Progress of chemical characterization of asteroid Ryugu samples

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It is believed that meteorites come from asteroids. Samples of asteroid (25143) Itokawa returned by the JAXA Hayabusa mission revealed that S-type asteroids are composed of materials consistent with the ordinary chondrite class [1, 2]. The JAXA Hayabusa2 [3] spacecraft launched on December 3rd, 2014 towards an asteroid (162173) Ryugu to clarify relationships between C-type asteroids and the carbonaceous chondrite class. Remote sensing observations from Hayabusa2 show that (1) the albedo of Ryugu is darker than those of every known meteorite class [4, 5], (2) an absorption band at 2.72 μm indicates that phyllosilicates are ubiquitous on Ryugu [5], (3) the strength and shape of the absorption band feature suggests that Ryugu materials experienced heating above 300 °C [6], and (4) thermal inertia suggests that Ryugu materials are more porous than every known carbonaceous chondrite [7]. These results suggest that carbonaceous chondrite class materials are plausible for Ryugu materials, but no known carbonaceous chondrite completely matches the results obtained from Ryugu.

The Hayabusa2 spacecraft made two successful landings operations onto Ryugu to collect asteroidal materials in 2019 and delivered the collected samples to the Earth on December 6th, 2020. The returned samples are detritus from pebbles to clay, exceeding 5 grams in total. Their colors, shapes and macro-structures are consistent with those of the remote sensing observations, indicating that the returned samples are representative of the asteroid Ryugu [8]. The initial analysis of the Ryugu samples began in June 2021. At that time, samples totaling ~125 mg, containing powder and particles from the 1st and 2nd touchdown sites, were allocated to the Initial Analysis Chemistry Team.

The goals of the Initial Analysis Chemistry Team analyses are to provide fundamental answers to questions relating to the provenance of Ryugu samples for in-depth research by international scientists in the future: (i) What are the elemental abundances of Ryugu? (ii) What are the isotopic compositions of Ryugu? (iii) Does Ryugu consist of primary materials formed in the protosolar disk or secondary materials altered on the parent body? (iv) When were Ryugu materials formed? and (v) What are the relations to known meteoritic samples?

Hydrogen, C and S are analyzed by combination of thermogravimetric analysis coupled with mass spectrometry (TG-MS) and by pyrolysis and combustion analyses (EMIA-Step). Major and minor elements are analyzed by X-ray fluorescence analysis (XRF) using laboratory X-rays and synchrotron radiation. Trace elements are analyzed by inductively coupled plasma mass spectrometry (ICP-MS) using calibration curve and isotope dilution methods after acid digestion. We quantify the abundance of 66 elements in Ryugu samples: H, Li, Be, C, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Tl, Pb, Bi, Th, and U. Inorganic and organic element concentrations are also analyzed for H and C.

For isotope analyses, the Ryugu samples are digested with acids, and the target elements are successively separated by ion-exchange column chromatography. We use thermal ionization mass spectrometry (TIMS) and ICP-MS with multi-collectors to measure isotope ratios. We determine isotope ratios for chronological systems of Rb-Sr, Sm-Nd, U-Th-Pb, Lu-Hf, Hf-W, Re-Os, Al-Mg, and Mn-Cr. We also determine stable isotope systematics of Ca, Ti, Cr, Fe, Ni, Sr, Ba, Zr, Mo, Ce, Gd, Ru and Nd to test isotopic dichotomy in the solar system. Oxygen isotope systematics of Ryugu are measured by laser-fluorination isotope-ratio mass-spectrometry (LF-IRMS) for bulk samples and by secondary ion mass spectrometry (SIMS) for individual components in the samples. The SIMS technique is also applied to the Mn-Cr chronological systematics to determine ages of aqueous alteration. Surveying for circumstellar and molecular cloud matter is conducted by isotope microscope and NanoSIMS.

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