TRACE ELEMENT GEOCHEMISTRY AND CHRONOLOGY OF THE BUNBURRA ROCKHOLE BASALTIC ACHONDRITE. L. J. Spivak-Birndorf[1], A. Bouvier[1], M. Wadhwa[1], P. A. Bland[2] and P. Spurný[3]. [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 (Lev.Spivak-Birndorf@asu.edu), [2]Impacts and Astromaterials Research Centre (IARC), Department of Earth Science and Engineering, Imperial College London, SW7 2AZ, UK, [3]Astronomical Institute of the Academy of Sciences, Fričova 298, CZ-251 65 Ondřejov Observatory, Czech Republic.

Introduction: Bunburra Rockhole (BR) is a recent meteorite fall that was observed by the Desert Fireball Network and collected later from the Nullarbor Desert, Australia [1]. It was originally classified as a basaltic eucrite based on mineralogical and petrographic considerations, but BR is now considered to be a unique achondrite on the basis of its oxygen isotope composition [1]. BR is brecciated and contains three distinct lithologies on the basis of grain size: coarse-grained (C), medium-grained (M) and fine-grained (F) [1]. Furthermore, these three lithologies have slightly different (although overlapping within errors) $\Delta^{17}O$ values [1].

We report an investigation of the trace element (including rare earth element) geochemistry and chronology (^{26}Al-^{26}Mg and ^{207}Pb-^{206}Pb systematics) of BR. The goals of the study are to better understand the petrogenesis of BR and the relationship between its three lithologies, as well as to determine the age of this meteorite.

Samples and Analytical Techniques: *Trace elements*. A polished thin section of BR containing all three lithologies was characterized using a JEOL 845 scanning electron microscope at Arizona State University (ASU). Trace element abundances were obtained using the Cameca ims-6f ion microprobe at ASU using methods similar to those described by [2]. While the C lithology has a uniformly coarse-grained texture, both the M and F lithologies contain large pyroxene phenocrysts embedded in medium- and fine-grained groundmass (composed of pyroxene and plagioclase), respectively. In the M lithology, both large pyroxene phenocrysts and smaller interstital pyroxenes were analyzed. In the F lithology, only the large phenocrysts could be analyzed due to the spatial resolution of the ion microprobe.

Al-Mg and Pb-Pb systematics. A fragment of the F lithology was split for Al-Mg and Pb-Pb studies. The Al-Mg systematics of an additional sample from the C lithology were also investigated. The samples were prepared and analyzed following methods similar to those described by [3] for Al-Mg and by [4, 5] for Pb-Pb isotopic analyses in the Isotope Cosmochemistry and Geochronology Laboratory (ICGL) at ASU. For the Al-Mg systematics, whole rock fractions and mineral separates (pyroxene and plagioclase) were analyzed from both the F and C lithologies. For the Pb-Pb systematics, two whole rock fractions and two mineral separates (pyroxene- and plagioclase-rich) were prepared from the F lithology. Each of these were subjected to an 8-step acid-washing protocol that involved increasingly more aggresive leaching to remove common Pb. The Pb isotopic composition of the final (8^{th}) leachates and residues from the whole rock fractions and mineral separates were then analyzed. The Mg and Pb isotopic compositions and Al/Mg ratios were measured using the Neptune MC-ICPMS in the ICGL.

Results and Discussion: *Trace Element Microdistributions.* The ranges of REE abundances in BR pyroxenes from the three lithologies are shown in Fig. 1. The REE abundances are fairly uniform within individual grains but vary between different grains, as is observed in some non-cumulate eucrites [6]. The ranges of REE concentrations in pyroxenes from the M and C lithologies are similar. The abundances in pyroxene phenocrysts in the F lithology are slightly lower and have a more restricted range. All BR pyroxenes have negative Eu anomalies (Eu/Eu* ~0.1-0.2 in M and C lithology pyroxenes; ~0.4-0.5 in F lithology pyroxenes). As can be seen in Fig. 1, the REE abundances in BR pyroxenes are within the range of those in non-cumulate eucrites [6].

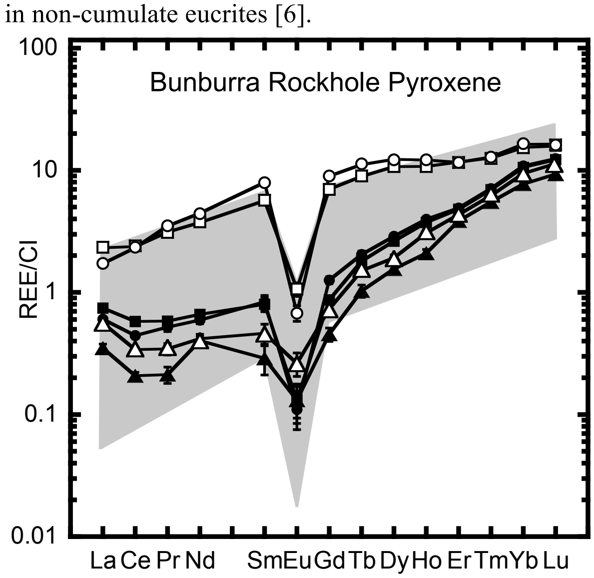

Fig. 1. Range of REE abundances in BR pyroxenes. Triangles = F lithology, squares = M lithology, circles = C lithology; black and white symbols represent analyses with the lowest and highest REE concentrations, respectively.The shaded grey area is the range of REE concentrations in pyroxenes from non-cumulate eucrites [6].

Plagioclases in BR are LREE-enriched and have large positive Eu anomalies (Fig. 2). The REE concentrations in plagioclase from the different lithologies of BR are similar. The REE abundances in BR plagioclase are also within the range of those in the non-cumulate eucrites [6].

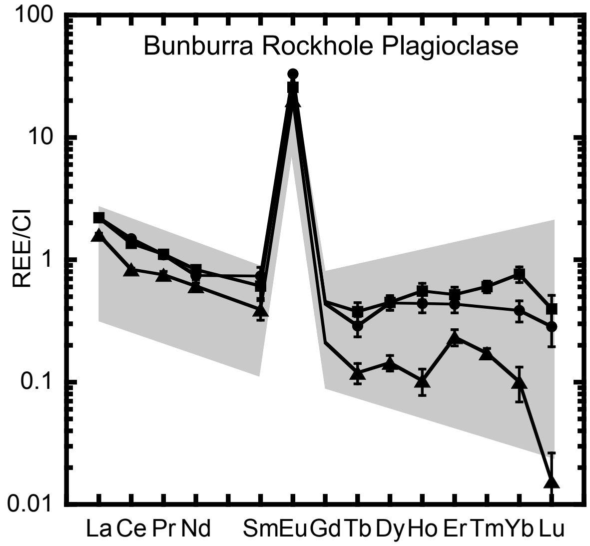

Fig. 2. Representative REE abundances in BR plagioclase. Triangles = F lithology, squares = M lithology, circles = C lithology. The shaded grey area shows theof REE concentrations in plagioclase of non-cumulate eucrites [6].

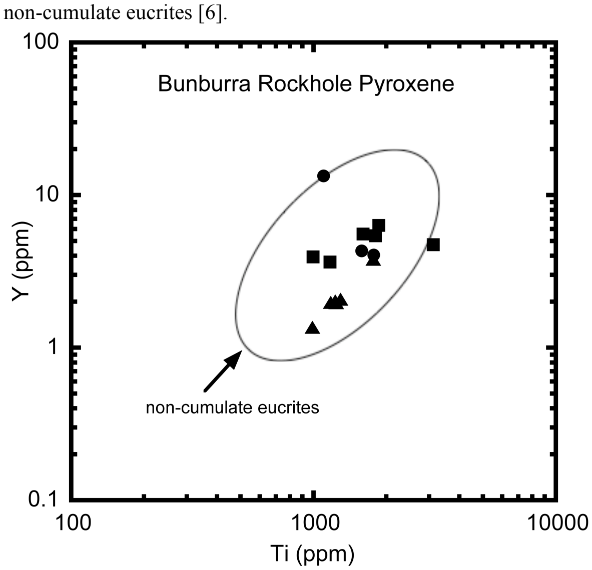

Fig. 3. Ti vs. Y in BR pyroxenes. Triangles = F lithology, squares = M lithology, circles = C lithology. The ellipse corresponds to the compositional range of pyroxenes in non-cumulate eucrites[6].

In addition to the REE, other selected trace elements were also measured in BR pyroxenes. The concentrations of Ti and Y in BR pyroxenes are plotted in Fig. 3, and define a trend that falls within the compositional range of pyroxenes from several non-cumulate eucrites [6].

Al-Mg and Pb-Pb Chronology. The ^{26}Al-^{26}Mg chronometer ($t_{1/2}$ ~0.73 Ma) can provide high-resolution, relative ages for early Solar System events, while the ^{207}Pb-^{206}Pb chronometer can yield absolute ages for such events with sub-Ma precision. The Al-Mg systematics were investigated in a whole rock fraction and mineral separates (plagioclase and pyroxene) from both the F and C lithologies of BR. The ^{27}Al/^{24}Mg ratios in these samples range from ~0.3 to ~27. All the BR samples have small (~25-45 ppm) excesses in radiogenic ^{26}Mg (δ^{26}Mg*) that are resolvable outside of ±2SE (but not outside of ±2SD). The slopes of the Al-Mg internal isochrons for the F and C lithologies are not resolved from zero and correspond to upper limits on the initial ^{26}Al/^{27}Al ratios of 1.14×10^{-6} and 1.31×10^{-7}, respectively. These data indicate that the Al-Mg systematics of BR were thoroughly equilibrated following the complete decay of ^{26}Al.

The Pb-Pb systematics of two whole rock samples and two mineral separates (pyroxene- and plagioclase-rich) from the F lithology of BR are also reported here. The mineral fractions show evidence of U-Pb redistribution and do not provide meaningful ages. However, a Pb-Pb isochron based on the on the last (8th) leachates and corresponding residues of the two whole rocks provides an absolute age of 4.10± 0.02 Ga. Since BR is brecciated and also shows evidence for sub-solidus equilibration [1], it likely that this age corresponds to a secondary heating event. Similar reset ages are also reported for some basaltic eucrites [7].

Conclusions: With the notable exception of O-isotopes, many characteristics of BR (e.g., major element mineral chemistry and modal abundances) are similar to those of the basaltic eucrites [1]. This is also true of the REE abundances in minerals from this meteorite. It is therefore likely that BR experienced a petrogenetic and thermal history similar to some eucrites. The close agreement of the REE abundances in pyroxenes in the M and C lithologies of BR suggests that these lithologies originated from the same parent melt. The pyroxene phenocrysts in the F lithology are slightly depleted in REE and other trace elements relative to pyroxenes in the other lithologies. This could result from formation from a less evolved melt or may reflect a different degree of equilibration of pyroxenes in the F lithology. The Al-Mg systematics of BR suggest that Mg isotope equilibration occurred following the complete decay of ^{26}Al. This is consistent with the young Pb-Pb age (~4.1 Ga) determined here for BR.

References: [1] Bland P. A. et al. (2009) *Science, 325,* 1525–1527. [2] Zinner E. and Crozaz G. (1986) *Int. J. Mass Spec. Ion Proc., 69,* 17-38. [3] Spivak-Birndorf L. et al. (2009) *Geochim. Cosmochim. Acta,* 73, 5202–5211. [4] Bouvier A. and Wadhwa M. (2009) *LPS XL,* Abstract #2184. [5] Bouvier A. and Wadhwa M. (submitted) *LPS XLI.* [6] Hsu W. and Crozaz G. (1996) *Geochim. Cosmochim. Acta,* 60, 4571–4591. [7] Tera F. et al. (1997) *Geochim. Cosmochim. Acta,* 61, 1713–1731.