Single-crystal X-ray diffraction of spinels from the San Carlos Volcanic Field, Arizona:
Spinel as a geothermometer

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ABSTRACT

Fourteen spinels from two types of mantle xenoliths from the San Carlos Volcanic Field in Arizona were characterized using single-crystal X-ray diffraction and electron microprobe analysis. The dominant feature seen in the chemistry of spinels from the Group I xenoliths is the extensive substitution of Cr for Al (Cr0.38Al1.62 to Cr0.63Al1.37) correlated with Mg for Fe2+ (Mg0.63Fe2+0.37 to Mg0.83Fe2+0.17). Although Group II spinels display consistently low Cr values, they also show a well-correlated substitution of Mg for Fe2+ (Mg0.63Fe2+0.37 to Mg0.80Fe2+0.20). Unit-cell parameters for spinels from the Group I xenoliths range from 8.1259 to 8.2167 Å, while those from the Group II xenoliths range from 8.1247 to 8.1569 Å. The cell parameters are linearly correlated with Fe2+ and Cr contents. Cation distributions were determined from experimental bond lengths and refined site occupancies using the algorithm of Lavina et al. (2002). The San Carlos spinels display variable degrees of order, with inversion parameters ranging from 0.10 to 0.16 for Group I and from 0.17 to 0.22 for Group II. Closure temperatures were computed with the Princivalle equation, giving averages of 808(37) °C for spinels from Group I xenoliths and 822(62) °C for samples from Group II xenoliths. We show that these results are reasonable, and thus extend the use of the Princivalle equation, or at least its functional form, to samples with significant Cr and Fe2+ contents. This study demonstrates that, in spite of the extensive chemical variability of the San Carlos spinels, and given that the origins of the two groups of xenoliths are different, the oxygen coordinates remain fixed, suggesting that the oxygen coordinate is a function of thermal history.

INTRODUCTION

Peridot Mesa in the San Carlos Indian Reservation, Arizona, is a late Tertiary to Quaternary basalt flow that contains abundant ultramafic xenoliths (Bromfield and Schröde 1956). Bernatowicz (1981) obtained a K-Ar age of 0.58 ± 0.21 Ma for the Peridot Mesa Vent. The geology of the San Carlos Volcanic Field was described by Marklowe (1961) and Wohletz (1978). Spinel lherzolite, pyroxenite, and herzbergerite xenoliths have all been reported from San Carlos (Galier and O’Nions 1989).

Mantle xenoliths are classified into two general types, defined primarily on the basis of major-element chemistry. In this paper they are designated as Group I and Group II, which corresponds to Group I and II of Frey and Prinz (1978) and to the Cr-diopside and Al-augite groups of Wilshire and Shervais (1975). Petrographic description of the San Carlos xenoliths can be found in Table 1 of Frey and Prinz (1978). Detailed geochemical and isotopic studies of San Carlos xenoliths have been reported by many authors (cf. Zartman and Terra 1973; Frey and Green 1974; Frey and Prinz 1978; Zindler and Jagoutz 1980, 1988; Galier and O’Nions 1989). The petrogenesis of mantle xenoliths has been the subject of much investigation. The REE studies of Frey and Prinz (1978) suggested that Group I xenoliths are not genetically related to the host basalt but rather represent a residue after extraction of various degrees of partial melt. In contrast, Group II xenoliths seem to be chemically related to the host lava and represent cumulate rocks produced by fractional crystallization of an evolved magma that was derived from the host magma earlier than the volcanic episodes.

Equilibration temperature and pressure of crystallization for peridotites can be estimated by a variety of thermometers using chemical exchange reactions between coexisting minerals. For example, Brey and Köhler (1990) estimated an equilibration temperature of 1052 °C for the San Carlos spinel lherzolite using two coexisting pyroxenes. Köhler and Brey (1990) estimated an equilibration pressure of 12.7 kbar for Group I spinel lherzolites with Mg-number ~90 from San Carlos using Ca exchange between olivine and clinopyroxene.

The temperature and pressure conditions of mantle xenoliths can also be ascertained by examining the relative occupancies of elements between crystallographically distinct sites within a single mineral phase. The methodology for this is still in the developmental stage but important studies include Stimpfl et al. (1999) and Stimpfl (2003) who studied thermodynamics and kinetics of the Fe-Mg order-disorder process in orthopyroxene to determine the cooling rates of the crystals, and Nimis (1995, 1999) and Nimis and Ulmer (1998) who investigated variations in the crystal structural parameters of C2/c clinopyroxene in response to increasing pressure and concluded that chemical substitution at the two cation sites allows the cell volume to decrease without inducing lattice strain.

Another potential way to study the pressure-temperature history of mantle xenoliths would be to conduct a complete crystal-chemical study, including unit-cell parameters, crystal