Characterization of Al-Si ordering state in an alkali feldspar using atom location by channeling-enhanced microanalysis (ALCHEMI)

JUN WU* AND DAVID R. VEBLEN

Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland 21218, U.S.A.

ABSTRACT

Atom location by channeling-enhanced microanalysis (ALCHEMI) was used to determine the occupancy of Al atoms in the T$_{1o}$ site (t$_{1o}$) of alkali feldspar. Building on the method demonstrated by previous research, analytical electron microscopy proves to be a viable technique for fully characterizing the Al-Si ordering state in the feldspar framework. We applied this method to orthoclase from Itrongay, Madagascar, and to its heated counterpart. Our preliminary results give 0.74 and 0.37 as 2t$_1$ (=t$_{1o}$ + t$_{1m}$) and 1m, respectively, for the original orthoclase, vs. 0.54 and 0.28 for heated orthoclase. Single-crystal X-ray diffraction experiments have been performed, and the results agree with our ALCHEMI measurements. This new method promises to help resolve some complex issues relating ordering paths, for example, twinning in feldspars and domain intergrowth in plagioclase.

Keywords: Al-Si ordering, alkali feldspar, channeling effect, ALCHEMI

INTRODUCTION

Al-Si ordering in feldspars bears on many problems in petrology and mineralogy. It records information about the thermal history of the feldspar, with petrological implications. Phase relationships at the sanidine-microcline transition zone remain a puzzle and mostly center on understanding the paths of Al-Si ordering. Various intergrowths and domain textures occur in plagioclase, as well as in alkali feldspar, that are likely a result of different ordering schemes in different compositions (Ribbe 1983). Understanding these textures requires the reliable measurement of ordering parameters in tiny and intergrown domains. Traditional X-ray or neutron diffraction techniques measure Al-Si ordering in a relatively large volume of sample on the order of 10$^{15}$ unit cells or more. Another technique, atom location by channeling-enhanced microanalysis (ALCHEMI), based on transmission electron microscopy (TEM), however, has proved successful in partly characterizing the ordering state of the feldspar framework (Taftø and Buseck 1983), with the occupancy of Al atoms on T$_1$ (=T$_{1o}$ + T$_{1m}$) sites estimated.

However, to fully describe the ordering status in the alkali feldspar structure, Al occupancy on both T$_{1o}$ and T$_{1m}$ sites should be determined because the bonding environments for these two sites are different when the temperature decreases. In this paper, we demonstrate that ALCHEMI is capable of measuring the site occupancies of T$_{1o}$ and T$_{1m}$ as well as of T$_{1o}$ + T$_{1m}$.

ALCHEMI technique

In describing two-beam diffraction phenomena, two wave vectors are conventionally used to denote the direct and diffracted beams. However, each of them is actually composed of two Bloch-wave components, and in turn, each pair of Bloch-wave components combines to form an independent Bloch wave. The interference between these two Bloch waves results in a modulated intensity throughout the crystal unit cell. Depending on the crystallographic orientation of the crystal with respect to the incident beam, this modulated wavefield may have an intensity maximum on a particular crystallographic site, which is the so-called channeling effect, and was observed for electrons first by Duncumb (1962). One of the direct consequences of this effect is that the secondary X-ray emission from atoms that lie on channeling planes will also depend on the orientation of the crystal with respect to the incident radiation, because previous research has shown that X-ray emission is localized around atom cores (Gjønnes and Høier 1971). ALCHEMI simply monitors the variations in the electron-induced X-ray emission rate from atoms of interest on specific sites, as a function of crystal orientation, and then takes advantage of the enhanced or suppressed X-ray intensity to derive the atomic occupancy. The theory upon which ALCHEMI is based has been treated in detail by Chrens et al. (1973), and the technique itself was first developed for TEM by Spence and Taftø (1983). Since then, it has been successfully applied to mineralogical research (Taftø and Spence 1982; Taftø and Buseck 1983), as well as in many other fields of solid-state science.

THE SAMPLES

Our sample is a gem-quality orthoclase from Itrongay, Madagascar, supplied by the American Museum of Natural History, New York (catalog no. 42981). The sample is transparent, light yellow, and featureless under a light microscope. Bright-field imaging displays a typical tweed texture in our sample, and electron diffraction shows no evidence of twinning except crossed streaks associated with intensity maxima, which is characteristic of orthoclase (Fig. 1). Quantitative analyses of its high-resolution TEM image reported elsewhere (Wu and Veblen, in preparation) indicate that the wavelength and wave

* Present address: School of Earth and Space Exploration, Arizona State University, Tempe, Arizona 85287, U.S.A. E-mail: junwu1@asu.edu

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