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# An evolutionary system of mineralogy. Part II: Interstellar and solar nebula primary condensation mineralogy (>4.565 Ga)

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## Abstract

The evolutionary system of mineralogy relies on varied physical and chemical attributes, including trace elements, isotopes, solid and fluid inclusions, and other information-rich characteristics, to understand processes of mineral formation and to place natural condensed phases in the deep-time context of planetary evolution. Part I of this system reviewed the earliest refractory phases that condense at $T > 1000$ K within the turbulent expanding and cooling atmospheres of highly evolved stars. Part II considers the subsequent formation of primary crystalline and amorphous phases by condensation in three distinct mineral-forming environments, each of which increased mineralogical diversity and distribution prior to the accretion of planetesimals >4.5 billion years ago.

(1) *Interstellar molecular solids*: Varied crystalline and amorphous molecular solids containing primarily H, C, O, and N are observed to condense in cold, dense molecular clouds in the interstellar medium ($10 < T < 20$ K; $P < 10^{-13}$ atm). With the possible exception of some nanoscale organic condensates preserved in carbonaceous meteorites, the existence of these phases is documented primarily by telescopic observations of absorption and emission spectra of interstellar molecules in radio, microwave, or infrared wavelengths.

(2) *Nebular and circumstellar ice*: Evidence from infrared observations and laboratory experiments suggest that cubic $H_2O$ ("cubic ice") condenses as thin crystalline mantles on oxide and silicate dust grains in cool, distant nebular and circumstellar regions where $T \sim 100$ K.

(3) *Primary condensed phases of the inner solar nebula*: The earliest phase of nebular mineralogy saw the formation of primary refractory minerals that solidified through high-temperature condensation ($1100 < T < 1800$ K; $10^{-6} < P < 10^{-2}$ atm) in the solar nebula more than 4.565 billion years ago. These earliest mineral phases originating in our solar system formed prior to the accretion of planetesimals and are preserved in calcium-aluminum-rich inclusions, ultra-refractory inclusions, and amoeboid olivine aggregates.

**Keywords:** Classification, mineral evolution, natural kinds, vapor deposition, condensation, nebular mineralogy, interstellar mineralogy, chondrite meteorites