ANALYSIS OF "STONE" SAMPLES FROM C-TYPE ASTEROID RYUGU.

T. Nakamura[1], M. Matsumoto[1], K. Amano[1], Y. Enokido[1], M. Zolensky[2], T. Mikouchi[3], H. Genda[4], S. Tanaka[5,6], M. Y. Zolotov[7], K. Kurosawa[8], S. Wakita[9], R. Hyodo[5], H. Nagano[10], D. Nakashima[1], Y. Takahashi[3], Y. Fujioka[1], M. Kikuiri[1], E. Kagawa[1], M. Matsuoka[11], A. J. Brearley[12], A. Tsuchiyama[13,14,15], M. Uesugi[16], J. Matsuno[13], Y. Kimura[17], M. Sato[3], R. E. Milliken[18], E. Tatsumi[19,3], S. Sugita[3,8], T. Hiroi[18], K. Kitazato[20], D. Brownlee[21], D. J. Joswiak[21], M. Takahashi[1], K. Ninomiya[22], T. Takahashi[23,3], T. Osawa[24], K. Terada[25], F. E. Brenker[26], B. J. Tkalcec[26], L. Vincze[27], R. Brunetto[28], A. Aléon-Toppani[28], Q. Chan[29], M. Roskosz[30], J.-C. Viennet[30], P. Beck[31], E. Alp[32], T. Michikami[33], Y. Nagaashi[34], T. Tsuji[35], Y. Ino[36,5], J. Martinez[2], J. Han[37], A. Dolocan[38], R. J. Bodnar[39], M. Tanaka[40], H. Yoshida[3], K. Sugiyama[41], A. J. King[42], K. Fukushi[43], H. Suga[16], S. Yamashita [6,44], T. Kawai[3], K. Inoue[43], A. Nakato[5], T. Noguchi[45], F. Vilas[46], A. R. Hendrix[47], C. Jaramillo[48], D. L. Domingue[46], G. Dominguez[49], Z. Gainsforth[50], C. Engrand[51], J. Duprat[30], S. S. Russell[42], E. Bonato[52], C. Ma[53], T. Kawamoto[54], H. Yurimoto[55], R. Okazaki[45], H. Yabuta[56], H. Naraoka[45], K. Sakamoto[5], S. Tachibana[3,5], S. Watanabe[57], Y. Tsuda[5], and Hayabusa2 initial analysis Stone team, [1]Tohoku University, Sendai 980-8578, Japan (tomoki.nakamura.a8@tohoku.ac.jp), [2]NASA Johnson Space Center, [3]The University of Tokyo, [4]ELSI, Tokyo Institute of Technology, [5]ISAS, JAXA, [6]SOKENDAI, [7]Arizona State University, [8]Chiba Institute of Technology, [9]Massachusetts Institute of Technology, [10]Nagoya University, [11]LESIA, [12]University of New Mexico, [13]Ritsumeikan University, [14]Guangzhou Institute of Geochemistry, CAS, [15]CAS Center for Excellence in Deep Earth Science, [16]JASRI/SPring-8, [17]Hokkaido University, [18]Brown University, [19]Instituto de Astrofisica de Canarias, University of La Laguna, [20]The University of Aizu, [21]University of Washington, [22]Insititute for Radiation Science, Osaka University, [23] Kavli WPI, The University of Tokyo. [24]Materials Sciences Research Center, JAEA, [25]Osaka University, [26]Goethe University, [27]Ghent University, [28]IAS, Université Paris-Saclay, [29]Royal Holloway University, [30]Muséum National d'Histoire Naturelle, [31]Université Grenoble Alpes, CNRS, IPAG, [32]Argonne National Laboratory, [33]Kindai University, [34]Kobe University, [35]Kyushu University, [36]Kwansei Gakuin University, [37]University of Houston, [38]The University of Texas at Austin, [39]Virginia Tech., [40]National Institute for Materials Science, [41]Tohoku University, [42]Natural History Museum, [43] Kanazawa University, [44]High-Energy Accelerator Research Organization, [45]Kyushu University, [46]Planetary Science Institute, [47]Planetary Science Institute, [48]The Pennsylvania State University, [49]California State University, [50]Space Sciences Laboratory, University of California, [51]IJCLab, UMR 9012 Université Paris-Saclay/CNRS, [52]DLR, [53]California Institute of Technology, [54]Shizuoka University, [55]Hokkaido University, [56]Hiroshima University, [57]Nagoya University.

Introduction: As a part of the Hayabusa2 initial analysis [1], we analyzed eighteen Ryugu "stone" samples of 1 ~ 8 mm in size: seven stones from the 1st touch down site and eleven from the 2nd touch down site. Ryugu stones were analyzed first using X-rays, UV, visible, near-infrared, mid-infrared, and muon probes for surface reflectance spectra, internal 3D structure and element distribution [2], crystal structures, and bulk composition of light elements such as C, N, and O. Measurements for magnetic, thermal, and physical properties using some stones were also performed. TOF-SIMS analysis of fluid inclusions is being continued [3]. Small particles separated from some stones were analyzed by IR-CT [4]. Based on 3D-CT images of individual stones, objects of interests were identified, separated by pFIB cutting, and exposed by polishing on the surface of epoxy disks. FE-EPMA/FE-SEM analysis was made on ~40 polished epoxy disks for chemical composition and textural observation [5-9]. FIB sections and small (~15 μm in diameter) fragments were separated from the polished surface and analyzed by TEM, STXM, XRF, and nano-CT.

Results and discussion: Eighteen stone 2D and 3D images indicate that Ryugu samples are breccias of small fragments (< ~1mm in size) of basically CI chondrite mineralogy [10]. Most of the fragments are heavily altered and consists mainly of phyllosilicates, carbonates (dolomite and breunnerite), Fe sulfides and oxides, and phosphates (F-bearing hydroxyapatite); this mineralogy we call the major lithology. The mineralogy of the fragments of the major lithology shows some diversity: the abundance and shape of carbonates and phosphates differ among fragments. On the other hand, some fragments in many stones are less altered and contain anhydrous silicates such as olivine and low-Ca pyroxene of typically Mg#>97 but down to Mg# ~50, which we call the less-altered lithology.

In the less-altered lithology, the abundance of olivine and pyroxene differs between fragments and some fragments contain them up to ~ 10 vol%. Therefore, fragments with the less-altered lithology can be classified as CI2-type chondrite material. Most, but not all, fragments with the less-altered lithology contain only calcite as carbonate, phosphides $(FeNi)_3P$ and $(Fe, Ni)_2P$ instead of apatite, and poorly-crystallized amorphous silicates. Small (< 20μm in size) type-I barred and porphyritic chondrules and CAI with spinel+hibonite+perovskite assemblages also occur. GEMS-like objects are abundant in the least-altered fragments. In summary, mineralogical and physical properties of Ryugu samples reveal incipient to advanced aqueous alteration in its parent asteroid.

References: [1] Tachibana S. et al. (2022) *Science* 375:1011–1016. [2] Tkalcec B. J. et al. (2022) this meeting. [3] Zolensky M. E. et al. (2022) this meeting. [4] Dionnet Z. et al. (2022) this meeting. [5] Harrison C. S. et al. (2022) this meeting. [6] Kikuiri M. et al. (2022) this meeting. [7] Bejach L. et al. (2022) this meeting. [8] Mikouchi T. et al. (2022) this meeting. [9] King T. J. et al. (2022) this meeting. [10] Nakamura T. et al. (2022) *LPS LIII*, Abstract #1423.