PERIODIC COMETARY SHOWERS: REAL OR IMAGINARY? R.A.F. Grieve, V.L. Sharpton, and A.K. Goodacre, Earth Physics Branch, EMR, Ottawa, Canada K1A 0Y3 and J.B. Garvin, Code 622, NASA - GSFC, Greenbelt, MD 20771, USA.

Introduction. Suggestions of ~ 26 m.y. and ~ 30 m.y. periodicities, depending on the statistic, in the marine extinction record (1), coupled with evidence for a major impact event at the K-T boundary, have resulted in claims of equivalent periodicities in the terrestrial cratering record (2, 3). This leads to the hypothesis that the earth is subjected to periodic cometary showers (2,3) and implies that a large portion of terrestrial craters are produced by cometary bodies. Before accepting these conclusions, it is important to consider some of the salient points of the record.
The number of craters. The known record is incomplete. Crater retention rates are variable but crater preservation indicates that a 20 km structure may be unrecognizable in as little as 100-200 m.y., even in cratonic areas (4). Few systematic studies aimed at crater recognition have been carried out and many craters have been recognized by chance. Known craters occur in a wide variety of geological circumstances (e.g., well-exposed to completely buried) and several new structures are discovered each year. Given the variability in geological and geophysical data, it is unlikely that any general listing (e.g., 5), taken at face value (2, 3), is representative.
The ages of craters. Considerable uncertainty is attached to age estimates of many structures. In some cases, different isotopic methods yield different ages (e.g., Boltysh, Carswell, Mistastin). Experience has shown that $^{39}Ar-^{40}Ar$ ages on unaltered, equilibrated melt rocks are probably the most reliable. Few structures, however, have been dated by this method (Table 1). Single K-Ar or biostratigraphic ages should be viewed with caution, particularly if emphasis is on detailed statistical analysis (Table 2).
The question of periodicities. The status of the record notwithstanding, we have undertaken a search for periodicities. The fit of the observed ages to $y_i = A + r_i t$ was tested, where A is the phase, r_i is an integer and t is the period. The rms of the departure of E_i/t, where E_i is the observed interval between events, from an integer (Q) is a measure of periodicity. For random events, Q has a mean of 0.29 (6) and a threshold of Q<0.29-3 s.d. is considered for discussion. A number of periodicities with different phase can be defined (Table 2), depending on what is considered the "best" dataset (D>20 km on the cratons, isotopic ages, all with ages ≤250 m.y, etc). This raises the question of which, if any, is physically valid.
Other considerations. It has been possible to identify the projectile type at some craters through siderophile and other data. At others, only a weak meteoritic signature, open to some interpretation, has been detected (5, 7). It is apparent, however, that a variety of projectile types produced the craters in Table 1. The recent terrestrial cratering rate is estimated at $5.4 \pm 2.7 \times 10^{-15}$ km^{-2} y^{-1} for D> 20 km (4) and is similar to an estimate of $6.0 \pm 3.0 \times 10^{-15}$ km^{-2} y^{-1} based on observations of Apollo bodies (8). The craters used to calculate the terrestrial cratering rate are in part the same craters used to call for periodic cometary showers. If the cometary hypothesis is correct, this raises the question of where are the craters formed by Apollos? This enigma is compounded by the similarity in the estimated cratering rates based on known craters and observations on Apollos.
Concluding remarks. Although the record may be sufficient to estimate the cratering rate over periods of 10^8y, the fact that various statistical periods can be retrieved limits confidence in their significance. Additional

data are required before statements on generalized cometary impact-extinction relationships can be considered categorical. Contrary arguments to periodic cometary impacts can be advanced, based on considerations of siderophile data and cratering rate estimates.

REFERENCES. (1) Raup, D.M. and Sepkoski, J.J. (1984) Proc. Nat. Acad. Sci., 81, 801. (2) Alvarez, W. and Muller R.A. (1984) Nature, 308, 718. (3) Rampino, M.R. and Stothers, R.B. (1984) Nature, 308, 709. (4) Grieve, R.A.F. (1984) Proc. Lunar Planet. Sci. Conf. 14th, in J. Geophys. Res., 89, B403. (5) Grieve, R.A.F. (1982) Geol. Soc. Amer. Sp. Paper, 190, 25. (6) Broadbent, S.R. (1955), Biometrika, 42, 45. (7) Palme, H. (1982) Geol. Soc. Amer. Sp. Paper, 190, 223. (8) Shoemaker, E.M. (1983) Ann. Rev. Earth Planet. Sci., 11, 461.

Table 1. Terrestrial impact craters with D > 5 km and well-constrained ages ≤ 250 m.y.

Structure	D, km	Age, m.y.	Dating* method	Projectile Type	Evidence
Zhamanshin	13	0.77±0.8	1,2	Iron	Siderophiles
Bosumtwi	10.5	1.3±0.2	3,4	Iron	Siderophiles
El'gygytgyn	19	3.5±0.5	1,3 (Ureilite)	Achondrite	Siderophiles
Karla	10	7.3±3.9	5	n.d.	-
Haughton	20.5	14.5±9.2	5	n.d.	-
Ries	24	14.8±0.7	1,3,6	Chondrite or Achondrite?	Siderophiles
Wanapitei	8.5	37±2	3	Chondrite	Siderophiles
Mistastin	28	38±4	6	Iron or Achondrite?	Siderophiles
Popigai	100	39±9	1,3		
Beyenchime-Salaatin	8	40±20	5	Iron	Taenite
Kara	50	60±5	3,5	n.d.	-
Ust-Kara	25	65±5	5	Iron?	Ni, Co
Kamensk	25	65±5	5	n.d.	-
Lappajarvi	14	77±4	6	n.d.	-
				Chondrite	Siderophiles
Logoisk	17	90±10	5	n.d.	-
Steen River	25	95±7	3	n.d.	-
Boltysh	25	100±5 (88±17)	1,(3)	Iron?	Ni, Co
Dellen	15	100±2	6	Stony?	Siderophiles
Carswell	37	117±8	6	n.d.	-
Mien	8	118±2	6	Stony?	Siderophiles
Gosses Bluff	22	130±6	1,3	n.d.	-
Oblon'	15	160±30	3?	n.d.	-
				Iron	Taenite,Kamacite
Rochechouart	23	163±10	3	Iron or Chondrite?	Siderophiles
Puchezh-Katunki	80	183±3	5	n.d.	-
Mainicouagan	100	210±4	3,4	?	Siderophiles
St. Martin	23	225±25	3,5	?	Siderophiles

* 1. Fission track. 2. Geomagnetic reversals. 3. K-Ar. 4. Rb-Sr. 5. Biostratigraphy. 6. ^{39}Ar-^{40}Ar. n.d. not determined.

Table 2. Statistical periodicities from Table 1

Data-set	N	Period, m.y.	Phase, m.y.	Q
All	26	30.0	6	0.1908
		20.5	19.5	0.2082
T > 5 m.y.	23	29.5	9	0.1921
		21.0	15	0.2038
N. American and European cratons	16	29.5	9	0.1751
Cratons, D > 10 km	14	30	4	0.1908
Cratons, D > 20 km	10	-	-	-
Cratons, D > 20 km, T < 150 m.y.	6	27	13	0.1219
Isotopic ages	19	18.5	2	0.1820
Alvarez and Muller (2)	11	28.5	13.5	0.1161
Rampino and Stothers (3)	41	31	5	?