ASTRONAUT'S GUIDE TO TERRESTRIAL IMPACT CRATERS

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INTRODUCTION

Thirty years ago, meteorite impact was regarded as an interesting but not particularly important phenomenon in the spectrum of geologic process. Our concept of the importance of impact processes, however, has been radically changed in large part through planetary exploration, which has shown that nearly all planetary surfaces are heavily cratered from the impact of meteorites, asteroids and comets. It is now clear from planetary bodies that have retained portions of their earliest surfaces that impact was a dominant geologic process throughout the early solar system. For example, the oldest lunar surfaces are literally saturated with impact craters (Fig. 1), produced by an intense bombardment—perhaps 100 times higher than that being experienced today—which lasted from 4.6 to approximately 3.9 b.y. ago. The Earth, as part of the solar system, experienced the same bombardment as the other planetary bodies.

EFFECTS OF IMPACT

Impact cratering has continued throughout the last 3.9 b.y. of solar system history. On the Earth, a variety of possible effects have been ascribed to impacts. The early intense bombardment has been advanced as the origin of both ocean basins and early continents. Heat generated by impacts may have led to outgassing and dehydration of Earth’s early crust, thus contributing to the primordial atmosphere and hydrosphere. Additionally, cometary impacts may have contributed to the Earth’s budget of volatiles. Evidence is mounting that a number of faunal extinctions, notably that of the dinosaurs and many other species 65 million years ago, may be linked to global effects caused by major impact events. Of more economic relevance, the vast copper-nickel deposits of the Sudbury Basin are possibly a related result of a large-scale impact 1850 m.y. ago. The disrupted rims and central uplifts of several impact structures in sedimentary rocks have also provided suitable reservoirs for economic oil and gas deposits.

Most of the terrestrial impact craters that ever formed, however, have been obliterated by erosion, tectonism, and other geological processes. Some examples remain, preserved either because of their young age, large size, occurrence in a relatively stable geologic region, or through relatively rapid burial by younger protective sediments, which erosion has since removed. To date, over a hundred impact crater have been identified on Earth. Almost all known craters have been recognized since 1950 and several new structures are found each year. Although these structures are distributed worldwide, there are concentrations in areas such as the Canadian and Baltic Shields, where a relatively uneventful geologic history has allowed preservation of some of the larger craters formed in the last 450 million years. Small, young craters are most easily recognized and best preserved in the world’s desert areas.

CRATER MORPHOLOGY

Extraterrestrial matter, which has collided with the Earth over geologic history, ranges in size from meteoric dust up to bodies several kilometers in diameter. At the extremes, the effects of such collisions range from being virtually undetectable to catastrophic. The most obvious result of the larger collisions is seen in the spectrum of crater sizes and morphologies. Studies on the Moon have demonstrated that the morphology of impact craters changes systematically with crater diameter, which in turn depends largely on projectile size and velocity. We illustrate the size-morphology
The recovery of meteorite fragments within or surrounding a

CRATER IDENTIFICATION

simpler bougy, and a dimpled im
central vein in the form of a peak and/or ring, an
...generally 3 km or more across, with a distinct
...complex impact structures and basins.

...ing the depressed floor creates progressively larger rim eroding-
...changes with increasing crater diameter or energy.

In a bowl-shaped cavity.

1. Simple craters, up to 2.5 km in diameter,

On Earth, the basic types are:

- Impact craters are caused by the collision of two objects, resulting in a range of crater sizes based on the impact velocity and mass.
- The presence of ejecta, which are materials thrown outwards from the impact site, is a common indicator of craters formed by impacts.
- The size distribution of craters on Earth is controlled by the energy of the impacting object, with larger impacts creating larger craters.

These crater types differ in their characteristics, such as the shape of the crater, the presence of ejecta, and the distribution of fragments.

Fig. 2: As illustrated by these lunar examples, impact crater morphology changes with increasing crater diameter or energy.
effects include hand-sized to house-sized conical fractures known as shatter cones, microscopic deformation features in minerals, and the occurrence of rocks melted by the intense heat and pressure of impact.

Some known structures have morphological characteristics consistent with simple or complex craters but lack either meteorites or definitive shock metamorphism. This may be because suitable samples cannot be readily recovered, being submerged beneath a deep, circular lake, buried under sediments, or having been almost completely eroded. Continued investigation may yet reveal evidence of shock metamorphism at some of these possible impact craters.

CRATER FORMATION

When extraterrestrial bodies tens of meters or larger impact the earth, they do so with undiminished velocity. Due to their high velocity (average impact velocity is 25 km per second), they have considerable kinetic energy. For example, the iron meteorite that formed the famous Meteor Crater in Arizona, U.S.A. had a kinetic energy equivalent to that contained in approximately 50 megatons of TNT. Upon impact, the bulk of this energy is transferred to the target rocks, leading to both the excavation of a crater and the production of diagnostic shock metamorphic effects.

Energy transfer is by means of a radially propagating shock wave, with peak pressures in the millions of bars at the point of impact. The shock wave drives the target rocks radially downward and outward (Fig. 3). A series of release waves follow the shock wave, returning the shocked target rocks to normal pressures. These release waves interact with the target rocks that are in motion, deflecting the movement of the rocks relatively close to the surface so that their direction of movement is changed to upward and outward. This leads to the formation of a cavity, known as the transient cavity, by the combined forces of upward ejection and downward displacement of the target rocks. Portions of the walls of this cavity, which is about one third as deep as it is wide, are unstable and collapse inwards, partially filling the crater with mixed and broken rock. Thus, a bowl-shaped or simple crater, with a circular outline and an uplifted rim and exterior ejecta blanket is produced.

The formation mechanisms of complex craters and basins with uplifted central peaks and/or rings are less well understood. It is believed that in these larger impacts, the initial stages of crater formation are similar to that at simple craters. Because the resulting craters are so large, excavation is still proceeding at the outer edges of the cavity, the downward displaced floor of the cavity rebounds upwards causing the formation of a central uplifted structure (Fig. 3b). The uplift of the floor also promotes collapse of the rim area, leading to a heavily modified, relatively shallow complex structure with an

Fig. 3: Schematic model for the formation of impact craters:
(a) Excavation and displacement form a transient cavity. (b) Uplift of the floor produces a central peak. (c) Partial collapse of over-heightened peak. (d) Formation of the outer rim by downfaulting, and ponding of impact melt. Diagram from the Lunar Source Book (edited by G. Heiken and D. Vaniman), Cambridge Univ. Press; 1988.
The impact crater, because the crater is large in size. From the different photographs, it seems like the crater is oval in shape. The second photograph is in an expanded view showing the center and the rim. The center is circular, and the rim is a ring of rocks. The third photograph is of the crater floor, showing the impact material scattered around. The fourth photograph is of the crater's edge, showing the outer boundary of the crater. The fifth photograph is of the crater's interior, showing the inner walls and the floor. Each crater is unique, and the study of these craters can provide valuable information about the history of the Earth and other planets.

In this guide, we have brought together optical photographs illustrating the appearance of terrestrial impact craters. Each crater is described by two photographs and a map. The map shows the location of the crater, and the photograph illustrates the crater's appearance from different angles and perspectives.

Acknowledgements

We thank Leslie Bodeker, Mildred Dickey, Mary Ann Hager, and the authors and editors of this guide for their contributions. The photographs and maps are courtesy of NASA/JPL/Caltech and the Lunar and Planetary Institute.

Discoveries of New Impact Craters

The number of known impact craters on Earth is small, but the potential for new discoveries is vast. The search for new craters is an ongoing process, and new findings are reported periodically. The search for new craters is important for understanding the history of the Earth and other planets. The study of impact craters can provide insights into the geologic history of the Earth and other planets, and the search for new craters is a key component of this effort.

There are three main methods for discovering new craters:

1. The search for new craters is an ongoing process, and new findings are reported periodically. The search for new craters is important for understanding the history of the Earth and other planets. The study of impact craters can provide insights into the geologic history of the Earth and other planets, and the search for new craters is a key component of this effort.

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Although the number of known impact craters on Earth is small, the potential for new discoveries is vast. The search for new craters is an ongoing process, and new findings are reported periodically. The search for new craters is important for understanding the history of the Earth and other planets. The study of impact craters can provide insights into the geologic history of the Earth and other planets, and the search for new craters is a key component of this effort.

Non-essential observations can also lead to the discovery of additional craters. The search for new craters is an ongoing process, and new findings are reported periodically. The search for new craters is important for understanding the history of the Earth and other planets. The study of impact craters can provide insights into the geologic history of the Earth and other planets, and the search for new craters is a key component of this effort.
METEOR CRATER
ARIZONA, U.S.A.

35°02'N; 111°01'W
Diameter: 1.2 km
Age: 50,000 yrs
Discernability: Excellent but small
Morphology: Circular bowl-shaped depression with rim

General Area: This best known of all impact craters is 60 km ESE of Flagstaff, AZ on a flat plain south of the Little Colorado River. Although the crater is only about 1 km wide, it is very conspicuous because its bright rim contrasts with the darker plain of sedimentary rocks.

Specific Features: Meteor Crater is the type example of simple, bowl-shaped impact craters. It has slightly polygonal sides and a rim that rises nearly 50 m above the surrounding plain. Beyond the rim are low mounds of material thrown out by the impact.
SIERRA MADERA
TEXAS, U.S.A.

30°36'N; 102°55'W
Diameter: 13 km
Age: < 100 m.y.
Discernability: Good
Morphology: Circular mound of hills

General Area: Flat-lying rocks of western Texas. The area is relatively featureless. The target rocks are sedimentary.

Specific Features: Structure is most evident as a mound of hills 6 km in diameter, in which the rocks have been uplifted over 1 km. This central uplift is surrounded by a poorly delineated annular trough about 13 km in diameter. The structure is relatively heavily eroded but forms a prominent feature in the Texas flatlands. An ephemeral stream arcing ~200° around the peaks defines the crater, and tributaries radiate from the peaks to the arcuate stream.
Specific Features: The 6 km wide crater forms an uncom.

Target rocks are sedimentary.

The origin concept have been found, proving that the feature is of impact.

400 m wide central uplift (exposed in a valley course) is not.

Although there is a monoy circular depression in a hilly terrain.

General Area: Dissected plateau region of the westernmost

morphology: Shallow depression

discernibility: Poor

age: > 400 My

diameter: 6 km

39.37 N, 83.44 W

KENTUCKY, U.S.A.

MIDDLESBORO

ORIGINAL PAGE OF POOR QUALITY

ORIGINAL PAGE IS
PILOT LAKE
NORTH WEST TERRITORIES, CANADA

60°17'N; 111°01'W
Diameter: 6 km
Age: 440 ± 2 m.y.
Discernibility: Good
Morphology: Circular lake

General Area: Low relief area in the Canadian Shield. The area is heavily forested and has been glaciated. The target rocks are crystalline.

Specific Features: Impact crater lies within Pilot Lake. A circle ~6 km can be defined within the lake that is island-free and has depths of up to 70 m. The shape of Pilot Lake itself is roughly square and contrasts sharply with the linear and irregular nature of the other lakes in the area. It gets its name from its use by pilots as a navigation aid. The geology of the structure is known only at the reconnaissance level.
mined, rocks of the core and upright sediments, uranium deposits are

diameter of 16 km. At the contact between the crystalline
significant rocks, there is a central core of amygdaloidal
of 40 km. These represent upright beds of essentially 10-
high, with an inner diameter of 30 km and an outer diameter
The principal morphological element is a ring of small hills ~50
Specific Features: The structure has been highly eroded.

General Area: Low relief area in the Canadian Shield Area

Morphology: Circular geologic structure

Describability: Poor

Age: 177 ± 8 Ma

Diameter: 37 km

58°27’N, 109°30’W

SASKATCHEWAN, CANADA

CARSWELL

Original Page

Original Page is of Poor Quality
GOW LAKE
SASKATCHEWAN, CANADA

56°27'N; 104°29'W
Diameter: 5 km
Age: < 250 m.y.
Discernability: Good
Morphology: Circular lake

General Area: Subdued topography in the Canadian Shield. The area is forested and has been glaciated. The target rocks are crystalline.

Specific Features: The crater is filled by a 4 km diameter circular lake, which contrasts sharply with the other irregular lakes in the area. The crater clearly transects the structural grain of the area. It is highly eroded with an estimated original diameter of 5 km. This is consistent with the occurrence of a central peak in the form of a 1 km diameter island in the center of the lake.
NICHOLSON LAKE
NORTH WEST TERRITORIES, CANADA

62°40'N; 102°41'W
Diameter: 12.5 km
Age: < 400 m.y.
Discernability: Average
Morphology: Roughly oval lake

General Area: Structure occupies a shallow depression in an area of subdued topography. Vegetation is limited, as the area is 150 km north of the tree-line. The target rocks are crystalline.

Specific Features: This crater is occupied by a roughly oval lake with a large promontory on the west and a central island. The lake contrasts with the generally linear lakes of the area. The structure is heavily eroded and glaciated. The central island is the dominant morphologic feature, rising some 50 m above lake level. No rim is preserved and regional elevations are within 10 m of the lake level.
Major ridges can be seen northwestern of the crater imposed upon the structural fabric of the rocks in the area. A hill rises 40 m around the lake. The crater is clearly superimposed in the immediate area. There is no faulting near the lake in the immediate area. The shape of the lake contrasts with the adjacent valleys. West Hawk Lake is circular and forms a distinct ring of tundra within the polygonal 3.6 km diameter. Specific Features: Stoney Lake, within the polygonal 3.6 km diameter.

General Area: Studied relief near the southwestern edge of the Canadian Shield. The area is heavily forested and has been glaciated. The larger rocks are cycled.

Morphology: Polygonal lake

Description: Average Age: 100 ± 50 My
Diameter: 27.7 km
49°46'N; 96°11'W

West Hawk Lake

MANITOBA, CANADA
HAUGHTON
NORTH WEST TERRITORIES, CANADA

75°22'N; 89°40'W
Diameter: 20 km
Age: 21.5 ± 1.2 m.y.
Discernability: Average
Morphology: Circular structure, partially outlined by small rivers

General Area: A dissected plateau of low relief on Devon Island in the Canadian Arctic. The area is a cold, semi-desert with almost no vegetation. The target rocks are mostly sedimentary, although the impact did excavate to the underlying crystalline basement.

Specific Features: Structure lies south of Thomas Lee Inlet and comprises an inner basin, 5-7 km in diameter, within a circular depression 20 km in diameter. The inner basin is 100 m below regional elevations and is drained by the Haughton River. The circular basin contrasts sharply with the general appearance of the dissected plateau. Erosion has not been severe and deposits of ejecta are still present, appearing as patches of grey rocks.
General Area: Sudbury lies close to the Lake Huron basin with smooth, elliptical basin with smooth.

Morphology: Elliptical basin with smooth.

Description: Average - Poor

Age: 1850 ± 150 My.

Diameter: 140 Km

Latitude: 81°34'W

ONTARIO, CANADA

SUDBURY
BRENT
ONTARIO, CANADA

46°05'N; 78°29'W
Diameter: 3.8 km
Age: 450 ± 30 m.y.
Discernability: Poor
Morphology: Circular area with partially circumferential lakes

General Area: South of the Ottawa River in the Canadian Shield in an area of rolling hills. The area has been glaciated. The target rocks are crystalline.

Specific Features: Brent crater has been heavily eroded and is partially in-filled by post-crater sediments. There are two lakes within the crater, forming a semi-circular hoof-print shape. The remnants of the crater form a 3 km circular depression 60 m deep. The interior of the crater is noticeably smoother than the surrounding terrain and the structure clearly cuts across pre-existing folds and tectonic trends in the crystalline bedrock.
Structure.

In the local bedrock surrounding the removed all traces of the rim. There is some indication of a small central peak which is submerged. Erosion has taken place in the area, The central island-free portion of the lake is 8 km wide and is taken as the diameter of the center. Its lakes in the area. The central island-free portion of the lake is circular, which contrasts sharply with the linear and ring-shaped area. The larger rocks are clearly visible. The area is underlain with glacial pavement, and has been glaciated.

General Area: Submerged Logging in the Canadian Shield.

Morphology: Circular Lakes

Discernibility: Good

Age: 450 + 25 m.y.

Diameter: 8 km

Black and White Photography

Original Page

Quebec, Canada

Lac Couture
NEW QUEBEC
QUEBEC, CANADA

61°17'N; 73°40'W
Diameter: 3.2 km
Age: < 5 m.y.
Discernability: Excellent but small
Morphology: Perfectly circular lake

General Area: North of the tree-line in an area of subdued topography in the Canadian Shield. The target rocks are crystalline and some bedrock structure is visible in the north. The area has been glaciated.

Specific Features: New Quebec crater is filled by an almost perfectly circular 3 km diameter lake which contrasts sharply with the irregular lakes of the area. Although glaciated, this relatively young structure retains an upraised rim and is surrounded by a faint zone of deformation extending 3 km from the rim. This may be best viewed at low sun angles. The lake has no exterior drainage. This closed system has developed its own local ecosystem, including fish with very large heads, which have adapted to minimal food sources. An intriguing question is how the fish got into the crater lake.
Clearwater Lakes

Quebec, Canada

BLACK AND WHITE PHOTOGRAPHS

ORIGINAL PAGE
LAC LA MOINERIE
QUEBEC, CANADA

57°26'N; 66°36'W
Diameter: 8 km
Age: 400 ± 50 m.y.
Discernability: Good
Morphology: Roughly circular lake

General Area: Subdued topography in the Canadian Shield. The area is only lightly wooded, being close to the tree-line, and has been glaciated. The target rocks are crystalline.

Specific Features: The structure is a roughly circular lake 8 km in diameter, which contrasts with other linear and irregular lakes in the area. The crater cuts regional structure that takes the form of a large southeasterly plunging fold. Erosion has removed all signs of the rim and the lake is taken as the original diameter. The geology at the structure has been examined only at the reconnaissance level.
best expressed in the west.

The large lake is surrounded by cirques and is cut by a large glacial cirque. A weak
landscape is exposed by glacial erosion. Although this is a fairly young crater, much of the original
landscape is unaltered by glacial erosion. A central hill rises 28 km in diameter, surrounded by a depression 400 m
above sea level.

Specific Features: Structure is defined by a ring of low

Central Area: Moderately filled, 200-300 m, close to the

Mistassin

Black and White Photographs

Neufoundland and Labrador, Canada
Speckled Features: Structure is most obvious as a ring of hills growing crystalline. Geologic drainage system. Target rocks are sedimentary over-}

General Area: Southern portion of the Amazon Basin. The area is relatively featureless, apart from a well-developed network of drainage features. 

Morphology: Circular ring of hills Diameter: 12 km

Age: > 300 My
Average: 46°25'W
RIACHO RING
BRAZIL

7°43'S; 46°39'W
Diameter: 4 km
Age: Unknown
Discernability: Average
Morphology: Circular bleached area

General Area: Low relief, tropical forest and pampas in Brazil. Some of the forest has been cleared for grazing. Structure is unique to the area, which is dominated by irregular and dendritic drainage. It is ~50 km north of the Serra da Canghala impact crater. Target rocks are sedimentary.

Specific Features: Structure appears as a slightly elevated ring, 4 km in diameter, of bleached sand, which is the by-product of the weathering and erosion of a ring of sandstone. There are chaotic uplifted blocks in the center. This structure was first discovered by Apollo astronauts during the Apollo-Soyuz Test Project.
Special Feature: Structure is most obvious as an annular belt of dark, coarse-grained, porphyritic rock. The structure is most likely a dome or circular feature. The structure is 10 km in diameter. Ground studies and remote sensing suggest that the structure may be a large, sub-surface feature.

General Area: Tropical forest of the Marajo Island of Brazil.

Morphology: Circular feature in otherwise featureless area.

Distinctive Significance: Age, > 250 Myr; Diameter, 40 km; Latitude, 6° 59'S; Longitude, 56° 46'W.
black and white photograph

Original Page

Containing impact melt glasses and building stones cut from the ejecta deposits, the structure of impact-derived rocks, especially those lying several kilometers to the east in the Czecho-Slovakia, the church in the valley can be found up to 20 km from the rim. The glass can contain up to 50% of the ejecta that are preserved and glassy, parts of the ejecta that have not been melted or melted to form ash and tuff that are still visible as the structure has not been post-erupted or buried. The structure is partially filled with glass, small 50 m hills with a diameter of 1.7 km. By a circular km - 24 km in diameter and 100.

Special Features: The crater is outlined in the structure.

Rocks: The area has not been glaciated.

General Area: The area is rural with ex-.

Morphology: Circular feature

Germar

Federal Republic Of

Reis
Special Features: This crater is only 40 km west of the radianing agricultural fields.

Central peak rises 50 m above the floor, which is covered by depression nearly 100 m deeper than the surrounding plains. The crater has a diameter of 1.2 km and is approximately circular. It was formed at the same time as the nearby younger crater.

Morphology: Circular depression with central hill.

Diameter: 34 m
Age: 14.8 ± 0.7 Myr
Origin: Black and white photograph

Original face

FEDERAL REPUBLIC OF GERMANY
STEINHEIM

Original face is of poor quality.
MIEN
SWEDEN

56°25'N; 14°52'E
Diameter: 9 km
Age: 118 ± 3 m.y.
Discernability: Good
Morphology: Polygonal lake

General Area: Low relief area in the Baltic Shield of southern Sweden. Area is partially forested and has been glaciated. Target rocks are crystalline.

Specific Features: The structural depression is partially filled by glacial deposits and appears as an isolated circular lake about 5 km in diameter. Geophysical data indicate an original diameter of about 9 km. The lake has a small central island about 500 m in diameter, which contains the only exposed impact melted rocks within the crater.
DELLEN
SWEDEN

61°55'N; 16°39'E
Diameter: 15 km
Age: 109.6 ± 1 m.y.
Discernibility: Average
Morphology: Two lakes, which define a rough circle

General Area: Low relief in the Baltic Shield in Central Sweden. The area is forested and has been glaciated. The target rocks are crystalline.

Specific Features: The structure includes two lakes which form a hoof-print, similar to the Brent structure in Canada. The lakes are ~5 km at their widest, and the northernmost lake has a semi-circular north shore. The area between the lakes is the vestige of a central uplift. The lakes have fingers on their eastern margins due to the scouring effects of glaciation. The structure has been highly eroded and little topography remains.
Specific Features: The structure has been highly eroded. The principal morphologic element is a lake about 5 km across with a rounded north shore. Glaciation has been from roughly northwest, impounding rocks from the floor of the crater. Rocks are common in glacial deposits to the southeast and have been found as far away as 25 km.

General Area: Generally low relief area in the Baltic Shield of Finland. It is forested and has been glaciated. Target rocks are crystalline.
LAPPAJÄRVI
FINLAND

63°09′N; 23°42′E
Diameter: 14 km
Age: 77 ± 4 m.y.
Discernability: Good
Morphology: Oval lake

General Area: Low relief area in the Baltic Shield of Finland. Area is forested and has been glaciated. Target rocks are crystalline.

Specific Features: The structure has been highly eroded. It is largely occupied by an isolated, teardrop-shaped lake. The lake is elongated north/south due to glaciation and measures 20 km by 10 km. A central peak occurs and is expressed by a 2 km island in the northern part of the lake.
Small islands almost at the center which represent a central peak.

Specific Features: The structure has been highly rounded.

Morphology: Irregular oval lake.

Description:
- Age: 695 ± 22 Ma.
- Diameter: 14 km.

61°59'N, 30°55'E

Black and white photograph

Original Page

Janis Jari

U.S.S.R.
Impact Craters in ASIA

Kara and Ust-Kara
Zhamanshin
Bigach
Logancha
Popigai
Elgygytgyn
Lunar
ZHAMANSHN
U.S.S.R.

ORIGINAL PAGE

BLACK AND WHITE PHOTOGRAPH

48°21'N; 60°58'E
Diameter: 13 km
Age: 0.75 ± 0.06 m.y.

Discernability: Poor
Morphology: Vague ring surrounded by triangular dark petals

General Area: Hilly semi-desert in Kazakhstan ~200 km north of the Aral Sea. The area is farmed in places. The target rocks are sediments overlying crystalline.

Specific Features: Zhamanshin is a 6.5 km wide circular feature partially filled by sandy deposits that are cut by dendritic drainage. This central area is surrounded by a brighter area 13 km in diameter. Although very young, the structure is not particularly evident in orbital imagery. This may be due to its complex form and the fact that erosion has partially destroyed some features without emphasizing other circular attributes. It has been suggested that the subdued morphology may be due, in part, to oblique impact.
LOGANCHA
U.S.S.R.

ORIGINAL PAGE

65°31'N; 95°56'E BLACK AND WHITE PHOTOGRAPH

Diameter: 20 km
Age: 50 ± 20 m.y.
Discernability: Good
Morphology: Round depression

General Area: In the basin of the Vivi River, Siberia. Area is relatively rugged with superimposed feathery drainage of the Vivi and Tembechi Rivers and their tributaries. The target rocks are a mixture of volcanic and sedimentary.

Specific Features: The structure has a gently undulating floor and is bounded by annular hills about 200 m higher than the floor. The topography is complicated by deeply incised canyons, which result from drainage which tends to be radial and circumferential, particularly in the east. The circular outline is breached in the southwest. Due to the occurrence of basaltic rocks in the target, Logancha is an analog for impact structures formed on the lunar mare.
BLACK AND WHITE PHOTOGRAPH

ORIGIAL PAGE

Polar ice cap has been observed but it should be
extrapolated from satellite images inside the rim. No
evidence of glacially overridden terrain is visible.
In the US, the best visibility is from the air.
Large ice cap is the largest ice cap in Canada. It is
about 1,500 km across, accounting for 50% of
the ice cap's area. The basin is about 200 km high,
with broken terrain and ice caps. The basin is
75 km in diameter and 100 km deep. The
bassinet is the highest and inner

Specific Features:
- Polar ice cap

General Area:
- In the northern portion of the

By Rivers:
- Vague circular feature outlined

Discovered by:
- Poor

Age:
- 30 My

Diameter:
- 100 km

112° 00' W, 71° 35' N

U.S.R.

Popigai
General Area: Moderately mountainous terrain in the Chunoko area. Area is above tree line and has been glaciated. The large rocks are crysdalerite.

Morphology: Isolated polygonal lake

Discrepancy: Excellent

Age: 3.5 + 0.5 My.

Diameter: 23 km

69°30'N, 172°05'E

U.S.S.R.
LONAR
INDIA

19°58'N; 76°31'E
Diameter: 1.8 km
Age: 62,000 yrs
Discernability: Good but small
Morphology: Isolated circular lake

General Area: Flat relief in the volcanic Deccan Plateau of west central India. The area is relatively dry with sparse vegetation in a farmed area. The target rocks are volcanic.

Specific Features: Lonar contains a circular, shallow, alkaline lake, which contracts and expands with seasonal rains. It is surrounded by an uplifted rim ~1.7 km in diameter. The rim rises ~200 m above the submerged crater floor and ~30 m above the surrounding plain. Local drainage is radial either into or away from the crater. Ejecta deposits are still preserved at this crater. The target rocks are volcanic basalts. Thus, they are good analogues to impact-modified rocks on the lunar mare.
OUARKZIZ
ALGERIA

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

29°00'N; 07°33'W
Diameter: 4 km
Age: < 70 m.y.
Discernability: Good
Morphology: Ring

General Area: Rocky desert in northwest Algeria. Target rocks are sedimentary.

Specific Features: Structure has the form of a well-defined ring open to the south, with interior drainage and walls 100 m high. The crater clearly cuts into local structure, which has a large arcuate form. A ring, 30-40 m high, occurs at the base of the main ring escarpment which may be the result of differential erosion. An incomplete arcuate ring of similar size and 15 km to the south warrants investigation: Is it an impact crater, too, or a volcanic ring?
Impact crater.

The original crater floor is at the top of an en echelon line of radial faults. The floor has apparent radial fractures, and there is evidence from mechanical and structural analysis that the structure is a multiple-impact feature.

No specific features are described on this page.
BOSUMTWI
GHANA

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

6°32'N; 01°25'W
Diameter: 10.5 KM
Age: 1.3 ± 0.2 m.y.
Discernability: Excellent
Morphology: Isolated circular lake

General Area: Relatively featureless area of tropical forest in the West African Shield. The circular lake is unique to the area. The target rocks are crystalline.

Specific Features: Structure is almost entirely filled by the 10 km diameter Lake Bosumtwi. Erosion has not been severe and the original rim, with a diameter of 10.5 km, rises 150-450 m above the lake. The lake has a number of local legends associated with it and has no external drainage. Beyond the rim, drainage is radial into circumferential rivers, presumably related to crater topography and fracturing. This structure is the source of the melted glassy objects known as Ivory Coast Tektites, which occur dispersed in the area and in offshore ocean sediments.
north may represent a double impact. 

Suggestions that Crater and the -2.8 km wide BP structure to the left suggest that the Crater is less similar to Crater Bluff in Australia. It has been surmised by a weakly expressed outer rim that its shape is partially representing a central uplift. This central peak is identified as the highest peak on the discontinuous hills. A 5 km in diameter and 100 m high hill stands out as the most prominent feature of Crater Bluff. 

**General Area:** The area is a bright desert in southern Libya, west of the dark Gial Kafir Pheasan and is relatively featureless. 

**Morphology:** Circular feature in otherwise featureless area. 

**Distinctibility:** Average 

**Age:** >100 my. 

**Diameter:** 11.5 km 

**20.35N, 24.3E**

**Libya OASIS**
BP
LIBYA

25°19'N; 24°20'E
Diameter: 2.8 km
Age: <120 m.y.?  
Discernability: Poor  
Morphology: Dark rings with central hill

General Area: Southeastern Libya. The area is a desert and is relatively featureless with respect to bedrock structure. Target rocks are sedimentary.

Specific Features: The BP structure is defined by two closely spaced rings of dark rocks rising 100 m above the surrounding desert. There is a 600 m wide central uplift. The structure is the remnants of a deeply eroded impact crater whose formation age is unsure. BP is 80 km from the Oasis impact structure. The two may have formed simultaneously, perhaps about 28 m.y. ago when Libyan Desert glass formed by the melting of desert sands. The name "BP" drives from the British Petroleum Co., which formerly worked in Libya.
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE

Specified Features: Predominant is outline by:

Vredefort

Target rocks are crystalline and sedimentary.

General Area: Structure is located in an

Morphology: Semi-circular ring

Disembryal: Good

Age: 1.970 ± 100 M.y.

Diameter: 140 K.m.

27°06' S 27°30'E

SOUTH AFRICA
Meteor Crater, Arizona.

From the rim, the structure is very similar in appearance to other, uplifted and disturbed zones. A crater can be seen extending out for a bowl-shaped depression 2.5 km in diameter. An existing formation is superimposed on the landscape. It has large rocks, some sedimentary and crystalline.

**General Area:** West of the Hams Mountains in the Desert of Namibia. Linear dune formations are evident in the area. The crater is located near the town of Roter Kamm, Namibia.

**Morphology:** Circular crater

**Discernability:** Excellent but small

**Age:** Unknown, but young

**Diameter:** 2.5 km

**Location:** 16°47'E, 27°45'S
particularly in the area of the ring and hanging contact. And the interior of the structure contains shallow angular lakes.

Below that, there is a well-developed internal drainage system. Many of the rocks are covered by lake deposits and wind.

In diameter of 5 km, a ring surrounded by a ring 25 km.

General Area: Structure is and Western Australia. Area is 25°S, 120°E.

Morphology: Archean age
Age: 1985 ± 5 Ma
Diameter: 25 km

Black and White Photogram
SPIDER
WESTERN AUSTRALIA, AUSTRALIA

16°43'S; 126°06'E
Diameter: 13 km
Age: < 600 m.y.
Discernability: Fair
Morphology: Spider-like pattern of radiating ridges

General Area: In the semi-arid grasslands of the central Kimberley plateau of northwestern Australia. The target rocks are sedimentary.

Specific Features: The deeply eroded structure consists of little more than a radiating pattern of distinct ridges, hence the name, and a poorly defined semi-ring of concentric faults. The Barnett Range lies adjacent to the structure, and it is possible that tectonic activity associated with mobile belt zone development has affected the impact feature. Spider represents the deep interior of a central uplift of a larger complex impact crater of possible Precambrian age.
Investigations of this interesting impact feature are warranted.

Western Australia, Australia

Goat Paddock

General Area: In the semi-desert plains south of the Kimberley plateau of northwestern Australia. Large rocks are black and white Photograph

Morphology: Crater depression

Dissection: Good

Age: > 55 my

Diameter: ~ 5 km

18°20'S; 126°40'E
PICCANNINY
WESTERN AUSTRALIA, AUSTRALIA

17°25'S; 128°26'E
Diameter: 7 km
Age: < 360 m.y.
Discernibility: Poor
Morphology: A circular plateau perched within a mountain range

General Area: The structure is developed in the Bungle-Bungle range of the Kimberley District of North Western Australia. The target rocks are sedimentary.

Specific Features: The structure consists of an elliptical zone of anomalous deformation within essentially undeformed sediments. A radial joint pattern is well-defined around the periphery of the structure, and the central region of Piccanniny consists of an eroded gentle dome. A subtle central peak is hinted at on the basis of the interior drainage pattern observable in LFC images.
Acraman: Target rocks are chlorite, calcite and plagioclase. 

General Area: Within the semi-desert

Morphology: A hexagonal shaped 20 km wide 

Described: Good

Size: About 50 km (or 160 km)

32°01'S 135°26'E

Australia

Acraman
Approximate location of the original crater rim.

...
**Original Page**

Types of Martian craters. Well-undisturbed sediments and may be a good analogy to some well-disrupted plains. If this is an impact structure, it formed in central peak in this area, higher areas are jungles, and lower superimposed upon old cliffs. There are some indications of a sedimentary origin.

**General Area**: Flat area, partly jungle, and partly plains.

**Morphology**: Roughly circular area

**Description**: Very poor

**Age**: 11,000 - 22,000 yrs

**Diameter**: 8 km

**Location**: 67°S, 123°W

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**BLACK AND WHITE PHOTOGRAPH**

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**ITURALDE**

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**BOLIVIA**
AOROUNGA
CHAD

19°6'N; 19°15'E
Diameter: 12 km
Age: unknown
Discernibility: Good
Morphology: Concentric ring pattern

General Area: Wind-swept, ruddy-colored desert, southeast of the dark Tibesti volcanic mountains.

Specific Features: Structure is first noticed as a light-hued, flat moat cutting into underlying dark rocks. The moat separates an outer rim from a 6 km wide inner ring of hills. In the structure's center a dark hill rises about 100 m above the surroundings. Because Aorounga is near the volcanic Tibesti Mts., there is great uncertainty if it is a volcanic feature or an impact crater; however, the morphology is very much like a multi-ringed impact crater.
more than speculative at this time.

(e.g., Lake Bosumtwi), but there is insufficient evidence to do so, except from the results of isolated circular lake

features. As one of the few circular lakes in the northern Africa, the origin of such lakes is uncertain. It is not

sugar cane. Target rocks are probably sedimentary.

General Area: Lac de Mitres in the Senegal region of south-

Morphology: Isolated, nearly circular lake

Descriptive: Excellent

Age: Unknown

Diameter: 12 km

10°6'N, 19°25'E

BLACK AND WHITE PHOTOGRAPH
ORIGINAL PAGE

CHAD

LAC IRO
AL MADAFAI
SAUDI ARABIA

28°40'N; 37°11'E
Diameter: 6 km
Age: <360 m.y.
Discernability: Good
Morphology: Nearly continuous circular ridge

General Area: Al Madafi lies in a sparsely vegetated desert about 60 km NE of the city of Tabuk. The area contains large numbers of subdued ridges cut by dry stream beds, and wind-blown materials thinly mantle the geology. Target rocks are sedimentary.

Specific Features: The suspected impact structure is defined by a remarkably circular ridge, about 6 km in diameter, open to the south. The ridge may be upturned sedimentary rocks, with terraces or slumps on the inner walls. There is no sign of a central peak. Al Madafi is morphologically unlike most volcanic landforms and is more than 50 km from the nearest volcanic rocks. Recent field reconnaissance has failed to reveal extensive shock features, however, in spite of severely folded strata and nearly vertical bedding.
The page contains a map and some text in Arabic. The map appears to be of a geographic area with various labeled features. The text includes a description of the map features, mentions of specific locations, and alphanumeric coordinates. The page is titled "Black and White Photograph Original Page".
RAMGARH
INDIA

25°20'N; 76°37'E
Diameter: 5.5 km
Age: Unknown
Discernability: Average
Morphology: Annular ring of hills

General Area: In eastern Rajasthan, 350 km SSW of New Delhi, India. Area is semi-arid and relatively featureless. The target rocks are flat-lying, crystalline, and generally buried by recent alluvium.

Specific Features: Structure appears as a ring of hills ~ 3 km in diameter. A small peak occurs within the ring. The structure is clearly unique to the area, being superimposed upon the surrounding flat plain. It has the form of a complex impact structure but no definitive evidence of shock metamorphism has been discovered. The structure can, therefore, only be considered as a possible impact crater. The area has only been geologically mapped at the reconnaissance level and requires detailed study.
Specific Features: China must possess many impact craters, based upon recognition of a circular pattern of lakes and craters. But none are known with certainty. One suspected crater, "Diaboli", is a known impact crater.

SHANGHEWAN

Black and white photograph

Original page 82

China
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Bosumtwi, Ghana

BP, Libya

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Carswell, Canada

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Elgygytgyn, USSR

Goat Paddock, Australia

Gosses Bluff, Australia

Gow Lake, Canada

Haughton, Canada
AIG 8.18.

Manicouagan impact crater, Quebec, Canada.

180. 66°-64°

Manicouagan impact structure, Quebec, Canada.

Manicouagan impact structure: Geology of the region.

Manicouagan impact crater: Sedimentary rocks of the Adirondack Mountains.

Manicouagan impact structure: Evidence for the origin of the crater.

Manicouagan impact structure: Radiometric age of the crater.

Manicouagan impact structure: Petrology of the Meteorite Cluster.

Manicouagan impact structure: Evidence for the origin of the crater.

Manicouagan impact structure: Sedimentary rocks of the region.

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