Platinum Jubilee

Physical Research Laboratory

MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

30th November, Tuesday

Session-5: Impact Shocking and Shattering!!!

Session Chairs: Deepak Dhingra & Dwijesh Ray

Abstract #	Time	Speaker	Title
Invited	13:30-13:45	Jayanta K. Pati	Overview of impact crater/structure
S5-01	13:45-13:55	Dwijesh Ray	The Ramgarh structure is 2.4 km or 10 km in size? Not settled yet!
S5-02	13:55- 14:03	Saranya R. Chandran*	Quantifying erosion rate for terrestrial meteorite (simple) impact craters using paleoclimate and other parameters
S5-03	14:03-14:11	Anuj kumar singh*	Fabric disposition of granitoid clasts in monomict breccia from the Dhala Structure, India
S5-04	14:11-14:19	Rahul Das Gupta *	Constraints on the age and diameter of the Dhala crater based on the provenance of the sedimentary rocks on the Central Elevated Area and the morphological characteristics of the crater
S5-05	14:19-14:27	S. James*	Terrestrial Impact Craters as Potential Sites for Exploration of Economic Resources
S5-06	14.27-14.35	Asif Iqbal Kakkassery	A Geomorphologic Study of Possible Glacio-Fluvial Landforms in An Unnamed Impact Structure in Xanthe Terra, Mars
S5-07	14.35-14.43	P. M. Thesniya*	Morphology and Ejecta Emplacement Dynamics of the Das Crater on the Lunar Farside: Insights into the Impact Dynamics and Cratering Mechanics of the Moon
S5-08	14:43-14:48	Harshal Ponekar	Numerical Modelling of Lonar Impact Crater

The Ramgarh structure is 2.4 km or 10 km in size? Not settled yet!

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The Impact-cratering is a fundamental geological process in our Solar System for shaping the surfaces of planetary solid bodies. When asteroids or comets struck on the planetary surface, it generates ellipsoidal/spherical depressions called impact craters with fracturing and finally melting of the target rocks [1]. The severity of impact process could include global biological mass extinction (e.g. Chicxulub crater in 66 Ma) and often produces valuable mineral (Sudbury Cu-Ni-PGE deposit) or a suitable reservoir for petroleum and groundwater reserves. Though the result of large impacts on Earth is devastating, the impact has also important implications for space exploration and could hold clues on understanding the origin of life [2].

The Ramgarh structure (centred at 25^{o}20$^/$N, 76^o 38$^/$E) in Rajasthan, India is the only known confirmed asteroid impact crater in India that excavated the sedimentary target-rock [3,4,5]. The target-rock includes Mesoproterozoic Vindhyan Supergroup of sedimentary rocks. Recent field investigation, palaeontological studies, along with studies on the high-resolution satellite images suggest that this complex crater formed in a shallow water environment during the Callovian (Upper-Middle Jurassic) by an oblique impact along SW to NE [4]. Further, in-situ microprobe analyses on the relict native iron globules present in glassy pieces recovered from the soil formed on the outer slope of the crater's rim suggest that the impactor could be a Cu-rich iron meteorite [5]. This structure is the third known confirmed asteroid impact crater in the Indian sub-continent after the Lonar crater and Dhala crater.

There is an ambiguity exists on the actual size of this complex, degraded, impact crater and currently two alternative opinions exist. It has been suggested that the Ramgarh crater is a ring-like prominently rectangular structure with a rim-to-rim diameter of ~2.4 km, it has a small conical peak of ~6 m and a diameter/depth ration of ~12 [5]. The alternative idea suggests that the structure has an apparent diameter of ~10 km, and its present exposed morphology actually represents its eroded central uplift [4]. However, the actual rim is hardly recognizable, and boundary of this ~10 km structure is mainly inferred based on a few discontinuous, arcuate shaped, concentric lineaments identified in satellite images to the northern part of the present exposed morphology of the Ramgarh crater [4]. Future drilling is necessary to resolve this issue and also to better understand the impact process and products at Ramgarh.

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Quantifying erosion rate for terrestrial meteorite (simple) impact craters using paleoclimate and other parameters

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Abstract

The surface of the earth is sculptured by the erosional activities of various geological agents. In the process of erosional landscaping several morphological features are continuously modified for ages. Hergarten and Kenkmann[1] have estimated the long term erosion rate on the surface of earth as a function of present-day topography and climate using the impact-crater inventory. Influence of erosion is most often manifested in positive relief features. The erosion rate of excessive erosive regimes such as shield, orogeny and igneous province are expressed through a linear relationship, $r = \Delta s$, connecting topographic relief and erosional efficacy[1]. The study aims to estimate the long-term erosion rate of thirteen terrestrial simple impact craters by taking into account the influence of various climatic zones experienced by the crater and the geological province in which the crater is located. Simple impact craters formed by hypervelocity meteorite impact events are chosen since they constitute immaculate geological formations preserving original morphology in most cases. The temporal range of each crater in distinct paleoclimatic zones is identified and analyzed in this study[2] for a better understanding of the influence of climatic zones on erosion. The erosion rate of the regional geological province hosting the impact craters and the erosion rate of the individual crater are estimated separately using two methods. The first method considers the relief of the geological province where the crater was originally formed and the second method calculated the initial relief of the transient impact crater using a set of crater morphological parameters. The relief calculated using these independent methods is substituted to the equation $r = \Delta s$ to identify the rate of long-term erosion. The estimated values of long term erosion rates are correlated with the erosion rates of craters reported in past literature. The variations observed between the actual and estimated erosion rates of some impact craters are attributed to dynamic evolutionary trends of terrestrial simple impact craters.

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[2] G. K. Indu, S. James, S. R. Chandran et al. (2022) Geomorph., **397**, 108007.

Fabric disposition of granitoid clasts in monomict breccia from the Dhala Structure, India

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The ~11 km wide Paleoproterozoic Dhala impact structure, north-central India comprises distinctive concentric domain of monomict granitoid breccia in the outermost annular region of the structure [1, 2]. This morpho-lithological unit holds a ring of more than 200 outcrops of irregular shape and elevation which are discontinuously exposed around the central elevated area (CEA) covering an annulus of about 28 km^2 areal extent [3]. These monomict breccias consist of granitoid clasts, larger grains of K-feldspar, and rare quartz fragments embedded in a clastic matrix of nearly similar composition. In the present study, we have carried out a comprehensive study of shape, size and orientation of granitoid clasts at various monomict breccia outcrops. The measurement was recorded for about six thousand clasts, generally of fine- to coarse-grained texture. The result shows that the clasts are of variable shapes (e.g., square, angular to sub-angular, rectangular to sub-rectangular, triangular, pentagonal etc.) and sizes (<1 cm to 2.81 m). These granitoid clasts originated during the brittle failure of the target rocks. The aspect ratios of clasts vary between 1 and 12.68. Their average aspect ratios also vary from one outcrop to the other in each of these eight zones (Zone-1: 1.000-4.435; Zone-2: 1.016-12.676; Zone-3: 1.100-4.800; Zone-4: 1.032-7.667; Zone-5: 1.026-5.125; Zone-6:1.000-4.159; Zone-7: 1.000-1.703; Zone-8: 1.040-8.333) classified at 45° angular interval with respect to the centre of the CEA. However, the frequency distributions of granitoid clasts measured in these zones are also variable (1091, 239, 267, 363, 266, 281, 2338, and 1175, respectively) depending upon the number of exposed monomict breccia outcrops and their areal extent. The outcrops as well as the size of clasts are relatively larger in the N-NNW direction with respect to the CEA. The long axes of granitoid clasts show random orientation indicating minor effect of post-impact tectonic deformation on monomict breccia bodies.

References: [1] Pati et al. (2008a) *MAPS*, **43(8)**, 1383-1398. [2] Pati et al. (2019) *MAPS*, **54(10)**, 2312-2333. [3] Singh et al. (2021a) *ESPL*, **46(8)**, 1482-1503.

Constraints on the age and diameter of the Dhala crater based on the provenance of the sedimentary rocks on the Central Elevated Area and the morphological characteristics of the crater

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Introduction: The Dhala structure near Jhansi, Madhya Pradesh, is a rare terrestrial impact crater formed in the Proterozoic Era [1]. This crater is hosted within the Bundelkhand granitoid rocks and its age is estimated to be 2.24 - 2.44 Ga, based on $^{207}Pb/^{206}Pb$ ratios of zircons in quartz reefs, near the rim of the Dhala crater [2]. The only large-scale identifiable feature of this complex crater in the field is a Central Elevated Area (CEA). The CEA is likely to be the central peak, which forms due to basement rebound in complex craters [1].

Research gap and significance of this work: The CEA comprises a sequence of sandstone and shale, which belong to the Vindhyan Supergroup of sedimentary rocks. The presence of shocked quartz grains in sandstone from the CEA has been attributed to fluvial deposition of crater ejecta into the crater cavity [3]. However, geochemical studies on these sedimentary rocks have not been done. In this study, the provenance of these sedimentary rocks from the CEA is further investigated using Nd isotopic compositions.

Results and Discussion: The distinctly radiogenic $\varepsilon_{Nd(0)}$ of the DH-CEA samples suggest their source is not linked to the brecciated granitoids in the Dhala crater (Fig. 1). The DH-CEA sample, DH-6, which is a shale from the base of the CEA, shows the least radiogenic $\varepsilon_{Nd(0)}$ and the oldest T_{DM} of 3.6 Ga (Fig. 1). In contrast, the sandstone sample, DH-8, collected near the top of the CEA, shows a younger T_{DM} of 2 Ga and the most radiogenic $\varepsilon_{Nd(0)}$ (Fig. 1). These results suggest that the sedimentary rocks in the CEA were derived from both the Lower Vindhyan and the Upper Vindhyan Supergroup, which implies that the Dhala crater formed before the deposition of the Vindhyan Supergroup ~ 1700 Ma ago [3]

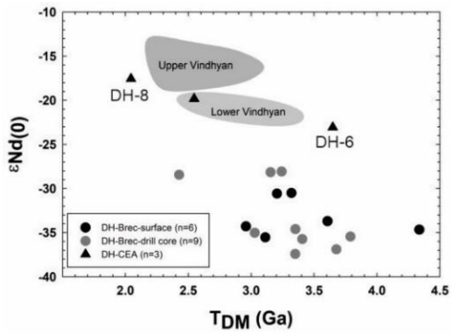

Fig. 1: Plot of T_{DM} versus $\varepsilon_{Nd}(0)$ for all samples from the Dhala crater. The data for the Vindhyan Supergroup rocks are taken from Chakrabarti et al. 2007.

The diameter of the CEA (D_{cp}) at Dhala is 2.5 Km and its altitude (h_{cp}) is 426 m [1]. Based on morphometric measurements of 15 complex craters, the diameter of the central uplift is 0.228 times the crater diameter [5]. Based on this relationship the diameter of the Dhala crater is 8.9 Km, which is similar to the estimate of 11 Km [1]. However, the altitude of 426 m is much less than the expected structural uplift, given by $h_{su} = 0.1D_c$ [6]. This discrepancy is due to deposition and erosion of sedimentary rocks, after the formation of the crater (Fig. 2).

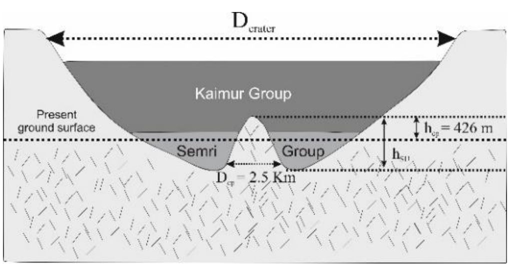

Fig. 2: Schematic representation of the morphological features of the Dhala crater

Conclusions: The origin of the sediments in the CEA from the Vindhyan Supergroup is consistent with the formation of the Dhala crater nearly 2.5 Ga ago. The morphology of the CEA and its relationship with the crater, confirms that this is the central uplift that typically forms in complex craters.

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Terrestrial Impact Craters as Potential Sites for Exploration of Economic Resources

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Contents of Abstract: Among the 210 terrestrial impact craters, 60 house economically significant natural resources. The resources range from metals such as iron, lead, zinc, nickel, copper and cobalt to uranium, coal and hydrocarbons, along with notable hydropower resources. The above resources are specifically critical to the energy industry today, given the growing stress on the demand-supply owing to continued global population growth. Impact craters catalyze the discoveries of associated resources/deposits, while mineral deposits help the identification of impact craters.

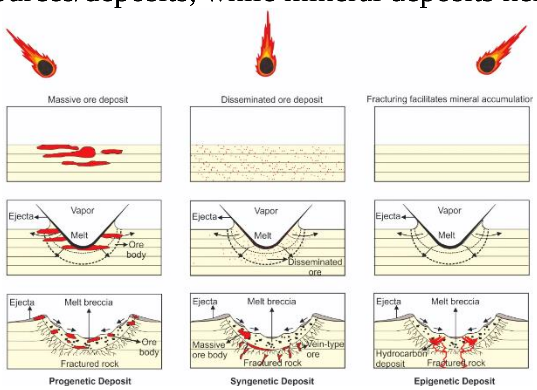

Fig1: Mineralization associated to impact cratering event

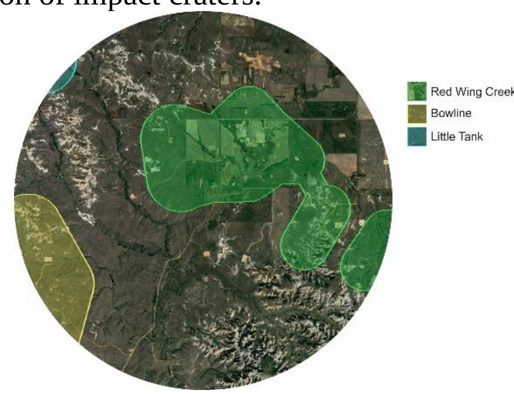

Fig2: Hydrocarbon centered at CEA of Red Wing crater

Terrestrial craters aid the exposure, formation and preservation of mineral resources, as signified by diverse modes of genesis of resources (Fig1). The progenetic deposits occur when the impact event exposes pre-established ore deposits which until the moment of the impact, was present at near/sub-surface levels. Gold and uranium ores at Vredefort (South Africa), iron ores at Ternovka (Ukraine) and uranium mineralization at Carswell (Canada) are major examples of progenetic mineralization [1,2].The syngenetic deposits form due to contributions of the impact melt in enriching and mobilizing elements present in target to economically significant quantities. Syngenetic mineralization mainly occurs during the mid to late excavation stages of the impact cratering event have produced the Ni-Cu and PGE deposits at Sudbury. Lastly, epigenetic deposits include the hydrocarbon deposits at craters such as Avak and Ames (USA), wherein the morphological and structural units of caters aid both the maturation and importantly, the preservation of the hydrocarbons. Mineral deposits associated with craters show two characteristics which are reflected as (1) circular/semi-circular/arcuate deposit distribution and orientation and (2) deposit associations with proximal impact derivatives such as ejecta deposits, melt units, brecciated target rock fragments and shatter cones. The application of remote sensing techniques will accelerate the discoveries of craters and mineral resources as shown in hydrocarbon field at Red Wing crater's CEA (Fig2). The study showcases the potential of remote sensing in reducing the time delay to provide the energy resources associated with impact craters, to the market supply chains.

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A Geomorphologic Study of Possible Glacio- Fluvial Landforms in An Unnamed Impact Structure in Xanthe Terra, Mars

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Impact craters on Mars are remnants of late heavy bombardment events that occurred at around 3.9 Gyr ago. The records of the geologic history of the surface are still preserved within Martian craters. Whereas from the impact craters of the Earth, little geological history is known due to active erosion [1]. This study focuses on the unnamed crater located in the Xanthe Terra (3^0 S 52^0 W) at around 200 km northwest of the Ganges Chasma region of Valles Marineris. The study area is an isolated depression in the region having an average depth of 3 km. Fluvial features like interior layered deposits (ILDs) [3], lakes[4], alluvial fans or deltas[5], massive landslides[6], valley network, and outflow channels[7] have been reported in the surrounding regions of the crater (e.g., Ganges, Juventus, Capri, Eos Chasmata of VM) where possible involvement of subsurface processes has been proposed. Therefore, similar features are expected to be present in the crater. Due to the great depth of the crater, it is likely to have preserved the evidence for the subsurface fluvial features. The study investigates the presence of fluvial or glacial features in the crater and attempts to address the associated subsurface processes using high-resolution imagery from Context Camera (CTX) and HiRISE onboard Mars Reconnaissance Orbiter combined with MOLA DEM,. The study area is a fairly large complex crater with an average diameter of 78 km, with a discontinuous peak ring complex around a central peak mound, terraced walls, and floor deposits. The crater floor is highly rugged in nature with aeolian features like Transverse Aeolian Ridges (TARs) and Large Dark Dunes (LDDs). The Theater-head valleys show fluvial activity, which emerged from the southern crater wall and spread out as alluvial fans to the crater floor. Similar alluvial fans are observed on the west wall and in the region between the central peak mound and the arc of the peak ring massif on the east part of the crater. Braided sinuous ridges are observed to be formed at the confluence of alluvial fans. At the terminus of alluvial fans, bench-cut-like eroded platforms are also noticed. The tongue-shaped flows observed on the hill slopes of peak ring complexes are interpreted as glacial flows with lateral and end moraines [10]. Large massive flows are encountered on the north, west, and east crater walls. Linear ridges, grooves, and the layered lobate base resemble the massive glacial flows seen on Earth. Hence, the flows observed in the study area are inferred as Gelifluction lobes which can be compared with the flows observed on the Taylor valley of McMurdo DryValleys, Antarctica, [11] [12]. Small scale overlapping viscous flow features noticed on the troughs of east and west crater walls have tongue-like shapes. These features are similar to the debris covered glaciers in the Mullins glacier, Antarctica [11]. The study put forward possible evidence for fluvial and glacial features resulted from an impact event that occurred in the Xanthe terra region where subsurface water is preserved.

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Morphology and Ejecta Emplacement Dynamics of the Das Crater on the Lunar Farside: Insights into the Impact Dynamics and Cratering Mechanics of the Moon

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Abstract

Impact cratering is considered to be the most fundamental geologic process in our solar system. The Copernican impact craters on the Moon are the best sites to study the lunar impact cratering mechanics. The present study attempted to carry out an in-depth mapping of the morphological units and ejecta facies of the Copernican Das crater on the lunar farside to get better insights into the cratering processes associated with projectile impacts on the Moon.

The morphological mapping interior to the crater cavity revealed the characteristic geological features of this complex impact crater, starting from the sharp and scalloped rim, an alcove of wall terraces, the distinct scarp-tread system with steep slopes on the scarp, wall slumping, impact melt deposits, flat floor with hummocky texture, slump hillocks on the floor, melt platform, and central mounds with bedrock exposures. These distinct morphological units suggest that the Das crater was originally formed as a simple bowl-shaped crater, which later modified to become a complex crater. The excavation of the transient crater cavity for the Das crater took place in less than 4 seconds. The maximum depth of excavation is estimated to be 3 km. The transient crater diameter is projected to be 30.4 km, and the transient crater depth ranges between 7.6-9.12 km. The crater excavation was concurrent with the ejection of shocked and melted debris outward as impact ejecta. The modification of the crater began even before the central mounds rose from depths of maximally compressed rocks at around 3.2 km. The subsequent gravitational collapse of the rim produced terraced, steeper walls resulting in a slight widening of the crater rim along W-E and enlargement of the final diameter to 38 km. The wall slumping occurred at a larger scale on the western inner wall, and the slumped materials slid down to form heaps of hillocks, mainly in the western section of the floor. The

rotational slumping of the inner wall with their toes reaching the base of the crater to form a small plug has partly contributed to a segment of rising central mounds. The eastern crater floor has undergone subsidence, likely due to structural failure and/or cooling of the initial melt column. The impact melts line the transient crater cavity throughout its growth and are emplaced in a variety of topographic settings ranging from ponds in the wall terraces to extensive melt sheets along the inner wall slopes and the melt-draped floor units. The melt breccia, fractured impact melt deposits with boulders at their margins, and distinctive flow features appearing as melt fronts or flow lobes concentrated on the inner wall of the crater are diagnostic in determining their origin as impact-generated melts. Exterior to the crater cavity, solid and melt phase ejecta are distributed around the crater, with the highly shocked debris materials occurring at radial distances beyond the rim and melted debris preferentially occupying the topographic lows and slopes both inward and outward the crater rim.

Four distinct ejecta facies identified around the crater exhibit similarity in physical characteristics, spatial distribution and maximum radial extents. The ballistic ejecta facies are emplaced as continuous ejecta blanket (proximal to the crater rim) and discontinuous ejecta (beyond the extent of contiguous ejecta blanket), both distributed at varying radial distances from the rim. The onset of discontinuous ejecta blanket is marked by the appearance of the herringbone pattern consisting of linear clusters of elongated secondary craters or V-shaped depressions pointing back to the crater. The radial facies showed a slight deviation from their expected orientation as a result of interaction with the underlying topography controlled by remnant ridges of the SPA basin ring. The emplacement of the radial ejecta facies, including the contiguous blanket and the secondary crater chains, occurred concurrently during the mixing of fallen ejecta with the surface materials. The resulting ground-hugging flow of mixed materials caused infilling of the secondary crater chains and subsequent overprinting by the contiguous ejecta blanket. The melt-bearing ejecta is distributed as rim veneer deposits and ponded melt and lobate deposits within 7 km radial extents from the rim crest, and they completely overlie the contiguous ejecta blanket.

The non-uniform distribution of ballistic ejecta facies around the crater and maximum radial extents to the northwestern and southeastern quadrants than the less extensive deposits towards the southwest and NNE indicates overall asymmetric ejecta with a bilateral symmetry along the line running NNE-SSW through the centre of the crater. The presence of a forbidden zone devoid of distal ejecta rays and secondary crater chains to the NNE suggests that the direction of the impact was NNE-SSW. The near circular form of the crater, along with a clearly defined forbidden zone in the uprange, indicate that the impact occurred at an angle between

15°-25° to the horizontal. The interpretations from the present study demonstrate that studying Copernican craters are crucial for expanding our knowledge on the impact dynamics and cratering mechanics of the Moon.

Numerical Modeling of Lonar Impact Crater

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Abstract:

Lonar Lake is one of the kind hyper velocity impact crater formed in basaltic terrain in Buldhana district of Maharashtra, India. It has radius of 915 m and maximum depth of 150 m [1]. There have been a few attempts to model the impact event and estimate the diameter and type of incoming meteor. These results are summarized in the Table 1. However most of these simulations are either empirical or use fairly crude approximations of the impact event. Moreover none of the studies so far have taken in to account the underlying granitic basement below the Deccan Traps. Here we investigate the role of granite gneiss serving as sub surface to basalt lavas at Lonar and finding size and impact velocity of meteorite that has produced the Lonar crater. We have numerically modeled and simulated impact event using both basalt only and basalt-gneiss target surface combinations, with help of state-of-art iSALE2D shock physics code [6]. Our analysis concludes that the crater is formed by the iron meteor of 55m radius with impact velocity of 60 km/s. We estimate that during the impact the transient crater reached the depth of 414m before settling to 154m within 4 seconds.

Meteorite Radius (m)	Meteorite Velocity (km/s)	Reference
17.5	20	[2]
20	50	[3]
27.5	20	[3]
30	25	[4]
50	18	[5]
55	60	Present study

Table 1. Summary of Meteorite Parameters from Previous Studies

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