Elliptical Crater (Oblique Impact)

Robert R. Herrick*
Geophysical Institute, University of Alaska, Fairbanks, AK, USA

Definition

An impact crater that forms with a rim planform that is noticeably elliptical in shape; an elliptical crater is often defined as having a major axis that is at least 120% of the minor axis (e.g., Bottke et al. 2000).

Synonyms

Elliptic crater; Elliptical basin; Elliptical crater; Elongated crater; Grazing impact crater; Oblique impact crater

Description

Impact craters exhibiting elliptical plan view. Features of elliptical craters typically include some combination of butterfly ejecta or saddle shaped rim, ricochet crater, median floor ridge (Bottke et al. 2000), systematically imbricated slices and enhanced shortening of the central uplift (Scherler et al. 2006), and preferential distribution of impact melts (Poelchau 2010, and refs therein) (Fig. 1).

The crater shape resulting from oblique impact may be:

1. Elliptical (elongated)
2. Elliptical (elongated)–irregular (elliptical with an extension downrange bordered by straight crater walls)
3. Multiple–irregular, e.g., “isolated crater clusters” on Mars (Barlow and Osborne 2001), ricochet craters

Morphometry

Aspect ratio: the crater’s ellipticity ($\varepsilon$) is defined as the quotient of its maximum and minimum rim-to-rim diameters (the ratio of the major to the minor axes, or length/width).

Formation of Elliptical Craters

Statistically, half of all impacts onto spherical surfaces occur at angles $\leq 45^\circ$ and about 7% at angles less than $15^\circ$, $\sim 4\%$ at angles less than $12^\circ$ (Kenkmann and Poelchau 2009). The most probable

*Email: rherrick@gi.alaska.edu
impact angle is 45°. Vertical and horizontal collisions are extremely unlikely. Thus, nearly all impacts are somehow oblique. Classes of oblique impacts are (Fig. 2):

1. Oblique impact: craters formed at angles between ~35° and ~15° from the horizontal.
2. Highly oblique or acute angled impact: below ~15° incidence (Kenkmann and Poelchau 2008).
3. Grazing impact refers to impact angles < 5°, but sometimes it is also called highly oblique.
Hypervelocity impact craters are circular even if the impact angle is not vertical (Melosh 1989). Late stages of excavation and collapse can mask the transient crater shape (Schultz and Wrobel 2012 and references therein). Crater shapes remain circular for impact angles steeper than 10°–15° from horizontal (Gault and Wedekind 1978; Bottke et al. 2000). Elliptical craters are produced by oblique impacts, at angles (θthresh) of less than about 12° from the surface (Bottke et al. 2000).

Laboratory-scale impact experiments have demonstrated that ellipticity also depends on the target material and the projectile-to-target density ratio. Craters formed in strong, ductile metallic targets and strong, brittle rock targets tend to be elliptical for impact angles up to 30°–40°, whereas craters formed in sand are only elliptical in highly oblique impacts (<5°) (Collins et al. 2011 and refs therein). Bottke et al. (2000) noted that elliptical crater threshold angle depends on the ratio of crater diameter to impactor diameter and thus gravity of the target body.

In highly oblique impacts (e.g., Hale, Mars) very high-speed ejecta (>10 km/s) skims across the surface, followed by a vapor blast and associated winds sweeping across the surface. High-speed sibling impacts (from the sheared-off projectile) spray downrange and impact, producing melt that sprays downrange as tertiary ejecta. It is followed by the arrival of the ejecta from the main crater, producing secondaries. Finally, the wind blast creates long-lasting wind streaks and scouring on this surface already peppered with secondary and tertiary impacts (Schultz and Wrobel 2012). Bottke et al. (2000) noted that elliptical crater threshold angle depends on the ratio of crater diameter to impactor diameter and thus gravity of the target body.

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Based on experimental data (Gault and Wedekind 1978), at angles below 40°–45° the ejecta blanket begins to shift downrange and departs from radial symmetry (Offset Ejecta). With increasing obliqueness (<20°), the ejecta begin to concentrate in the crossrange direction and a wedge-shaped forbidden zone begins to form uprange void of ejecta (uprange forbidden zone) and is then followed by a second forbidden zone downrange, leading to a bilaterally symmetric butterfly ejecta at very shallow angles (<10°) (Poelchau 2010) where the rim planform becomes elliptical (Herrick and Hessen 2006).
Schultz and Lutz-Garihan (1982) suggested that a portion of the many elliptical craters of Mars may represent the impacts of a former population of Martian moonlets (small moons) whose orbits tidally decayed (Chappelow and Herrick 2008).

**Formation Model of Elliptical Basins**

For projectiles that are large relative to the size of the target planet, the surface of the planet curves away from the projectile path. This curvature of the planetary surface increases the elongation of the projectile footprint (the projection of the projectile onto the surface of the planet) for even moderate impact angles, thus increasing the likelihood of an elliptical basin formation (Andrews-Hanna and Zuber 2010).

**Prominent Examples: Craters**

Rahe near Ceraunius Tholus, Mars; Messier, Moon; Graham, Venus. **Basins**: Borealis, Hellas, Utopia (Mars), and South Pole–Aitken (Moon) basins have aspect ratios ranging from 1.2 to 1.4 (Andrews-Hanna and Zuber 2010).

**Distribution**

Models and observational data suggest that about 5 % (Bottke et al. 2000) or 2–4 % (Collins et al. 2011) of all 5–100 km sized craters in terrestrial planets have elliptical shapes. Craters >100 km in diameter show a significant increase in the fraction of elliptical shapes. The largest impact basins tend to have an elliptical rather than circular shape (Collins et al. 2011).

**Terrestrial Examples**

Rio Cuarto field, Argentina, Matt Wilson impact structure (with central uplift), Northern Territory, Australia (Kenkmann and Poelchau 2009).

**Artificial Analog**

An experimental study of oblique impact cratering has been conducted by Gault and Wedekind (1978).

**History of Investigation**

Angle below which impact craters become elliptical was previously calculated to be 5°, which would represent 1 % of the total projectile population (Gault and Wedekind 1978).
Database

Herrick and Hessen (2006) created a database of Martian oblique craters >5 km in diameter using Viking and THEMIS imagery.

Similar Landforms Derived from Different Processes

Deformed Crater (Tectonized)

See Also

- Butterfly Ejecta
- Catena
- Crater Chain (Impact, Primary)
- Crater Cluster (Atmospheric Breakup)
- Ricochet Crater
- Uprange Forbidden Zone

References