Special Issue: The Kobe meteorite consortium

Preface

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The Kobe meteorite fell on September 26 (local time 20:23), 1999, in Kita-ku in the north of Kobe city, Japan. The meteorite fall was widely observed in Kobe and the surrounding area, and was photographed by an amateur photographer in Imabari city, 200 km southwest of Kobe. The meteorite struck a house with an explosive sound but otherwise caused only minor property damage. The approximately 20 fragments of the meteorite (total mass 136 g) were soon after delivered to Kita Police Headquarters, then transferred to the Forensic Science Laboratory (FSL) of Hyogo Prefectural Police Headquarters where nondestructive tests and X-ray fluorescence analyses were carried out under the guidance of the present author (Figs. 1~3).

One of the largest fragments, Kobe A (65 g), was promptly transferred to the Ogoya Underground Laboratory (low-level radioactivity laboratory, LLRL) of Kanazawa University for cosmic-ray induced radioactivity measurements (see Komura et al., 2002). Several small chips (about 0.5 g each) were donated by the owner of the building struck by the meteorite (Mr. R. Hirata). One of the small chips was taken for petrographic examination at the National Institute of Polar Research (NIPR; Prof. H. Kojima) and another small chip was petrographically examined at Kobe University (Prof. K. Tomeoka). The meteorite was classified as a Karoonda-type (CK4) chondrite (metamorphosed carbonaceous chondrite) and was registered with the Nomenclature Committee of the Meteoritical Society (see Meteoritical Bulletin No. 84, 2000).

Two large fragments, Kobe C (14.5 g) and Kobe E (3.7 g) were provided to the present author on loan from Mr. Hirata for scientific research. Kobe C is the third largest of the recovered Kobe meteorite fragments (see Fig. 3) and was partially covered by a fusion crust and white ceiling material (later scraped away) adhered to the fusion crust. Kobe E had no fusion crust and no apparent contaminants, suggesting that the specimen fragmented from inside the meteorite. Approximately half (1.4 g) of Kobe E was pulverized at NIPR for bulk chemical analysis of the major elements. Wet chemical analyses were carried out at NIPR, and major and trace element analyses were carried out by isotope dilution at Kobe University and instrumental neutron activation analysis (INAA) at the Tokyo Metropolitan University. Oxygen isotopes in a small chip from Kobe E were analyzed at the University of Chicago (Prof. R. N. Clayton). The major chemical and oxygen isotopic compositions were found to be consistent with the classification of CK-group chondrites, although anomalous REE patterns were identified. The preliminary results of chemical, petrological and oxygen isotope examinations, as well as cosmic-ray induced radionuclides were reported at the 31st Lunar and Planetary Science Conference held at NASA, Houston, U.S.A. (Nakamura et al., 2000).

The Kobe meteorite is a new member of the carbonaceous sub-group (CK) of chondrites recently classified for a series of metamorphosed

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carbonaceous chondrites including the sole observed fall, Karoonda (Kallmeyn et al., 1991). The CK chondrites are particularly important with respect to understanding the thermal evolution of carbonaceous chondrites. However, this group has yet to be extensively investigated chemically or petrologically, and the evolution of these chondrites remains poorly understood.

A consortium of 10 leading laboratories in Japan and the US have recently conducted intensive research on Kobe C in order to determine a wide range of properties of the Kobe meteorite. Within 2 years (2000 and 2001), more than 20 short papers describing preliminary results have been presented in the special session of the Kobe meteorite at the Antarctic Meteorite Symposium and the annual meeting of the Meteoritical Society. Results of noble gas analyses and petrological examinations of the meteorite were reported by Matsumoto et al. (2001) and Tomeoka et al. (2001), respectively. The 7 papers included in this special issue for the Kobe meteorite include reports on chemical compositions by Oura et al. (2002) and Hirota et al. (2002), petrology and mineralogy by Tachibana et al. (2002), gamma-ray measurements for cosmic-ray induced radionuclides by Komura et al. (2002), noble gas analyses by Matsumoto et al. (2002) and Takaoka et al. (2002), and X-ray computed tomography (CT) results for discussion of the nondestructive digital curation of meteorite samples by Tsuchiyama et al. (2002).

Oura et al. (2002) employed neutron-induced prompt gamma-ray analysis (PGA) to analyze several lumps of sample of the Kobe meteorite, as well as a powdered sample and separated chondrules. A total of 15 elements including key elements of cosmochemical importance were determined nondestructively, and it was revealed that
the CK chondrites including the Kobe meteorite are characterized by the highest Mg/Si ratios of all carbonaceous chondrites. They proposed a S/Mn vs. Al/Mn diagram for classification of carbonaceous chondrite, on which the individual group of CI, CM, CV, CO and CK cluster in discrete localities. These three key elements, S, Al and Mn, were determined for voluminous and irregularly shaped samples by PGA, demonstrating the utility of PGA in the analysis of newly fallen meteorites such as the Kobe chondrite.

Hirota et al. (2002) report the high-precision isotope dilution analysis of 17 lithophiles including REEs, 2 alkalis, 4 alkaline earths and Fe for 10 bulk CK chondrites including the Kobe meteorite. The Kobe and CK chondrites are characterized with respect to REE pattern. Kobe E is found to exhibit an anomalous REE pattern indicative of nebular signatures, and efforts are made to obtain a more representative REE pattern for Kobe and the CK group. While CK chondrites exhibit flat REE patterns with minor negative Ce and Eu anomalies and an appreciable light/heavy REE gap and Yb anomaly. Less metamorphosed CK3-4 chondrites were found to exhibit a larger negative Ce anomaly (about –10%) compared to highly metamorphosed CK5-6 chondrites, suggesting that these REE features are properties inherited from the refractory precursors of the CK chondrites produced in the early solar nebula.

Tachibana et al. (2002) describe the petrography and mineralogy of the Kobe meteorite using one of the polished sections of the Kobe meteorite. They report that porphyritic olivine chondrules are dominant, and one barred olivine was observed in the section. Olivine grains in both chondrules and the matrix are homogeneous. Orthopyroxene and augite grains also homogeneous due to parent-body metamorphism. They estimate the equilibrium temperature of the Kobe meteorite to be around 800°C based on pyroxene geothermometers and an olivine-spinel geothermometer. The cores of augite grains in chondrules, however, are richer in Ca and Fe than the rim, suggesting that the augite grains formed at lower temperature (below 600°C) prior to equilibration at 800°C. As the estimated temperature of the Kobe meteorite (CK4) is significantly higher than petrologic type 4 and comparable to type 6 ordinary chondrites, they suggest that the duration of metamorphism on the CK parent body was much shorter than that of ordinary chondrites.

Komura et al. (2002) measured the gamma-ray emission of the largest fragment (Kobe A) using an ultra low-background Ge-detector over about 4 days beginning 21 h after the meteorite fall, and then detected 19 cosmic-ray induced radionuclides including very short-lived 24Na. In particular, the detection of 28Mg and 43K may be a first for meteorites. The low activities of 60Co (~1 dps/kg) and 26Al (38 dps/g) observed for the Kobe meteorite suggest that the pre-atmospheric size of the meteorite was quite small (<10 cm). Based on a comparison of the activities of spallogenic products in the Kobe chondrite with those in the Tsukuba meteorite, the authors suggest that the Kobe meteorite fell at around the solar maximum whereas the Tsukuba meteorite fell at near the solar minimum.

Matsumoto et al. (2002) have investigated the elemental and isotopic compositions of noble gases in the Kobe meteorite by stepwise heating. They report the cosmic-ray exposure age derived
from cosmogenic $^{21}$Ne and $^{38}$Ar to be 38 Ma. Based on neutron-produced $^{80}$Kr, they estimate a pre-atmospheric size of the Kobe meteorite of larger than 23 cm in radius, in contrast with the results of cosmogenic radionuclides reported by Komura et al. (2002). The authors therefore suggest that these results indicate a two-stage exposure history for the Kobe meteorite. They also report the primordial noble gas pattern for the Kobe meteorite and note that the Q-Xe expected from HL-Xe is as low as that for a carbonaceous chondrite, explained as due to preferential loss of Q-Xe due to shock events at high temperature.

Takaoka et al. (2002) also report the results of noble gas analyses for bulk samples and preliminary results for chondrules of the Kobe meteorite. They report the concordant cosmic-ray exposure ages obtained from spallogenic $^{21}$Ne, $^{38}$Ar and $^{83}$Kr. The $^{21}$Ne-based exposure age is 42 Ma, which is in agreement with that obtained by Matsumoto et al. (2002). They also report a K-Ar age of 3.3 Ga. From the observed neutron-induced $^{80}$Kr, $^{82}$Kr and $^{128}$Xe, they suggest that the Kr isotopes were produced by epithermal neutron captures on $^{79}$Br and $^{81}$Br. They estimate the minimum pre-atmospheric size to be 24 cm in radius or 200 kg in mass. They also report preliminary results of laser-microprobe analyses of He, Ne and Ar for chondrules, showing the heterogeneous distributions in components of chondrules.

Tsuchiyama et al. (2002) report the images of a micro X-ray CT scan of the Kobe meteorite and discussed the possibility of three-dimensional, nondestructive digital curation of meteorite samples. Materials including major minerals in the meteorite were also imaged to obtain a quantitative relationship between CT values and the X-ray linear attenuation coefficients of the materials. A composite of 380 successive slice images of a piece of the Kobe meteorite were taken and thin sections were made to compared the CT images with the results obtained by optical microscopy, scanning electron microscopy and X-ray fluorescence microscopy. Plagioclase, ferromagnesian silicates, magnetite-pentlandite and molybdenite are distinguishable in the CT images, although the distinction between ferromagnesian minerals such as olivine, orthopyroxene and clinopyroxene is difficult. Rimmed chondrules can be recognized in the CT images but not for unrimmed one. After examination of the CT images, the sample was cut into 7 plates for analysis at different laboratories.

The Kobe meteorite has now been extensively studied by this consortium and the following 7 papers will contribute significantly to clarifying evidence of the origins and evolution of CK chondrites and their parent body. The persistent problems related to the thermal history of the Kobe meteorite, such as shock events noted in petrological and chemical analyses, have been discussed by several authors and caught our particular attention. Further study is required to address these areas, and isotopic analyses and age determination will be important in any such study.

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REFERENCES


