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[*Manuscript received 9 March 1971*]

MINERALOGICAL MAGAZINE, MARCH 1972, VOL. 38, PP. 627–9

The metal phase of the Bustee enstatite achondrite

WASSON AND WAI (1970) have recently evaluated the compositions of the metal phase and the associated schreibersite of eight enstatite achondrites and have defined a sequence among these achondrites on the basis of the Si concentrations in the metal. They have further examined the properties of both the enstatite chondrites and achondrites and have suggested the possibility that these objects can be considered to form a single evolutionary sequence. Among the nine enstatite achondrites listed in the Hey (1966) catalogue, Bustee is the only one not included in their study. Because of the aroused interest in the relationship between the enstatite chondrites and achondrites, it was desirable to find out whether Bustee fits into the suggested sequence or not.

We obtained a polished thin section of Bustee with a metal grain inclusion about 3 mm in diameter from the British Museum. A schreibersite inclusion of approximately 200×300 μm in dimension was found in the metal grain. The metal grain and schreibersite were analyzed using an ARL–EMX–SM electron microprobe available at the Idaho Bureau of Mines and Geology. Results of probe analysis for Si, Ni, P, Co, Cu, and Cr in the metal grain and associated schreibersite of Bustee are given below; the standards used were alloys from the National Bureau of Standards having an equivalent matrix and minor amounts of Si etc.

	Si	Ni	P	Co	Cu	Cr
Kamacite	0·059 %	5·5 %	0·056 %	0·29 %	0·046 %	< 0·015 %
Schreibersite	< 0·010	40·1	15·3	0·088	0·067	< 0·014

The Si and Ni contents in the metal of Bustee fall between those of Pesyanoe (Si 0·58–0·05 %; Ni 5·2–3·7 %) and Khor Temiki (Si < 90 ppm; Ni 5·9 %) enstatite achondrites reported previously (Wasson and Wai, 1970).

If we define a sequence in the order of decreasing Si content in the metal phase for all nine enstatite achondrites, it would be Shallowater–Norton County = Aubres–Pesyanoe–Bustee–Khor Temiki = Bishopville–Cumberland Falls = Peña Blanca Spring. Bustee lies in the middle of this sequence. Enstatite achondrites after Bustee in the sequence have very low Si content in the metal phase ($<$ 100 ppm), whereas those higher in the sequence than Bustee have higher Si content in the metal phase (ranging from 0·05 % to 1·0 %).

The Si and Ni contents in schreibersite of Bustee also fall between those of Pesyanoe (Si $<$ 80 ppm; Ni = 25 %) and Khor Temiki (Si $<$ 60 ppm; Ni = 48 %) reported previously. It is known that the Si and Ni content in schreibersite of both the enstatite chondrites and achondrites show an inverse correlation (Keil, 1968; Wasson and Wai, 1970). A plot of Ni vs. Si in schreibersite of enstatitic meteorites shows a continuous trend extending from Type I—Intermediate—Type II enstatite chondrites to enstatite achondrites in the order of decreasing Si and increasing Ni content (Wasson and Wai, 1970). In the plot shown by Wasson and Wai the enstatite achondrites Aubres and Norton County overlapped with Type II enstatite chondrites whereas Khor Temiki and Bishopville (both with low Si and high Ni content in schreibersite) are located at the other extreme end with only Pesyanoe lying in the vast region between them. If the Bustee datum is added to this plot, it fits nicely in the open region between the Type II enstatite chondrites and the achondrites, and hence greatly strengthens the plot in supporting the hypothesis of similar origin for these objects.

The cosmic-ray age of Bustee (44 megayears (Myr)) is in the same range with Pesyanoe (43 Myr), Khor Temiki (39 Myr), Bishopville (43 Myr), Cumberland Falls (49 Myr), and Peña Blanca Spring (38 Myr) but is considerably longer than Shallowater (18 Myr) and Aubres (11 Myr) (Eberhardt *et al.*, 1965). A plot of cosmic-ray age vs. the Si content of metal for the enstatic meteorites shown by Wasson and Wai (1970) indicates a trend of decreasing cosmic-ray age with increasing Si content of the metal from Type I—Intermediate—Type II enstatite chondrites to enstatite achondrites. Bustee and Pesyanoe again fit into this plot in the open region between Type II enstatite chondrites (overlapped with Shallowater and Aubres) and the other four enstatite achondrites with very low Si content in the metal.

The Cr concentration in the metal phase of Bustee is less than 150 ppm. Wai and Wasson (1970) have observed an association between Si and Cr in the metal of reduced iron meteorites. They have found high Si content in the metal of two iron meteorites, Tucson (0·8 %) and Nedagolla (0·14 %), both of them having high Cr content in the metal (0·22 % and 0·26 %, respectively). This result can be obtained in a system of low P_{O_2} associated with high bulk Cr/S ratio (Bunch and Fuchs, 1969). The very low Cr concentration in the metal of Bustee and Norton County previously reported by Wai and Wasson (1970) suggests a low Cr/S ratio in the bulk material of the enstatite achondrites. Consequently, we may rule out a possible genetic relationship between the enstatite achondrites and these reduced iron meteorites.

This note completes the study of the metal and associated schreibersite of the enstatite achondrites. We regard the Bustee data as strong support for the evidences provided by Wasson and Wai (1970) for the existence of a relationship between the enstatite chondrites and achondrites.

Acknowledgements. The authors wish to thank Dr. J. T. Wasson for providing the Bustee sample. The electron micoprobe employed in this study was made available through the courtesy of the Idaho Bureau of Mines and Geology, University of Idaho.

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[*Manuscript received 17 March 1971*]

MINERALOGICAL MAGAZINE, MARCH 1972, VOL. 38, PP. 629–31

The relationship between Si–O distances and Si–O–Si bond angles in the silica polymorphs

A DETAILED study of bond distances and angles in framework silicates (Brown, Gibbs, and Ribbe, 1969) has shown that individual *T*–O distances ($T =$ Si, Al) decrease with increasing *T*–O–*T* angle. They found that the slope of the regression line for the relationship above was steeper for the silica polymorphs than those calculated for the other framework silicates.

The present paper re-examines the relationship above after the *T*–O bond lengths have been corrected for the anisotropic thermal motion of their oxygens. Unfortunately anisotropic temperature factors were not available for keatite and α-cristobalite so that they could not be included. The maximum root-mean-square thermal motions of the oxygen atoms in coesite and α-quartz at room temperature are similar, 0·118 to 0·154 Å, and so the corrections are similar and small. The maximum root-mean-square thermal motion of the oxygen atoms in β-quartz at 600 °C and high tridymite at 220 °C are much greater, 0·285 and approximately 0·40 Å respectively, and cause significant shortening of the Si–O bond lengths. The correction for the thermal motion of the oxygen atoms was obtained by an approximation after Cruickshank (1956): $y = s^2/2r$ where y is the apparent shortening, r the observed bond length, and s^2 the mean squared amplitude of oscillation of the oxygen atom relative to the silicon atom (in the present work this is taken to be the maximum root-mean-square thermal motion of the oxygen atom). After correcting for thermal motion a straight line was fitted