CHARACTERIZING HIDDEN IMPACT BASINS DISCOVERED BY GRAIL GRAVITY DATA. J. W. Conrad[1], F. Nimmo[1], G. A. Neumann[2], S. Kamata[3], and C. I. Fassett[4],. [1]Dept. Earth and Planetary Sciences, University of California Santa Cruz, 1156 High St, Santa Cruz, CA 95064, USA (jwconrad@ucsc.edu). [2]NASA Goddard Space Flight Center. [3]Creative Research Institution, Hokkaido University. [4]Dept. Astronomy, Mount Holyoke College.

Summary: New ancient lunar impact basins have been uncovered thanks to the GRAIL mission's gravity measurements [1]. We have dated these basins using crater counting methods [2] and characterized their properties to improve our understanding of the early thermal evolution of the Moon [3].

Introduction: Lunar impact basins have received great research interest in the past few years thanks to the GRAIL mission [4]. Many large basins on the Moon are not significantly relaxed. Some of these basins, however, can be identified based on their Bouguer gravity signature [1], but do not correspond strongly with any topographic features. Such basins have potentially undergone relaxation, which requires a relatively hot ancient lunar crust [3].

GRAIL and Gravity Anomalies: Thanks to high resolution gravity and topography provided by the GRAIL and LOLA instruments, the effect on gravity of surface topography can be removed, yielding a Bouguer gravity map [5]. Places with a higher Bouguer gravity imply a thinner (or denser) crust and vice versa.

Maps of the Bouguer anomaly have been used to identify previously unrecognized basins [1]. These candidate basins are obscured by mare deposits, later craters, post-impact relaxation, or a combination thereof. TOPO-22 (Fig. 1) is one of these candidate basins. Its name is based on its initial identification as a topographic depression [6] that, in retrospect, points towards the existence of an impact basin. Yet the real smoking gun is the large Bouguer gravity anomaly. Based on [1], our list of initial candidate impact basins is in Table 1.

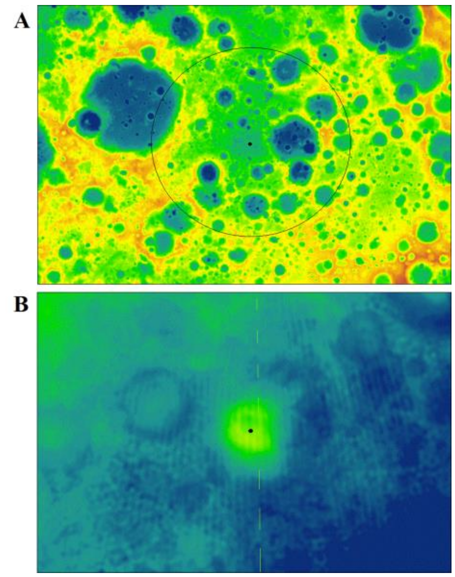

Figure 1: Topographic (A) and Bouguer Gravity (B) Maps of TOPO-22. Rough size of TOPO-22 is indicated by the circle and the center dot represents the center of the basin, which is located at 179^{0}E, 49.4^{0}N [1]. Note that the signature of the basin is quite clear in the Bouguer anomaly, but the topography is very subdued.

Table 1:

Name	Center	Diameter (km)	Impact Origin
Szilard-North	106ºE 34ºN	200	Probably
Copernicus-H	18W 7.2N	210	Probably
Sinus Medii	0.6E 1.1N	328	Unlikely
Fowler-Char.	142W 39N	375	Probably
Mare-Vaporum	3.1E 14.2N	410	Unlikely
Serenitatis-Nor.	17E 35.8N	420	Probably
Crisium-East	66E 16.7N	428	Probably
TOPO-22	179E 49N	500	Definitely
Fitz.-Jackson	169W 25N	564	Definitely
Fecundiatis	52E 4.6S	690	Unlikely
Asperitatis	26.8E 7.7S	720	Definitely

Our set of candidate impact basins, modified from [1]. Three degrees of certainty (Unlikely, Probably, Definitely) show our confidence in whether or not they are of impact origin.

Crater Counting Method: Many of these candidate basins have had other, younger material superposing the material excavated during that basin's formation. To that end, the buffered crater count method as outlined in Fassett 2008 [2] was used to date the impact basins. This approach also considers craters whose centers lie outside the counting area but some section of the crater is within the chosen area. This allows craters partially covered by mare basalts to be reliably counted, but limits the count areas to features that are thought to have formed at a similar time. Typically, this is where basin ejecta surrounding the basin was deposited.

For the actual counting, we began with the catalog of lunar craters larger than 20km in diameter derived from LOLA data [7,8]. In addition, the CraterTools extension to ArcMap [9] was used to measure the number of craters within the chosen area. The count of TOPO-22, for example, is shown in fig. 2.

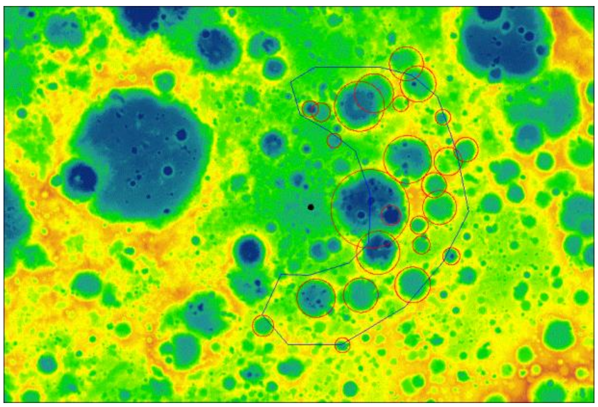

Figure 2: Identification of craters for the proposed TOPO-22 basin. Note the buffered crater counting technique allows a single geologically consistent unit to be counted, in this case a ridge to the east of the basin center, which is taken to be associated with the original basin-forming event.

From our list of candidate impact basins in Table 1 a list of basins that met the standards for reliable crater counts is shown in Table 2. Their inferred ages are based on the chronological scheme of Wilhelms 1987 [10] using the Pre-Nectarian, Nectarian, Imbrium age classification system. In general, successful counts occurred for basins that either had very little mare near them and/or a lack of larger, newer nearby basins.

Table 2:

Name	Age[a]	Crustal Thickness Ratio
Szilard-North	PN2	0.498 ± 0.013
Fowler-Char.	PN3	0.806 ± 0.075
TOPO-22	PN3	0.645 ± 0.034
Fitz.-Jackson	PN2	0.787 ± 0.078
Asperitatis[b]	PN (#?)	0.621 ± 0.025

[a] Based on the Pre-Nectarian, Nectarian, Imbrium age classification [10] . With PN#1-8 going from older to younger.

[b] Age based on superposition with Nectaris.

Discussion: The relatively ancient ages derived for these basins is not really a surprise. Now that we have their relative ages, however, their degree of relaxation can be used to place constraints on the early thermal evolution of the Moon. A reasonable proxy for the degree of relaxation can be obtained by finding the ratio of the crustal thickness at about 2-3 radii to the thickness at the center, where the crustal thickness values of [5] are used. Fig 3 compares the four new basins we have identified with results from an earlier compilation [3]. The newly-identified basins match the previously identified trend of decreasing crustal thickness ratio with decreasing age, suggesting that basin relaxation was an important process early in lunar history.

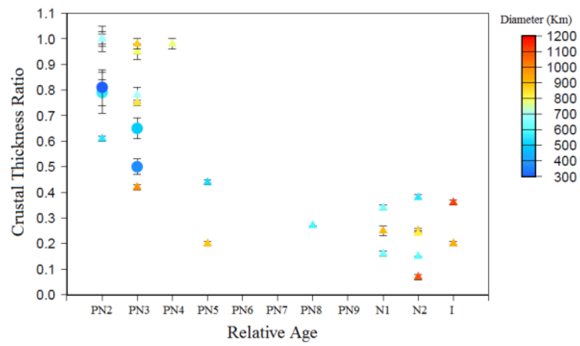

Figure 3: Crustal thickness ratio as a function of relative age formation for lunar impact basins. A GRAIL crustal thickness model (34 km on average)[5] and relative age data from Wilhelms (1987) [10] are adopted. The first four basins from Table 2 are represented by circles on the graph and triangles are for previously-analyzed basins [3].

Additional work is needed to verify which basins in the candidate list are in fact impacts and to obtain a better age for many of the basins where conventional or buffered crater counts fails to work. However, the method of buffered crater counts and crustal thickness ratios does appear to work rather well for the four basins with well-defined ages.

References: [1] Neumann G.A. et al. (2015) *Science Advances*, *1*, e1500852. [2] Fassett C.I. et al. (2012) *JGR*, *117*, E00H06. [3] Kamata S. et al. (2015) *Icarus, 250*, 492-504. [4] Zuber M.T. et al. (2013) *Science*, *339*, 668-671. [5] Wizoerick M.A. (2013) *Science*, *339*, 671-675. [6] Frey H. (2011) *Spec. Pap. Geol. Soc. Am.*, *477*, 53-75. [7] Head J.W. et al. (2010) *Science*, *329*, 1504-1507. [8] Kadish S.J. et al. (2011) *LPS XLII*, Abstract #1402. [9] Kneissl T. et al. (2011) *Planet. Space Sci.*, *59*, 1243-1254. [10] Wilhelms D.E. (1987) *USGS Prof. Pap. 1348.*