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The period dichotomy in terrestrial impact crater ages

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ABSTRACT

Impact cratering on the Earth during the past 250 Myr has occurred with either of two apparent periodicities, ∼30 or ∼35 Myr, depending on the set of impact crater ages that is adopted. When the craters are segregated by size and the possible age errors are explicitly taken into account in the analysis, only the longer periodicity survives, and does so only in the case of the largest craters (diameters $\geqslant$ 35 km). Smaller craters exhibit no robust periodicity. Despite their relative abundance, the inclusion of data points for the small craters merely degrades, without shifting or destroying, the periodic signal of the largest craters when all of the craters are analysed together. The possible consequences for quasi-periodic Galactic perturbations of the Oort comet cloud are briefly discussed.

Key words: methods: numerical – comets: general – Earth – Solar system: general – Galaxy: kinematics and dynamics.

1 INTRODUCTION

Impact cratering on the Earth is thought to be cyclic with a mean periodicity of roughly 30 Myr (Rampino & Stothers 1984; Alvarez & Muller 1984). The apparent robustness of this periodicity, despite the persisting uncertainty about its exact length, is suggested by its insensitivity to the selection of impact craters by size, age and magnitude of the analytical dating error. As more and more craters have been discovered and dated, this periodicity has consistently appeared in nearly all time-series analyses (see, most recently, Stothers 1998; Yabushita 1998, 2002, 2004; Chang & Moon 2005). Although Jetsu (1997) and Jetsu & Pelt (2000) have claimed that the periodicity is just an artefact due to integer rounding of the published crater ages, this possibility has long been discounted by directly detecting the spurious rounding signal in addition to the bona fide periodicity (Rampino & Stothers 1984) and, more importantly, by analysing slightly perturbed time series in which the crater ages have been randomized within their published measurement errors (Stothers 1988; Napier 1998).

A striking curiosity about all of these results, however, is this: in every analysis, the highest spectral peak for those trial periods that can be tested in a statistically meaningful way (say, periods longer than ∼22 Myr) nearly always occurs inside one of two narrow period ranges, 26–32 and 34–38 Myr. Although these two ranges are separated by only 2 Myr, the apparent period dichotomy is confirmed by a large number of independent time-series analyses [see the references in Stothers (1998) and Yabushita (2004)].

Does it really matter which period (if any) is correct? There are in fact two potentially important implications to consider. First, if different selections of crater ages yield different best-fitting periods, the whole meaning of the analysis may possibly be doubted, in view of the persistent lack of formal statistical significance of the best-fitting period when this period is tested as if the period itself, and not just its spectral power, were accidental. In most previous tests, including those of Yabushita (2004) who claimed some statistical significance, the period was assumed to be known and the tests were performed on that known period. Secondly, a period of 34–38 Myr is tantalizingly close to the half-period of the vertical oscillation of the Solar system about the Galactic plane, for which the most recent estimate is approximately 41 Myr (Holmberg & Flynn 2000, 2004; Yabushita 2004), although a value as low as 34 Myr might still be possible (Stothers 1998). Since theoretical models exist that exploit Galactic perturbations of the Oort comet cloud to create quasi-periodic comet impacts on the Earth, the particular value of the derived cratering period does matter. The present paper investigates the nature and origin of the cratering period dichotomy.

2 ANALYSIS OF THE PERIOD DICHOTOMY

The most recent work has not investigated the period dichotomy *per se*, but does illustrate it well. In the case of the largest craters, possessing diameters $D \geqslant 35$ km, the best-fitting period based on a variety of data sets as well as of analytical methods is ∼36 Myr (Matese et al. 1998; Rampino & Stothers 1998; Stothers 1998; Yabushita 2002). For smaller craters, lying in the range $D = 5$–34 km, spectral analyses have yielded a shorter period of ∼30 Myr or even no periodicity at all – results which are the same as those found for all craters with $D \geqslant 5$ km analysed together (Yabushita 1996a,b; Montanari, Campo Bagatin & Farinella 1998; Rampino & Stothers 1998; Stothers 1998). The finding for all craters analysed together is not a complete surprise because the many smaller craters dominate the analysis statistically. Recently, Yabushita (2004) has shown that

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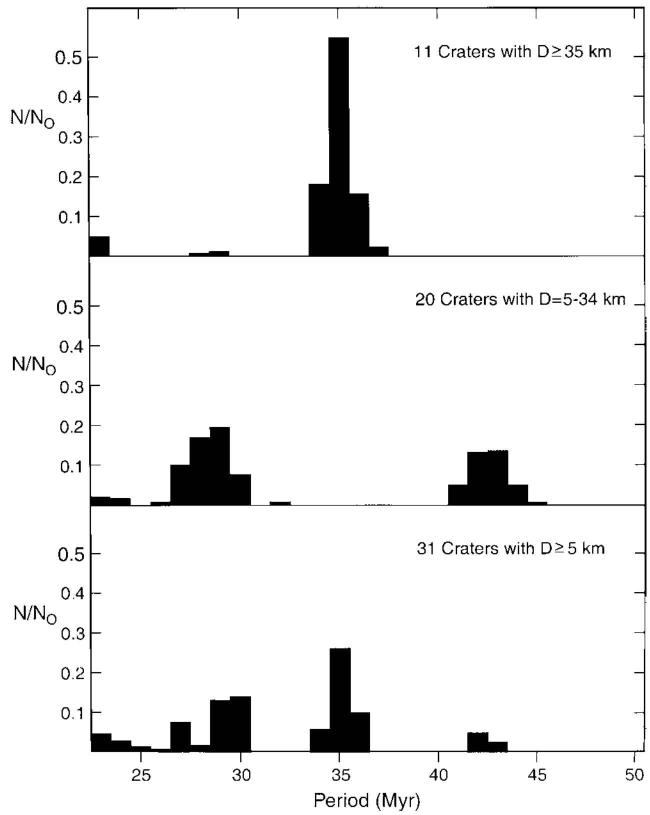

Figure 1. Histogram of the periods at which the highest spectral peak occurs, for 1000 perturbed time series of impact crater ages. Ages are varied within their analytical measurement errors.

if each crater is weighted either by its diameter or by its impact energy, the best-fitting period falls close to 38 Myr. Since in this case the largest craters must dominate the analysis, a long period such as this one might have been anticipated.

All of these recent studies have treated the adopted crater ages as error-free. Here we examine the effects of the age errors themselves, quite apart from the effects of the different selections of craters and ages that were used in the previously published studies. Our list of crater ages and age errors comes from Grieve & Pesonen (1996), with a few updates added later (Stothers 1998); all craters used are younger than 250 Myr and have analytical age errors of less than 10 Myr. This is a standard list of craters, and our results are not noticeably sensitive to the inclusion or rejection of more or fewer craters; it is chiefly the age errors that matter for the present analysis. The crater ages are randomly perturbed here by treating their published error estimates as 1σ Gaussian errors. The chosen method of spectral analysis is a generalized version of Broadbent's method that we have used before. On the basis of 1000 perturbed time series, a period histogram can be constructed, showing the number of time series for which the best-fitting period occurs at each trial period longer than 22 Myr. A period cut-off is imposed because earlier studies have shown that periods shorter than 22 Myr fall in the noise band (Alvarez & Muller 1984; Trefil & Raup 1987; Stothers 1988).

Fig. 1 displays the resulting histograms for the three groups of craters selected by size: 11 craters with $D \geqslant 35$ km, 20 craters with $D = 5$–34 km, and the whole set of 31 craters with $D \geqslant 5$ km. As expected, the large craters and the small craters show preferred periods near 35 and 29 Myr, respectively. Two previous analyses of the same type for mostly large craters and for mostly small craters yielded 34 and 30 Myr, respectively (Stothers 1988; Stothers & Rampino 1990), in agreement with the present results.

The big surprise, however, comes when all of the craters (with $D \geqslant 5$ km) are analysed together. Despite the fact that the small craters outnumber the large ones by a ratio of 2 : 1, the most frequently occurring period appears near 35 Myr. How can this be? A glance at the histogram for the small craters shows that the frequency maximum near 29 Myr is not very high and that another frequency maximum almost as high occurs near 43 Myr, but with no trace of anything near 35 Myr. This suggests that a sizable random component is present among the small craters. In fact, if there had been any inbuilt period at all, it would have shown up in a histogram of this type (Napier 1998). When mixed in with the strongly periodic large craters, the small craters degrade the periodic signal, but do not shift or destroy it. Another possibility is that they split this period into two periods of 29 and 43 Myr, since 35 Myr lies mid-way between.

3 CONCLUSION

The principal conclusions to be drawn from this study are as follows. The largest impact craters display a remarkably strong periodicity, which is not strictly regular but is at least robust against possible errors in the crater age measurements. Its mean length from the present data is 35 Myr, but could be, for other selections of the data, as long as 36–38 Myr (Yabushita 2002, 2004). Recently, Chang & Moon (2005) found 26 Myr, but this was a weak period, and our Fig. 1 shows that such a short period can sometimes arise even for our selection of large craters. Small impact craters exhibit no obvious periodicity when their potential age errors are included in the analysis. For these craters, previously derived periods of 26–30 Myr are now seen to be most likely accidental due to particular choices of ages. Despite their relative abundance, the small craters do not destroy the periodic signal of the large craters when all of them are analysed together. This important result further illustrates the great robustness of the periodicity detected in the large craters.

Since the large craters are expected to result chiefly from impacts of comets rather than of asteroids (Shoemaker, Wolfe & Shoemaker 1990), a physical tie to the Oort comet cloud and thence to Galactic quasi-periodic gravitational perturbations of the Solar system can be tentatively made. This speculative hypothesis will ultimately stand or fall on the basis of improved accuracy in deriving both the period of impact cratering on the Earth and the half-period of the vertical oscillation of the Solar system through the Galaxy. The accuracy needed will require more and better observational data.

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REFERENCES

Alvarez W., Muller R. A., 1984, Nat, 308, 718
Chang H.-Y., Moon H.-K., 2005, PASJ, 57, 487
Grieve R. A. F., Pesonen L. J., 1996, Earth, Moon, Planets, 72, 357
Holmberg J., Flynn C., 2000, MNRAS, 313, 209
Holmberg J., Flynn C., 2004, MNRAS, 352, 440
Jetsu L., 1997, A&A, 321, L33
Jetsu L., Pelt J., 2000, A&A, 353, 409

Matese J. J., Whitman P. G., Innanen K. A., Valtonen M. J., 1998, Highlights Astron., 11A, 252
Montanari A., Campo Bagatin A., Farinella P., 1998, Planet. Space Sci., 46, 271
Napier W. M., 1998, Celest. Mech. Dyn. Astron., 69, 59
Rampino M. R., Stothers R. B., 1984, Nat, 308, 709
Rampino M. R., Stothers R. B., 1998, Highlights Astron., 11A, 246
Shoemaker E. M., Wolfe R. F., Shoemaker C. S., 1990, Geol. Soc. Am. Spec. Pap., 247, 155
Stothers R. B., 1988, Observatory, 108, 1
Stothers R. B., 1998, MNRAS, 300, 1098
Stothers R. B., Rampino M. R., 1990, Geol. Soc. Am. Spec. Pap., 247, 9
Trefil J. S., Raup D. M., 1987, Earth Planet. Sci. Lett., 82, 159
Yabushita S., 1996a, Earth, Moon, Planets, 72, 343
Yabushita S., 1996b, MNRAS, 279, 727
Yabushita S., 1998, Celest. Mech. Dyn. Astron., 69, 31
Yabushita S., 2002, MNRAS, 334, 369
Yabushita S., 2004, MNRAS, 355, 51

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