PHYSICOCHEMICAL CONDITIONS OF CLINOPYROXENE CRYSTALLIZATION IN THE PARENTAL BODIES OF ORDINARY CHONDRITES

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Thermo- and barometry of ortho- and clinopyroxene in ordinary chondrites indicate that these minerals crystallized from chondritic melts, first, under progressively more reduced conditions and significant pressures in large parental bodies and then continued to crystallize in much smaller bodies, under a pressure of approximately 9 kbar. The radii of the parental bodies of ordinary during the second (planetary proper) phase could be of the order of 750–850 km.

In order to evaluate the physicochemical conditions under which the parental bodies of ordinary chondrites were produced, we examined chondrites of different chemical groups and petrological types: low—I (3.0–3.7), intermediate—II(3.8–4), and high—III(5–7), exemplified by Yamato-82133 I(3), Raguli II(3.8), Okhansk II(4) (group H); and Yamato 74417 I(3), Saratov II(4), Fucbin III(6), and Berdyansk III(6) (group L), as well as used literature data on other ordinary chondrites. To evaluate the crystallization temperatures of chondrules, we utilized the compositions of ortho- and clinopyroxene, which are the most widely spread minerals (along with olivine) of ordinary chondrites. The crystallization temperatures of the chondrules were calculated by four clinopyroxene–orthopyroxene thermometers [14, 13, 3, 11] and indicate that the chondrules of ordinary chondrites of types I and II have crystallized within broad temperature ranges: 938–1466°C for Yamato-82133 HI(3), 1106–1306°C for Yamato-74417 LI(3), 874–1479°C for Raguli HII(3.8), and 1032–1490°C for Saratov LII(4). Conversely, the chondrules of chondrites of types III have crystallized at an almost constant (within the accuracy of the calculations [12]) temperature: 985–1000°C for Berdyansk LIII(6) and 992–1030°C Fucbin LIII(6). These results are in good agreement with the widths of the crystallization temperature ranges published in [9] for ordinary chondrites of the different petrological types of group LL and calculated for the clinopyroxene by the geothermometer [4] but differ from these data by the absolute values of the temperatures. The crystallization temperatures calculated for ordinary chondrites of petrological types 6 and 7 by four two-pyroxene geothermometers [14, 13, 3, and 11] vary insignificantly (within ±48ºC), and the temperatures calculated by each of these thermometers are practically constant for chondrites of type 6 (for example, the temperatures calculated by [13] for clinopyroxene–orthopyroxene pairs are 1011 ± 19ºC for different chondrules in Fucbin L6 and 993 ± 8ºC for Berdyansk L6) and vary insignificantly (within the accuracies of the thermometers) when calculated by different thermometers for Yamato-74160 LL7 of type 7 (1053 ± 52ºC).

The crystallization pressure of chondrites was evaluated by model [7], which makes use of a baric dependence for the unit-cell parameters of clinopyroxene (the volume of the unit cell and of the M1 polyhedron). This model is less than the previous models dependent on the chemistry of the melt and the mineral assemblages.

The applicability of this model to estimates of clinopyroxene crystallization pressure is justified in [12]. The average pressure values yielded by the clinopyroxene geobarometer [10] for ordinary chondrites of different petrological types (I, II, and III) and discrete chemical groups vary from 2.4 to 8.4 kbar, with the pressure under which clinopyroxene crystallized in equilibrium chondrites of type III varying within a narrower range, from 3.05 to 8.33 kbar, than the pressures of unequilibrated chondrites of types I and II (0–10.55 kbar). Moreover, chondrites of types I and II were found out to contain single clinopyroxene grains that crystallized under a much higher pressure, up to 14.5 kbar, with such clinopyroxene occurring much more frequently in the most strongly unequilibrated chondrites (type I), which bear silicate chondrules whose composition varies within broader ranges. Our earlier petrological analysis of chondrules with such clinopyroxene grains [8, 15] revealed that all of them bear pyroxene and olivine grains that are complicatedly zoned, with a reversed zoning in the silicates giving way to their normal zoning as a reflection of two crystallization stages of the chondrites [6].

Petrologically, the early high-temperature crystallization stage of ordinary chondrites follows from the occurrence of relict grains (such as silica-oversaturated pyroxene, jadeite–ureyite clynopyroxene and other [15, 16]) with exsolution textures comparable with those of terrestrial high-pressure solid solutions.

The presence of relict grains of high-pressure minerals, the crystallization of native silicon simultaneously with kamacite [8], and the occurrence of diamond in the matrix of chondrites provide evidence that the crystallization of the immiscible (exsolved) chondritic melts ("recorded" in the textures of chondrites) took place after a time period when they evolved under reduced conditions and much higher pressures. The crystallization pressure of relict grains of jadeite-ureyite pyroxenes (found in chondrites types II and III) was avaluated by the clinopyroxene barometer as 63-71 kbar.

The second crystallization stage of chondritic melts proceeded under progressively more oxidizing conditions [7, 8, 15] after the breakup of the parental planets, within much smaller bodies, as also follows (in addition of pressure estimates obtained for the crystallization of clinopyroxene: the maximum pressure in chondrites of type III did not exceed 8.5 kbar) from the presence of protopyroxene in chondrites of types I, II, and III, with this mineral known to crystallize under pressures of no more than ~8 kbar [1, 2]. The fact that protopyroxenes are less typical of chondrites of type III suggests that the pressures within their parental bodies could have been slightly higher than 8 kbar.

Assuming that the pressure within the stage-II parental body could be close to 8–9 kbar, using the dependences of the radius of a body on its inner pressure obtained for ice satellites [5], and taking into account the greater density of a silicate sphere (3000 kg/m^3) that an ice sphere (1000 kg/m^3) (thereby we ignored the compressibility of the spheres), we arrived at the conclusion that the radii of the parental bodies of ordinary chondrites during the second (planetary) stage of their evolution could be as great as 750–850 km.

Hence, our earlier conclusion that chondritic melts were formed in two stages, first, under increasingly more reducing conditions within large parental bodies and, then, under more and more oxidizing conditions within much smaller bodies [7, 8] receives further support from the thermobarometry of pyroxenes contained in ordinary chondrites of different petrological types and chemical groups (LL, L, and H).

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