The flight of impact craters based on paleo-positions and its unrestrained latitudinal distribution

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Abstract

Earth's impact craters were analyzed to know the paleo-positions as well as the distance and displacement they have undergone due to plate tectonics. Further, we have verified whether there is any selective distribution across the latitudinal segments. This was achieved through GPlates, a tectonic reconstruction model. The results are intriguing with several craters travelled across the globe. The oldest crater studied was Beaverhead, which travelled from southern to northern hemisphere covering ~39,289 km in 900Ma but with shorter displacement of ~8467km. On the other hand craters like Jänisjärvi and Suvasvesi South have travelled longer distances (27,781 and 29,050km, respectively) and have the distinction of being the most displaced craters (17,400 and 16,988km, respectively). Similarly the paleo-position and the distance as well as displacement for all the craters were recreated.

The latitudinal dependency was also studied. Being a planet with varying land area during different geological ages, calculating area is an arduous task. The area of the equal latitudinal segments, viz. 0-30°, 30-60° and 60-90°, were calculated for the respective number of times of impact crater events and compared with the total land area. Results showed that the first two segments have equal crater frequency whereas the polar segment has lesser frequency and we attribute to plates like Antarctica that remained in polar region throughout the Earth history are less explored owing to harsh climatic conditions. These results are compared to that of the Moon and Mars. This reveals that there is a non-selective distribution of impact craters across latitudinal segments.

Keywords: Impact craters, GPlates, paleo-position, latitudinal dependency, plate tectonics

1 INTRODUCTION

Impact cratering is one of the most fundamental processes of the Solar System *(Shoemaker 1983; French 1998; Osinski and Pierrazo 2013; Schmieder and Kring 2020)*. The existence and importance of meteorite impact events on the Earth, which was not considered an important terrestrial geologic process earlier, has now been generally recognized and accepted as of significance *(Marvin 1986, 1990, 1999; Hoyt 1987; Mark 1987; French 1990b, 2004; Grieve 1991, 1998; Grieve and Shoemaker 1994; Reimold 2003; Reimold and Koeberl 2008)* owing to its role in shaping the planetary surface by forming large circular geological structures, major crustal deformations and generation of large volume of igneous rocks *(French and Koeberl 2010; Li et al., 2018)*. Even the formation of the Moon is described by a 'Giant Impact Hypothesis' when the proto-Earth, called 'Gaia', and a Mars-sized asteroid called 'Theia' collided and the ejected materials aggregated to form the Moon, approximately 4.5 billion years ago *(Daly 1946; Hartmann and Davis 1975; Cameron and Ward 1976; Cameron & Benz 1991; Canup and Asphaug 2001)*. Meteorite impact events also resulted in the generation of important economic mineral and hydrocarbon deposits such as Sudbury (Canada), Ternovka (Ukraine), Carswell (Canada), Redwing Creek (USA), Siljan crater (Sweden) and many more *(Masaitis 1992)*. Huge impact events also had catastrophic effects leading to the mass extinction of several species on Earth *(French and Koeberl 2010)* with the mostdevastating one being the mass extinction event at the Cretaceous-Tertiary (K/T) boundary around 65 Ma due to the impact at

Chicxulub, Mexico *(Alvarez et al. 1980; Schulte et al. 2010)*. Some views consider meteorite impacts as the triggering factor for the commencement of plate tectonics *(Sears and Alt 1992; Tianfeng et al. 1997)*.

Thus, identifying and characterizing impact craters have paramount importance in understanding several global geological processes *(Keerthy et al. 2019)*. Yet, in all crater related studies, be it either solely based on craters and associated features or results derived with craters as the primary focus, the current geographic positions are used. This is despite plate tectonics having forced these craters to chart an itinerary through different latitudinal and longitudinal waypoints from their paleo-positions before ephemerally mooring at the current positions. Plate tectonics not only made the journey of craters possible, but also obliterated and destroyed several of them, leaving only ca. 200 impact craters on Earth. This rarity contrasts to the the presence of numerous craters on other terrestrial bodies like Moon and Mars, ranging in size from less than a meter to hundreds of kilometersin diameter and ages spanning different time periods. Not only plate tectonics, but weathering, erosion and deposition, have all eroded and/or sepulchered many of the earth impact craters. Hence an understanding of the paleo-position of the impact crater, i.e., the geographical graticule at the time of an impact crater’s formation, and its journey from its paleo-position to the current position is essential in gaining a better understanding of several global geological phenomena and possibly alternative theories to explain them.

This study thus is an attempt to decipher the position of the earth impact craters at the time of their formation and to elucidate the journey it has undergone since then. The paleo-position of the terrestrial impact craters was determined using a crossplatform plate tectonic geographic information system (GIS), called GPlates, that enables an interactive manipulation of platetectonic reconstructions (*Müller et al. 2018*). Based on the paleo-reconstruction, an effort has also been made,wherein the position, time and size were compared to understand the latitudinal distribution of impact craters, to know whether any latitude-dependency for meteorite impact events exists. A comparative study on the number and latitudinal distribution of impact craters on the Lunar and Martian terrain is also done, thereby quantifying the cosmic impact events to study its effects on different planetary settings.

Literature review on impact craters reveal that only a few studies have been done using the paleo-positions and also in latitudinal-dependency, but they differ from the aim and scope of the present study. *Kresák's (1964)* work is the first available literature wherein he studied the latitudinal variation of meteor shower using 24 major shower events and with some sporadic background. *Halliday (1964)* was the first to attempt a study exclusively on impact events and concluded that the meteorite falling on the earth is moderately dependent upon latitude. *Thackeray et al. (2006)* studied the latitudinal distribution of impact craters based on crater paleo-positions by correcting the apparent effect of plate tectonics, though the exact paleo-coordinates of impact craters have not been provided. *Wieczorek and Le Feuvre (2008)* studied both the impact flux and cratering rate as a function of latitude using a model distribution of planet crossing asteroids and comets for all the terrestrial planets wherein they concluded a non-uniform impact cratering mechanism. Crater paleo-position was utilized by *Spray et al. (1998)* and *Telecka and Matyjasek (2011)* to study the catena events. Seldom studies, like *Spray et al. (1998)* and *Telecka and Matyjasek (2011)*, been successful in reconstructing the exact paleo-coordinates, but with limited geological time-scale. Thus our study differs from the above mentioned works, by studying the paleo-positions of all the earth impact craters and its journey, latitudinal dependency,and its comparison with the Moon and the Mars.

2 MATERIALS & METHODS

2.2 Database of impact craters on Earth, Moon and Mars

The list of confirmed impact craters of Earth is mainly collected from the Earth Impact Database (*http://www.unb.ca/passc/ImpactDatabase/*), developed and maintained by the Planetary and Space Science Centre, University of New Brunswick, Canada, as well as from several published literatures. Today the total number of confirmed impact craters on Earth comes around 200 in number. Of these structures, the paleo-position reconstruction has been carried out for craters younger than 1100 Ma due to constraints associated with GPlates plate motion model.

The Lunar impact database was obtained from *Robbins (2019)* that is freely available in the website of United States Geological Survey's (USGS) National Aeronautics and Space Administration (NASA) Planetary Data System (PDS) (*https://astrogeology.usgs.gov/search/map/Moon/Research/Craters/lunar_crater_database_robbins_2018*). This database presents a comprehensive record of all the craters with diameter greater than 1-2 km. With 2,033,574 number of identified Lunar impact craters, *Robbins (2019)* presents the largest database than any other previously published data by more than a factor of 10.

Martian global crater database, prepared by *Robbins and Hynek (2012*), is used for the present study. This was also downloaded from the USGS' NASA PDS (*https://astrogeology.usgs.gov/search/details/Mars/Research/Craters/RobbinsCraterDatabase_20120821/zip*). This database is composed of a total of ~ 632,000 craters including those with diameters down to ~ 0.5 km. The global database of Martian impact craters with diameter >1-2 km is used for the present study with a record of 384,343 craters. They provided the extensive database of Martian impact craters, identified manually by using daytime infrared image mosaic by Thermal Emission Imaging System (THEMIS Day IR) aboard the 2001 Mars Odyssey NASA spacecraft; Viking Mars digital image model 2.1 (Viking MDIM 2.1) and Context Camera (CTX) mosaics from Mars Reconnaissance Orbiter (MRO); and Mars Orbiter Laser Altimeter (MOLA) data from the Mars Global Surveyor mission.

2.2 Elucidating the paleo-position of Earth impact craters using GPlates

Paleo-position and latitudinal distribution of Earth impact craters are mainly generated by the plate tectonic reconstruction models offered by the GPlates 2.2.0 software. GPlates, a free desktop software that can be downloaded from *www.gplates.org* and designed for interactive visualization of plate tectonics, was developed by an international team of scientists and software developers at the EarthByte Project (www.earthbyte.org) in the School of Geosciences at the University of Sydney, the Division of Geological and Planetary Sciences (GPS) at Caltech, and the Centre for Geodynamics at the Norwegian Geological Survey (NGU) (*Boyden et al. 2011*). GPlates provides a compiled output of GIS-based interactive plate tectonic reconstructions, and raster data visualization. The application of GPlates, both in visualization and manipulation of plate-tectonic reconstructions and associated data through geological time, enables its usage in finding the paleo-position of terrestrial impact craters distributed over all the continents. The major advantages of using GPlates include handling and visualizing data in a variety of geometries and formats, link plate kinematics to geodynamic models, which serve as an interactive client in a grid-computing network and facilitate the production of high quality paleo-geographic maps. GPlates facilitate the reconstruction of tectonic plates for a single instant in geological time or animate a sequence of reconstructions over a user-specified geological time-period *(Boyden et al. 2011)*. The present study on the paleo-position of impact craters has primarily made use of the PALEOMAP PaleoAtlas for GPlates by *Scotese (2016)* grouped under the paleogeography portal of the GPlates resource (*https://www.earthbyte.org/category/resources/data-models/paleogeography/*). It is composed of 91 paleo-geographic maps spanning the Phanerozoic and late Neoproterozoic. PaleoAtlas database is designed up to only 1100 Ma and therefore in the present study craters of age less than 1100 Ma were selected and that come only 174 craters. The technical constraints limit the reconstruction of plate movements further backwards to its exact origin and would probably be overcome in the near future.

The PaleoAtlas can be directly loaded into GPlates as a time-dependent raster file. For the present study PALEOMAP Global Plate Model has been used, which consists of three separate files -PlateModel, -PlatePolygons, and –PoliticalBoundaries. These files are opened and exported from GPlates to ArcGIS for plotting all the impact craters on its respective plates. The map files of impact craters have been exported into a shapefile suitable for working in the GPlates. The shapefile that consist the craters is opened in the GPlates as a separate layer.

2.3 Ascertaining ages to impact craters

The major constrain faced is in deciding the exact age of impact event as the age determined for the craters comes in different forms like some craters had specific ages (e.g., Spider, Australia with 700 Ma; *Flamini 2019*), whereas some others with minor uncertainties around a specific value (e.g., Lonar crater, India with 0.576±0.047 Ma; *Jourdan et al. 2011*), while some had a range of ages (e.g., Connolly Basin, Australia with ~66 to 23 Ma; *Shoemaker & Shoemaker 1986*), whilst some showed the upper age limit (e.g., Eagle Butte, Canada with <65 Ma; *Grieve 2006*), and some other craters showed only a lower age limit (e.g., Crawford, Australia with >35; *Haines et al. 2005*). Therefore to avoid further confusions, an age, called optimum age, was considered in the present study to compute the paleo-position of the crater, along with distance and displacement recorded by the crater from its original paleo-position. For example, optimum age for Spider was ascertained 700 Ma; Lonar 0.576 Ma; Connolly Basin 66 Ma; Eagle Butte 65 Ma and Crawford 35 Ma. Further paleo-positions were also calculated for the secondary and tertiary ages. For example, where A±U (A=Age Value and U=Uncertainty Value) is mentioned as the age of the crater, we consider A as the optimum age; while A+U is the secondary age (Upper Age Limit) and A-U is the tertiary age (Lower Age Limit); and if crater's age is in a range such as A-B/<A-B/~A-B (where A>B), A is the optimum age and B is the secondary age; whereas for craters with ages <A/≤A/~A, A is considered as the optimum age as it is the only available age for the crater. Thus, there are uncertainties in the paleo-positions, distance and displacement of the craters. For example, Connolly Basin exhibits the paleo-coordinates of -49.86 and 115.04, a distance of 3179.71 km and a displacement of 3041.93 km for the optimum age when compared to paleo-coordinates of -36.92 and 118.28, a distance of 1608.54

km and a displacement of 1608.21 km for the secondary age. The uncertainties can be reduced by the availability of more precision dating techniques.

In the next step plate IDs have been assigned to each crater for establishing the paleo-position and plate motions are animated according to the desired age of reconstruction. For each crater, plate motions have been reconstructed from the time of its formation to present day. The paleo-position of each crater is determined at the age of formation by zooming to the maximum extent at the preposition of craters. Further the motion path of all the craters have been generated marking the trail of craters; this exercise helps estimate the distance covered by craters as they journeyed to their present day location.

2.4 Dissection of Earth into different latitudinal zones and reclassification of impact craters

A little fuzziness was there when the latitudinal division required for the present study had to be selected. Initially the curvature of the arc of the earth at different locations was calculated (Supporting Information 1). But there were no major changes in the curvature at poles and equator. Also the climatic zone classification as Tropic of Cancer and Capricorn as well as Arctic and Antarctic Circles is based on obliquity of the ecliptic. Hence we were prompted to discard the above mentioned two classifications and opt an equal latitudinal distribution classification in which the Earth is divided into three equal latitudinal groups viz., 0°-30°, 30°-60° and 60°-90° (for both Northern and Southern Hemispheres). The reason why an equal latitudinal distribution classification was selected was that it is unbiased in terms of category selection and each category is given the same proportion of the range of values.

After plotting the paleo-position of the impact craters in the latitudinal segments, the crater frequency within each latitudinal segment was calculated. This was carried out by estimating the land area within the three respective zones (in order to achieve a true comparison, we focus solely on the land area. Ocean area was excluded as we have few crater records from it) during the impact event. In order to estimate the land area within the zones, Earth is projected by applying Cylindrical Equal Area Projection. In this projection, the latitudes and longitudes are represented as perpendicular straight lines. Even though the meridians are equally spaced, the spacing between consecutive latitude decreases from the equator to poles (higher latitudes). The main advantage of this projection is conservation of area of Earth by retaining the actual dimensions of features on Earth (*ESRI 2015*). Consequently, there is significant distortion of scale, shape, direction and angle from the equator to the poles; making it a non-conformal projection. Irrespective of this we proceed with this projection to acquire area within each latitudinal segment. It is to be noted that all this study is done from 900 Ma (age corresponding to Beaverhead, the oldest crater considered in this study) to the present day.

The present total surface area of Earth is 510.1 million sq.km, where the area occupied by present day land and ocean are 148.9 million sq. km. and 361.1 million sq.km, respectively. On categorizing the present area of Earth to three zones, the total area (inclusive of land and ocean) of 0-30^{o} segment is 254.7 million sq. km., 30-60^{o} is 186.9 million sq.km and 60-90^{o} is 68.8 million sq.km. While the total area of Earth remains the same in our calculations, the total current land area on Earth computed by shapefiles, imported from GPlates, stand at 190.5 million sq.km and oceans constitute an area of 320 million sq.km. The disparity in actual and computed land and ocean area is associated with the calculation method, where values are retrieved through the summation of area of projected shapefiles, provided in ArcGIS. This method essentially adds the area of oceanic plates like Pacific Plate and oceanic regions of plates like African and South American plates that contain a substantial part of the Atlantic, resulting in additional areas associated with land. For the study, a computed Earth area of 190.5 million sq.km is thus used. On measuring land area of latitudinal zones, areas of oceanic regions are not measured; thereby giving us precise values in these segments for the paleo-positions. The surface area of the Earth is thus downsized to 190.5 million sq.km by eliminating the area constituted by oceans (Video file (3 parts) of the entire methodology is shown in supporting information 2).

3 RESULTS

3.1 Paleo-position and journey of Earth impact craters

Since establishing the first Earth impact crater at Barringer to the present day, the study of terrestrial impact craters has been consequential in providing comprehensive information about several aspects of the planet and the Solar System. But almost all the studies were restricted to the current position of the impact craters, without considering the paleo-position and the journey it has undergone. Therefore, here we done a paleo-tectonic reconstruction of the impact craters and studied the paleo-coordinates, paleo-plates, and the distance travelled as well as the displacement for all the terrestrial impact craters, which was reproduced using GPlates (only the 8 oldest craters are shown in Table 1 due to space constrain and the rest in Supporting Information 3).

Figure 1 shows the paleo-position as well as the present position of the impact craters. The trails in figure 1 connect the paleo- to the current position and this shows that the terrestrial impact craters are geographically sprawled over all continents with the exception of Antarctica. However, when craters are categorized according to paleo-tectonic plates (Table 1), it can be noted that these 174 craters are contained in only 26 tectonic plates (inclusive of micro- and macro-plates) present on Earth. The most extreme case is when a tectonic plate represents the entire continent like Australia, where all craters lie in Australian Plate,whereas Asia form the other end of the extreme, where a comparatively large number of plates constitutes the continent. The Central Honshu, Arabia, Indian Craton, Siberian Craton, North Slope Alaska, Kazakhstan, Indochina and North China Platform plates accommodate the Asian craters. Other major plates like the North American Craton plate contain more than 80% of total crater belonging to North America, while minor plates like Baffin Islands, Yucatan, North Slope Alaska and Piedmont-Florida contain the remaining craters. In South America, the South American Craton contains 73% of craters while the minor Parana Basin plate constitutes the rest of the craters. The African craters are present in 3 plates namely, African Craton, Northwest African and Northeast African Plates. Similarly, European craters are found in North European Craton and Eurasian plates, along with Central Europe and Central Svalbard plates.

The journey of impact craters were derived by ascertaining a single age to crater (which we call here as optimum age), while the age of craters are mentioned with uncertainties, like any other geological samples. In this study the single age, represented by the optimum age, was substituted to all the paleo-positions of the craters. Regarding the journey of the craters, obviously the older craters tend to cover greater distance from respective paleo-positions to reach current positions than the younger craters as plates containing older craters are subjected to longer durations of plate tectonics (Table 1) (paleo-position, distance and displacement covered by the impact craters with respect to the secondary and tertiary ages for all the craters are given in the supporting information 4 and 5, respectively). That being said, it is to be noted that the youngest of craters, like Carancas, Sikhote Alin, Sobolev, Wabar, Whitecourt, Dalgaranga, Kallijärv, Campo Del Cielo, Veevers, Kamil and Luna, hardly describe any movement and therefore, there is not significant change in their proposition. Beaverhead in the USA, the oldest crater in the present study with an age of 900 Ma, covers maximum distance from its paleo-position to current position, valued at 39,289.44 km. With the exception of Beaverhead, there are 3 more craters that have traveled distances greater than 30,000 km, which are Ramgarh, India (750 Ma), Spider, Australia (700 Ma) and Strangways, Australia (657 Ma). The least distance is covered by Ilumetsä (0.007 Ma) at 40.3 m, apart from the above mentioned 11 youngest craters. The distance covered by craters progressively increases from Ilumetsä to Beaverhead. Though distance traveled increases with age, it also depends on crater position on their respective plate and plate velocities. Therefore, craters with similar age might not record similar distance. For example the African craters Gweni-Fada and Aorounga, belonging to Northeast African Plate, with both have primary age 383 Ma, covers similar distance at 11929.38 km and 12033.63 km, respectively. Whereas, the 383 Ma Piccaninny Crater of Australia covered 19114.27 km and North American crater Flynn Creek with an age of 382 Ma covered 15,592.88 km from its paleo-position. Therefore, distance helps in quantifying the path of a crater since its formation.

Displacement is another important parameter. It will be difficult to rely on distance covered (derived from motion path) by a crater to give a simplistic trend in position change of crater as path traversed by a crater changes at several intervals. So, we use displacement to accomplish the same. Unlike distance, which increases with age of the crater, displacement does not show any such correlation and is random. Notably, distance and displacement values are the same for younger craters with ages <5 Ma and are also the same for craters up to age <35 Ma, but beyond 35 Ma, large variations are visible. Jänisjärvi, Russia, has recorded maximum displacement of 17399.78 km (Fig. 2), closely followed by Suvasvesi South, Finland, with 16987.58 km. Many of European craters have moved from the Southern Hemisphere all the way to the Northern Hemisphere, producing displacement values greater than 10,000 km, such as Granby, Lumparn, and Sääksjärvi to name a few. After European craters, Australian craters show significant displacement by moving South from Western Hemisphere through Eastern Hemisphere. Spider Crater has a displacement greater than 10,000 km in Australia. Older aged craters need not show greater displacement than younger craters and this can be exemplified by two North American craters, namely Beaverhead (900 Ma) and Flynn Creek (382 Ma), where Beaverhead is displaced 8467.53 km and Flynn Creek is displaced 9858.21 km. Though the general path followed by both is northward, Flynn Creek is positioned at higher latitude than Beaverhead, by virtue of the different tectonic plates these belong to.

3.2 Dissection of Earth into different latitudinal zones and reclassification of impact craters

The paleo-positions of craters are then classified into one of these three divisions (0°-30°, 30°-60° and 60°-90°). Through this we intend to study crater frequency for each latitudinal class. Several studies have ascertained that meteorite and impact fluxes witness notable variation with geographic latitude (*Halliday, 1964; Halliday and Griffin, 1982; Feuvre and Wieczorek, 2008; Evatt et al., 2020*). The above mentioned studies incorporate a large number of influx events and varied components for analyzing latitudinal variation but the fairly small numbers of terrestrial impact craters restrict our capability of replicating the exact set of results. Hence, we attempt to draw a moderate comparison of our results with the earlier studies.

The land area contained in each latitudinal zone at the time of formation of impact craters is calculated (only the 8 oldest craters are shown in Table 2 due to space constrain and the rest in Supporting Information 6). Figure 3 shows the entire latitudinal segments together with 174 craters with respect to area and age. The latitudinal segment 0-30^{o} constitutes 78 of 174 craters with a diversified age: the oldest crater being Beaverhead (900 Ma) and youngest is Carancas (0.000012 Ma). Between the two age limits, land areas reached their peak in two time periods, namely Ordovician period and Pliocene–Holocene epochs. The average area of this zone, from 900 Ma to present day, is 73 million sq.km. Therefore, a crater is present in every 0.94 million sq.km. area which makes for 1.28% land area of the segment. Proterozoic contributes only two craters in this zone while the remaining 76 craters were added in the Phanerozoic; where Paleozoic with 42 craters contributing over 55% of craters, followed by Cenozoic having 20 craters (26.3%) and Mesozoic recording 14 craters (18.4%)(Fig.4). The 30-60º segment received the maximum number of craters with 80. The most recent crater in this zone is Sikhote Alin aged 0.000072 while the oldest crater is Ramgarh, aged 750 Ma. The variation of land area proportion depicts a hither and thither pattern in the 30-60º latitudinal segment. Land area increases from 27% to 44% from Tonian to Cyrogenian period, after which it consistently decreases till late Ordovician (27%). The average area of this zone computed from 750 Ma to present day is 66.6 million sq.km., where 0.83 million sq.km. area contains a crater. Out of the total 80 craters, 8 (10%) were formed in Proterozoic and 72 craters (90%) in Phanerozoic; wherein, Paleozoic has 12 craters (15%), Mesozoic 26 craters (32.5%) and Cenozoic accounts for 34 craters (42 5%) (Fig.4). The 60-90º latitudinal segment has a relatively small number of craters, probably giving a rather incomplete picture for the segment. The average area of the segment stands at 41.6 million sq.km. Phanerozoic contains the bulk of the crater count with 14 craters (87.5%) and Proterozoic has 2 craters (12.5%). Here, 8 craters (50%) formed in Mesozoic and 6 craters (37.5%) in Cenozoic (Fig.4). The oldest crater formed is Sääksjärvi at 602 Ma, which is closely followed by Saarijärvi at 600 Ma, after which no craters are recorded till Mjølnir at Cretaceous (143 Ma). Macha crater formed at 14 Ma is the most recent crater.

The size distribution of impact craters in these three segments was also studied. Only with 16 craters, 60-90º latitudinal segment has the highest average diameter of 24.08 km owing to the presence of three bigger craters viz. Popigai (100 km), Kara (65 km) and Tookoonooka (50 km). This latitudinal segment was followed by 0-30º segment with 14.84 km average diameter and this segment was characterized by five bigger craters namely, Chicxulub (180 km), Manicougan (100 km), Acraman (90 km), Beaverhead (60 km) and Charlevoix (54 km). 30-60º latitudinal segment has the comparatively smaller average diameter with 12.73 km. Puchezh-Katunki (80 km), Morokweng (70 km) and Kara-Kul (52 km) are the bigger craters in this latitudinal segment.

4 DISCUSSION

The paleo-reconstruction of the modest number of Earth impact craters using GPlates suggests that all the craters, barring the youngest ones, was in different geographical graticule and has travelled several kilometers. The absence of craters between 1100 and 900 Ma makes it difficult to generate a coherent conclusion for older craters. The haphazard movement of plates across the globe also has made the craterstravel from eastern to western hemisphere and vice-versa as well as northern to southern hemisphere and vice-versa. A few of the craters that transitioned between western and eastern hemispheres are Acraman, Spider, Strangways, Lockne, Mizara, Kardla and Malingen; while Kentland, Saqqar, Beaverhead, Suvasvesi South, Janisjarvi and Acraman are a few examples that depict movement between northern and southern hemispheres. Similarly the craters that have formed at similar time have shown differing movements that give indications on which part of the plate moved very fast and which part has movedless. At 458 Ma, the craters Calvin and Brent formed on the North American Craton. Calvin covered 329 km more than Brent to reach its current position, indicating that the portion of the North American plate accommodating Calvin traversed faster than the part containing Brent.

The three different latitudinal segments viz., 0-30^{o}, 30-60^{o} and 60-90^{o} show different crater frequencies. Though the first two segments show similar frequencies irrespective of the ratio of land they possess, the 60-90^{o} segment has less frequency. The 0-30^{o} segment contributes for the most area among the three segments. The comparatively higher crater frequency in this zone is attributed to this increased surface area. The 30-60^{o} segment accommodates a relatively greater proportion of land area (especially in the Northern Hemisphere), increasing the exposure to impact events. This segment has the highest crater frequency with 46%, even though this segment has less surface area than the 0-30^{o} segment. Of the 16 craters in the 60-90^{o} segment, 11 have formed at latitudes between 60-70^{o} ranges, confirming the inaccessibility of the higher latitudes for crater hunting. Additionally the smaller proportion of continental crust also exposes the lower frequency of impact events in the 60-90^{o} segment. But irrespective of the crater locations in the latitudinal segments, most of the youngest craters identified are from developed nations pointing to the importance given to crater research in these nations.

Just to validate the results of the latitudinal dependency of Earth impact craters, we have compared the results with those of the neighboring two terrestrial body viz. Moon and Mars. Selection of these terrestrial bodies are not biased, rather these three, including Earth, form a three end member system: one with active plate tectonics (Earth), one devoid of plate tectonics (Moon) and the other which witnessed plate tectonics initially, but is now a geologically dead planet (Mars). Compared to these two distinct cosmic objects, Earth has only a very small number of confirmed impact craters on its land surface owing to the active surficial geological processes and also due to plate tectonics, which has led to the dynamism of the itinerant Earth across latitudinal zones over time. For example, from 900 Ma to present day, the 0-30^{o} segment has changed from 79.4 million sq.km land area, making for 53% of the total land area on Earth (150.8 million sq.km) and at 0.000012 Ma when the last crater was formed in this segment, it contained 41% of total land with 79 million sq.km out of 190.4 million sq.km. This was overcome by calculating the land area for the respective latitudinal zones for 'n' times ('n' represents the number of impact crater events) and summation was done, which was further used to calculate the average land area. The average land area was used to derive a ratio with respect to the total land area of the Earth at that particular time. This ratio was normalized and the frequency of the impact craters was studied (Table 3).

The databases of impact craters on Moon and Mars were taken from two different sources. Lunar global impact crater database of *Robbins (2019)* is enriched with a total number of ~2 million craters (Supporting Information 7). The database is particularly composed of 1,296,879 craters having diameter ≥1 km, 83,000 having ≥5 km diameter and 6,972 craters having ≥20 km diameters. In the case of Mars some 384,343 impact craters with diameters ≥1 km were analyzed by *Robbins and Hynek (2012)*. Similar to the latitudinal distribution classification applied to the Earth surface, Lunar and Martian surfaces were also classified into three latitudinal groups, viz., 0^{o}-30^{o}, 30^{o}-60^{o} and 60^{o}-90^{o} (for both Northern and Southern Hemispheres). Unlike the terrestrial planetary conditions, there is no scope for determining the paleo-position of lunar craters since there is no change in the location of these craters owing to the absence of plate-tectonics. The paleo-position of Martian impact craters were also not done owing to the limitations in the available reconstruction models for Mars. Therefore the Lunar and Martian impact craters paleo-positions were considered to be the same as of today. Seemingly the geologically dead nature of both Moon and Mars resulted in the preservation of a large number of impact craters across the latitudes, which resulted in the huge difference in impact crater record between Earth, Moon and Mars.

The percentage of crater in each latitudinal range shows good correlation between Earth and Moon (Fig. 5), whereas the slightly variable yet promising values obtained for Mars might be the reflection of long-ceased paleo-plate tectonics that once prevailed on the planet (*Sleep 1994; Connerney et al. 1999*). Despite the technical constraints while collecting the database of impact craters on Earth, Moon and Mars the data that we present here shows a fairly greater percentage of impact craters at the equatorial bulge of the planetary bodies. Meanwhile the crater distribution in the polar regions is sparse. In between the equatorial and polar regions, in the 30°-60° range, the percentage of crater distribution is more or less similar for the Earth, Moon and Mars. While the first two latitudinal segments show high frequency, the polar regions shows less frequency for all the three bodies. The lower surface area exposed in the polar region might have resulted in the lower frequency of impact craters in this segment on the Earth.

Thus in the present study we were able to bring about the latitudinal dependency of impact crater generation on Earth compared to two other neighboring planetary bodies. Besides, comparative latitudinal dependency of impact cratering events, the paleo-position or the original position of the crater at the time of impact have been traced out using GPlates. The paleo-position of impact craters have been obtained for all the possible ages for a particular crater based on its established age. This gives more robust data for the comparison of impact craters on earth to that of the tectonically dead lunar and tectonically dormant Martian surfaces.

5 CONCLUSIONS

The plate tectonic process has immensely modified the surface of the earth, either constructively or destructively. One such ruined geological feature that has a vital role in elucidating several global geological processes is the meteorite impact craters. Though a fistful of studies have been carried out in the field of impact craters, most of the studies were restricted to the present day geographic position of the impact crater. But these impact craters have travelled along with the lithospheric plates through the process of plate tectonics all across the geological time scale. Hence there is a requirement of understanding the paleo-position of impact craters and the flight they have undergone. And thus this study focuses on these issues. Moreover, the rarity of craters in the polar area also prompted us to study whether there is any latitudinal dependence of the impact craters.

With the available capabilities of GPlates, the study was successful in deciphering the paleo-positions of impact craters and the journey they have undertaken since origin through the process of plate tectonics.

Being a paleo-reconstruction study, it has its own advantages and limitations. The main advantages of this study are

i. The vast database generated on the paleo-coordinates, and the distance and displacement the craters have experienced will be robust information that can be used for other studies.

ii. In comparison with the two adjacent terrestrial bodies and the random observation of impact craters of differing sizes on different latitudes, it is suggested that impact events are unrestrained by latitudes.

iii. The haphazard movement of impact craters, owing to plate tectonics, opens anew avenue for studying the plate tectonic history of the earth.

Whereas the major limitations are:

i. The geologic age of all the craters has an ambiguity. Hence to eliminate this ambiguity, we have considered the optimumage. So the paleo-position as well as the distance and displacement will also be an approximation.

ii. The paleo-position of the craters older than 1100 Ma was not deciphered owing to the limitations of the GPlates and this will be overcome when the model is refined.

iii. Projectiles and directions of meteorite fluxes were not attempted as it is beyond the scope of our present work.

Acknowledgments

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References

1. Alvarez, L. W., Alvarez, W., Asaro, F., & Michel, H. V. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science*, ***208*(4448)**, 1095-1108(1980).
2. Boyden, J. A.*et al.* Next-generation plate-tectonic reconstructions using GPlates(Cambridge University Press, 2011).
3. Cameron, A. G. W., & Benz, W. The origin of the Moon and the single impact hypothesis IV. *Icarus*, ***92*(2)**, 204-216(1991).
4. Cameron, A. G., & Ward, W. R. The origin of the Moon. In *Lunar and Planetary Science Conference* (**Vol. 7**)(1976).
5. Canup, R. M., &Asphaug, E. Origin of the Moon in a giant impact near the end of the Earth's formation. *Nature*, ***412*(6848)**, 708-712(2001).
6. Connerney, J. E. P.*et al.* Magnetic lineations in the ancient crust of Mars. *Science*, ***284*(5415)**, 794-798(1999).
7. Daly, R. A. Origin of the Moon and its topography. *Proceedings of the American Philosophical Society*, ***90*(2)**, 104-119(1946).
8. ESRI (2015) https://pro.arcgis.com/en/pro-app/help/mapping/properties/cylindrical-equal-area.htm
9. Evatt, G. W.*et al.* The spatial flux of Earth's meteorite falls found via Antarctic data. *Geology,* **48(7),** 683-687(2020).
10. Le Feuvre, M., &Wieczorek, M. A. Non-uniform cratering of the terrestrial planets. *Icarus*, ***197*(1)**, 291-306(2008).
11. Li, S.S.*et al*. Anatomy of impactites and shocked zircon grains from Dhala reveals Paleoproterozoic meteorite impact in the Archean basement rocks of Central India. *Gondwana Research*, **54**, 81-101 (2018).

12. Flamini, E., Di Martino, M., &Coletta, A. (Eds.). *Encyclopedic Atlas of Terrestrial Impact Craters*(Springer2019).

13. French, B. M. 25 years of the impact-volcanic controversy: Is there anything new under the Sun or inside the Earth?*Eos, Transactions American Geophysical Union*, ***71*(17)**, 411-414(1990).

14. French, B. M. (1998) Traces of catastrophe: A handbook of shock-metamorphic effects in terrestrial meteorite impact structures 1-120 (LPI Contribution no. 954)

15. French, B. M. The importance of being cratered: The new role of meteorite impact as a normal geological process. *Meteoritics& Planetary Science*, ***39*(2)**, 169-197(2004).

16. French, B. M., &Koeberl, C. The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why. *Earth-Science Reviews*, ***98*(1-2)**, 123-170(2010).

17. Grieve, R. A. (1991) Terrestrial impact: The record in the rocks. *Meteoritics*, *26*(3), 175-194.

18. Grieve, R. A. Extraterrestrial impacts on earth: the evidence and the consequences. *Geological Society, London, Special Publications*, ***140*(1)**, 105-131(1998).

19. Grieve, R. A. F. *Impact structures in Canada* p. 210.(Geological Association of Canada 2006).

20. Grieve, R. A., & Shoemaker, E. M. The record of past impacts on Earth in*Hazards due to comets and asteroids*(ed. Gehrels, T.) 417-462(1994).

21. Haines, P. W. Impact cratering and distal ejecta: the Australian record. *Australian Journal of Earth Sciences*, ***52*(4-5)**, 481-507(2005).

22. Halliday, I. The variation in the frequency of meteorite impart with geographic latitude. *Meteoritics*, ***2*(3)**, 271-278(1964).
23. Halliday, I., & Griffin, A. A. A study of the relative rates of meteorite falls on the earth's surface. *Meteoritics*, *17*(1), 31-46(1982).
24. Hartmann, W. K., & Davis, D. R. Satellite-sized planetesimals and lunar origin. *Icarus*, ***24*(4)**, 504-515(1975).
25. Hoyt, W. G. *Coon Mountain controversies: Meteor Crater and the development of impact theory*. (University of Arizona Press1987).
26. Jourdan, F., Moynier, F., Koeberl, C., &Eroglu, S. $^{40}Ar/^{39}Ar$ age of the Lonar crater and consequence for the geochronology of planetary impacts. *Geology*, ***39*(7)**, 671-674(2011).
27. Keerthy, S.*et al.* Reconstructing the dimension of Dhala Impact Crater, Central India, through integrated geographic information system and geological records. *Planetary and Space Science*, ***177***, 104691(2019).
28. Kresák, L. The latitude variation of the meteor shower influx. *Bulletin of the Astronomical Institutes of Czechoslovakia*, ***15***, 53(1964).
29. Mark, K. (1987) Meteorite Craters. University of Arizona Press, Tucson, AZ. 288.
30. Marvin, U. B. Meteorites, the Moon and the history of geology. *Journal of Geological Education*, ***34*(3)**, 140-165(1986).
31. Marvin, U. B. Impact and its revolutionary implications for geology in*Global catastrophes in earth history*147-154 (ed. Sharpton, V. L. & Ward, P. D.1990).
32. Marvin, U. B. Impacts from space: the implications for uniformitarian geology. *Geological Society, London, Special Publications*, ***150*(1)**, 89-117(1999).

33. Masaitis, V. L. The Barringer Medal Address: Impact craters: Are they useful?*Meteoritics*, ***27*(1)**, 21-27(1992).
34. Müller, R.D.*et al.*Gplates: Building a virtual earth through deep time. Geochemistry, Geophysics, Geosystems.**19**, 2243-2261(2018).
35. Osinski, G. R., &Pierazzo, E. Impact cratering: Processes and products. *Impact Cratering*, 1-20(Wiley 2013).
36. Reimold, W. U.) Impact cratering comes of age. *Science*, ***300*(5627)**, 1889-1890(2003.
37. Reimold, W. U., Koeberl, C., Gupta, H., &Fareeduddin, F. Catastrophes, extinctions and evolution: 50 years of impact cratering studies. *Golden Jubilee Memoir of the Geological Society of India*, ***66***, 69-10(2008).
38. Robbins, S. J.) A New Global Database of Lunar Impact Craters> 1–2 km: 1. Crater Locations and Sizes, Comparisons with Published Databases, and Global Analysis. *Journal of Geophysical Research: Planets*, ***124*(4)**, 871-892(2019.
39. Robbins, S. J., &Hynek, B. M. A new global database of Mars impact craters≥ 1 km: 1. Database creation, properties, and parameters. *Journal of Geophysical Research: Planets*, ***117*(E5)**(2012).
40. Schmieder, M., &Kring, D. A. Earth's Impact Events Through Geologic Time: A List of Recommended Ages for Terrestrial Impact Structures and Deposits. *Astrobiology*, ***20*(1)**, 91-141(2020).
41. Schulte, P.*et al.*The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary. *Science*, ***327*(5970)**, 1214-1218(2010).

42. Scotese, C. R. PALEOMAP PaleoAtlas for GPlates and the PaleoData Plotter Program, PALEOMAP Project. *See http://www. earthbyte. org/paleomap-paleoatlas-for-gplates (accessed 17 October 2017)*(2016).

43. Sears, J. W., & Alt, D. Impact origin of large intracratonic basins, the stationary Proterozoic crust, and the transition to modern plate tectonics in *Basement Tectonics 8* (pp. 385-392). (Springer1992).

44. Shoemaker, E. M. Asteroid and comet bombardment of the Earth. *Annual Review of Earth and Planetary Sciences*, ***11*(1)**, 461-494(1983).

45. Shoemaker, E. M., & Shoemaker, C. S. Connolly Basin: a probable eroded impact crater in Western Australia in *Lunar and Planetary Science Conference.***17**, 797-798(1986)

46. Sleep, N. H. Martian plate tectonics. *Journal of Geophysical Research: Planets*, ***99*(E3)**, 5639-5655(1994).

47. Spray J.G., Kelly, S. P., & Rowley, D.B. Evidence for a late Triassic multiple impact event on Earth. *Nature*, **392**,171-173(1998).

48. Telecka, M., &Matyjasek, J. Paleopositions of the chains of the meteorite craters on the Earth in *AnnalesUniversitatisMariae Curie-Sklodowska.***66(1)**, 53) (De Gruyter Open Sp. zoo.2011)

49. Thackeray, S., Walkden, G.M., & Dunn, G.Geological aspects of terrestrial impact cratering rates; simulating the processes and effect of crater removal in *Proceedings of the 40th ESLAB–1st International Conference on Impact Cratering in the Solar System*, ESA-ESTEC,Noordwijk,Netherlands,123-127(2006).

50. Tianfeng, W., Yanhong, Y., &Changhou, Z. On the extraterrestrial impact and plate tectonic dynamics: a possible interpretation. In *Comparative planetology, geological education, history of geology: proceedings of the 30th International Geological Congress, Beijing, China, 4-14 August 1996.* **26**, 87 (1997).

51. Wieczorek, M. A., & Le Feuvre, M. Did a large impact reorient the Moon? *Icarus*, ***200*(2)**, 358-366(2009).

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Figure 1.

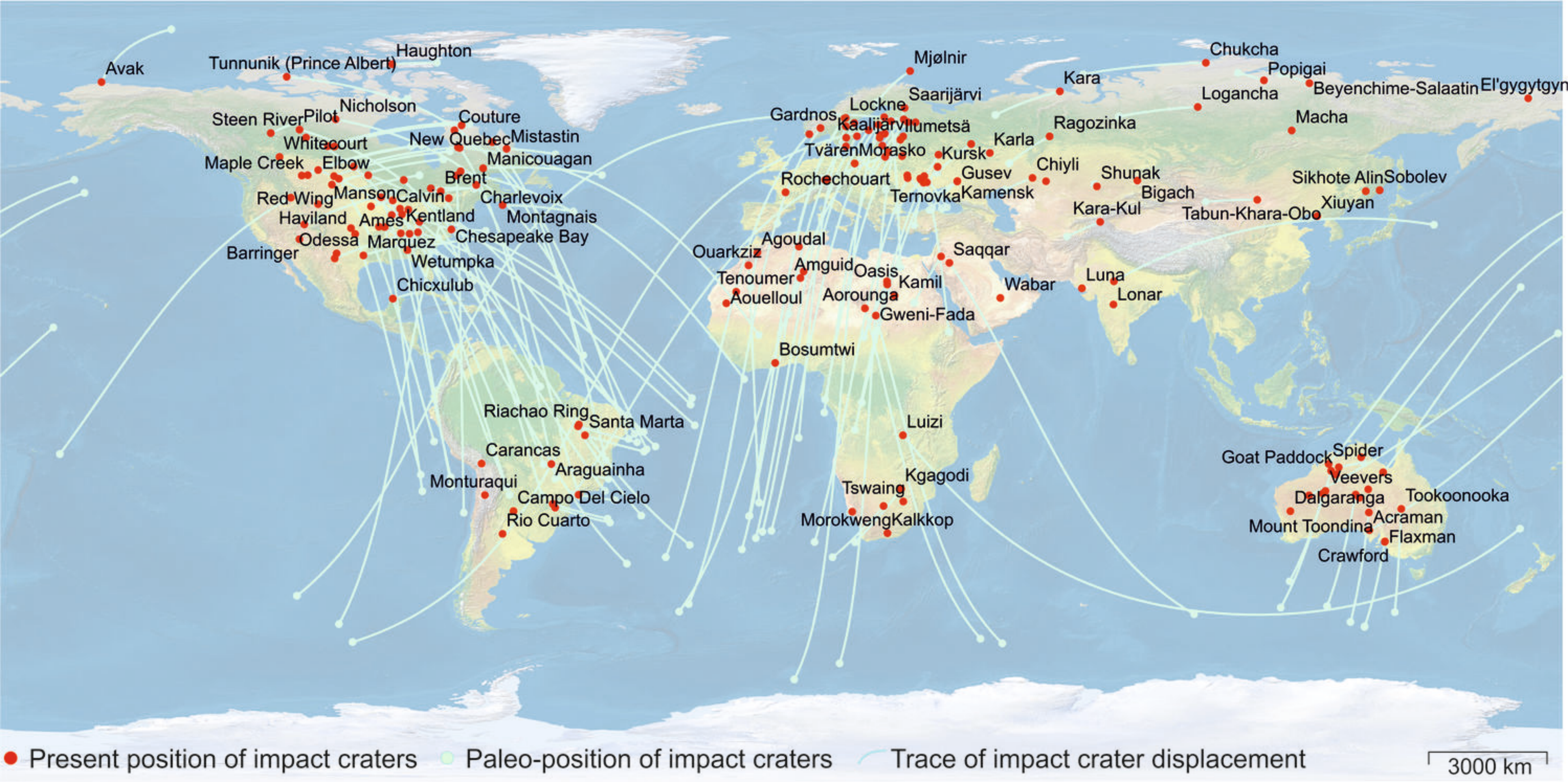
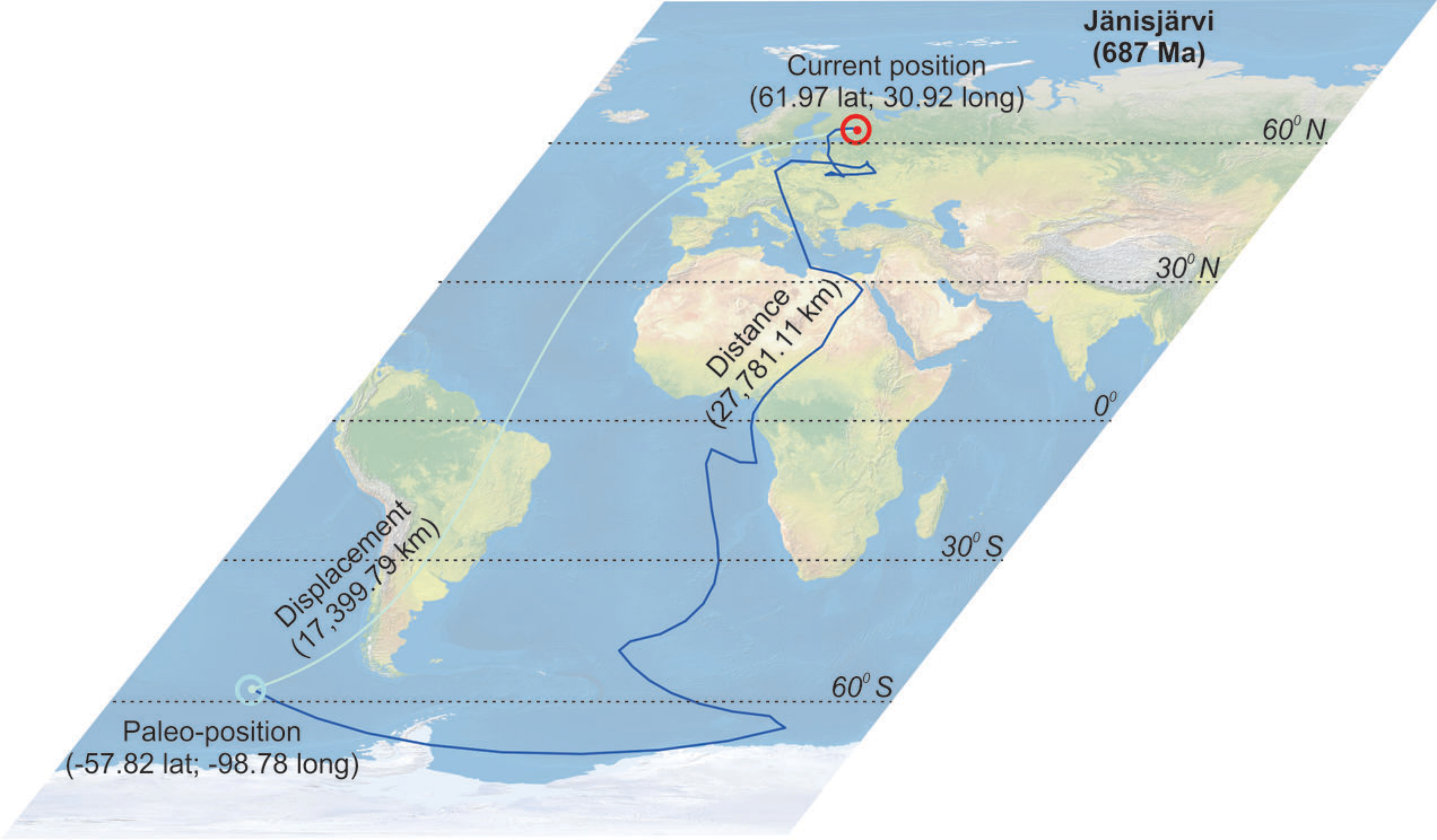
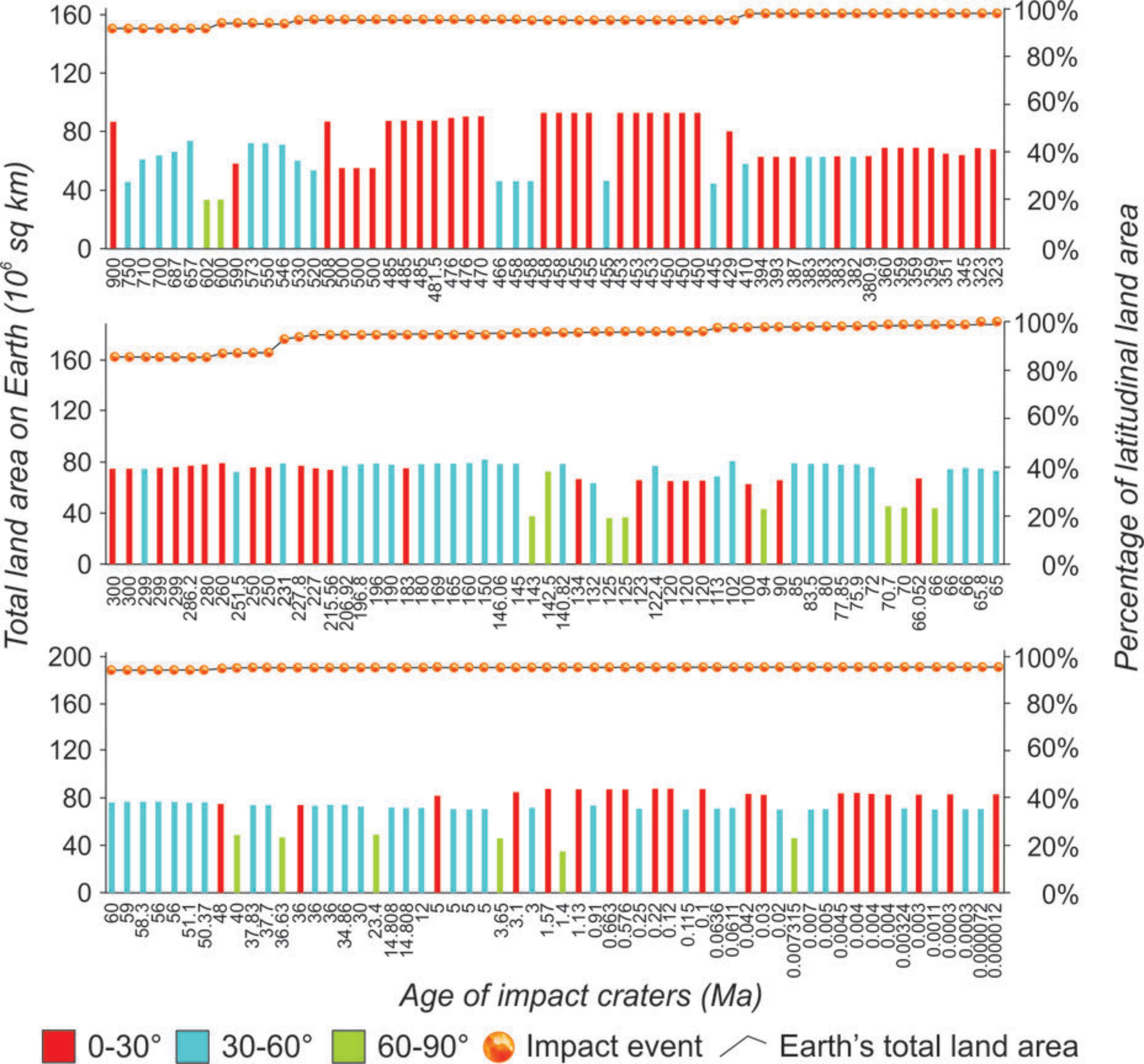

Avak
Tunnunik (Prince Albert)
Haughton
Nicholson
Steen River
Pilot
Couture
Whitecourt
New Quebec
Mistastin
Maple Creek
Elbow
Manicouagan
Brent
Red Wing
Manson
Calvin
Charlevoix
Haviland
Ames
Kentland
Montagnais
Odessa
Marquez
Chesapeake Bay
Barringer
Wetumpka
Chicxulub
Mjølnir
Saarijärvi
Lockne
Gardnos
Kaalijärvi
Ilumetsä
Tvären
Morasko
Kursk
Karla
Rochechouart
Gusev
Ternovka
Kamensk
Kara
Ragozinka
Chiyli
Shunak
Bigach
Kara-Kul
Chukcha
Popigai
Logancha
Beyenchime-Salaatin
El'gygytgyn
Macha
Sikhote Alin
Sobolev
Tabun-Khara-Obo
Xiuyan
Ouarkziz
Agoudal
Saqqar
Amguid
Oasis
Tenoumer
Kamil
Aouelloul
Aorounga
Gweni-Fada
Wabar
Luna
Lonar
Bosumtwi
Riachao Ring
Santa Marta
Carancas
Araguainha
Monturaqui
Campo Del Cielo
Rio Cuarto
Luizi
Kgagodi
Tswaing
Morokweng
Kalkkop
Goat Paddock
Spider
Veevers
Dalgaranga
Tookoonooka
Acraman
Mount Toondina
Flaxman
Crawford
Present position of impact craters
Paleo-position of impact craters
Trace of impact crater displacement
3000 km

Figure 2.



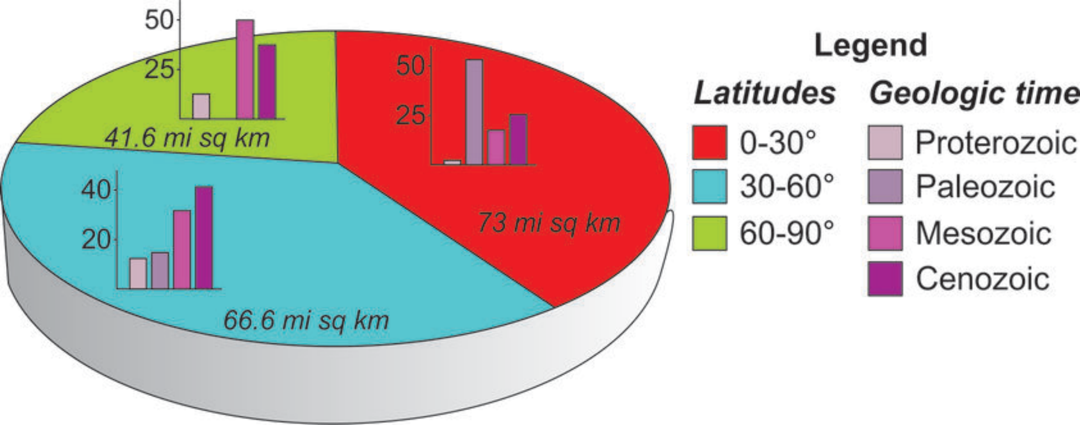
Jänisjärvi
(687 Ma)
Current position
(61.97 lat; 30.92 long)
60° N
30° N
0°
30° S
60° S
Distance
(27,781.11 km)
Displacement
(17,399.79 km)
Paleo-position
(-57.82 lat; -98.78 long)

Figure 3.



Total land area on Earth (10⁶ sq km)
Percentage of latitudinal land area
160
120
80
40
0
200
100%
80%
60%
40%
20%
0%
900 750 710 700 687 657 602 600 590 573 550 546 530 520 508 500 500 500 485 485 485 481.5 476 476 470 466 458 458 458 458 458 455 455 455 453 453 453 450 450 450 445 429 410 394 393 387 383 383 383 382 380.9 360 359 359 351 345 323 323
300 300 299 299 299 286.2 280 260 251.5 250 250 231 227.8 227 215.56 206.92 196.8 196 190 183 180 169 165 160 150 146.06 145 143 142.5 140.82 134 132 125 125 123 122.4 120 120 120 113 102 100 94 90 85 83.5 80 77.85 75.9 72 70.7 70 66.052 66 66 66 65.8 65
60 59 58.3 56 56 51.1 50.37 48 40 37.83 37.7 36.63 36 36 36 34.86 30 23.4 14.808 14.808 12 5 5 5 5 3.65 3.1 3 1.57 1.4 1.13 0.91 0.663 0.576 0.25 0.22 0.12 0.115 0.1 0.0636 0.0611 0.042 0.03 0.02 0.007315 0.007 0.005 0.0045 0.004 0.004 0.004 0.00324 0.003 0.0011 0.0003 0.0003 0.00072 0.000012
Age of impact craters (Ma)
0-30°
30-60°
60-90°
Impact event
Earth's total land area

Figure 4.



Legend
Latitudes
0-30°
30-60°
60-90°
Geologic time
Proterozoic
Paleozoic
Mesozoic
Cenozoic
41.6 mi sq km
73 mi sq km
66.6 mi sq km
50
25
50
25
40
20

Figure 5.

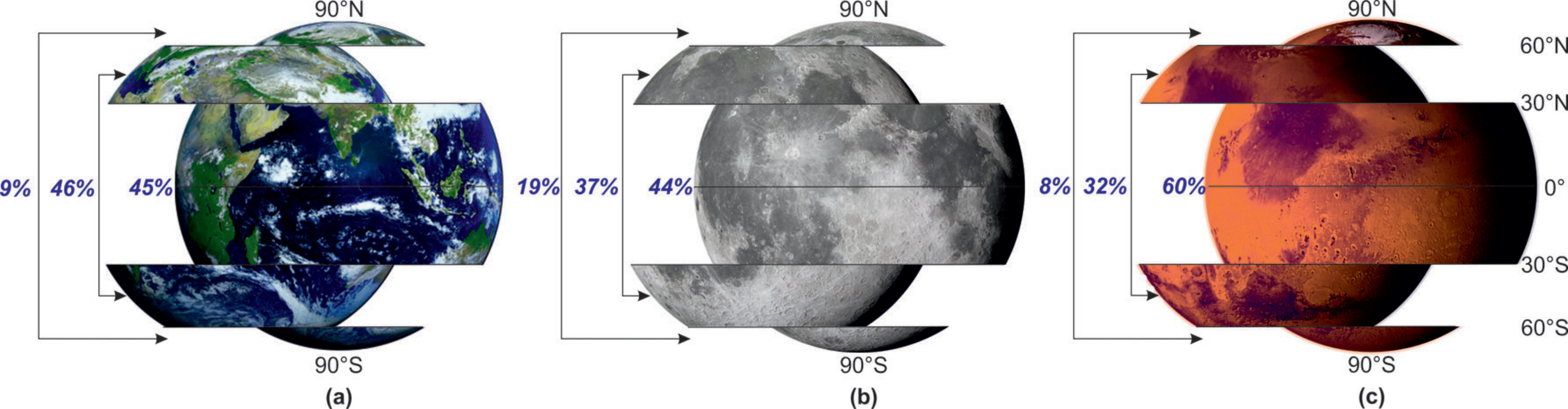

90°N
90°S
9%
46%
45%
(a)
90°N
90°S
19%
37%
44%
(b)
90°N
90°S
8%
32%
60%
60°N
30°N
0°
30°S
60°S
(c)

Table 1 Inventory of Earth impact crater showing diameter, age, paleo- and present coordinates, paleo- and present plates, distance and displacement it has undergone since its origin

1(a)												
Sl No.	***Name of crater***	***Present Coordinates***		***Paleo Coordinates***		***Diameter (km)***	***Age (Ma)***	***Age ascertained to obtain paleoposition (Ma)***	***Present Continent***	***Palaeo Plate***	***Distance Travelled (km)***	***Displacement (km)***
		Latitude	*Longitude*	*Latitude*	*Longitude*							
1	Beaverhead	44.60	-113.00	-14.48	-166.25	60	900-470	900	North America	Eastern Basin and Range	39289.44	8467.53
2	Ramgarh	25.33	76.62	38.35	150.35	10	~750-165	750	Asia	Indian Craton	34781.57	6944.90
3	Suvasvesi South	62.59	28.21	-47.15	-111.63	3.8	710	710	Europe	Northern European Craton and Eurasia	29049.88	16987.59
4	Spider	-16.74	126.08	48.70	-162.90	13	700	700	Australia	Australia	30648.55	10062.85
5	Jänisjärvi	61.97	30.92	-57.82	-98.78	14	687±5	687	Asia	Northern European Craton and Eurasia	27781.11	17399.79
6	Strangways	-15.20	133.58	45.73	-160.56	25	657±43	657	Australia	Australia	30061.48	9434.53
7	Sääksjärvi	61.41	22.38	-66.43	2.93	6	602±17	602	Europe	Northern European Craton and Eurasia	22157.92	14270.45
8	Saarijärvi	65.29	28.39	-62.72	13.41	1.5	<600-520	600	Europe	Northern European Craton and Eurasia	22229.02	14254.54

Table 2 Latitudinal distribution of Earth impact craters

Sl. No	***Crater***	***Optimum Age***	***Paleo-latitude***	***Latitudinal Segment (degree)***	***Total land area on Earth (sq. km)***	***Land Area at segment (sq. km)***	***Latitudinal land area: Total land area***
1	Beaverhead	900	-14.47977	0 - 30	150822000	79449771.58	0.53
2	Ramgarh	750	38.354821	30 - 60	150747700	41344488.96	0.27
3	Suvasvesi South	710	-47.148474	30 - 60	150893900	54716479.65	0.36
4	Spider	700	48.697584	30 - 60	150930000	57177834.07	0.38
5	Jänisjärvi	687	-57.818	30 - 60	150974400	59951241.09	0.4
6	Strangways	657	45.725044	30 - 60	150974400	66464619.2	0.44
7	Sääksjärvi	602	-66.426342	60 - 90	151119200	29884525.5	0.2
8	Saarijärvi	600	-62.722825	60 - 90	154362700	31108415.89	0.2

Table 3 Comparison of impact craters on Earth, Moon and Mars for the different latitudinal segments

	Earth				Moon			Mars		
Latitudinal Segments	***Ratio of latitudinal area to total area***	***Normalized ratio***	***No of Craters***	***% of crater***	***Ratio of latitudinal area to total area***	***No of Craters***	***% of crater***	***Ratio of latitudinal area to total area***	***No of Craters***	***% of crater***
0°-30°	0.4309	0.4182	78	45	0.5607	576155	44.43	0.5781	231912	60.34
30°-60°	0.3726	0.3616	80	46	0.3635	479174	36.95	0.3490	122997	32.00
60°-90°	0.2269	0.2202	16	9	0.0758	241467	18.62	0.0729	29434	7.66
TOTAL	***1.0304***	***1.0000***	***174***		***1.0000***	***1296796***		***1.0000***	***384343***	

°