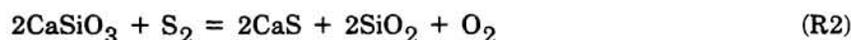


METAMORPHIC TEMPERATURES AND ENSTATITE CHONDRITES. R. A. Fogel, P. C. Hess and M. J. Rutherford, Department of Geological Sciences, Brown University, Providence, Rhode Island 02912.

There appears to be no clear consensus as to the temperature and duration of enstatite chondrite metamorphism. Estimates of temperature range from 600°C to 1470°C. Clearly our understanding of this topic is still unsatisfactory.

One favoured method that has won wide use (Larimer and Buseck, 1974) referred to in this abstract as the Wollastonite–Oldhamite Geothermometer (WOG), makes use of the three equilibria:

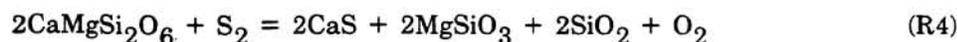


to determine metamorphic temperatures, f_{Si} and f_{O_2} . Of critical importance is the value of the activity coefficient of Si in kamacite (γ_{Si})² and the activity coefficient of CaSiO₃ in enstatite (γ_{CaSiO_3}). Previous approximations for these two quantities appear to be inconsistent with present thermodynamic data on these values.

Sakao and Elliott (1975) have determined γ_{Si} in α -Fe in the range 1100°C < T < 1350°C and 0.028 < X_{Si} < 0.084. They found that γ_{Si} is a strong function of T and is reasonably sensitive to composition in obedience with Henry's Law. Their expression for γ_{Si} is cast in a thermodynamically valid form for extrapolation to lower temperatures. Thus, the previous approximation of Log $\gamma_{\text{Si}} = -3.5$ can be shown from their data to be invalid; the values being considerably lower at metamorphic temperatures below 1100°C (Table 1).

The value of γ_{Ca} in enstatite is relatively unconstrained. (It is solely a matter of convenience whether $\gamma_{\text{CaMgSi}_2\text{O}_6}$ or γ_{CaSiO_3} is used as the calcium-rich component in enstatite.) Several studies have shown that the value of $W_{\text{G}}(\text{OPX})$ —the regular solution margules parameter for orthopyroxene—can vary over a wide range (20kJ/mole < $W_{\text{G}}(\text{OPX})$ < 50kJ/mole). Since $\gamma_{\text{CaMgSi}_2\text{O}_6}$ is related to $W_{\text{G}}(\text{OPX})$ via: $\text{Ln } \gamma_{\text{CaMgSi}_2\text{O}_6} = X_{\text{Mg}_2\text{Si}_2\text{O}_6} W_{\text{G}}(\text{OPX})/RT$, the uncertainty in $\gamma_{\text{CaMgSi}_2\text{O}_6}$ is directly related to $W_{\text{G}}(\text{OPX})$. The approximation of $\gamma_{\text{CaSiO}_3} = 10$ used in the WOG deserves no reserved place in these calculations since this value is relatively unknown. Moreover, this value certainly varies with temperature (see Ln $\gamma_{\text{CaMgSi}_2\text{O}_6}$ relation above) which further reduces the usefulness of this approximation.

The reaction:



may be used instead of R2 for the determination of metamorphic temperatures. This is necessary if $\gamma_{\text{CaMgSi}_2\text{O}_6}$ is used as the Ca-bearing component in orthopyroxene. Reactions R1, R3 and R4 may be combined with the γ_{Si} expression of Sakao and Elliott and the relation between $\gamma_{\text{CaMgSi}_2\text{O}_6}$ and $W_{\text{G}}(\text{OPX})$ to give the following relation:

$$T = \frac{A_1 + A_4 - A_3 + 18,300X_{\text{Si}} - 7,070 + 2(X_{\text{Mg}_2\text{Si}_2\text{O}_6}^2 W_{\text{G}}^{\text{OPX}}/2.3026R)}{B_1 + B_4 - B_3 - 2\log X_{\text{CaMgSi}_2\text{O}_6} + 2\log a_{\text{Fe}} - \log X_{\text{Si}} - 1.19 + 6.30X_{\text{Si}}} \quad (1)$$

Here, A_i and B_i represent the enthalpic and entropic terms of the general thermodynamic relation: $\text{Log } K_i = A_i/T - B_i$; where K_i is the equilibrium constant for reaction i . Values used for the constants A_i and B_i are as follows: $A_1 = 47,488$, $B_1 = 9.28$; $A_3 = 16,690$, $B_3 = 6.54$; and $A_4 = -22,276$, $B_4 = -1.03$. They were derived from the thermodynamic data from Robie et al., (1978) Chace et al., (1982) and Pankratz, (1982). Results of calculations using equation (1) for values of $W_{\text{G}}(\text{OPX})$ of 25 and 50kJ/mole are given in Table 1. The compositional data of Keil,

Fogel et al.

(1968) and Buseck and Holdsworth, (1972) were used in these calculations.

Meteorite	Type	T ^o C	W _G (OPX)=25		T ^o C	W _G (OPX)=50	
			Log γ _{Si}	Log f _{S₂} /f _{O₂}		Log γ _{Si}	Log f _{S₂} /f _{O₂}
Adhi Kot	EH4	432	-7.51	32.3	779	-4.78	20.6
Indarch	EH4	532	-6.49	27.9	925	-4.11	17.7
Kota-Kota	EH4	482	-7.26	29.5	873	-4.49	18.4
Abee	EH4	387	-8.16	34.7	716	-5.18	22.1
St. Sauveur	EH5	377	-8.47	35.0	710	-5.31	22.1
St. Marks	EH5	398	-7.90	34.1	726	-5.05	21.9
Yilmia	EL6	417	-8.68	31.5	820	-5.09	18.6
Ufna	EL6	482	-7.57	29.0	896	-4.55	17.6
Atlanta	EL6	458	-8.04	29.8	872	-4.75	17.8
Jajh deh.	EL6	464	-7.93	29.6	879	-4.70	17.7
Khairpur	EL6	461	-8.00	29.6	877	-4.73	17.7
Daniels Kuil	EL6	462	-7.98	29.6	879	-4.72	17.7
Hvittis	EL6	456	-8.10	29.8	872	-4.77	17.7
Pallistfer	EL6	473	-7.79	29.3	889	-4.63	17.6
Bliethfield	EL6	502	-7.39	28.2	926	-4.42	17.1

Table 1. Metamorphic T, Log γ_{Si} and Log f_{S₂}/f_{O₂} of enstatite chondrites as determined by equation (1) for values of W_G(OPX) of 25 and 50 kJ/mole.

The absolute temperature of any given meteorite is a strong function of both γ_{Si} and γCaMgSi₂O₆. Thus without further information constraining γCaMgSi₂O₆ to within a few kJ, absolute metamorphic temperatures cannot be determined using this method. However, while absolute T varies, the difference in temperatures between meteorites and thus the overall spread in T is at best only a weak function of W_G(OPX). Thus, the relationship of metamorphic temperatures between the meteorites may be assessed with some degree of confidence.

Of interest, is the fact that the entire enstatite chondrite clan shows a maximum spread of about 200^oC. This value is quite small for a group of meteorites that range texturally from partially unequilibrated to highly equilibrated. Moreover, this range is probably smaller than 200^oC because no temperature dependence has been given to W_G(OPX) for the present analysis. Since W_G = W_H - TW_S, it follows that W_G must increase with decreasing temperature for values of W_H and W_S that are positive. From Table 1 it is observed that higher W_G(OPX) produces higher temperatures. Therefore, any temperature dependence displayed by W_G(OPX) would serve to shorten the range of metamorphic T.

Possible explanations for the small spread in metamorphic T for the entire E chondrite clan are:

- (1) Lack of heterogeneous equilibria in the E chondrite system.
- (2) Different rates of reequilibration of the components involved in the system.
- (3) Incorrect values of γ_{Si} due to the presence of minor components in kamacite.
- (4) The range in metamorphic textures displayed by the E chondrites are primarily a function of time or duration of the metamorphic event rather than temperature.

These questions are addressed fully in Fogel et al., (1986) (to be submitted).

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