THE EXCAVATION OF LUNAR MULTI-RING BASINS: ADDITIONAL RESULTS FOR FOUR NEARSIDE BASINS. Paul D. Spudis, Dept. of Geology, Ariz. State Univ., Tempe AZ 85287 and U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff AZ 86001.

INTRODUCTION The formation of multi-ring basins is one of the most important processes in the early geologic history of the Moon. Exhaustive study of these features has produced no clear consensus on their original size and depth of excavation (e.g., compare 1,2). One problem encountered in the approach of many basin studies is that they focus on only one aspect of basin geology (photogeology, sample studies, etc.). This effort utilizes information from photogeologic, lunar sample, geophysical and remote sensing data to address the problem of the original basin cavity diameter and depth of excavation. This study extends results obtained for the Orientale basin (3) to the lunar basins Nectaris, Crisium, Serenitatis and Imbrium (4).

GEOLOGY AND EJECTA OF LUNAR BASINS. This section briefly summarizes the compositions of ejecta from five lunar basins and some constraints on the size of each original basin cavity. Detailed geologic rationale for these constraints may be found in (4).

Orientale. The Orientale basin (930-km diameter) formed in a 90-100 km thick (5) highland crust and contains several pre-basin structures (6,7) that suggest the boundary of the original basin cavity probably occurs within the outer Rook ring of that basin (cavity diameter 500-600 km). Mixing models derived from orbital geochemical data (8) suggest the Orientale ejecta is composed of a 2:1 mixture of anorthosite and anorthositic gabbro. These results suggest Orientale effectively excavated to depths no greater than about half the thickness of the crustal target (about 50 km; 3); if the original cavity size had been greater than this estimate, a significantly higher mafic content in the basin ejecta would be seen.

Nectaris. The Nectaris basin (860-km diameter) formed within a typical nearside highlands crust (average T=70 km; 5). Apollo 16 obtained orbital data of the northern and western ejecta and its landing site lies 200 km NW of the outer Nectaris ring. Nectaris is too degraded to recognize any pre-basin structures within the outer ring but results for Orientale suggest the original cavity was within the outer ring and was about 500 to 600 km in diameter. Mixing model results for Nectaris ejecta (9,10) indicate a 3:1 mixture of anorthositic gabbro and low-K Fra Mauro basalt. This suggests excavation to middle crustal levels, about 50 km in this region of the Moon.

Crisium. The Crisium basin (635-km diameter) impact occurred in a highlands target (average T=60 km; 5), geochemically similar to the Nectaris target. An unusual basin modification style, involving long-term endogenic modification with concurrent mare flooding in ring troughs (4), precludes identification of pre-basin structures. Orbital geochemical coverage of the southern ejecta blanket indicates Crisium ejecta consists of anorthositic gabbro and low-K Fra Mauro basalt (10) in about the same proportions as in Nectaris ejecta (3:1). This suggests Crisium basin excavation to crustal stratigraphic levels comparable to Nectaris. Due to the thinner crust in this region (5), Crisium probably sampled depths of 35 to 45 km.

Serenitatis. The Serenitatis basin (880-km diameter) impact occurred within a crust of average thickness (60 km; 5) that was geochemically distinct from both Crisium and Nectaris basin targets (4,9). Extensive mare flooding and morphologic degradation by the Imbrium impact prohibit the identification of pre-basin topography. Mixing model studies of the Taurus-Littrow highlands material (9) suggest Serenitatis ejecta is more than 90 percent norite with minor amounts of KREEP, mare basalt and anorthosite. This composition suggests Serenitatis may have excavated nearly the entire crustal column in this region of the Moon, as deep as 50 to 60 km; these results are consistent with those obtained for other basins in this study (cf. Nectaris, of similar size).

Imbrium. Imbrium (1200-km diameter) is one of the most complex lunar multi-ring basins. Gravity data (5) suggest a relatively thin crust for the pre-basin target region (average 50 km thick) composed of complex mare and KREEP volcanic lavas overlying a predominantly noritic highland crust (4). Numerous pre-Imbrian basins intersect the Imbrium outer ring; in particular, the preservation of an inner-basin topographic high near the Apennine Bench (11,12) may have resulted from the intersection of the Imbrium basin outer ring with the ancient Insularum basin (13). This suggests an original Imbrium cavity of about 600 to 800 km diameter (4). Mixing model studies of Imbrium ejecta indicate subequal amounts of low-K Fra Mauro basalt, KREEP and mare basalts with minor amounts of anorthositic gabbro (14). A new geochemical map of the Apennine mountains that displays a large component of norite within the Imbrium ejecta (15) suggests Imbrium excavated at least the entire crustal thickness in this region and possibly some upper lunar mantle materials (4).

DISCUSSION. The five basins described here represent a spectrum of basin sizes, ages and morphologies. Where the original cavity diameter can be constrained by preservation of pre-basin topography (Orientale, Imbrium), the original cavity is found to be significantly smaller than the present basin topographic rim. The inferred depths of basin excavation based on ejecta composition and regional crustal thickness are typically less than the local crustal thickness and are about one-tenth the diameter of the inferred original basin cavity. This relation has been suggested previously from an entirely different line of reasoning (16). An attempt was made to compute the total volume of material excavated by these impacts by assuming a hemispherical cavity with a penetration depth of one-tenth the inferred diameter, excavating a spherical Moon (3,4). Results for Orientale range from 4.9 to 9.3×10^6 km^3 of ejecta, a result in good agreement with previous estimates based on gravity (17) and photogeologic data (18). Analysis of this geometric figure of excavation further indicates that for Orientale, 90 percent of the basin ejecta is derived from depths shallower than about 30 to 40 km (3), which agrees well with the highly anorthositic composition of Orientale ejecta (8). In the case of Imbrium (the largest basin studied), this analysis indicates as much as 16 percent of the total ejecta volume may be derived from upper mantle regions. This material may be largely buried by mare flows that fill the basin, but detailed study of the orbital geochemical data indicates the presence of minor amounts of ultramafic material within the Apennines (19).

CONCLUSIONS. Lunar multi-ring basins form by the structural modification of initially smaller, shallow transient cavities. The results of this study suggest an initial excavation cavity with a diameter approximately 0.55-0.6 times the present basin topographic rim diameter. The geochemical data suggest the depth of excavation is about 0.1 times the diameter of this cavity. These results support hypotheses that basin outer rings form by gravity slumping around an initially smaller transient crater (e.g., 20-22). Basin inner rings may result from stratigraphic uplift (23,24) combined with minor oscillatory movement (23,25). This excavation model is consistent with a wide variety of studies of Apollo lunar highland samples that indicate a paucity of material derived from the lunar mantle (e.g.,26) within the lunar highlands.

REFERENCES

1) Hodges C.A. and Wilhelms D.E. (1978) Icarus 34, 294. 2) Head J.W. et al. (1975) PLSC 6, 2805. 3) Spudis P.D. (1982) LPS XIII, 760. 4) Spudis P.D. (1982) Ph.D. Dissertation, Ariz. State Univ., 291 pp. 5) Bills B.G. and Ferrari A.J. (1976) PLSC 7, frontispiece. 6) Scott D.H. et al. (1977) USGS Map I-1034. 7) Schultz P.H. and Spudis P.D. (1978) LPS IX, 1033. 8) Hawke B.R. et al. (1982) LPS XIII, 306. 9) Spudis P.D. and Hawke B.R. (1981) PLPSC 12B, 781. 10) Hawke B.R. and Spudis P.D. (1979) Conf. Lunar Highlands Crust, 53. 11) Spudis P.D. and Head J.W. (1977) PLSC 8, 2785. 12) Head J.W. (1977) Imbrium Consort. 2, 120. 13) Wilhelms D.E. (1980) Conf. Multi-ring Basins, 115. 14) Hawke B.R. and Head J.W. (1978) PLPSC 9, 3285. 15) Spudis P.D. and Davis P.A. (1982) Conf. Pristine Rocks, (in press). 16) Croft S.K. (1981) Multi-ring Basins, PLPSC 12A, 207. 17) Scott D.H. (1974) PLSC 5, 3025. 18) Moore H.J. et al. (1974) PLSC 5, 71. 19) Clark P. and Hawke B.R. (1981) PLPSC 12B, 727. 20) Mackin J.H. (1969) GSA Bull. 80, 735. 21) Head J.W. (1974) Moon 11, 327. 22) Schultz P.H. (1976) Moon Morphology, U. Texas Press, 626 pp. 23) Grieve R.A.F. et al. (1981) Multi-ring Basins, PLPSC 12A, 37. 24) Schultz P.H. et al. (1981) Multi-ring Basins, PLPSC 12A, 181. 25) Murray J.B. (1980) Moon and Planets 22, 269. 26) Taylor S.R. (1975) Lunar Science, Pergamon, 372 pp.