GEOLOGICAL ASPECTS OF TERRESTRIAL IMPACT CRATERING RATES; SIMULATING THE PROCESSES AND EFFECT OF CRATER REMOVAL. S. N. D. Thackrey[1], G. M. Walkden[1], G. Dunn[2]
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ABSTRACT

Regression impact flux models have been accepted by many to be the best way of representing flux trends for quite some time. However, through the creation of these models, key factors have been overlooked that play a vital role in impact flux trends. These factors are associated with geological and astronomical processes. To develop a new flux model, regression trends have to be replaced by computer simulations as to develop higher accuracies and flexibility.

INTRODUCTION

Impact cratering has been an area of keen interest for a number of decades and is now well established as an important geological process. Research developed by various workers such as [2] provided an impact flux model where it could be established that a crater of diameter ***X*** should occur every ***Y*** years somewhere on the Earths surface.

When considering these well established models, a number of problems are immediately recognizable. Primarily the influence of geological or rather Earth surface processes has been poorly represented. Furthermore, the concentrations of impacts will inevitably vary as a function of Latitude; the affects of these two fundamental factors form the basis of this paper.

THE IMPACT FLUX

The impact flux is the frequency at which impactors (Asteroids and Comets) of a given diameter collide with Earth. Establishing when the next large impact is going to occur on the Earths surface has long since been hailed as the “Holy Grail” of impact related studies. The impact flux was initially very high. This period is known as the “heavy bombardment period” [4]. The heavy bombardment period was a time when the solar system was still somewhat chaotic, large asteroids were common forming some of the very large craters seen on the Moon. However from about 3.8Ga, the impact flux greatly reduced by about a factor of five, and since c. 1Ga, has remained relatively constant.

[2] were the first to try and quantify Earths impact flux. The methodology mainly involved studying the terrestrial and lunar record. The lunar impact record was seen to be the most complete due to the fact that there have been no significant surface processes influencing the craters. The only mechanism influencing craters on the moon is the subsequent reworking by other impacts. By calculating the age and diameter of craters and also their surface concentrations, a LOG regression trend model can quickly be established. The latest version of the model by [2] can be seen in Eq.1, where C is the concentration per Km^2 and D is the diameter of the crater in Km.

$$\text{Log } \Phi c = -(11.67 \pm 0.21) - (2.01 \pm 0.13) \text{ Log } D \quad (1)$$

There are three fundamental weaknesses with the regression trend approach. Firstly, the model produced is only as reliable as the limited data used. Secondly, it does not take into consideration latitudinal variations in impact concentrations. Thirdly, it does not recognize and take account of model the effects of geological processes.

The latest version of the model produced by [3] does attempt to take into consideration the effects of geological processes. However, in doing so the available database used becomes severely restricted. The rational was that craters between the diameters of 19-45Km, younger than 105Ma and occurring in stable cratonic areas were seen to represent the crater concentration expected even with the influence of Geological processes. By focusing the criteria down to this level, it only left six craters to base the new model on. This in turn only served to exaggerate the already inherent inaccuracies with the regression models.

GEOLOGICAL AND ASTRONOMICAL EFFECTS.

To create an holistic model, every possible aspect that influences crater preservation, formation and distribution must be fully integrated. This information can be derived through knowledge of both planetary surface processes (geology) and orbital/geometric processes (Astronomy). Three key geological processes that contribute to the deletion of craters are: - Tectonics → Erosion → Burial / Sedimentation. These are hierarchically inter-linked, with plate tectonics having the most effect on crater preservation

Geological processes not only affect Earth. Many other planets show evidence that geological processes play or once played an important role in developing a planets surface. Earth and Venus are perhaps the best examples in our solar system of planets with well established active geological systems. Mars also shows good evidence of volcanism and plate tectonics, but these processes now seem to be dormant with only Aeolian erosional processes actively affecting the cratering record. There is also evidence of relic fluvial erosion. These geological systems act to both mask and erase the impact record of a planet which in turn leads to difficulties when attempting to derive an impact flux model from a database of impact craters.

On Earth, oceans occupy over 70% and of this oceanic crust the oldest is c.185Ma. That means that plate tectonics (crustal recycling through subduction) has removed over 2/3 of the entire impact record spanning in excess of 3Ga.

The terrestrial cratering record seems to be restricted to the cratonic areas of continental crust Fig. 1.

diameters of 64Km to 120Km. This uncertainty in crater diameter directly influences the impact database that regression models are based upon. Crustal deformation and volcanism also contribute to the deletion of craters from the record.

A particular feature of the terrestrial cratering record is that the distribution of impact craters that we see today is not the primary distribution. Plate tectonic movements have radically altered the positions of continents and consequently the position of impact craters. Craters that are older than c.20Ma are likely to have been moved from there original positions. Fig. 2. shows the latitudinal distribution of all known craters corrected back to their original latitude at time of impact (This was achieved by using palaeocontinental data [5]).

What is immediately apparent in Fig. 2. is the variation in crater distribution patterns through time.

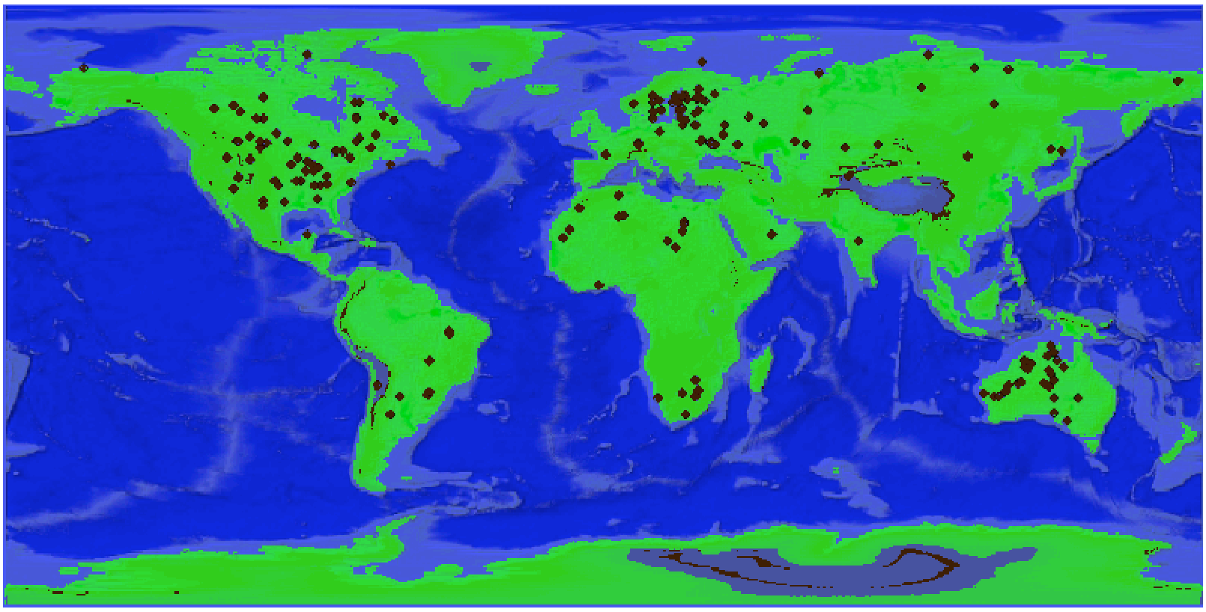

Fig. 1. Global distribution of impact craters. DEM image from ESRI

These cratonic areas have been exposed for much longer periods of time and hence more craters can be observed. Nonetheless, even within cratonic areas there is a bias towards well populated or well researched regions such as Western Europe, North America and Australia. This bias probably reflects the distribution of researchers and accessible field areas as much as it reflects the distribution of craters.

Erosion produces vast amounts of sediment in various forms and also at various rates depending on topography and climate. The sediment generated from erosion can rapidly bury an impact crater beyond detection. A secondary effect of erosion and burial is the misinterpretation of impact crater diameter. Manicouagan is an excellent example where workers have suggested pre-erosional

Zone 1. Shows the Polar Regions devoid of preserved impact craters. During these time periods, there were comparatively small areas of continental crust around the poles. There is also an astronomical factor that concentrates impacts to the equatorial belt, but this will be covered when discussing *zone 4*.

Zone2. The equatorial concentration observed during pre-Triassic periods is not continuous. *Zone 2* illustrates a marked decrease in preserved impact craters. The equatorial regions during this time had a very low coverage of continental crust. Marine craters only make up about 7% of the entire cratering record, for this reason, we find very little craters preserved in this zone. Furthermore, Equatorial regions, due to the climate, exhibit elevated erosional rates through rock decomposition (particularly in feldspar rich rocks).

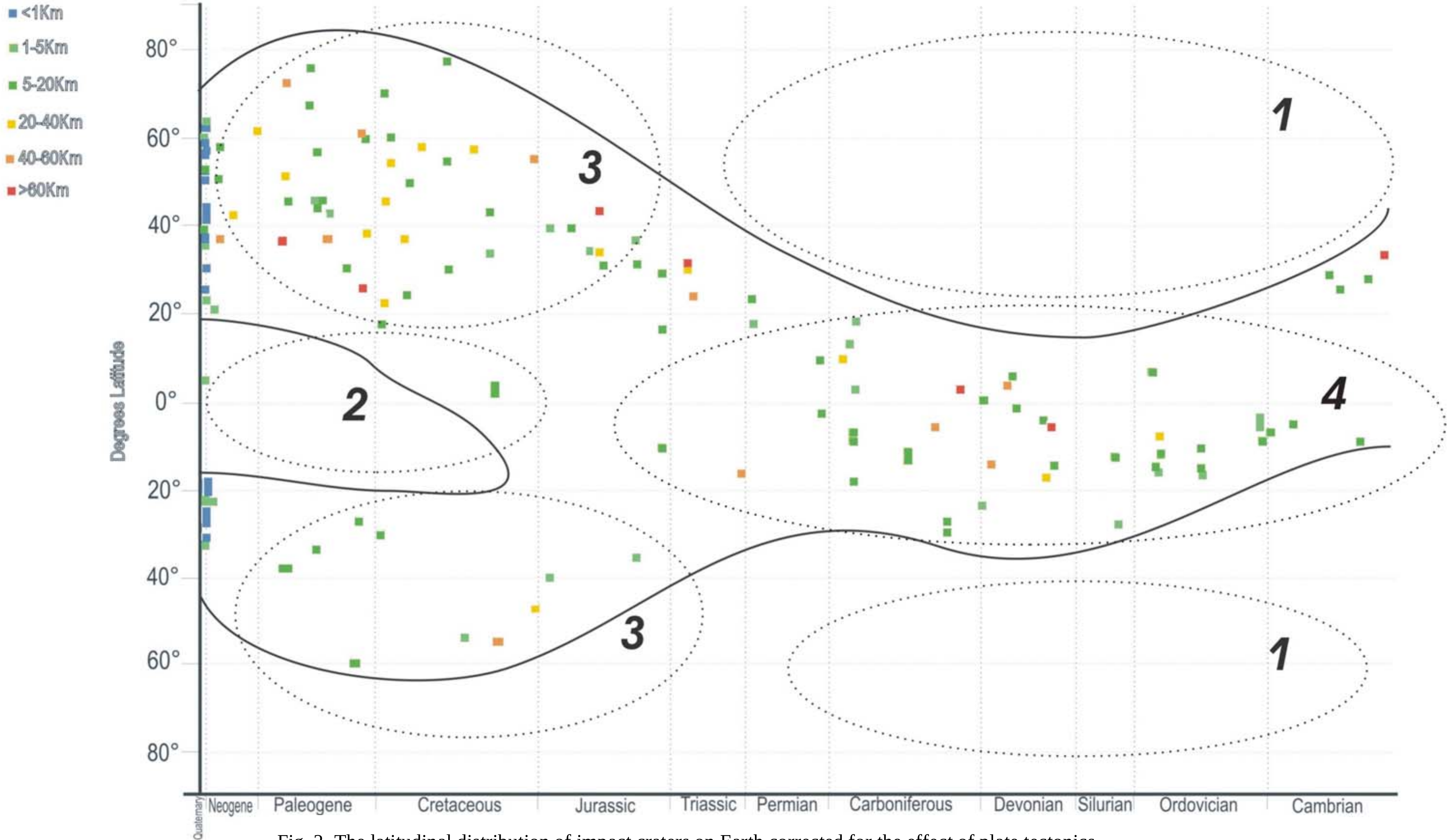

Fig. 2. The latitudinal distribution of impact craters on Earth corrected for the effect of plate tectonics.

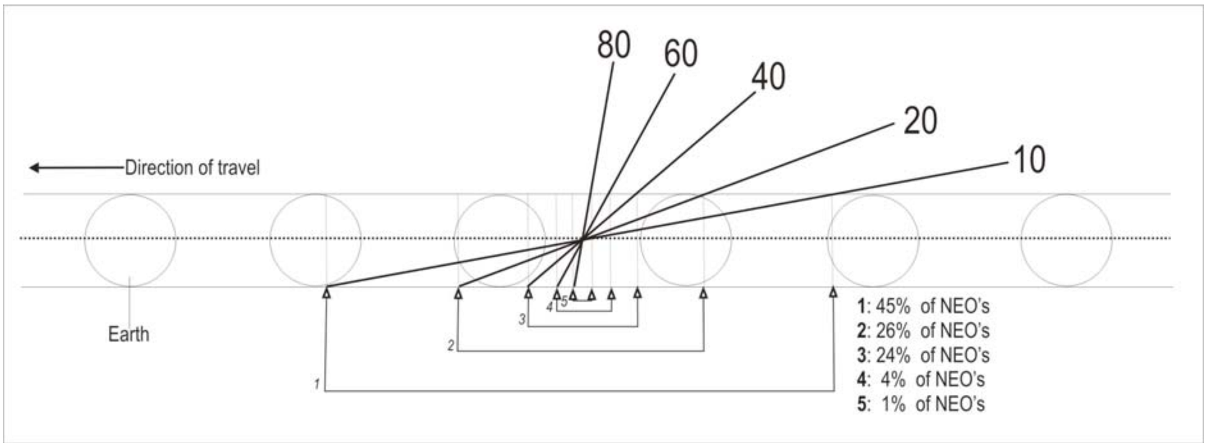

Fig. 3. NEO orbital inclination density with respect to the ecliptic.

Zone 3. Shows a significant number of preserved impact craters in the mid latitudes both in the northern and southern hemisphere (Note that polar latitudes have no preserved craters). These impacts are still preserved due to the locations of continental crust. Here the opposite is true of *Zone 2*. whereby craters are preserved where there are sufficient areas of continental crust. Quaternary and late Neogene impacts are quite plentiful; this is due to the fact that geological processes have had very little time to act upon them.

Zone 4. This zone covers a broad span of time that seems to highlight a natural tendency for craters to be concentrated across the equatorial latitudes. It does however reflect the equatorial distribution of continental crust during this time. With the continental crust occupying large areas of the equator, a large number of craters can be preserved.

An equatorial concentration is, however, to be expected. This is an astronomical feature that is influenced by two key factors; orbital inclination of impactors and impact obliquity. Potential impactors, in the form of asteroids and comets, have three sources: - the asteroid belt (which resides in the orbit between Mars and Jupiter), the Kuiper belt (which resides in the orbits of the outer solar system) and the Oort cloud. These objects can be perturbed from their original orbits into potential Earth crossing orbits. These objects are classified as Near Earth Objects (NEO's). Over 3000 NEO's have been identified to date along with their attributes, such as orbital properties. Fig. 3. is a representation of all the current NEO's orbital inclination. Over 70% of all NEO's lay in the 0- 20º inclination range (with respect to the ecliptic). In analogy of the suns radiation as it strikes the Earth, the Polar Regions present a larger surface area. This means that less energy is delivered per Km^2 at the poles compared to the equator. This can be applied to the NEO populations where the exact same is true whereby a large percentage of NEO's orbits follow close to the ecliptic. For this reason, there is a considerably higher concentration of impact craters at the equator compared to the poles. Fig.4. is an impact probability plot using current NEO orbital data. The simulation also integrates the effect of the Earths rotational axis "wobble" and differences in the impact trajectory aspect (i.e. the simulation does not assume that all NEO's are aiming directly towards the centre of the Earth). When analyzing the model, it can be seen that there is generally a 2:1 ratio of probability when comparing the equator with the poles. This equatorial concentration could also be a further reason why the polar gaps are observed in *zone 1* Fig. 2.. Furthermore, the Polar Regions present impactors with a more oblique impact trajectory that may result impact craters being smaller due to prolonged re-entry times and a reduced energy release during impact.

DEVELOPING A NEW MODEL

With the identification of the significance of both Astronomical and Geological factors, how can a new model for impact flux be developed? To answer this, the techniques of developing regression models must first of all be established. With regression models there must first of all be a good reliable database to deduce trends. Once there is a reliable database, then a reliable trend model can be produced. In the case of modelling impact flux, this complete database does not exist. The best alternative to a regression model would be a simulation that approaches the problem from a different stance. Instead of relying on the observed, geological processes could be simulated to establish a rate at which impact craters disappear. From this the flux can be established, for once the correct flux is attained then direct comparisons can be made to the known.

To develop a holistic model we have been developing a simulation that will not only model Astronomical and Geological processes but can also integrate already well established equations for re-entry effects, crater diameter, and effect of impact obliquity such as [1]. This provides a far more accurate way of producing a new model. Our simulation, although still in its basic development stages, is already modelling continental drift and the effects of erosion.

With the simulation complete we will be able to test current models and also develop a new alternative model based on more factors than ever before. Furthermore, the results of the simulation could be applied to other studies and aid in our understanding of other planets.

CONCLUSIONS

Impact flux models based upon regression trend LOG functions were initially seen to be the best way of representing impact flux. However, there are some major factors that have either been overlooked or poorly represented.

As the regression models rely on a database of craters, then producing a model based upon Earths preserved craters would provide a inaccurate model. This is due to the fact that geological processes (Tectonisim, Erosion, and Burial respectively) have removed a vast amount of craters from the Earths surface. Some attempts have been made to integrate a geological aspect into these models [3]. The problem with integrating a geological aspect into a regression model is that the database resolution becomes severely reduced to the point that the model becomes unreliable.

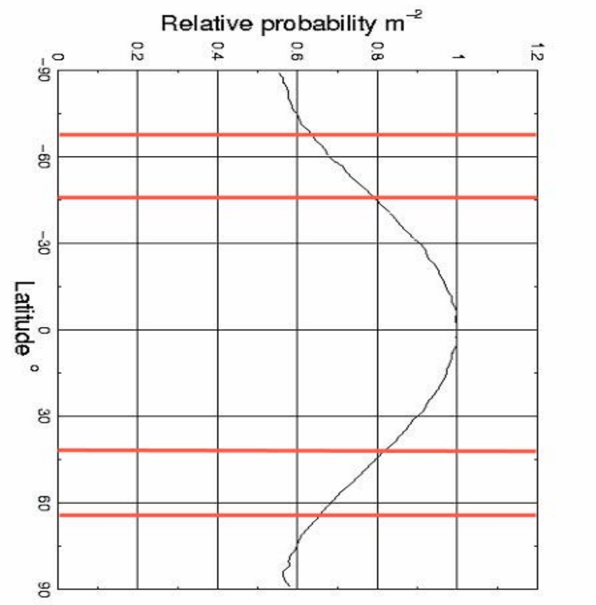

Fig. 4. Impact probability plot using NEO orbital data.

Furthermore, current regression models are expressed in the form of: - A crater of diameter D will occur every X years per $1Km^2$ somewhere on the Earths surface. The problem here is the “somewhere on Earths surface”. It has been proved by our probability simulations that there is a definite equatorial bias of impact crater concentrations. The ratio of concentration between the poles and the equator is about 2:1. This is quite a significant difference and highlights that current regression models cannot be applied accurately to planetary studies.

We regard the best way to develop a new impact flux model would be to produce a simulation that encapsulates all aspects of impacts. By approaching the problem from an alternative perspective, the new model will be far more accurate and furthermore, as the science of impacts develops, so can the simulation.

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