In-situ U-Pb dating of phosphates in lunar basaltic breccia Yamato 981031. K. Terada[1,2,] Yu Sasaki[1] and Y. Sano[3], [1]Department of Earth and Planetary System Sciences, Hiroshima University, Higashi-Hiroshima 739-8526, JAPAN (terada@sci.hiroshima-u.ac.jp), [2]MIRAGE Project Center, Hiroshima University, Higashi-Hiroshima 739-8526, JAPAN, [3]Center for Advanced Marine Research, Ocean Research Institute, The University of Tokyo, Nakano-ku 164-8639, JAPAN.

Introduction: The lunar meteorites have been valuable sources for understanding the evolution of the Moon's crust, because each meteorite could potentially provide a new insight into the thermal history of unexplored regions of the Moon. In spite of their scientific interests, chronological studies of Very-Low-Ti (VLT) basaltic meteorites have not be well understood, since the most VLT basalt meteorites are brecciated and consist of mixtures of materials with different origins. In this paper, we report ion microprobe U-Pb isotopic analyses of the phosphates in brecciated lunar meteorite Yamato 981031.

Yamato 981031 is a regolith breccia that consist of roughly 3:1 mix of VLT mare basalt and highland materials and is considered to be paired with Yamato 793274 [1-4]. Moreover, based on the similar launching ages in addition to many textural and mineralogical similarities, Arai and Warren [5] and Warren and Ulff-Møller [6] proposed that Yamato 793274, Yamato 981031, QUE 94281, EET 87521 and EET 96008, which are VLT mare basalt brecciated meteorites, were launched from the Moon by a single impact event. Recently, Korotev et al. [7] thoroughly investigated the chemical composition of these meteorites, and also suggested that there are not significant impediments to the hypothesis that they were launched by a single event. However, Terada et al. [8] pointed out that the previously reported chronological data do not necessarily match to this scenario. For example, Tatsumoto and Premo [9] carried out 0.5N HBr leaching and U-Pb measurements, and concluded that the Yamato 793274 clast formed at ~4.4 Ga and that a disturbance to the U-Pb system occurred at ~4.0 Ga assuming an appropriate initial lead composition. On the other hand, Eugster et al. [10] also reported a K-Ar age of 3300 Ma (without analytical uncertainties) for EET 87521, and in-situ U-Pb dating of phosphates in EET 96008 and EET 87521 are 3569 ± 100 Ma for EET 96008 [11] and 3521 ± 138 Ma for EET 87521 [8], respectively. This inconsistency of chronology ages raised the question that the validities of bulk age analyses for the Yamato 793274/981031 meteorites in the literature and/or the hypothesis of a single-crater origin. Thus, the chronological assessment of VLT meteorites still remain matter for debate.

In order to illustrate the thermal history of Yamato 981031, an in-situ U-Pb dating of phosphates was performed using the Sensitive High Resolution Ion MicroProbe (SHRIMP) installed at Hiroshima University, JAPAN. Our in-situ analysis techniques attain high sensitivity at high mass resolution of ~5800 [12], providing the following advantages in comparison with the conventional TIMS analyses: (1) a much smaller amount of sample is required, (2) the mineralogy of the phosphates and textural relationships with other minerals can be investigated, (3) U-Pb systematics in various phases are independently investigated. This in-situ U/Pb dating method has been successfully applied to extraterrestrial phosphates in some Martian meteorites [13-15], some ordinary chondrites [16-17] and some lunar meteorites [8, 11, 18]. The primary purpose of the present work was to investigate the U-Pb systematics of phosphates in Yamato 981031. The second purpose was to compare the thermal histories of other VLT mare basalt meteorites EET 87521 and EET 96008 and to place a chronological restraint on the hypothesis that all these meteorites originate from the same place on the Moon and were launched by a single impact.

Sample and Analytical Methods: For this study, the polished thin sections of Yamato 981031 (No. 53-2) was provided by the National Institute of Polar Research in Japan. First, the back-scattered electron images of the thin section were obtained with the major chemical components by an Electron Probe Micro Analyzer (EPMA), in order to identify the location and mineralogy of phosphates. Then, the chemical composition of pyroxenes next to the phosphate grains were also investigated by EPMA in order to identify whether the phosphates grains are mare origin or highland origins. Finally, for SHRIMP analysis, only parts of the phosphates grains free from such inclusions or cracks were selected

After EPMA analysis, an ~ 1 nA O_2^- primary beam with acceleration voltage of 10kV was focused to sputter an area ~ 10 μm in diameter on the phosphates and positive secondary ions were extracted. The mass resolution was set to about 5800 at ^{208}Pb for U-Pb analyses. The abundance ratios of ^{238}U to ^{206}Pb were obtained from the observed $^{238}U^+/^{206}Pb^+$ ratios using an empirical quadratic relationship between the $^{206}Pb^+/^{238}U^+$ and $^{238}U^{16}O^+/^{238}U^+$ ratios of standard apatite derived from an alkaline rock of Prairie Lake circular complex in the Canadian Shield (1156±45 Ma at 2 sigma level). Experimental details of the U-Pb analysis and the calibration of the data are given in [12].

Result and Discussion: To reduce the model dependency on common lead composition, the three-dimensional U-Pb plot in $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ - $^{204}Pb/^{206}Pb$ was used (total Pb/U isochron)). The crucial advantages of this method are that it is not necessary to know the isotopic composition of common Pb, and that both ^{238}U and ^{235}U decay schemes are used at the same time, yielding a smaller justifiable age uncertainty for the U-Pb systematics [19]. The preliminary results show that observed U-Pb data of phosphate grains from Yamato 981031 are well expressed by LINEAR regressions in the $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ - $^{204}Pb/^{206}Pb$ space, indicating that a formation age of phosphates is roughly ~3.5Ga. This is apparently younger than those of Yamato 793274 (4.0 Ga and/or 4.4 Ga reported by [9]), which is considered to be paired. It should be noted that our obtained U-Pb age of about 3.5 Ga for Yamato 981031 is identical to those of EET 87521 [8] and EET 96008 [11], indicating that there is no chronological impediment to the hypothesis that all these meteorites originate from the same place on the Moon and were launched by a single impact. The "apparently" older ages of Yamato 793274 obtained by the chemical leaching of bulk samples probably might be attributable to the contamination of highland components, because the highland components often shows older age than those of typical mare basalts.

Recent global and high-resolution mappings of chemical composition and mineralogical composition on the Moon observed by Clementine and Lunar Prospector enable us to discuss on the ejection sites of some lunar meteorites; NWA 032 [20], Sayh al Uhaymir 169 [21] and Yamato 981031 [22]. Assuming the scenario for Yamato 981031 proposed by [22], our data suggest that the formation age of northern parts of mares of near-side of Moon (possibly, Mare Frigoris or Lacus Somniorum or Lacus Mortis) might be about 3.5 Ga. In the future work, our in-situ dating techniques of lunar brecciated meteorites coupled with the higher-resolution remote-sensing data would provide a radiometric (not based on the crater density) chronological assessment of unexplored regions on the Moon.

References: [1] Arai T. et al. (2002) *Antarctic Meteorites XXVII,* 4-6. [2] Arai et al. (2002) *LPS XXXIII,* Abstract #2064. [3] Arai et al. (2002) *Meteoritics & Planet. Sci., 37,* A12. [4] Korotev et al. (2003) *LPS XXXIV,* Abstract #1357. [5] Arai T. and Warren P. H. (1999) *Meteoritics & Planet. Sci.,* 34, 209-234. [6] Warren P. H. and Ulff-Møller F. (1999). *LPS XXX,* Abstract #1450. [7] Korotev R. L. et al. (2003) *Antarctic Meteorite Research* 16, 152-175. [8] Terada et al. (2005) *GRL* 32, L20202. [9] Tatsumoto M. and Premo W. R. (1991) *Antarctic Meteorites Research* 4, 56-69. [10] Eugster O. et al. (1996) *Meteoritics & Planet. Sci.,* 31, 299-304. [11] Anand M. et al. (2003) *GCA* 67, 3499-3518. [12] Sano Y. et al. (1999) *Chemical Geology* 153, 249-258. [13] Sano Y. et al. (2000) *Meteoritics & Planet. Sci.,* 35, 341-346. [14] Terada K. et al. (2003) *Meteoritics & Planet. Sci.,* 38, 1697-1703. [15] Terada K. and Sano Y. (2004) *Meteoritics & Planet. Sci.,* 39, 2033-2041. [16] Terada K. and Sano Y. (2002) *GRL* 29, pp.98-1~4. [17] Terada K. and Sano Y. (2003) *Applied Surface Science* 203/204: 810-813. [18] Anand M. et al. (2005) *GCA* 70, 246-264. [19] Ludwig K. R. (2001) Berkeley Geochronology Center Special Publication No.1a. [20] Fagan T. J. et al. (2002) *Meteoritics & Planet. Sci.,* 37, 371-394. [21] Gnos E. et al. (2004) *Science* 305, 657-659. [22] Sugihara T. et al. (2004) *Antartic Meteorite Research* 17, 209-230.