Evaluation of Lindsley pyroxene thermometer for chondrites. Y. Nakamuta[1], Y. Shibata[2] and K. Urata[3], [1]Kyushu University Museum, Kyushu University, Fukuoka 812-8581, Japan. [2]Sawara P.O., Japan Post Co., Fukuoka 814-8799, Japan. [3]Faculty of Science, Kyushu University, Fukuoka 819-0395, Japan.

Introduction:

The Lindsley thermometer [1] allows temperatures to be derived from both clinopyroxene (CPx) and orthopyroxene (OPx) and has been widely applied to estimate metamorphic temperatures of chondrites [2-4]. The Lindsley thermometer requires a lengthy calculation using an entire pyroxene analysis to compute Wo, En and Fs values for CPx, although such a lengthy calculation is not necessary for OPx. Temperature is then obtained graphically from the temperature-contoured pyroxene quadrilateral. CPx shows temperature consistently higher than OPx [3], suggesting that Ca-partitioning between CPx and OPx is not equilibrated even in type 6 ordinary chondrites.

Kosmochlor ($NaCrSi_2O_6$) is known to occur in iron meteorites [5] and CPx in chondrites also contains Na and Cr as minor elements, although kosmochlor has never been found in terrestrial rocks [6]. The Lindsley thermometer is made empirically for terrestrial rocks and the kosmochlor component is not considered in the calculation to compute Wo, En and Fs values. In this study, the effect of the kosmochlor component on the Lindsley thermometer is investigated. The regression equations to calculate temperature from Wo and Fs values are also derived to accurately determine temperature on the temperature-contoured pyroxene quadrilateral.

Correction for Kosmochlor component:

Chemical compositions of CPx and OPx in the Dhurmsala LL chondrite were analyzed by electron-probe micro-analyzer (EPMA), JEOL JXA-8530F, with 15 Kv accelerating voltage, 2 nA beam current, and 1 μm beam diameter. Histograms of molar abundances of Al, Cr and Na are shown in Fig. 1. It is clear in the histograms that these minor elements are richer in CPx than OPx. CPx in chondrites contains Na more than a negligible quantity (Fig. 1). Lindsley [1] allocated Na to aegirine and jadeite based on the $2M^+ \rightarrow NaM^{3+}$ substitution where M^{2+} is Mg^{2+}, Fe^{2+} or Ca^{2+} and M^{3+} is Fe^{3+} or Al^{3+}. In this substitution the amount of Na should be the same as the sum of trivalent cations in octahedral sites. Fig. 2 shows the relation between the amount of Na and the sum of trivalent cations. The sum of Fe^{3+} and Al^{3+} is less than the amount of Na as shown by crosses in Fig. 2. The sum of trivalent cations is roughly the same as the amount of Na when Cr^{3+} is added to the sum of Fe^{3+} and Al^{3+} as shown by solid circles in Fig. 2. Na should be therefore allocated also to kosmochlor ($NaCrSi_2O_6$) in the case of chondrites, whereas the kosmochlor component is not found in terrestrial CPx [6] and [1] allocates Cr^{3+} to Cr-Tschermakite ($CaCrAlSiO_6$). A manner of allocation of Na and Cr^{3+} cations may affect the determination of Wo, En and Fs values. It is then necessary to add kosmochlor to the sequence of calculation presented by [1] as follows.

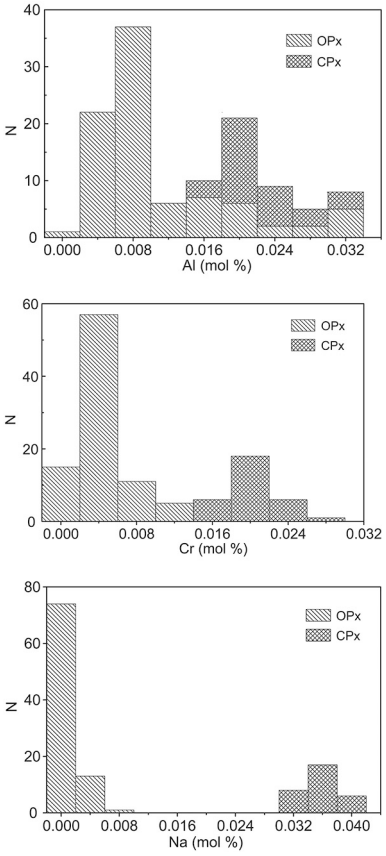

Fig. 1

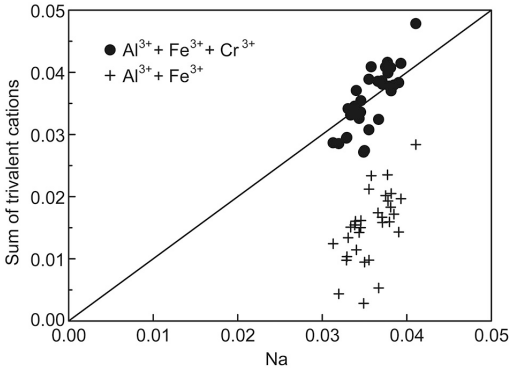

Fig. 2

(1) Ko = $NaCrSi_2O_6$ = Na or Cr, whichever is smaller.

Table 1. Coefficients of regression equations and statistics.

	C_0	C_1	C_2	C_3	C_4	R	SE	N
CPx	860.9	-1.548	70.55	0.3166	-23.51	0.998	10.1	50
Opx	601.9	-14.60	227.3	-0.1587	-1.708	0.998	11.5	50

R: multiple correlation coefficient. SE: standard error. N: number of read data on the diagram.

(2) Ae = $NaFe^{3+}Si_2O_6$ = Na or Fe^{3+}, whichever is smaller.
(3) Jd = Al(VI) or any remaining Na, whichever is smaller.
(4) FeCaTs = remaining Fe^{3+}.
(5) CrCaTs = remaining Cr.
(6) AlCaTs = remaining Al(VI).
(7) Wo = [Ca + Ae – AlCaTs – FeCaTs – CrCaTs]/2, En = [(1 – Wo)(1 – X)], and Fs = (1 – Wo)(X), where X = $Fe^{2+}/(Fe^{2+} + Mg)$.

(1) is the line added to the sequence of [1].

Regression equations to calculate temperature from Wo and Fs values:

Wo and Fs values were read along the isotherms on the temperature-contoured pyroxene quadrilateral of 1 atom by [1]. Fifty sets of data, temperature and Wo and Fs values for each set, were obtained for each of CPx and OPx regions on the diagram. By using the data sets, the coefficients of the regression equation which relates temperature and Wo and Fs components, i.e. $T = C_0 + C_1 \cdot Wo^2 + C_2 \cdot Wo + C_3 \cdot Fs^2 + C_4 \cdot Fs$, are determined by the least squares method. The results for CPx and OPx are summarized in Table 1 and the differences between read and calculated temperatures are shown in Fig. 3. Standard errors of both regression equations are about 10 °C and reveal that it is possible to calculate temperatures with an error less than 20 °C (2σ) by using the regression equations.

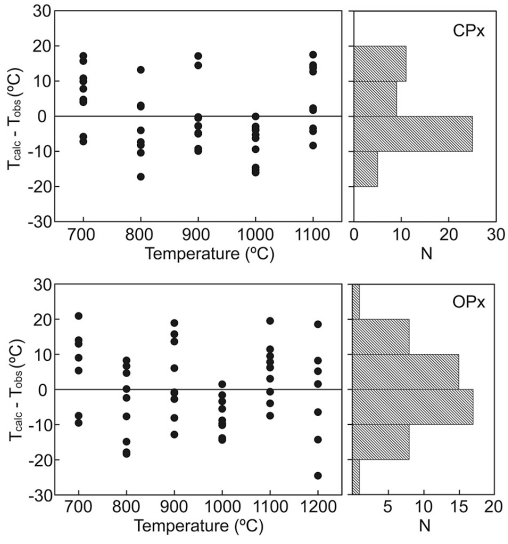

Fig. 3

Metamorphic temperature of the Dhurmsala LL6 chondrite:

Temperatures of Dhurmsala chondrite are obtained by using the analyses which are within one relative percent of the ideal sum and stoichiometry of the structural formula of pyroxene with 6O. Fig. 4 shows the histograms of temperatures obtained for CPx with the calculation of [1] (CPx old), CPx with the calculation presented here (CPx new) and OPx by using the regression equations derived in this study. The mean of CPx temperature obtained with the calculation presented in this study, 835 °C, is about 50 °C lower than that obtained with the calculation of [1] and agrees well with the mean of OPx temperature, 818 °C. The result reveals that Ca-partitioning between CPx and OPx is equilibrated in type 6 ordinary chondrites. The pyroxene temperature also agrees well with the temperature of 800 °C estimated from the structural state of plagioclase [7].

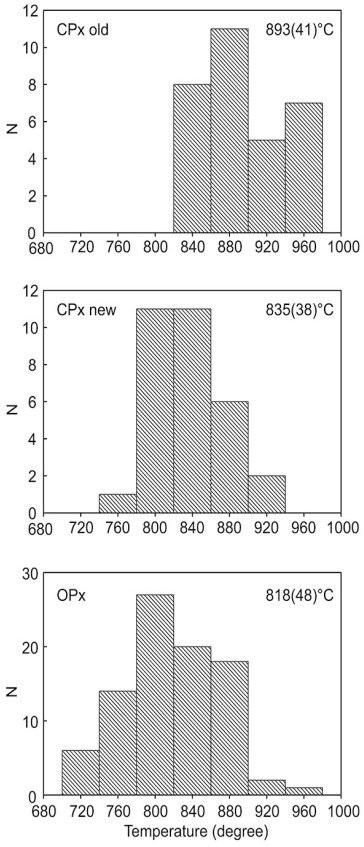

Fig. 4

References:

[1] Lindsley, D. H. (1983) *Amer. Mineral., 68*, 477-493. [2] Olsen, E. J. and Bunch, T. E. (1984) *GCA, 48*, 1363-1365. [3] McSween, H. Y. and Patchen, A. D. (1984) *Meteoritics, 24*, 219-226. [4] Slater-Reynolds, V. and McSween, H. Y. (2005) *Meteorit. Planet. Sci., 40*, 745-754. [5] Couper, A. G. et al. (1981) *Mineral. Mag., 44*, 265-267. [6] Ikeda, K. and Yagi, K. (1972) *Contrib. Mineral. Petrol., 36*, 63-72. [7] Nakamuta, Y. and Motomura, Y. (1999) *Meteorit. Planet. Sci., 34*, 763-772.