ORIGIN, DISTRIBUTION, AND CHRONOSTRATIGRAPHY OF ASYMMETRIC SECONDARY CRATERS ASSOCIATED WITH NEARSIDE LUNAR BASINS.

W. A. Ambrose[1], [1]Bureau of Economic Geology, The University of Texas at Austin, University Station, Box X, Austin, TX 78713-8924, william.ambrose@beg.utexas.edu.

Introduction: Many asymmetric, non-main-sequence lunar craters are inferred to be secondary-impact features caused by major, basin-scale impacts. Ranging in diameter from 10 to 35 km, they have polygonal outlines, are narrow rimmed, shallow (commonly <1.5 km deep), and occur tens to hundreds of kilometers beyond the outer rim of major impact basins. Some are teardrop shaped, reflecting low-angle impacts; similar morphologies for low-angle impacts have been demonstrated experimentally and are documented for a variety of asymmetric lunar craters [1, 2]. The trajectory and source area of ejecta blocks that formed asymmetric secondary craters can be inferred from the orientation of teardrop-shaped rims, which typically point away from associated impact basins. In conjunction with genetically related crater chains and scours, they are significant chronostratigraphic features that can be used to constrain estimated ages of overlapped extrabasinal landforms and other craters.

Recognition Criteria: Several criteria exist for differentiating asymmetric secondary craters from morphologically similar, primary craters. They include asymmetric outline; shallow floors; lack of slumps that produce asymmetry in small, complex, main-sequence craters; moderate to high levels of degradation; location beyond outer rings of impact basins; and association with scours and crater chains.

Asymmetric outline and shallow floors. Ballistic ejecta from lunar basins are inferred to have been expelled in a wide range of angles, with many at an angle of 45° ±10° from the horizontal [3]. Oblique primary impacts also change the distribution of ejecta angles and increase the potential for low-angle impacts from secondaries [4, 5]. Large secondaries interpreted to have formed from low-angle impacts are asymmetric and have shallow floors (commonly <1.5 km) and beak-shaped rims pointing away from genetically associated basins. Asymmetric secondaries are distinguished from morphologically similar, main-sequence craters such as Lassell and Jansen which have shallow floors owing to lava floor-flooding.

Rim structure. Minor asymmetry in small, complex, main-sequence craters such as Triesnecker and Euler is interpreted to have resulted from postimpact, gravitational collapse rather than from impact trajectory [6, 7]. Asymmetric secondaries are differentiated from these small, complex craters by their narrow rims and by a lack of significant slumps.

Degradation. Secondary craters are inferred to exhibit similar levels of degradation with genetically associated impact basins. Nectarian and Pre-Nectarian secondaries should therefore have smooth, degraded rims and high cratering densities. However, some asymmetric craters in the 10- to 35-km-diameter range, such as Proclus, Messier, and Messier A, have sharp rims, low cratering densities, bright ejecta, and are therefore interpreted to postdate large basins.

Basins: The preservation potential for asymmetric secondary craters, scour features, and crater chains is inferred to be high for the relatively younger Imbrium and Orientale Basins and moderate for the Nectaris, Humorum, Serenitatis, and Crisium Basins, which are Nectarian in age [8]. Isolated examples may exist along the margins of the Pre-Nectarian Nubium, Fecunditatis, and Tranquilitatis Basins.

Nectaris Basin. Examples of asymmetric craters of secondary origin, scour features, and crater chains are present on several margins of the Nectaris Basin. Valles Rheita, southeast of Mare Nectaris, is a well-known example of a large, complex scour feature composed of overlapping, asymmetric craters [9]. Other asymmetric secondary craters are inferred westward and southwestward of the Nectaris Basin. Examples include Abulfeda D and Andel E, 750 and 660 km, respectively, from the center of the Nectaris Basin (Fig. 1). Abulfeda D has a minor-axis diameter of 17 km and a major-axis diameter of 21 km, whereas Andel E varies in diameter from 8.5 to 12.5 km. Both craters are shallow (<1.0 km) and have teardrop-shaped rims oriented westward, radially away from the Nectaris Basin. They are both degraded, having smooth rims and cratering density values of 0.011 and 0.006 impacts/km^2, respectively, by craters with diameters ≥0.5 km. Alphonsus B, a teardrop-shaped crater west of Abulfeda D, overlaps ejecta on the east margin of Alphonsus, suggesting that Alphonsus may be Pre-Nectarian, older than previously interpreted [8, 10]. Scour features and secondaries are inferred on the northeast margin of the Nectaris Basin and include Isidorus B and C, which overlap Nectaris ejecta, and Goclenius UC in Mare Fecunditatis. Isidorus B and C are elongate, northeast-trending, degraded scours, whereas Goclenius UC is a degraded, elongate crater <1.0 km deep.

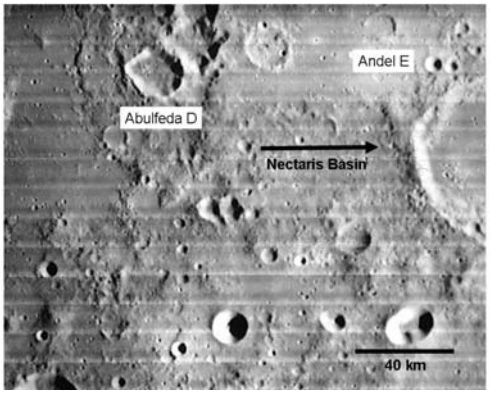

Figure 1. Abulfeda D and Andel E. Modified from Lunar Orbiter 4 Photograph 4LO 096 H2.

Imbrium Basin. Polygonal, shallow-floored craters such as Gambart, Encke, Reinhold B, and Kunowsky, located 300 to 350 km south of Mare Imbrium, may be secondaries associated with the Imbrium impact event [9]. These craters, ranging in diameter from 18 to 28 km, are superimposed on Imbrium ejecta, do not appear to be lava flooded, and have shallow floors ranging from 0.5 to 1.1 km. However, these Gambart-type craters differ from Abulfeda D, Andel E, and Alphonsus B by having no preferred axis of asymmetry, possibly the result of high-angle impacts. Imbrium-related asymmetric secondaries in the North-Central Highlands are poorly developed, where elongate scour features are predominant. However, the south margin of Vogel is overlapped by an elongate, southeastward-tapering shallow crater aligned parallel to multiple Imbrium scour features. Vogel is therefore inferred to predate the Imbrium impact event and is interpreted to be Nectarian or older. La Condomine, a flat-floored, narrow-rimmed crater in Montes Jura, may be an Imbrium secondary. However, its north rim appears to have been obliterated by ejecta from Sinus Iridum, making determination of asymmetry difficult. The area northeast of the Imbrium Basin is marked by 75-km-long Archytas K, an elongate compound feature east of Timaeus composed of scours and asymmetric craters, and Calippus, a flat-floored, irregular crater in Montes Caucasus. Although Calippus has two axes of asymmetry, the northwestern rim is slumped, indicating postimpact gravitational collapse, whereas the northeast-tapering rim has no slumps, from which a low-angle impact is inferred radially from Mare Imbrium.

Orientale Basin. The Orientale Basin is flanked by a well-preserved ejecta complex composed mainly of overlapping valleys and ridges reflecting ground-hugging ejecta flow [3]. Long, prominent valleys such as Vallis Bouvard (280 m in length), Vallis Inghirami, and Vallis Baade overlap older highlands material. Northeast-trending scours north of Schlüter contain northeast-tapering secondaries, and minute, southeast-trending crater chains and irregular patches of Orientale ejecta overlap Schickard and surrounding areas.

Humorum Basin. Crater chains and asymmetric secondaries exist south of the Humorum Basin, including a short (20-km) chain of four overlapping and degraded craters on the south rim of Hainzel. The area west of the Humorum Basin may contain two asymmetric secondaries, Cavendish E and Zupus D, although sharp rims of Cavendish E suggest post-Nectarian age. Other possible Humorum secondaries include a southwest-trending, elongate crater east of Drebbel and south-trending craterlets on the southwest margin of the Pre-Nectarian crater Mee.

Serenitatis Basin. Asymmetric secondaries from the Serenitatis Basin may be preserved southeast of Montes Apenninus. Marco Polo K and S are elongate, degraded craters approximately 300 km southwest of the rim of Mare Serenitatis. Both have westward-tapering rims and diameters of 13.7 by 14.7 km and 16.0 by 18.0 km, respectively. However, these craters have been affected by Imbrium ejecta and may instead be degraded primaries.

Summary: Large asymmetric secondaries associated with lunar basins are unique morphological features that can be used to constrain estimated ages of extrabasinal landforms. However, there are clear differences in morphology and abundance of preserved secondaries for each basin, and additional work can be done to understand the role that impact dynamics (velocity and impact angle) have on the genesis, distribution, and preservation potential of large secondaries. Other investigations could be done to infer the presence of ancient, degraded basins from isolated asymmetric craters that may be of secondary origin.

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