LONAR IMPACT CRATER, INDIA: DID IT FORM BY OBLIQUE IMPACT? Saumitra Misra[1], P. K. Srivastava[1] and Anand Dube[2], [1]Department of Geology & Geophysics, Indian Institute of Technology, Kharagpur - 721 302, India (saumitra@gg.iitkgp.ernet.in , pankajkgp@yahoo.com); [2] 147/3, Janak Road, Kolkata-700 019, India.

Introduction: The uniqueness of the ~52,000±6000 year old Lonar Crater, India (Fig. 1) is that it is one of the few known terrestrial meteoritic impact craters [1-3] that was excavated on basaltic target-rock and therefore comparable to those formed on the rocky planetary bodies of our inner Solar system. The target-rock of this crater is the sub-horizontal Deccan basalt flows of ~67 M.y. age [4]. The crater has an average rim crest diameter of ~1710m, circularity of ~0.90, rim crest height of ~30m over the surrounding basalt flow and crater floor depth of ~90m below the pre-impact surface [5]. The core of the crater is presently occupied by a shallow saline lake, which has a depth of ~7m, followed downward by ~63m thick unconsolidated sediments overlying the highly weathered traps [6]. There is a small, relatively shallow, roughly triangular depression about 700m north of the rim of Lonar Crater (Fig.1). This depression, known as Little Lonar, has a diameter of ~300m and is suggested to represent a twin crater [2, 7].

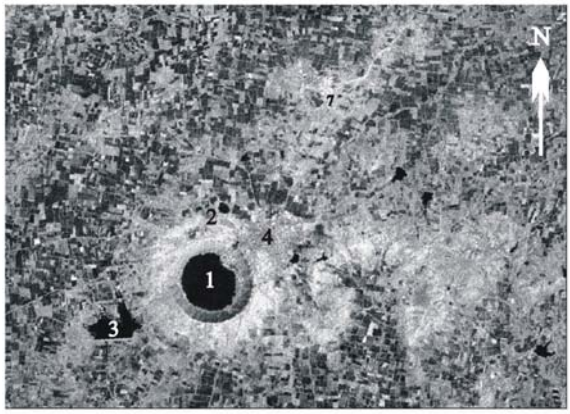

Fig. 1. Landsat 7 ETM+ image of Lonar Crater, India, 1-Lonar Crater, 2- Little Lonar, 3- Artifical reservouir, 4-Lonar village.

The Lonar Crater, though has been suggested as a meteoritic impact crater since last 40 years [8], no conclusive idea exists on the direction and angle of impact of the projectile for this crater. Ghosh [9] suggested a direction of impact of N45^{o}W assuming a near spherical cometary impactor of diameter ~90m for this crater, but the nature of impactor is now being questioned [10, 11]. As the nature of distribution of ejecta blanket around the crater and shape of the crater's rim are more informative to understand the projectile path [12], we use Landsat 7 ETM+ (enhanced thematic mapper plus) and DEM (Digital Elevation Model) [13] images in present study to understand the shape and distribution of ejecta around of the Lonar Crater. This study coupled with our December'2004 field observations on the tilts of basalt flows around the crater's rim is used to understand the possible projectile path for this crater.

Landsat image: The panchromatic band of Landsat 7 ETM+ image of October 24, 2000 (Path/Row: 146/046) having spatial resolution of ~15 meter is used in the present study. The shape of the Lonar Crater in this Landsat image is found to be very similar to that in the aerial photograph of the crater published earlier [2,5]. However, besides the present image, DEM data of the year 2000 acquired from SRTM (Shuttle Radar Topographic Mission) with 90 meter spatial resolution was also draped over Landsat 7 ETM+ digital data with band combination of 432 for further interpretation of three dimensional image of the Lonar Crater.

The geometric shapes of the rim of Lonar Crater and the distribution of ejecta blanket around the crater's rim, as understood from the Landsat image, DEM and during our field observation, are shown in figure 2. As suggested earlier [5], the crater's rim is nearly circular with circularity of ~0.95 and eccentricity of ~0.22. Outside the crater, there is a wide, almost continuous ejecta blanket encircling the crater's rim, which has high reflectivity over the surrounding target-rock basalts and top-soil on these basalt flows (Fig. 1). The DEM image shows that this continuous ejecta blanket is very gently sloping away from the crater's rim. The slope angle varies between 2-6^o [5]. The maximum extension of this continuous ejecta blanket away from the crater's rim has been examined in the field and it appears that this extension is original and suffers little modification by post-impact erosion [5] and formation of younger soils. Our conclusion is based on two observations: (a) low average rainfall of ~60-80 cm/year due to semi-arid climate in this region, and (b) low-gentle slope (2-6^o) of the ejecta blanket away from the crater's rim. The first factor is responsible for low erosion rate in this area and the second one provides more geomorphic stability to the ejecta blanket. The maximum extension of the ejecta blanket from the crater's rim can be visualized as a geometric shape of an ellipse having a circularity of ~0.87 and eccentricity of ~0.36 (Fig. 2). The crater's rim and the ejecta ellipses, however, have the same major axis, which has east-west trend, but the north-south minor axis of the latter has relatively shifted towards west by ~200 m.

The deep vertical notch at the northeast of the crater, which is radially arranged and cross cuts the crater's rim (Fig. 1), is a part of a NE-SW trending lineament that extends beyond the ejecta blanket in the west. A vertical scarp plane of height 2-3m is also developed along this linear structure at the northeast of the crater. Therefore,

this linear structure represents a sub-vertical fault that has been reactivated in the post-cratering period. Further, marginal collapse of the crater's rim is also seen at the west on this fault for a width of ~60 m.

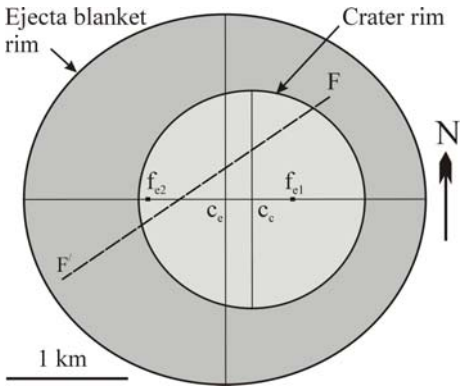

Fig. 2. Geometric map of Lonar Crater drawn from Landsat 7 ETM+ image, C_c and C_e- centers of crater rim's ellipse and ejecta blanket rim ellipse respectively, f_{e1} and f_{e2}- focus of ejecta blanket ellipse, FF$^{/}$- fault.

Field observations: The attitudes of the basalt flows exposed around the crater's rim have been systematically measured during our December' 2004 field trip. It is seen that the basalt flows show variable dips around the crater's rim. In the NNW, NNE, ENE, ESE, SSE and SSW sectors the basalt flows around the crater's rim show quaquaversal dips that vary between 17 and 36^o in average. Additional structural feature is the appearance of a fracture cleavage in the SSE and SSW sectors, which is sub-vertical and dipping north with an average dip of 53-60^o. Only in the WSW and W sectors the basalt flows on the crater's rim show recumbent dips that vary between 51 and 56^o in average. In the WNW sector only a fracture cleavage is observed that has an average attitude of 46^o towards southeast.

Discussion: As the shape of the Lonar Crater has not been significantly changed from its original shape due to little post-cratering erosion of its ejecta [5], the present Landsat image and structural data can, therefore, be used to understand the projectile path of the impactor for this crater. The bilateral symmetry of the ejecta blanket around the crater's rim (Fig. 2) suggests that the Lonar Crater was formed by an oblique impact of an angle <45^o and the projectile path was confined on a east-west vertical symmetry plane that passes through the major axis of the enveloping ellipse drawn on the ejecta blanket of the crater [12, 14]. The circularity of the crater's rim and the continuous extension of the ejecta blanket around the crater's rim, on the other hand, suggest that the angle of impact would be greater than 30^o [14]. Extent of more ejecta material to the west of the crater (Fig. 2) further suggests that the impactor of the Lonar Crater came from east [14,15]. This fact is also supported by the recumbent tilts of the basalt flows on the crater's rim only along the western part of the Lonar Carter. This is because if the impact on the pre-crater surface was vertical or sub-vertical, the tensional stresses in the displaced zone, which were displacing materials mainly upward near the transient crater's rim during the excavation stage [16], should be radially symmetrical. Hence symmetrical deformation of basalt flows all around the crater's rim was expected in this situation. More deformation towards west of the Lonar Crater, therefore, suggests that the tensional stresses, which were directed towards west, were stronger during opening of the Lonar Crater. It implies that the impact on the pre-crater surface was oblique and the impactor came from the east. In summary, it therefore can be concluded that the impactor of the Lonar Crater came from east and hit the pre-impact surface at an angle between >30^o and < 45^o.

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