DETERMINATION OF LUNAR LAVA FLOW AGES IN NORTHEASTERN OCEANUS PROCELLARUM: THE NEED FOR CALIBRATING CRATER COUNTING PROCEDURES ACROSS THE FIELD. T.A. Giguere[1], J.M. Boyce[1], J.J. Gillis-Davis[2], and J.D. Stopar[3]. [1]Hawaii Institute of Geophysics and Planetology, Univ. of Hawaii, Honolulu, HI 96822, [2]Washington University, Department of Physics, One Brookings Drive, St. Louis, MO 63130. [3]Lunar and Planetary Institute, USRA, Houston, TX 77058. (giguere@hawaii.edu).

Introduction: Our study yields a deeper understanding of the age, composition, and origin of lava flows in Northeastern Oceanus Procellarum (NE-OP). NE-OP is located in the high-thorium (Th) Procellarum KREEP Terrane (PKT) [1], and is the sample location of the China National Space Administration's (CNSA) Chang'E 5 (CE-5) mission. Crater model ages for mare surfaces in this area (e.g. [2-8]) suggest both a complex emplacement history as well as details of the technique needing further refinement (Table 1). The NE-OP flows exhibit intermediate TiO_2 compositions (4.0 – 6.8 wt. %), which is an underrepresented basalt type in the current sample collection [9,10]. Hence, remote sensing observations of this area are critical to place CE-5 samples into a broader geologic context, to further our understanding of source region compositional heterogeneity, to decipher the timing of mare basalt emplacement, and to reveal insight into the thermal and eruptive history of the NE-OP volcanic province. These results will have the most bearing once crater counting procedures are cross-calibrated between research groups [11].

Table 1. NE-OP and CE-5 Landing Site Model ages[a]

Study	Age[b]	Location[c]
Boyce[2]	3.2	East
Hiesinger et al.[3,12]	1.33	East
Morota et al., Model B[4]	2.20, 3.46	CE-5
Qian et al. [5]	1.21	CE-5
Wu et al. [6]	1.49	West
Jia et al. [7]	2.07	CE-5
Qian et al. [8]	1.53	CE-5
Giguere et al.[This Study]	3.0	CE-5

[a]Model ages from this study and previous studies.
[b]Ages (Ga) are for author defined count areas in NE-OP and unit P58.
[c]Count location includes the CE-5 landing site (CE-5) or the location within unit P58 if the CE-5 landing site not within the count area.

Results and Discussion: To determine model ages, we performed crater counts and produced Cumulative size-frequency distribution curves (CSFDs) in twenty-one areas in the NE-OP region. Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) images were used for this task [13,14]. Crater size count data provide a means of determining relative age, and a means of estimating absolute (model) age (here after simply called "age") [15]. CSFD curves were constructed from the crater count data, with ages calculated from these data using the Craterstats2 program [15], and the lunar production function of Neukum et al. [16] to estimate the age for these curves. Secondary and volcanic craters were excluded from the counts. In addition, count areas are located between major secondary crater rays (Fig. 1) to improve the accuracy of model ages and geochemical values.

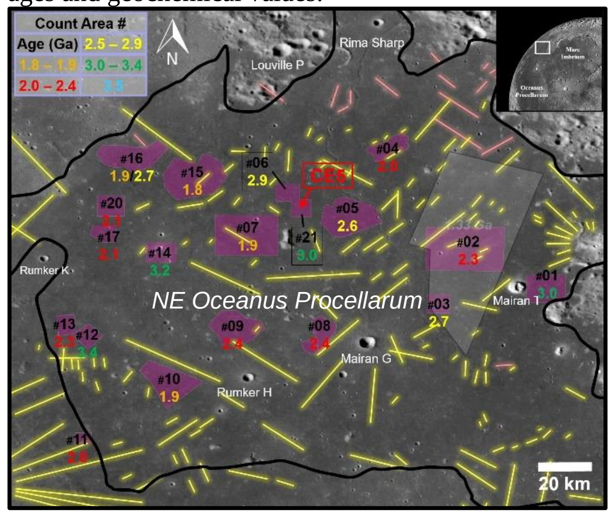

Figure 1. *NE-OP overview (inset) and detail view. Numbered count locations (purple) display average CSFD ages (Ga). Mare crater count area (white shape) and mare age unit P58 (black outline) used in previous studies [3,12]. Major secondary crater rays (yellow) are identified via morphology and lower geochemical values. Count areas located to avoid major rays. Some secondary crater rays were identified by morphology only (pink). Count area #18 is located north of Mons Rumker (west of image). WAC Global Morphologic base map.*

The count areas were distributed throughout the study area to identify variations of mare age and range from 27.4 km^2 to 570.6 km^2 (Fig. 1). Our counts indicate that of the twenty-one count areas, six areas dated are

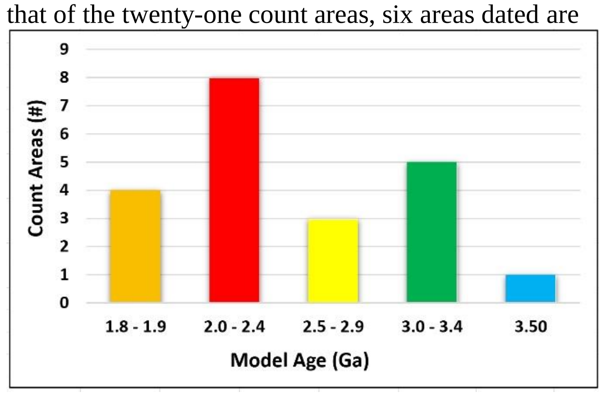

Figure 2. *NE-OP lava flow eruption frequency. Two eruption peaks are observed at ~2.0 - 2.4 Ga and 3.0+ Ga.*

3 Ga or older (including the CE-5 landing site, area #21, ~ 3.0 +0.2/-0.3 Ga), eleven areas are between 2 and 3 Ga, and four areas are younger than 2 Ga. Our results reveal two modes in the relative number of mare surfaces at 3.0-3.4 Ga and 2.0–2.4 Ga compared to few mare surfaces for the ages >3.5Ga, 2.5-2.9 Ga, and <2.0 Ga (Fig. 2). We infer the variations in mare surface area correspond with peaks in eruption frequency/effusion.

Both eruption peaks in NE-OP (Fig. 2) show that the majority of volcanism in the region is younger than the apparent peak of lunar eruption activity, which occurred between 3.4 and 3.7 Ga (see Figure 18 in [12]). The patchwork of flow ages and extended duration (1.7 Ga spanning 60% of lunar volcanic history), may be due to the location of NE-OP within the PKT, which has a thin crust [17] and concentration of radiogenic elements [1] that promote partial melting in mantle sources.

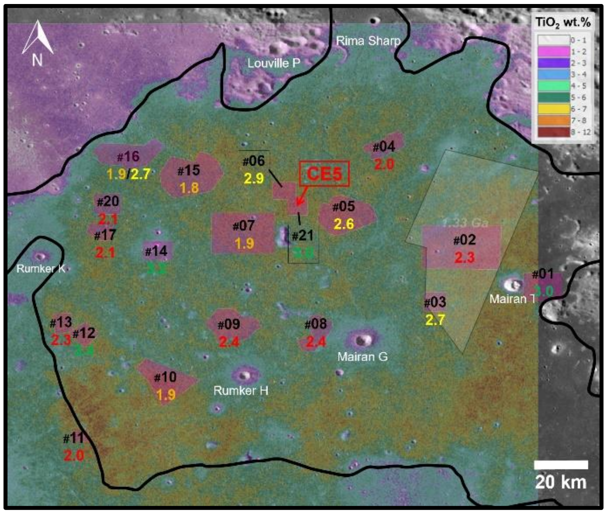

Figure 3. *SELENE (Kaguya) TiO_2 wt. % and numbered count locations on a LROC WAC basemap.*

Image data from the SELENE (Kaguya) monochromatic Terrain Camera (TC) [18, 19] and the Multiband Imager (MI) [20] visible and near-infrared multispectral camera were used for detailed surface and geochemical analysis. The maximum FeO for our count areas ranges from 16.7 to 18.4 wt. %; TiO_2 varies from 4.6 to 7.7 wt. % (Fig. 3). Maximum FeO and TiO_2 values were determined for each count location by averaging 30m/pixel over a 1 km^2 area. Likewise, averages of FeO and TiO_2 values for each count area show a narrow range in FeO (16.1 to 17.6 wt. % with a median value of 17.2 wt. %) and TiO_2 (4.0 to 6.8 wt. % with a median value of 6.1 wt. %) (Fig. 3). A basalt sample from this region can help to resolve the question whether the basalts from NE-OP are of intermediate TiO_2 composition or a mixture of high- and low-Ti rocks. Generally, high-FeO areas in each count area are co-located with high-TiO_2 areas. Furthermore, NE-OP mare display relatively uniform FeO and TiO_2 values, which may be due to either a single mantle magma source that did not change with time, or if there were multiple magma sources they were similar in composition [21].

Chang'E 5 Sample Ages. The CE-5 "sample" will be small rock fragments and regolith (limited to the size of the surface sampler and the drill core diameter, [22]), ages, and composition. Based on our new data, we suggest that the CE-5 samples will likely have a dominant sample age of ~3.0 +0.2/-0.3 Ga (our area #21) (Fig. 1-3). However, similar to Apollo and Luna regolith samples [9], CE-5 will likely provide samples with a distribution of ages and compositions. The CE-5 core may reveal multiple horizontal regolith layers. In addition, minor amounts of material with ages in the 1.8 – 2.6 Ga range may be present in the returned sample. These ages reflect younger eruption debris thrown to the site from nearby and distant impact events. Both younger and older sample ages, outside the main distribution have the potential to provide additional calibration information for the CSFD curves.

Contrasting Absolute Model Ages. Ages for areas that include the landing site by other researchers range from 1.21 - 3.46 Ga, a span of nearly 2.3 Ga (Table 1). Our CE-5 landing site age is ~ 3.0 +0.2/-0.3 Ga. We find this difference disconcerting because of its large age range despite the fact that the count areas were comparable and the methods used were similar. Most model age studies use the same Chronology Function (CF, [16]) and Production Function (PF, [16]), processing software (Craterstats2, [15]), and work processes (eliminating secondaries, measuring fresh, degraded crater diameters, etc.). Although, the overall process of using crater count data to determine relative age, and in turn, absolute (model) age is well established, there may be steps in the process that are less rigorously defined.

Summary and Recommendation: In our study, the ages for all count areas in NE-OP range from 1.8 – 3.5 Ga with individual eruptions peaking at ~ 3.2 Ga, and again around 2.2 Ga. We find that mare at the CE-5 site is ~ 3.0 +0.2/-0.3 Ga; emplaced during the older peak. Our CE-5 age is in disagreement with ages determined by other researchers, which commonly disagree with each other, most of which are substantially younger (i.e., 1.21, 1.49, 1.53, 2.2, 3.46 Ga). We recommend that researchers in this field review their crater counting procedure with one another to resolve why such large differences occur. This can be at special workshops, conferences or other venues.

References: [1] Jolliff et al. (2000) JGR, 105. [2] Boyce (1976) LPS 7. [3] Hiesinger et al. (2003), JGR, 108(E7). [4] Morota et al. (2011) EPSL, 302(3-4). [5] Qian et al. (2018) JGR, 123(6). [6] Wu et al. (2018) JGR, 123(12). [7] Jia et al. (2020) EPSL, 541. [8] Qian et al. (2020) EPSL, 555. [9] Taylor et al. (1991) Lunar Sourcebook, 183–284. [10] Giguere et al. (2000) MAPS, 35(1). [11] Crater Studies/Dating of Plan. Surf. (2015) LPI. [12] Hiesinger et al. (2011) GSA Spec. Prs, 477. [13] Robinson et al. (2010) Spac Sci. Rev. 150, 81. [14] Speyerer et al. (2011) LPSC 42, #2387. [15] Michael and Neukum (2010) EPSL, 294 (3-4). [16] Neukum G. et al. (2001) Space Sci. Rev., 96. [17] Wieczorek et al. (2013) Science, 339(6120). [18] Haruyama et al. (2008) Adv. Space Res, 42(2). [19] Haruyama et al. (2012) LPSC 43, #1200. [20] Ohtake et al. (2008) Earth Plan. Space, 60. [21] Shearer et al. (2006) Rvw in Min. & Geochem. 60(1), 365-518. [22] Qian et al. (2020) Icarus, 337. Submitted 12/24/2020.