is that there was modification of the Scl assemblage (metamorphic cleavage) during the last recrystallization episode at ca. 2900 Ma [18]. We assume here that the assemblage reflects equilibrium recrystallization that was in part mimetic after the Scl assemblage. Mimetic recrystallization was perhaps aided because conditions of the final event greatly overlapped those of the earlier episode and because a penetrative fabric did not form in the ultramafic or adjacent supracrustal rocks during the final event. The assemblage indicated above is approximately equivalent to the sillimanite zone amphibolite facies boundary with the granulite facies [19], and is consistent with the assemblage quartz+biotite+sillimanite+cordierite+garnet+K-feldspar in the metapelites. The two assemblages in ultramafic and pelitic rocks, respectively, are consistent with the equilibria 1) chlorite = 2 orthopyroxene+olivine+spinel+vapor, and 2) quartz+sillimanite+biotite = cordierite+garnet+K-feldspar+liquid/vapor [19,20].

The equilibrium P-T curve for equation (1) calculated recently [21] gives a temperature of about 770°C at 5 kbars for pure Mg end member thermodynamic data where water pressure and total pressure are the same. Recalculation of the curve to include compositions of analyzed minerals in sample KWF72 (Table 1) gives a temperature of about 25°C lower at the same pressure. Thus, the effects of Fe-Mg and other substitutions in the minerals of Surs ultramafic assemblages reflect conditions of equilibration not greatly different from Mg end member reactions. Results of olivine-spinel geothermometry in five ultramafic rock samples with an assemblage close to that of (1) indicate continued re-equilibration during cooling following the main recrystallization.

Some additional data for the minerals analyzed by electron microprobe in samples containing green spinel+orthopyroxene+olivine+amphibole \pm chlorite in Kangerdlugssuaq Fjord ultramafic rocks are given in Table 1. We also note that olivine and pyroxenes have nearly identical compositional range and variation in the five rock samples analyzed. Fo and En contents in olivines and pyroxenes vary from about 75 to 87 mol %; these compositional variations in the minerals are consistent with bulk compositional variations of their host rocks (MgO varies from 20 to 32 wt%). The green spinels are aluminous and Fe-rich, but with variable Cr contents; compositional variations on an atomic

basis are: $Y_{Al} = 0.86$ to 0.96 ; $Y_{Cr} = 0.04$ to 0.14 ; $X_{Fe} = 0.39$ to 0.58 ; $X_{Mg} = 0.42$ to 0.61 . We note too that the amphiboles are colorless pargasite and greenish edenitic hornblende. Analyzed chlorite of KWF-72 is clinocllore according to the nomenclature of Hey [22].

Summary and Conclusions: Studies in a number of localities in the North Atlantic region including Kangerdlugssuaq Fjord indicate that elongate Archean ultramafic bodies have intrusive contacts with rocks of supracrustal sequences that are mostly older than 2800-2900 Ma. Thus, the ultramafic rocks may prove to be reliable markers that identify Archean crustal sections older than the voluminous accretionary magmatism at ca. 2700-2900 Ma. In some locations, as in Kangerdlugssuaq Fjord, the bodies have preserved compositional banding that is probably related to crystal accumulation or some similar magmatic process. Such layering provides another reference surface with which to "re-orient" Archean crust with respect to subsequent deformation and recrystallization. The surface, such as Sum1 in Kangerdlugssuaq Fjord, also has the potential to provide ages of primary Archean rock emplacement earlier than that of accretionary magmatism and earlier than the metamorphism of the supracrustal sequences that contain the bodies. Widespread distribution of the ultramafic bodies suggests the possibility of an important tectonic event associated perhaps with dilatational fracturing of the craton. Such an event would contrast markedly with the tectonic setting that followed and in which there was massive addition of calc alkaline magma to the Archean cratonic nucleus. Mineral assemblages of the ultramafic bodies also provide reliable markers of the temperature conditions of their metamorphic equilibration, and appear to offer proof in Kangerdlugssuaq Fjord of polymetamorphism compatible with that of the associated supracrustal sequence.

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