High temperature clinoenstatite discovered in the heavily shocked ordinary chondrite Grove Mountains 022115：Implication for the decomposition of pyroxene. Zhuang Guo[1,2], Yang Li[1], Zhidong Xie[3], Shiejie Li[1], Xiongyao Li[1], Shen Liu[2], Shijie Wang[1]. [1]Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China; [2]Northwest university, Xi'an, China;[3]Nanjing University, Nanjing, China.
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Introduction: The high-pressure mineral assemblages have been commonly discovered in the shock-induced melt veins of ordinary chondrites [1-4]. The formation conditions of those high-pressure minerals usually used to recover the impact events that take placed on the asteroid.

High temperature clinoenstatite (HT-CEn) is an important polymorph of the low-Ca pyroxene [5-9], and has been rarely reported in natural rocks, especially in meteorites. Our work focuses on the origin of Nano-sized fiber like HT-CEn in the shock-induced melt vein of Grove Mountains 022115 (GRV 022115). The HT-CEn crystals were embedded in pyroxene glass and surrounded by vesicles rich silica glass as well as nano-sized iron particles.

According to the results of HR-TEM observation, quantitative EDS mapping as well as nanoscale diffraction, we obtained the crystal structure and element composition of HT-CEn. Overall considering the phase map and the high-pressure mineral assemblages in the shock vein, we clarified the formation process of HT-CEn crystals in the impact history of GRV 022115's asteroid body.

Sample and analytical techniques: Ordinary chondrite GRV 022115 was collected by Chinese Antarctic Research Expedition Team in Grove mountain, 2003, and were classified as L6 S6 ordinary chondrite. The polished thin section of GRV 022115 was observed and analyzed by the FEI Scios dual-beam scanning microscope (SEM&FIB). The mineral composition was analyzed by JEOL 8230 electron microprobe(EPMA). The two FIB cross sections were prepared by the FEI Scios focus ion beam. We obtained the results of HR-TEM, quantitative EDS mapping as well as nanoscale diffraction by FEI Talos field-emission scanning transmission electron microscope(FE-STEM).

Results: Ordinary chondrite GRV 022115 has a network of black shock veins which enclose abundant host rock fragments. The major host rock minerals in the GRV 022115 include olivine (Fa_{24}), orthopyroxene (Fs_{20}), and plagioclase, with minor amount of iron-nickel alloy and troilite. The melt vein matrix mainly contains Majorite-pyrope solid solution, magnesiowüstite and ringwoodite high-pressure mineral assemblages.

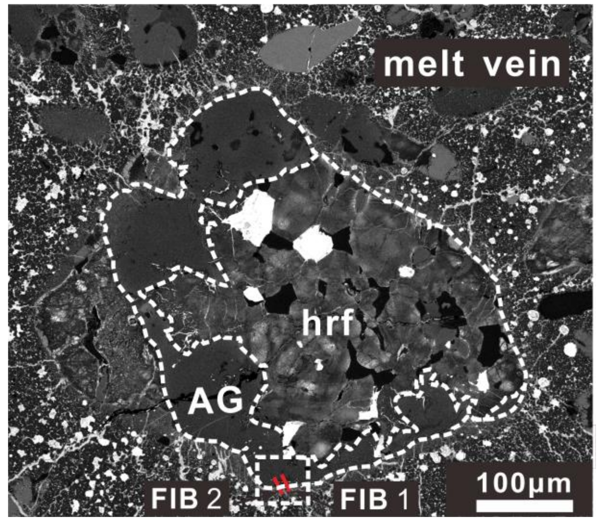

Fig 1. BSE image of the host rock fragment (hrf) in the main shock melt vein of GRV 022115. The two red lines on the bottom of the host rock fragment are the locations of the FIB slices. AG: amorphous glass.

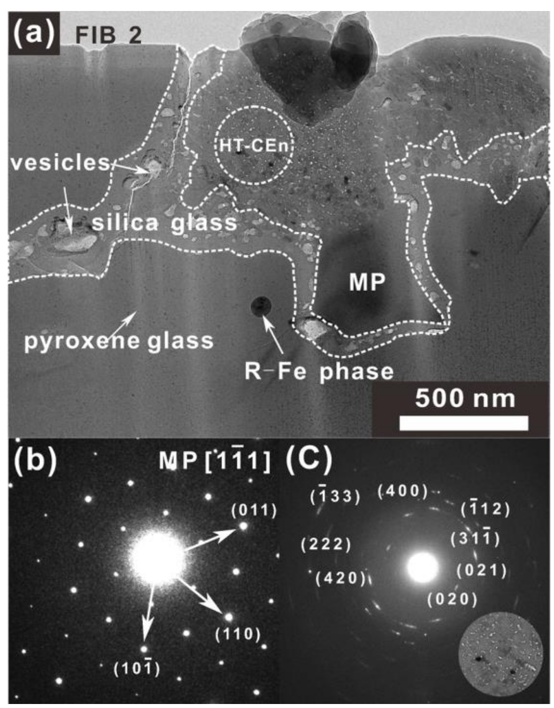

Fig 2. (a) Bright-field TEM image of the mineral assemblage in FIB 2 slice. The area circled by the dotted line is the position for the SAED pattern of HT-CEn. MP: Majorite-pyrope solid solution. (b) The SAED

pattern showing the $[1\bar{1}1]$ zone axis of the MP with a cubic structure. (c) The diffraction ring pattern of HT-CEn in the dotted circle. Indices of crystallographic planes imply the space group of clinopyroxene is C2/c.

In BSE images, an amorphous glass layer was observed at the edge of one big(0.5mm) host rock fragment (olivine) in the wide (~1.2mm) shock-induced melt vein in GRV 022115 (Fig. 1). The bulk composition of the amorphous glass is consistent with the host rock pyroxene. Two FIB cross sections were prepared in our study. the HT-CEn display nano-sized crystallite and associate with silica glass in the amorphous glass (Fig 3.). Based on the TEM data, the amorphous glass further divided into following parts: pyroxene glass, HT-CEn and rich-Fe phases associated with silica glass and vesicles (Fig 2.). EDS of TEM analyses of six HT-CEn areas and nine pyroxene glass areas give an average composition of $Na_{0.01}Ca_{0.01}Mg_{0.86}Fe_{0.13}Si_{0.96}O_3$ and $Na_{0.08}Ca_{0.02}Mg_{0.70}Fe_{0.18}Si_{0.96}O_3$, respectively. The pyroxene glass display enrichment of Fe, Na and Ca (a little), as well as depletion of Mg. Whereas, the HT-CEn is on the opposite, which indicate the redistribution of Mg and Fe elements in the shocked process. The structure of HT-CEn was confirmed by the SAED pattern (Fig 3), and these HT-CEn crystals represent C2/c space groups with orthopyroxene composition. Considering that HT-CEn only appears on the edge of the MRB near the melt vein matrix, the formation of the HT-CEn must have a close relationship with matrix.

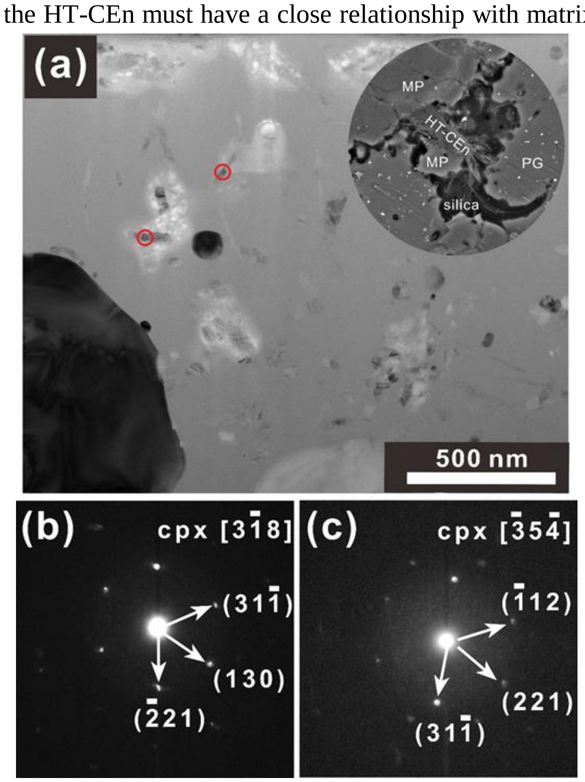

Fig 3. (a) Bright-field image of the HT-CEn crystals in the FIB 1, red circles represent the location of obtained diffraction pattern. The inserted back-scattered electron image showing the close relation between majorite and HT-CEn. MP: Majorite-pyrope solid solution; PG: pyroxene glass. (b) The diffraction pattern is the $[3\bar{1}8]$ zone-axis pattern of the HT-CEn crystal; $d_{(130)}$=2.865Å; $d_{(31\bar{1})}$=2.996Å; $d_{(\bar{2}21)}$=3.142Å, angle between (130) and $(31\bar{1})$ is 56.6°,this pattern is consistent with clinopyroxene (space group C2/c). (c) The diffraction pattern is the $[\bar{3}5\bar{4}]$ zone-axis pattern of the HT-CEn crystal; $d_{(221)}$=2.483Å; $d_{(\bar{1}12)}$=2.550Å; $d_{(31\bar{1})}$=2.996Å, angle between $(31\bar{1})$ and $(\bar{1}12)$ is 114.6°, this pattern is also consistent with clinopyroxene (space group C2/c).

The Fe-rich phases show their composition are not pure metal, but contain the Mg, Si, O and abundant Fe. Leroux et al. (2000) and Xie et al. (2011) have reported the similar compositions in the Tenham meteorite, which were explained to form in rapid quenched condition [10-11]. In our study, it most like the blend of pyroxene glass in TEM analysis because of their nano-sized.

Discussion: The formation of amorphous glass is result of quenching. The melt vein matrix mainly contains Majorite-pyrope solid solution, magnesiowüstite and ringwoodite high-pressure mineral assemblage, indicating the crystallization pressure of 18-24GPa [12]. The distribution of elements and the presence of silica and vesicles in the amorphous glass suggest the reduction of initially pyroxene to the following reaction: (Mg, Fe) $SiO_{3\ \mathrm{in\ pyroxene}} \rightarrow Mg^{2+}_{\mathrm{in\ HT\text{-}CEn}}$ +Fe_{metal} + $SiO_{2\ \mathrm{in\ melt}}$ + $1/2O_2\uparrow_{\mathrm{in\ gas}}$

Based on the close relationship between matrix (Majorite-pyrope solid solution) and HT-CEn, it is considered that HT-CEn should be the degenerative product of the majorite during the decompression under high temperature. According to the results of the simulation experiments, the formation temperature of HT-CEn is about 1600℃.

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