ENSTATITE CHONDRITES II: GENESIS. C.A. Leitch and J.V. Smith, Dept. of the Geophysical Sciences, University of Chicago, Chicago, IL 60637.

Whereas the preceding abstract has presented experimental facts and a conservative model for mechanical aggregation of two types of source materials, the present abstract flies into the wide blue skies of speculation: caveat emptor!

As far as possible, the proposed scenario is chosen to a) give the closest approach to equilibrium condensation during progressive cooling, and b) remain plausible in the context of dynamical ideas for progressive accretion from dust to planetesimals via collisions. Of key importance are those elements which can vary from oxyphilic to chalcophilic.

Unfortunately there appears to be no way to explain the mineralogy of enstatite chondrites in terms of equilibrium condensation during progressive cooling if the present thermochemical calculations [1,2,3] are correct. In these calculations, oldhamite should be replaced by diopside and anorthite before enstatite, albite and troilite begin to crystallize. A safe conclusion from the observed mineral assemblages and the chemical calculations is that the source region was reducing, but all other conclusions are suspect. One possible cause is disequilibrium condensation [e.g. 4] in which nucleation kinetics imposed constraints on equilibrium condensation. Perhaps enstatite actually began to precipitate before diopside could nucleate, thereby allowing metastable persistence of oldhamite.

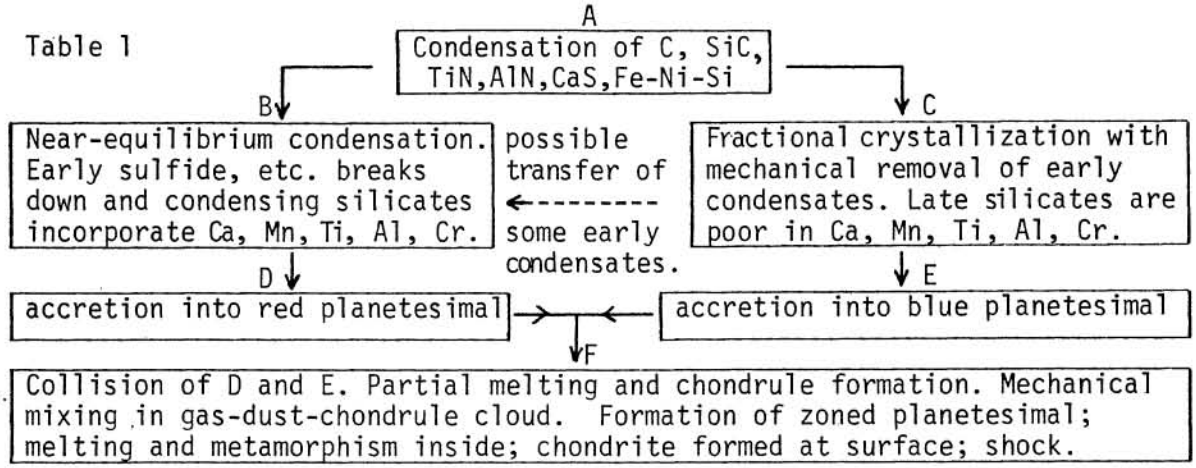
The initial discussion minimizes dynamical processes and emphasizes the chemical aspects. Table 1 is a suggested flow-sheet for multistage condensation. For simplicity, assume that the nebula was totally gaseous, though a gas-solid mixture might be required to explain isotope ratios. A. Condensation occurs in a reduced region of the solar nebula to produce the following high-temperature condensates: C,SiC,TiN,AlN,Fe-Ni-Si,CaS. In region B, further condensation occurs as the temperature falls. Although a strict equilibrium path is not followed, the final assemblage of kamacite, enstatite, albite and minor phases is fairly close to a theoretical assemblage. In particular, most or all of the oldhamite and nitrides react with the gas upon cooling, and the forsterite and clinoenstatite incorporate significant amounts of the elements originally bound in sulfide, nitride and other refractory minerals. Specifically Ca, Cr and Mn are released from sulfide and Al and Ti from nitride. In region C, fractional crystallization occurs with sequestering of the above elements in early condensates which do not react strongly with the gas. Mechanical transfer of the condensates to region B is allowed, but not necessary. The silicates of the late condensates crystallize from a gas depleted in the above elements. Condensates from regions B and C aggregate into separate planetesimals D and E which are characterized by red and blue clinoenstatite respectively. Collision of the planetesimals to produce a hot dust-droplet-gas cloud is responsible for formation of a zoned planetesimal, and the chondrites are attributed to the unmetamorphosed exterior. Further discussion of the physical aspects is given later.

Two chemical features are bothersome. First, the blue clinoenstatite tends to contain more Na than the red type. Perhaps the simplest solution is for region C to condense to a lower temperature than B. Mechanical transfer of early condensate from C to B should dilute the Na content of region B. Loss of Ca-rich early condensate from region C would make it easier for Na-rich plagioclase to condense there, thus bypassing the theoretical field for anorthite condensation. Second, the blue and red clinoenstatites contain the same amount of Fe, as do the blue and orange

ENSTATITE CHONDRITES II GENESIS.

Leitch, C.A. and Smith, J. V.

Table 1



olivines. Unless this is an accidental coincidence, some kind of "buffering" reaction appears desirable. Perhaps the simplest possibility is that clinoenstatite, forsterite and Fe-Ni-Si are crystallizing simultaneously and that the partial pressure of iron in the vapor is controlled by the vapor pressure of the crystallizing Fe-Ni-Si: ion probe analyses of Ni in clinoenstatite are planned as a test.

Turning now to the dynamical aspects, the relevant mechanics of planetesimal collisions were briefly considered in [5]. Figure 1 shows how the red and blue planetesimals from Table 1 might collide to produce enstatite chondrites and other products. To achieve abundant production of chondrules, it is probably necessary to begin with hot planetesimals, and heating by short-lived radioactive species (^{26}Al?) is one possible mechanism. Because the enstatite chondrites of Type I contain approximately a solar ratio of silicate to metal, it seems desirable to not have formation of a metal core in the D and E planetesimals, or at least not in the parts of the planetesimals that yielded silicate chondrules. Perhaps raisins of metal-sulfide eutectic were distributed throughout a silicate matrix just prior to collision. If so, metamorphic equilibration of element distribution would be expected. An off-center collision of the planetesimals should favor retention of debris in a single rotating cloud. Upon settling, the massive debris would form the interior of the product planetesimal, and differentiation into achondrite and iron types of material might occur. However, there is no necessity that aubrites [6] derive from the same planetesimal as enstatite chondrites of type I. Aerodynamic sorting of fine debris should occur, and shock waves from colliding bodies would cause rapid settling without development of grading in the surface sediment. Metamorphism would increase inwards. The main argument for collision of planetesimals is to allow rapid mixing and cooling of blue and red crystalline and liquid materials. Processes involving isolated grains and chondrules floating in the solar nebula do not seem adequate to explain the petrographic textures.

An even wider dynamical question concerns the relative position of the condensates and planetesimals in the solar nebula. It is assumed that the condensation took place in the inner part of the nebula, though the chemical factors are not understood. If material in the median plane were hotter than material away from the plane, condensation should proceed more slowly in the plane. Perhaps early condensates drifted towards the median plane and became reheated. For this type of mechanism, the B type of planetesimal might develop close to the median plane and the C type away from the plane before migration to the median position. The model of

ENSTATITE CHONDRITES II GENESIS.

Leitch C.A. and Smith J. V.

Baedeker and Wasson [7] for elemental ratios is roughly consistent with this mechanism.

It is unfortunate that a complex model has so many loopholes, and there is no doubt that simple models are psychologically appealing. Ockham's razor is certainly preferable if a simple solution is allowed. We conclude that the mineralogy and petrography of enstatite chondrites are so complex, as recognized by Keil [8], that a simple model of progressive equilibrium condensation cannot be applied. The growing evidence of complex textures in ordinary and carbonaceous chondrites supports a similar conclusion. In spite of the textural complexity there is still hope that the existing cosmochemical models for meteorites provide a basic framework for further development of ideas on the differentiation of the solar nebula, but it seems necessary to proceed from bulk chemical properties to those for individual minerals in known textural positions.

[1] J.W. Larimer 1975 GCA 39, 389. [2] J.M. Lattimer, L. Grossman 1978 The Moon and the Planets 19, 169. [3] J.W. Larimer, M. Bartholomay 1979 GCA 43, 1455. [4] M. Blander 1971 GCA 35, 61. [5] J.V. Smith 1979 LPSC XI, 1054. [6] T.R. Watters, M. Prinz 1979 PLPSC 10, 1073. [7] P.A. Baedecker, J.T. Wasson 1975 GCA 39, 735. [8] K. Keil 1968 JGR 73, 6945.

NASA 14-001-171

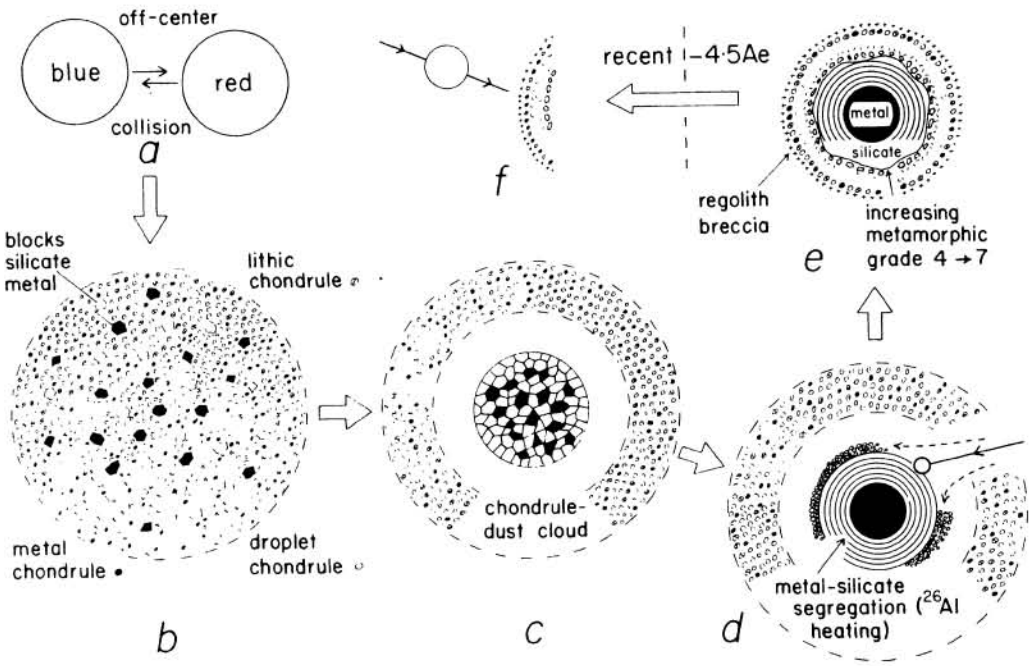


Fig. 1. Schematic diagram for growth of zoned planetesimal (e) from off-center collision of two differentiated planetesimals (a). Blocks collect together (c) from the cloud of impact debris (b), and a shock wave from impact (d) causes settling of the chondrule-dust cloud. For ordinary chondrites, the two colliding planetesimals might have similar mineralogy and chemistry, but for enstatite chondrites different properties are needed to explain blue- and red-luminescing clinoenstatites. Slightly modified from [5].