A CLASSIFICATION OF METEORITE IMPACT CRATERS

NSR-09-051-001

FRIEDRICH HÖRZ

LUCIANO B. RONCA

THE LUNAR SCIENCE INSTITUTE
3303 Nasa Road 1
Houston, Texas 77058

The Lunar Science Institute contribution no. 15

Accepted for publication in "MODERN GEOLOGY" Dec. 1970

ABSTRACT:

A systematic classification of meteorite impact craters based on $\log_{10}$ crater diameter (km) is proposed. The following classes were differentiated:

2 μ - 200 μ diameter: NANOCRATERS
200 μ - 2 cm diameter: MICROCRATERS
2 cm - 2 m diameter: CRATERLETS
2 m - 200 m diameter: SMALL CRATERS
200 m - 20 km diameter: INTERMEDIATE CRATERS
20 km - 2000 km diameter: LARGE CRATERS

Such a classification is believed to facilitate the discussion of lunar craters and impact structures on other planetary surfaces.

INTRODUCTION:

Investigations of natural and experimental impact craters have become an increasingly important tool for the interpretation of planetary surfaces, especially the Moon. In the case of the Moon such investigations yielded basic information about the morphology of the lunar surface, relative ages of various surface regions, determination of the thickness and origin of the lunar regolith etc. Thus meteorite crater studies aided considerably in revealing the history and evolution of the lunar surface (Levinson, 1970).

The diameters of lunar impact craters vary considerably because they reflect a wide variation in masses and velocities of oncoming projectiles. While the formation of large ring-basins, e.g. Mare Orientale or Mare Imbrium is probably due to collisions with asteroidal objects, small craters are believed to be formed by comets and/or meteorites. A continuous range of crater sizes could be observed in the Ranger, Orbiter and Surveyor photographic series, the lower size limit always being the resolution of the optical system employed. With the return of actual lunar surface material during Apollo 11 and 12 it was observed that most of the rock surfaces including individual constituents of the fine-grained soil are heavily pitted by microcraters. While Mare Imbrium has a diameter of roughly 600 km, the smallest craters measured on glass-spheres in the lunar soil are in the 1-2 μ size range.

Accordingly lunar impact craters differ in diameter over 11 orders of magnitude. Over such a size range the formation mechanism of impact craters changes from a process governed by material strength (small craters) into a process exclusively controlled by gravitational forces (large craters). The geological significance of individual impact events ranges from no more than a small indentation on the surface of a little soil grain to that of a catastrophic event with global consequences. While small impacts rupture and "erode" already existing rocks, large events can produce extensive volumes of "new" rocks either via impact melting or by triggering internal magmatic activity. Thus the geological implications of meteorite impacts vary significantly with crater diameter.

Many investigators emphasized these significances by separately treating individual crater size classes. In doing so it was always necessary to specify the size class with numerical values. The presentation of a numerical value mostly involves the formulation of a small sentence, which can be tiresome writing, reading or speaking. "Small" and "large" craters are frequently ill defined - if at all. Without memorizing the overall size interval an individual was working with, it is impossible to compare "small" and "large" craters from one publication to another.

The problem is similar to that faced by sediment petrographers before introduction of a rigorous classification of grain sizes or similar to that experienced by investigators of meteorites before classification of meteorites based on chemical grounds.

We would like to suggest a similar approach in the classification of meteorite craters. This classification is based on one parameter only, namely the crater radius and its $\log_{10}$ based on 1 km. The scheme proposed tries to satisfy the geological implications of individual size classes. Numerical simplicity for classification and easily understandable terminology were other prime considerations.

GENERAL CLASSIFICATION:

The general scheme proposed is shown in figure 1, covering the size range of impact craters observed on the lunar surface. The size range indicated certainly covers also all impact structures reported from other planetary surfaces like Earth or Mars (French, 1968, Leighton et al, 1970). The lower size range can possibly be expanded one additional order of magnitude. If craters between .1 and 1 μ will be found, we would suggest to incorporate these craters in the class of nano-craters. An expansion in the larger crater range is improbable. Structures of more than 2000 km diameter are not known at present and their existence is highly improbable. Such a crater would be a geologic feature of such dimensions that it certainly would deserve a special name. Therefore the size range covered in figure 1 probably never needs to be expanded. It can basically be applied to all planetary surfaces.

Few statistical data on crater diameters are available for Earth and Mars. Consequently the scheme proposed is heavily influenced by craters observed on the lunar surface. Especially the boundaries of various size classes are placed exclusively with lunar applications in mind. This we consider presently not a big distraction from the validity of the overall scheme, because it will probably be a long time til we obtain appropriate information from other planetary surfaces which possibly necessitate some modifications. We purposely propose a scheme applicable to the Moon. Future investigations will demonstrate to which extent such a scheme can be transferred to other planetary surfaces.

The terminology chosen is most likely subject to criticism. However we tried to keep it as simple as possible. A straight forward mathematical prefix like centi-, deka-, kilo- etc. seems rather awkward; so does probably an entirely new greek or latin terminology. We tried to adapt names which are not too contrary to many investigators' traditional thinking.

Similar considerations were used to establish the boundaries between individual crater classes. Rather than setting up a new arbitrary scheme, we tried to stay within a traditional framework dictated by the geological significance of individual classes. Some violations to this rule were unavoidable and are certainly subject to criticism. Difficulties arise especially for craters larger than 200 m, where possibly more crater classes with different boundaries could be established. However we refrain from such a procedure in order to maintain the simplicity of the scheme. It leaves enough flexibility to individual workers without being handicapped by a too rigorous classification. The diameters of the subclasses indicated in figure 1 are completely arbitrarily defined.

Such a general crater classification can aid in describing and relating craters of vastly different diameters. Especially useful however could be the introduction of short abbreviations as indicated in figure 1. The crater class is always denoted in a capital letter, the subclass in a small letter, e.g. Ms crater = small microcrater. Such abbreviations could speed up and simplify the discussing of specific crater sizes because numerical values could be largely deleted.

SIGNIFICANCE OF EACH SIZE CLASS:

The following chapter outlines the significance of each crater class and simultaneously presents an attempt to justify the boundaries between individual classes. A graphical illustration assists such an attempt (figure 2). The basis for our considerations were mainly the geological significance and resolution of various observational techniques.

NANO-CRATERS: 2 μ - 200 μ diameter

This crater class is exclusively confined to observations on returned lunar materials and includes craters with or without glass-lined, central pit. Most of the N-craters are observed on the lunar fines. The detailed description of N-craters requires the application of Scanning Electron Microscopes (McKay et al, 1970, Carter and McGregor, 1970, Neukum et al, 1970, Levinson, 1970).*

MICRO-CRATERS: 200 μ - 2 cm diameter

This crater class is again confined to observations on returned lunar materials and includes craters with or without glass-lined, central pits. The majority of M-craters is responsible for the surface texture of whole lunar rocks. They also aid in reconstructing the orientation of rocks on the lunar surface. The prime technique for their observation is a binocular microscope (PET, 1969 and 1970, Hörz et al, 1970, Hörz and Hartung, 1970, Levinson, 1970).

CRATERLETS: 2 cm - 2 m diameter

Though under specific circumstances some exceptions to this rule can exist, these craters are confined to the lunar regolith which they never penetrate to expose bedrock. They are therefore together with S-craters to a large extent responsible for a thorough mixing and turn over rate of the lunar regolith on a local level. They are

---

*Footnote: The references given here and in the following sections are only a few considering the vast amount of literature published on lunar cratering. It is impossible in this context to refer to all contributions. The references listed serve only as sources for more detailed information.

observable by surface photography such as obtained during Surveyor and Apollo missions (Morris and Shoemaker, 1968, Shoemaker et al, 1970a and 1970b).

SMALL CRATERS: 2 m - 200 m diameter

This is a very important size class as it yielded basic information on the distribution, thickness and evolution of the regolith as well as relative ages of various surface areas. The Sl-craters penetrate in general the lunar regolith. Their prime mode of identification is based on various Orbiter high resolution photographic series. (Shoemaker et al, 1970a and 1970b, Oberbeck and Quaide, 1968, Shoemaker, 1968, Shoemaker, 1969, Soderblom, 1970, Gault, 1970).

INTERMEDIATE CRATERS: 200 m - 20 km diameter

This is a rather wide span in diameters for our traditional thinking. Most of the statistical crater counting concerned with the evolution of the lunar surface was done with I-craters. Such investigations yielded relative ages of various lunar surface areas and may possibly be a clue to reconstruct the flux of meteorites in the past. Together with S-craters they are responsible for local surface topography and relief. Is-craters are resolvable with orbital photography, while Il craters are accessible with earth-based observations, i.e. high powered telescopes

(Shoemaker, 1968, Shoemaker et al, 1970a and 1970b, Oberbeck and Quaide, 1968, Gault, 1970, Hartmann, 1970, Marcus, 1970a, Ronca, 1970, Ronca and Green, 1970).

LARGE CRATERS: 20 km - 2000 km diameter

Ls-craters are relatively rare on mare surfaces but abundant on highland areas. They again yield information about the flux of meteorites. Their relative concentration on the highlands coupled with absolute age dating on lunar materials may eventually result in a better understanding of meteorite flux in the early history of the Moon. Some of these craters are characterized by central peaks with or without a flooded crater floor implying that some of the events were energetic enough to trigger internal magmatic activity.

Ll-craters represent impacts of global dimensions. All circular major maria presumably belong to this category. Thus Ll-craters are responsible for large topographic features. They have without exception flooded crater floors, though the height of the filling may vary. Consequently they all triggered internal magmatism. Lunar Mascons are confined to Ll-craters, though not each Ll-crater needs to be a mascon. The term "mare" is frequently synonymous with Ll-crater and should certainly not be abandoned (Ronca and Green, 1970, Ronca, 1970, Urey, 1969, Müller and Sogren, 1969, Hartmann, 1970, Baldwin, 1963, Trask, 1967, Öpik, 1960, Kopal, 1966).

Because we deal with a continuous range of crater sizes, any classification based on their radius must be artificial. Some overlap in the geological significance of individual crater classes is unavoidable. We believe however that the scheme proposed is not only justifiable but also very useful.

The suggested classification and terminology is for impact craters only, regardless whether they are formed by primary or secondary projectiles. It is also independent of detailed crater morphology, because the only relevant parameter is the radius. We propose also that this classification be applied to all circular structures on the Moon and other planetary surfaces as long as their origin is undertermined. Therefore it includes craters in all stages of degradation, which prevents the reconstruction of their origin. Only if such structures are clearly of volcanic or other endogeneous origin should they be classified and termed accordingly.

CONCLUSIONS:

The collisions of meteorites and other objects with planetary surfaces, especially that of the Moon, results in impact craters which may differ in diameter over 11 orders of magnitude. In order to simplify and facilitate the discussion of individual size classes we propose a classification based on crater radius, i.e.

$\log_{10}$ based on 1 km. This classification tries to accomodate the geological significance of various size classes. We incorporated in our scheme as much as possible of the preexisting large amount of literature published on the subject. Some artificialities were unavoidable. However we do believe that a classification of meteorite impact craters is timely and justifiable. Whether this particular classification, any modification thereof, or a completely different one will eventually be accepted is immaterial. If this paper stimulates some thoughts on the subject, it has served its purpose. We are grateful for all comments and criticisms.

ACKNOWLEDGMENT:

This paper was prepared at The Lunar Science Institute, Houston, Texas, under the joint support of the Universities Space Research Association, Charlottesville, Virginia and the National Aeronautics and Space Administration Manned Space Craft Center, Houston, Texas under contract No. NSR-09-051-001.

REFERENCES:

Baldwin, R. B. Lunar Crater Counts, Jour. Astronomy, V. 69, 377-392, 1964.

Carter, J. L. and MacGregor, J. D. Mineralogy, Petrology and Surface Features of Some Apollo 11 Samples. Proceed. Apollo 11 Lunar Science Conference, Vol. 1, 247-265, 1970.

French, B. M. Shock Metamorphism as a Geological Process, in Shock Metamorphism of Natural Materials, French, B. M. and Short, N. M. eds, Mono Book Corp., Baltimore, p. 1-17, 1968.

Gault, D. E., Saturation and Equilibrium Conditions for Impact Cratering on the Lunar Surface: Criteria and Implications, Radio Science, 5, 273-291, 1970.

Hartmann, W. K. Preliminary Note on the Lunar Cratering Rates and Absolute Time Scales, Icarus 12, 131-133, 1970.

Hörz, F. and Hartung, J. B. The Lunar Surface Orientation of Some Apollo 12 Rocks, submitted for publication, 1970.

Hörz, F., Hartung, J. B. and Gault, D. E. Micrometeorite Craters on Lunar Rock Surfaces, submitted for publication, 1970.

Leighton, R. B., Horowitz, N. H., Murray, B. C., Sharp, R. P., Herriman, A. H., Young, A. T., Smith, B. A., Davies, M. E., and Leovy, C. B. Mariner 6 and 7 Television Pictures: Preliminary Analysis, Science, 166, 49-67, 1969.

Levinson, A. A. ed. Proceedings of the Apollo 11 Lunar Science Conference, Pergamon Press, 1970.

Lunar Sample Preliminary Examination Team; Preliminary Examination of Lunar Samples from Apollo 11, Science, 165, 1211-1227, 1969.

Lunar Sample Preliminary Examination Team; Preliminary Examination of Lunar Samples from Apollo 12, Science, 167, 1325-1339, 1970.

Marcus, A. H. Comparison of Equilibrium Size Distribution of Lunar Craters, J. Geophys. Res. 75, 4977-4984, 1970a.

McKay, D. S., Greenwood, W. R. and Morrison, D. A. Origin of Small Lunar Particles and Breccia from the Apollo 11 Site; Proceed. Apollo 11 Lunar Science Conference, Vol. 1, 673-694, Levinson, A. A. ed., Pergamon Press, 1970.

Morris, E. C. and Shoemaker, E. M. Television Observations from Surveyor. Surveyor Project Final Report; Part II, Science Results, 65-69, NASA TR 32-1265, 1968.

Müller, P. M. and Sjogren, W. L., Mascons: Lunar Mass Concentrations, Science 161, 680-684, 1968.

Neukum, G., Mehl, A., Fechtig, H. and Zahringer, J. Impact Phenomena of Micrometeorites on Lunar Surface Materials, Earth and Plan. Science Letters 8, 31-35, 1970.

Oberbeck, V. R. and Quaide, W. L. Genetic Implications of Lunar Regolith Thickness Variations, Icarus, 9, 446-465, 1968.

Öpik, E. J. The Lunar Surface as an Impact Counter, Roy. Astronom. Soc. Mon. Not., 120, 404-411, 1960.

Ronca, L. B. and Green, R. R. Statistical Geomorphology of the Lunar Surface, Geol. Soc. of Am. Bull 81, 337-352, 1970.

Shoemaker, E. M. The Lunar Regolith, in Extraterrestrial Matter, C. A. Randall, ed. Northern Illinois Universal Press, 1968.

Shoemaker, E. M., Batson, R. M., Holt, H. E., Morris, E. C., Rennilson, J. J. and Whitaker, E. A. Observations of the Lunar Regolith and the Earth from the Television Camera on Surveyor 7, J. Geophys. Res. 74, 6081-6119, 1969.

Shoemaker, E. M., Hait, M. H., Swann, G. A., Schleicher, D. L., Schaber, R. L., Sutton, R. L., Dahlem, D. H., Goddard, E. N., Waters, A. C., Origin of the Lunar Regolith at Tranquillity Base, Proceed. Apollo 11 Lunar Science Conference, Vol. 3, 2399-2412, 1970.

Shoemaker, E. M., Batson, R. M., Bean, A. L., Conrad, C., Dahlem, D. H., Goddard, E. N., Hait, M. H., Larson, K. B., Schaber, G. G., Schleicher, D. L., Sutton, R. L., Swann, S. D., and Waters, A. C. Preliminary Geologic Investigations of the Apollo 12 Landing Site, Apollo 12, Preliminary Science Report, NASA SP-235, p. 113-157, 1970.

Short, N. M. and Forman, M. L. Thickness of Impact Crater Ejecta on the Lunar Surface, NASA-GSFC-X-652-70-336 (preprint) 1970.

Soderblom, L. A. A Model for Lunar Impact Erosion Applied to the Lunar Surface, J. Geophys. Res. 75, 2655-2661, 1970.

Trask, N. J. Distribution of Lunar Craters According to Morphology from Ranger VIII and IX photographs. Icarus, 6, 270-276, 1967.

Urey, H. Early Temperature History of the Moon. Science, Vol. 165, 1275, 1969.

Figure captions:

Fig. 1: Classification of meteorite craters based on crater radius.

Fig. 2: Criteria used to justify the boundaries of various crater-classes.

FOLDOUT FRAME

ABBREVIATIONS	N		M		C		
	S	1	S	1	S	1	S
CLASS	NANO-CRATERS		MICROCRATERS		CRATERLETS		SMAL
SUBCLASS	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL

LOG_{10} RADIUS Km	-9	-8	-7	-6	-5	-4	-3
DIAMETER	2μ	20μ	.2 mm	2 mm	2 cm	20 cm	2 m

FOLDOUT FRAME

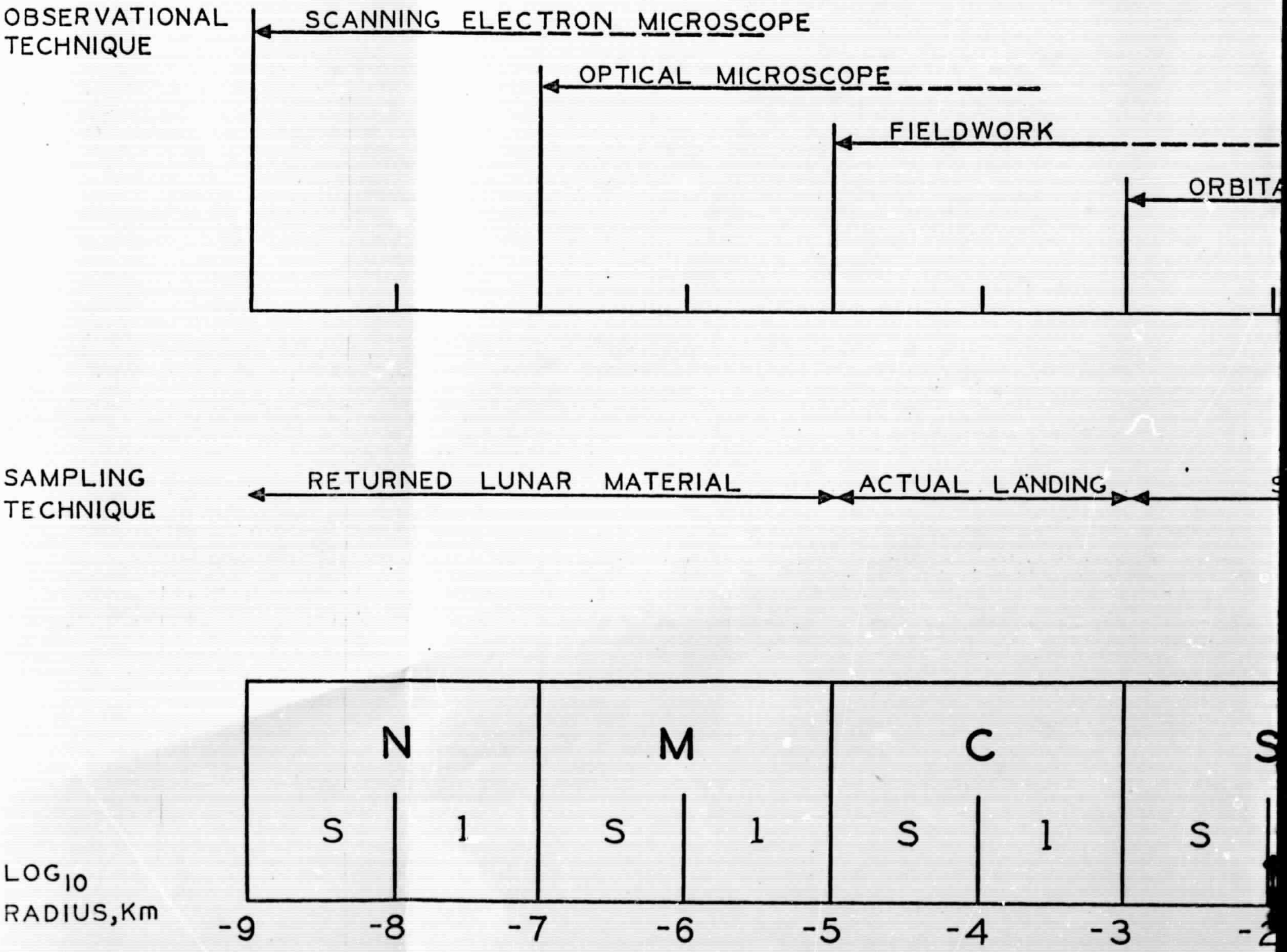
2

M	C		S		I		L	
1	S	1	S	1	S	1	S	1
CRATERS	CRATERLETS		SMALL CRATERS		INTERMEDIATE CRATERS		LARGE CRATERS	
LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE

-5 -4 -3 -2 -1 0 1 2

2 cm 20 cm 2 m 20 m 200 m 2 Km 20 Km 200 Km

FOLDOUT FRAME



FOLDOUT FRAME

2