Minerals in meteorites: A review. M. Kimura[1], [1]Faculty of Science, Ibaraki University, Mito, Japan, makotoki@mx.ibaraki.ac.jp.

Meteorites consist of minerals. The variety of these minerals is very wide, and they should give important constraints on the formation conditions of meteorites, such as redox state, temperature and pressure. Here I review the mineralogy in meteorites.

Minerals in meteorites were reviewed by some authors [1-3]. Kimura [3] reported 200 kinds of minerals in meteorites. However, recent progress of technique to identify mineral, especially micron sized fine-grain, enables identification of abundant new minerals [e.g., 4]. At present, 327 kinds of minerals have been noticed from various meteorites.

However, the number of such minerals in meteorites are not so large, in comparison with terrestrial minerals, ~4,700. The main reason for it is that meteorites are not extensively differentiated, compared with terrestrial rocks. In the history for ~4.5Ga, the kind of minerals in terrestrial rocks has increased [5]. At any rate, major minerals in meteorites are only olivine, low- and high-Ca pyroxene, plagioclase, Fe-Ni metal and troilite. Especially in chondrites, their abundance reflects the solar elemental abundance in general.

On the other hand, many kinds of distinctive minerals are encountered in some meteorites, especially enstatite meteorites, refractory inclusions, heavily shocked meteorites, and polymict ureilites. Enstatite meteorites were formed under extremely reducing conditions, which is reflected by the occurrence of some unusual reducing minerals, such as niningerite, oldhamite, sinoite and perryite. Weisberg and Kimura [6] reviewed mineralogy and geochemistry in such enstatite chondrites. Some reducing reservoir was present in the solar nebula.

Refractory inclusions, typical in carbonaceous chondrites, were primarily formed under highest temperature conditions in the primitive solar nebula. The occurrences of refractory minerals, especially hibonite, perovskite, and melilite, reflect not only the high-temperature condition, but also silica-undersaturated condition. Recently, many new minerals have been discovered from such inclusions. Some of them, especially refractory minerals such as panguite, are regarded as the earliest minerals in the solar system [7]. Pyroxene is one of the most important rock-forming minerals both in terrestrial and extraterrestrial rocks. New minerals in pyroxene group have also been identified in refractory inclusions [4, 8]. One of them, kushiroite, reflects rapid cooling under Ca-Al-rich environment in the early solar nebula [4].

Shock veins and melt pockets in heavily shocked meteorites also abundantly contain unusual minerals, such as ringwoodite, majorite, and lingunite. They were formed under ultrahigh-pressure conditions, such as 20GPa or higher. New minerals, such as seifertite, were recently discovered from such shocked meteorites [9]. These minerals are important, because most of them are regarded to be major minerals in the terrestrial mantle. In addition, these minerals show the physical conditions for asteroidal collision [e.g., 10]. Recently, an eclogitic mineral assemblage, including omphacite and pyrope-rich garnet, is also reported from clasts in CR chondrites, which was formed under ~3GPa [11]. The pressure conditions for meteorite formation vary much wider than previously understood.

Polymict ureilites also contain many kinds of unusual minerals [12]. They show wide range of formation conditions, especially redox states, for ureilite components. Mineralogy of CH chondrites is partly similar to those in ureilites, reflecting oxidizing to highly reducing conditions [13]. These meteorites and their components were formed under wide range of redox condition.

Thus, minerals in meteorites directly reflect wide range of formation conditions. Especially the discovery of new minerals is important not only to give constraints on the formation conditions for meteorites, but to mineralogical sciences.

References:

[1] Mason, B. (1972) *Meteoritics*, 7, 309-326. [2] Rubin, A.E. (1997) *Meteorit. Planet. Sci.*, 32, 231-247. [3] Kimura, M. (1996). *Kobutsugakuzassi* (in Japanese), 25, 49-60. [4] Kimura, M. et al. (2009) *Am. Mineral.*, 94, 1479-1482. [5] Hazen, R.M. et al. (2008) *Am. Mineral.*, 93, 1693-1720. [6] Weisberg, M.K. and Kimura, M. (2012) *Chemie der Erde*, 72, 101-115. [7] Ma, C. et al. (2012) *Am. Mineral.*, 97, 1219-1225. [8] Ma, C. and Rossman, G.R. (2009) *Am. Mineral.*, 94, 845-848. [9] El Goresy, A. et al. (2008) *European J Mineralogy*, 20, 523-528. [10] Ohtani, E. et al. (2004) *Earth Planet. Sci. Let.*, 227, 505-515. [11] Kimura M. (2012) *Am. Mineral.* (in press). [12] Ikeda, Y. et al. (2000) *Antarctic Meteorite Research*, 13, 177-221. [13] Kimura M. et al. (2011) *Meteorit. Planet. Sci.*, 46, A124.