ENSTATITE CHONDrites I: MINERALOGY AND PETROGRAPHY. C.A. Leitch and J.V. Smith, Dept. of the Geophysical Sciences, University of Chicago, Chicago, IL 60637.

The details of the mineralogy and petrology of meteorites testify to the complexity of the processes responsible for their development from a primitive solar nebula. Simple models for equilibrium progressive condensation remain extremely valuable as a theoretical reference, but must be augmented by complex nonequilibrium factors coupled to dynamical considerations. Unequilibrated chondrites provide important information on events occurring prior to igneous and metamorphic events responsible for the present state of most meteorites. Enstatite chondrites were selected for study because their oxygen isotope ratios are closer to those of the Earth and Moon than those of all other meteorites, and because they may provide a useful chemical reference for modeling the chemical composition of the inner planets (abstr., this conference, Smith). Keil [1] concluded that "major differences in chemical and mineralogical composition between types I and II were essentially established before or during chondrule formation and agglomeration by, for example, igneous differentiation or fractionation during condensation from a solar nebula", and discussed the subsequent role of metamorphism. Baedeker and Wasson [2] explained E-group fractionation by four processes: loss of oxidizing agents (i.e. H₂O) and refractory materials from solar-composition materials, partial loss of moderately-volatile elements perhaps by gas escape, more efficient agglomeration of metal than silicate, and late increase of nebular temperature. Larimer and Bartholomay [3] and Lattimer and Grossman [4] presented equilibrium calculations for condensation of a reduced nebula with C/O ~ 1, and Sears [5] presented a complex accretion model for E chondrites and aubrites involving isolation of condensates.

Four unequilibrated enstatite chondrites (Indarch, Kota-Kota, Adhi-Kot, Abee) were studied [6,7]. Particular emphasis was placed on the textural relations and minor-element chemistry of the blue- and red-luminescing clinoenstatites, and of the blue and orange olivines found as a trace constituent in Indarch and Kota-Kota. Textural relations were clearer in Indarch and Kota-Kota, perhaps because of lower shock. These meteorites contain four types of clinoenstatite-rich chondrules: porphyritic > fine-grained > barred > radiating. Porphyritic chondrules are extremely complex and a single chondrule may contain all four phases (Fig. 1). Red clinoenstatite grains may enclose blue clinoenstatite, orange olivine and/or blue olivine, while individual blue clinoenstatite grains may enclose orange and/or blue olivine. Red clinoenstatite was not found inside blue clinoenstatite. Fine-grained chondrules contain blue clinoenstatite and rare blue olivine. Both barred and radiating chondrules are composed mainly of lamellae of either red or blue clinoenstatite. All chondrule types are surrounded by a shell of fine-grained minerals. The red clinoenstatite (Table 1) is consistently higher in Ti, Al, Cr, Mn and Ca than the blue, and mostly lower in Na (Figs. 2-7). Orange olivines contain more Cr and Mn than blue ones.

The observed textures and bimodal chemical compositions of the olivines and clinoenstatites rule out formation of these meteorites by direct condensation from the solar nebula. Mechanical aggregation from two sources is needed to explain the blue and red varieties, and the observed textures indicate a complex sequence of events such as in Fig. 8. The optically sharp boundary between blue and red clinoenstatites indicates that aggregation was rapid and that metamorphism was absent or very brief. Orange olivine and red clinoenstatite are assumed to derive from the same source because of comparable Cr and Mn, and similarly for blue olivine and clinoenstatite. Enclosure by red clinoenstatite of blue clinoenstatite, orange olivine and blue olivine rules
Table 1. Average enstatite analyses.

<table>
<thead>
<tr>
<th></th>
<th>Red</th>
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<th>Blue</th>
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<tbody>
<tr>
<td></td>
<td>IN</td>
<td>KK</td>
<td>AK</td>
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<td>SiO₂</td>
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<td>MnO</td>
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<td>Na₂O</td>
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Table 2. Average metal analyses.

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<th>AK</th>
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<th>IN</th>
<th>KK</th>
<th>AK</th>
<th>AB</th>
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<tr>
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Table 3. Average sulfide analyses.

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<th>Niningerite</th>
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</tr>
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<td>0.93</td>
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</tr>
<tr>
<td>Mg</td>
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<tr>
<td>S</td>
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<td>36.1</td>
<td>36.3</td>
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The following abstract presents a speculative model in which nonequilibrium condensation and planetesimal collision are the main features.

Fig. 1. Schematic representation of a porphyritic chondrule. Black, clear, hatched and stippled areas are respectively orange olivine, blue olivine, red clinoenstatite and blue clinoenstatite. Blue clinoenstatite is polycrystalline but individual grain boundaries are not shown. The chondrule is 410μm wide.

Figs. 2-7. Histograms of clinopyroxene compositions. Filled areas represent blue clinoenstatite; unfilled, red.

Fig. 8. Schematic representation of chondrule formation from a gas-dust-liquid droplet cloud. Angular shapes are crystals; circles are liquid. a-d shows the formation of a porphyritic chondrule: (a) some blue enstatite, blue olivine and orange olivine becomes surrounded by red liquid, (b) red liquid forms crystals enclosing blue enstatite, blue olivine and orange olivine; (c) crystals become aggregated and a porphyritic chondrule similar to that in Fig. 1 is formed, (d) chondrule becomes surrounded by a shell of fine-grained dust. e-h shows the formation of a barred chondrule with an olivine inclusion: (e) blue liquid droplet comes in contact with an orange olivine, (f) olivine is trapped inside blue liquid droplet, (g) liquid crystallizes and take on typical barred appearance, (h) chondrule becomes surrounded by a shell of fine-grained material.