Journal of Thermal Analysis, Vol. 40 (1993) 99-105

THERMAL REACTIVITY OF JADEITE AND NEPHRITE

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The thermal reactivity of the naturally occurring silicates jadeite, $NaAl[Si_2O_6]$, and nephrite, a variety of actinolite, $Ca_2(Mg,Fe)_5[(OH,F)Si_4O_{11}]_2$, have been investigated by thermogravimetric and thermomechanical analysis as well as temperature-dependent X-ray diffraction and analytical electron microscopy. TG shows that nephrite undergoes a weight loss at around 900°C. Mass spectrometry reveals that this irreversible reaction corresponds to the evolution of H_2O, and XRD shows that a phase related to diopside $CaMg[Si_2O_6]$ is formed. Jadeite does not undergo any observable weight changes up to 1000°C. Thermomechanical analysis indicates a reversible phase transition at about 950°C. Temperature-dependent X-ray diffraction shows that jadeite is again present on cooling (peak temperature: 1000°C), but that this is accompared by an additional unidentified phase. The mechanism of this process is not yet clear although it has been observed in several samples from different origins and with different metal impurities.

Keywords: jadeite, nephrite, thermal reactivity

Introduction

In many cultures jadeite, a silicate mineral of the pyroxene group with the ideal composition $NaAl[Si_2O_6]$ [1, 2], is a highly valued gemstone which since neolithic times has been used as symbolic material for ornamental, ritual and funeral purposes [3–5]. It is also called Stone of Heaven. Often alkaline earth and/or transition metal impurities lead to variations in colour, which may indicate the origin of the material. Owing to its hardness of 6.5–7, relatively high specific gravity of 3.34 g/cm^3 and chemical inertness, jadeite and gemstone jade are difficult to handle and to carve. Chinese craftsmen are said to have studied a piece of jadeite stone for years before starting to work on it by grinding it down with

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the aid of abrasive sand. Nowadays good quality jadeite is very expensive and as a consequence many jade simulants are purchased. The most prominent among these simulants is nephrite, a member of the amphibole silicate group closely related to tremolite and actinolite, with the ideal composition $Ca_2(Mg,Fe)_5[Si_4O_{11}(OH,F)]_2$ [1, 2]. Ratios of iron to magnesium as well as hydroxide to fluoride are variable. The hardness of nephrite is 6–6.5 and the specific gravity 2.95 g/cm^3. Further simulants with even more different properties are summarized in [3]. As an example, calcite is a cheap and often offered simulant material.

This paper presents a comparison between the thermal reactivities of jadeite and nephrite. Thermogravimetry, thermomechanometry, temperature-dependent X-ray diffraction together with analytical and scanning electron microscopy have all been applied.

Results

Thermoanalytical investigations

Samples of jadeite and nephrite were heated in air at 1 deg·min^{-1} to 1000°C. For jadeite, no substantial weight loss was observed; nephrite, however, shows a weight loss of about 0.2% between 850°–970°C [5].

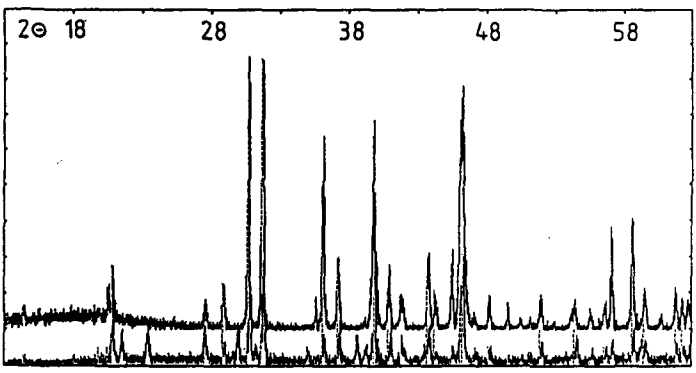

Fig. 1 X-ray diffraction traces of jadeite. The upper trace was obtained from unheated jadeite and all reflections correspond to the literature values. The lower spectrum was obtained from jadeite heated to 1000°C and cooled to room temperature in air. Apart from the jadeite reflections, reflections of an unidentified phase are apparent

Thermomechanical measurements show that jadeite undergoes a reversible expansion of the order of 4% between 900°–1000°C. This effect has been observed for jadeite of many different origins and its reversibility has been con-

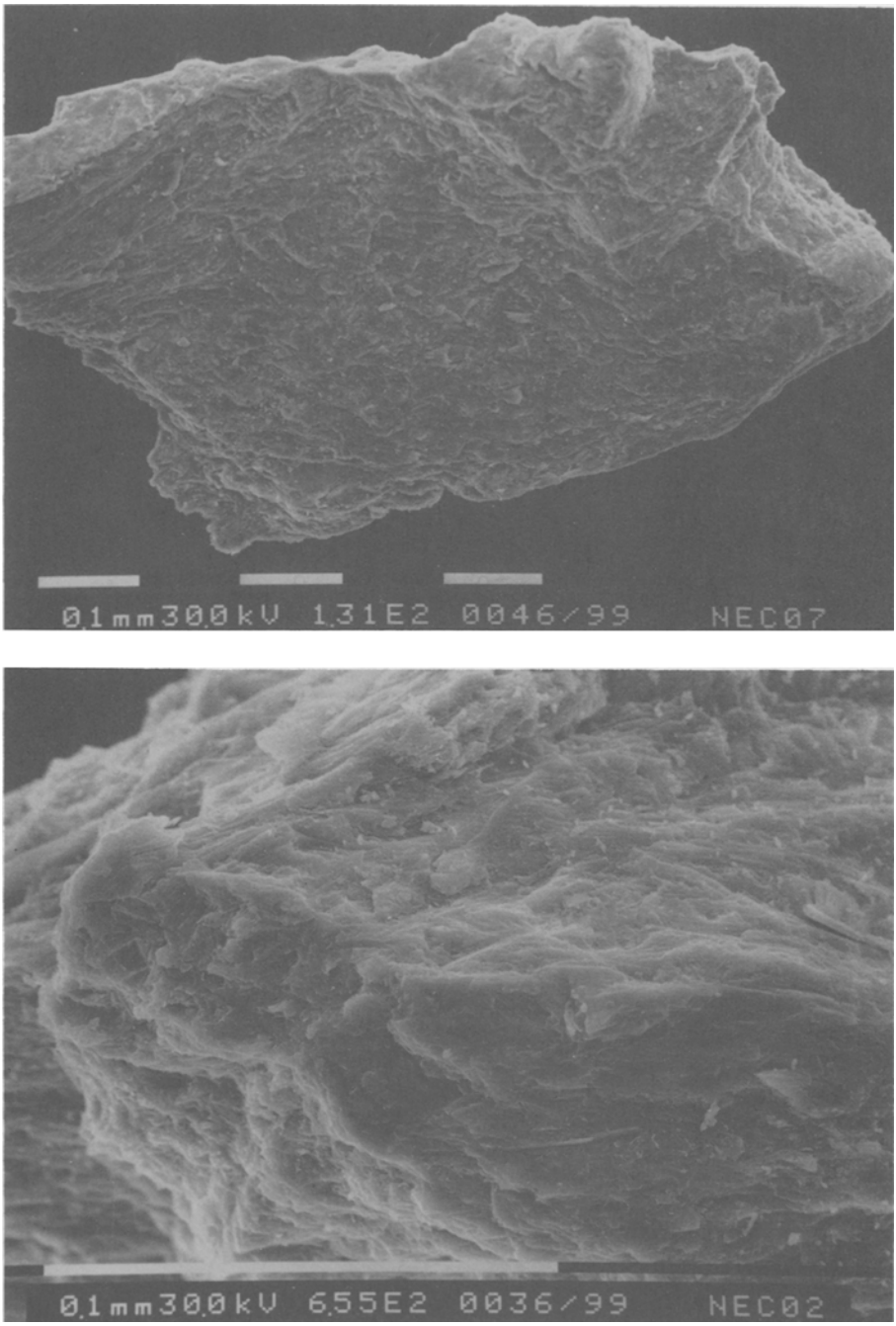

Fig. 2 Scanning electron micrograph of (*a*) bulky, granular nephrite, (*b*) detail

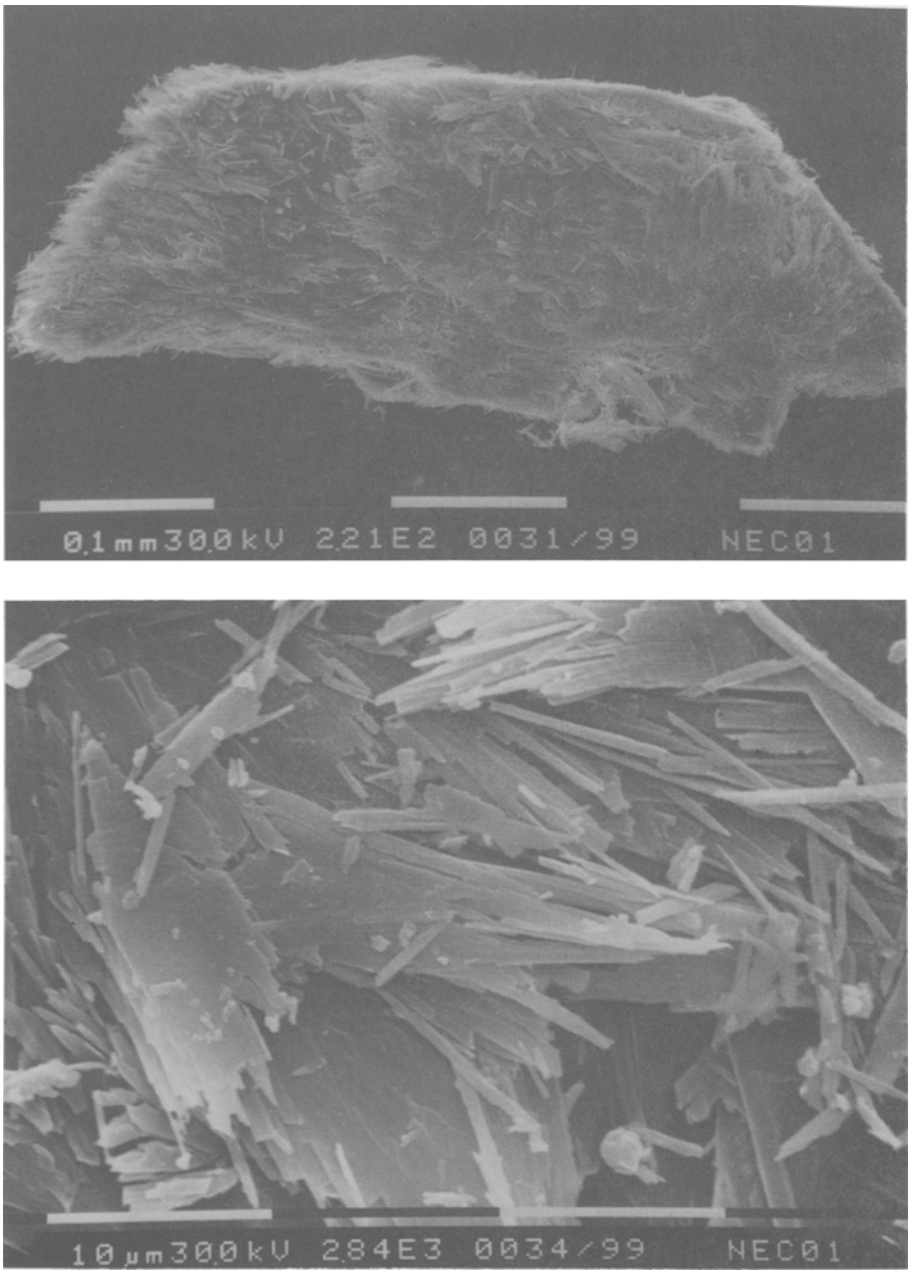

Fig. 3 Scanning electron micrograph of (*a*) fibrous nephrite specimen, (*b*) detail, showing individual fibres with dimensions in the range of ~10 μm (length) and ~1 μm (thickness)

firmed by repeated heating/cooling cycles in the temperature interval 30°–1000°C. Thermomechanical measurements of nephrite show the expected expansion in the decomposition temperature range. H_2O is evolved from decomposition of the amphibole OH-groups [5].

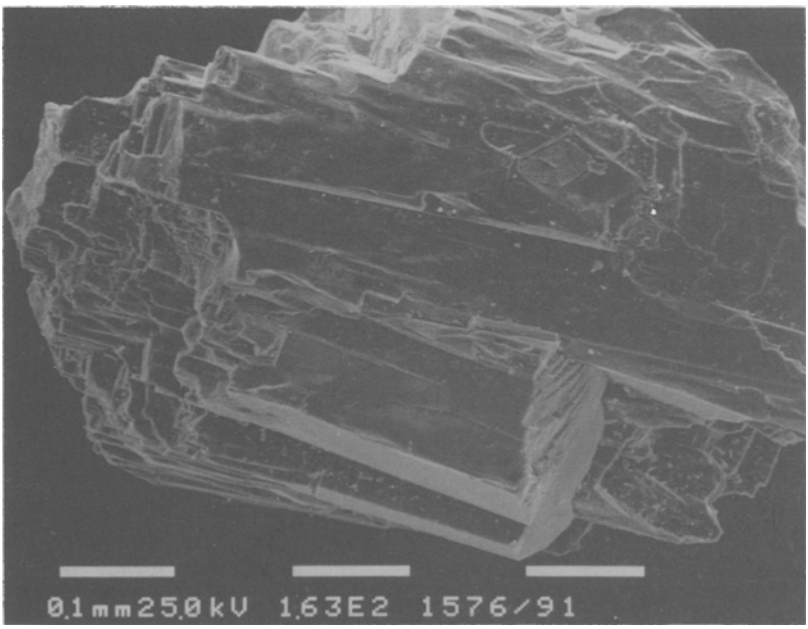

Fig. 4 Scanning electron micrograph of a jadeite crystallite heated to 1000°C and cooled to room temperature

Temperature-dependent X-ray diffraction

Possible structural changes on heating were investigated for jadeite. In spite of the thermomechanically-identified reversible process, no structural change was observed in the diffraction trace taken at 1000°C (Fig. 1, upper spectrum), all reflections being assigned to jadeite. On cooling to room temperature, reflections of an unidentified phase were also observed, but the main product was still jadeite.

The product of the decomposition of nephrite is diopside, $CaMg[Si_2O_6]$.

Analytical and scanning electron microscopy

Electron microscopical studies were carried out in order to investigate any morphological changes in jadeite and nephrite as a function of temperature. Natural nephrite appeared as bulky (Figs 2a, b) or fibrous material (Figs 3a, b).

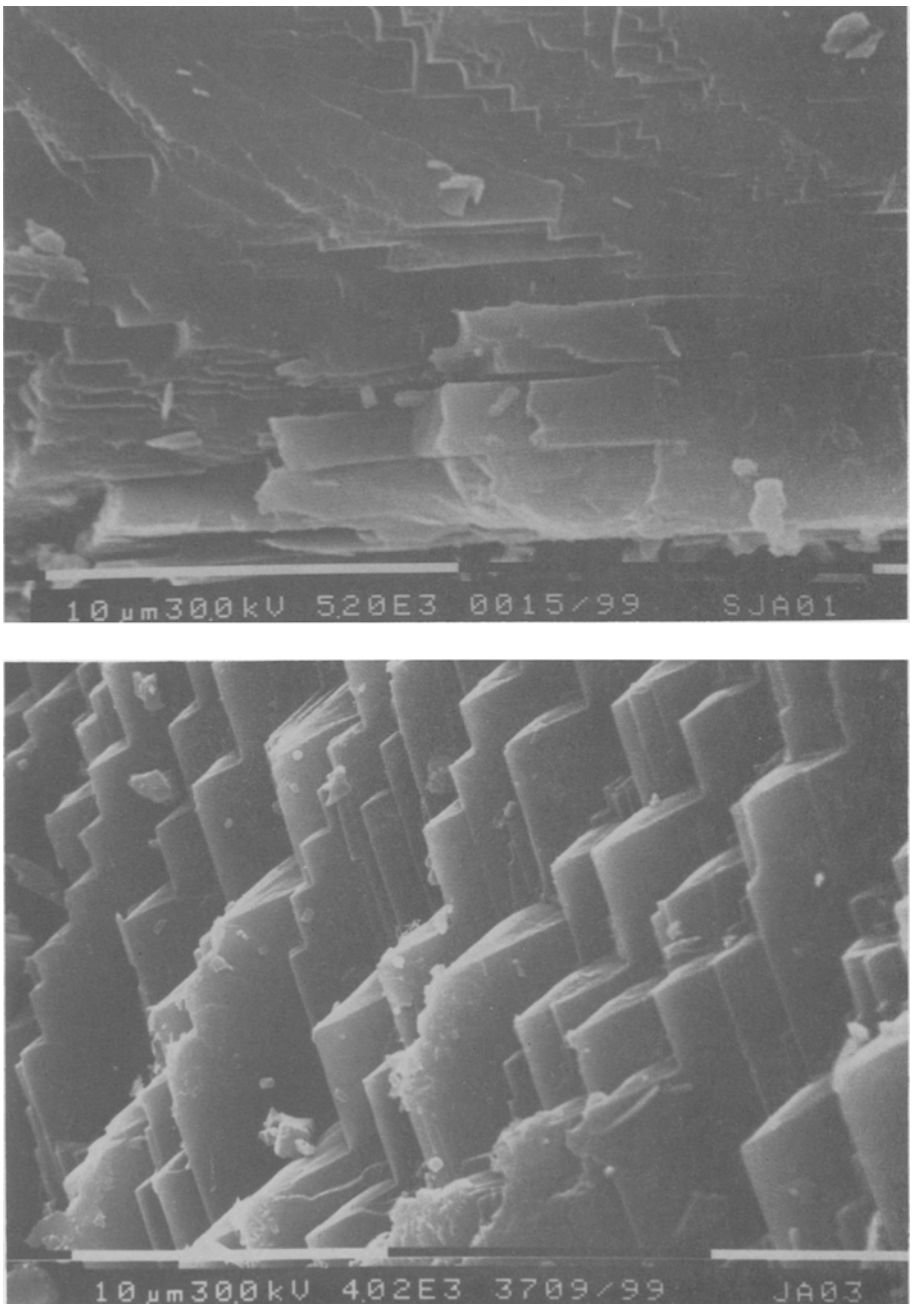

Fig. 5 Scanning electron micrographs of (*a*) unheated jadeite showing highly orientated agglomerate of plate-like crystallites, (*b*) jadeite heated to 1000°C and cooled to room temperature

Energy dispersive analysis (EDX) confirmed, however, that both forms had the nephrite composition. Apart from the main constituents Mg, Si and Ca, Fe and Al were also detected. On heating to >1000°C, decomposition led to pronounced morphological changes.

For jadeite, comparison of original and heat-treated samples showed no morphological changes: the crystallite in Fig. 4 has been heated to 1000°C, but its morphology is similar to unheated samples. Higher magnifications support this finding: in Figs 5a and b domains of well-shaped jadeite platelets are shown. The specimen shown in Fig. 5b has been heated to 1000°C. EDX analysis confirms the presence of small amounts of Ca, Mg and Fe, as well as Na, Al and Si. It is not clear whether these impurities are responsible for the formation of the unidentified phase found after cooling jadeite to room temperature.

Conclusions

This investigation has shown that the different thermal reactivity of these two natural silicates may allow distinction between them.

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The authors thank M. Wyss, Inst. of Inorg. Chem., Univ. of Zürich, Switzerland, for his competent accomplishment of the X-ray diffraction measurements.

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Zusammenfassung — Mittels thermogravimetrischen und thermomechanischen Methoden sowie mit Hilfe von temperaturabhängiger Röntgendiffraktion und analytischer Elektronenmikroskopie wurde die thermische Reaktivität der in der Natur vorkommenden Silikate Jadeit $NaAl[Si_2O_6]$ und Nephrit, einer Abart von Aktinolith $Ca_2(Mg,Fe)_5[(OH,F)Si_4O_{11}]_2$ untersucht.
Laut TG zeigt Nephrit einen Gewichtsverlust bei etwa 900°C. Die Massenspektrometrie besagt, daß diese irreversible Reaktion mit der Freisetzung von H_2O verbunden ist und die Röntgendiffraktion zeigt, daß dabei eine Phase Diopsid $CaMg[Si_2O_6]$ gebildet wird. Jadeit zeigt bis 1000C keinerlei beobachtbaren Gewichtsverluste. Die thermomechanische Analyse zeigt eine reversible Phasenumwandlung bei etwa 950°C. Die temperaturabhängige Röntgendiffraktion zeigt, daß Jadeit beim Kühlen wieder anwesend ist (Peaktemperatur: 1000°C), daß dies jedoch von einer zusätzlichen, nicht identifizierten Phase begleitet wird. Der Mechanismus dieses Prozesses wurde noch nicht vollständig geklärt, obwohl er an zahlreichen Proben verschiedenen Ursprunges und mit verschiedenen metallischen Verunreinigungen beobachtet wurde.