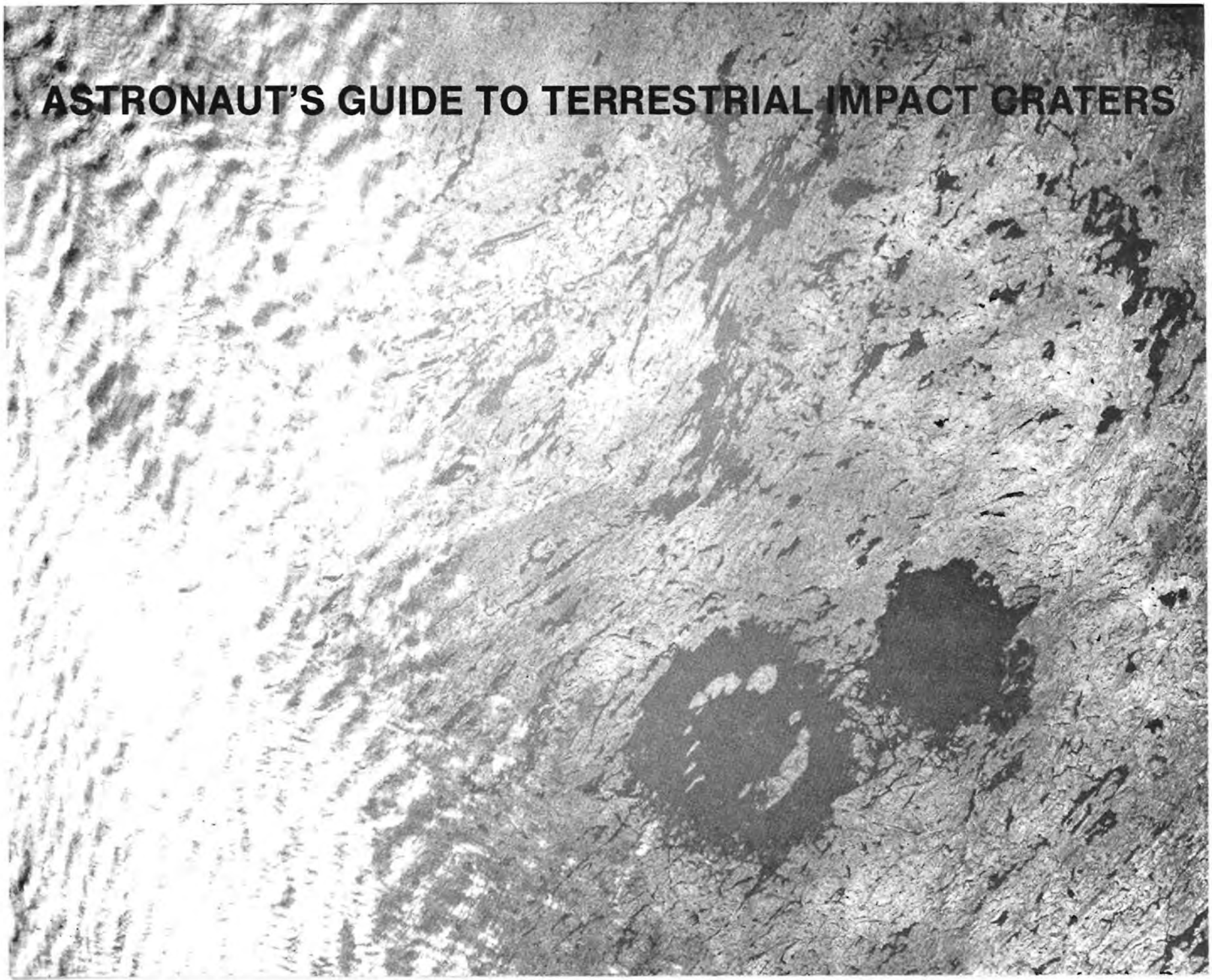
ASTRONAUT'S GUIDE TO TERRESTRIAL IMPACT CRATERS



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.

Fig. 1: Impact craters - such as these which pepper the far side of Earth's Moon - are the dominant landform on nearly all solid bodies in the solar system.

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 one hundred impact craters 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 meteoritic 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

Fig. 2: As illustrated by these lunar examples, impact crater morphology changes with increasing crater diameter or energy. Left: Taruntius H is an 8.5 km wide simple crater with smooth walls and a relatively flat floor. Center: Tycho (85 km wide) is a magnificent complex crater with terraced walls and massive central peak. Right: In large basins such as Orientale (930 km diameter) the central peaks are replaced by a series of concentric rings, and an ocean of frozen lava fills the floor.

relation with fresh-appearing craters from the Moon (Fig. 2). As crater diameters increase, slumping of the inner walls and rebounding of the depressed floor create progressively larger rim terracing and central mountains. At larger diameters, the single central peak is replaced by one or more peak rings. This same progression in crater morphology is observed throughout the solar system, including on the Earth, although terrestrial craters are less well-preserved and hence more challenging to classify. One notable difference between lunar and terrestrial impact craters is the smaller diameter range for each morphological type on Earth. Apparently this difference is due to the differing gravity fields of the two bodies: comparative planetological studies suggest that the transition diameters (from simple to complex to basin structures) decrease as "g" increases.

On Earth, the basic types are:

1. **simple craters**, up to 2-5 km in diameter, with uplifted and overturned rim rocks, surrounding a bowl-shaped cavity.
2. **complex impact structures and basins**, generally 3 km or more across, with a distinct central uplift in the form of a peak and/or ring, an annular trough, and a slumped rim

CRATER IDENTIFICATION

The recovery of meteorite fragments within or surrounding a crater is the most persuasive evidence for an impact origin, but the criterion is not ubiquitously applicable. For impact events that form craters larger than roughly 1.5 km across, the shock pressures and temperatures produced upon impact are sufficient to completely melt and even vaporize the meteorite and some of the target rocks. Thus, meteorite fragments are not found at these sites. In such cases, the recognition of a characteristic suite of rock and mineral deformations, termed "shock metamorphism", which are uniquely produced by extreme shock pressures (100,000 to several million bars) is indicative of a hyper-velocity impact origin. Examples of shock

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

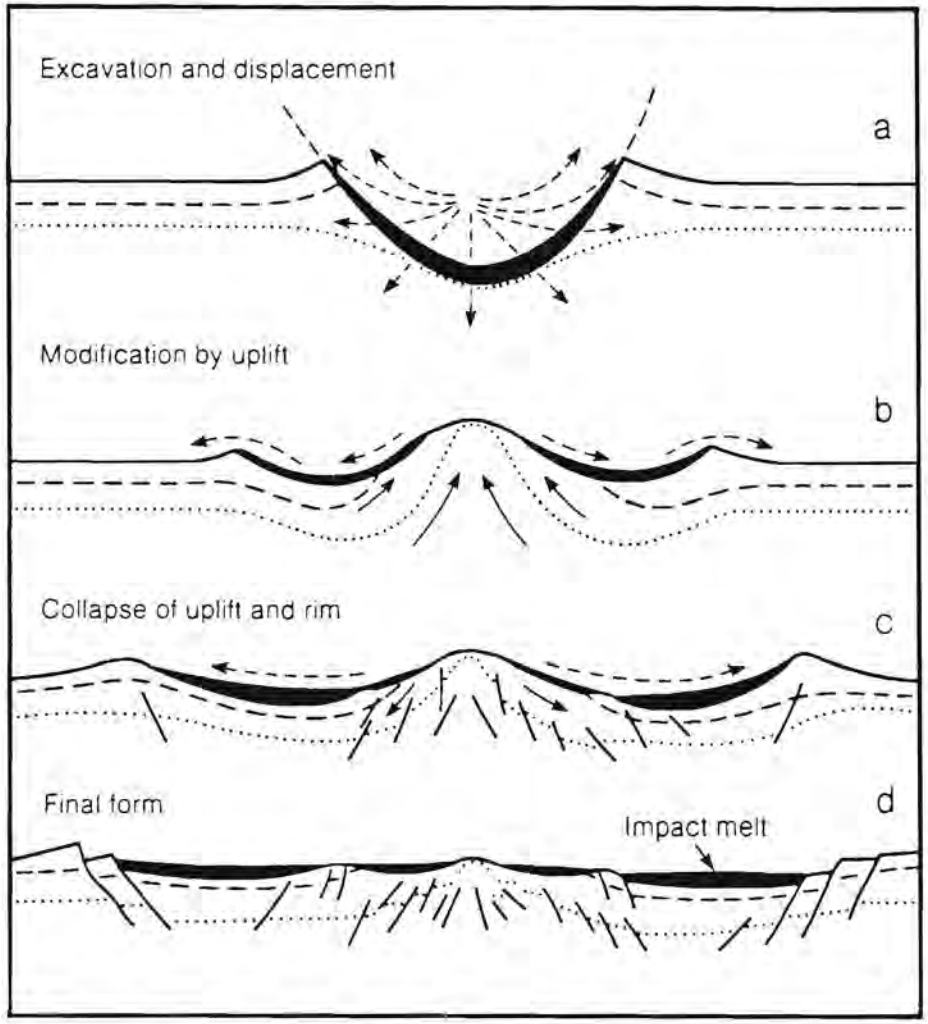

Fig. 3: Schematic model for the formation of impact craters: (a) Excavation and displacement form a transient cavity. (b) Uplift of the floor produces a central peak. (c) Partial collapse of overheightened peak. (d) Formation of the outer rim by downfaulting, and ponding of impact melt. Diagram from the ***Lunar Source Book*** *(edited by G. Heiken and D. Vaniman), Cambridge Univ. Press; 1988.*

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

uplifted center, an annular trough and a collapsed and highly faulted rim area.

DISCOVERY OF NEW IMPACT CRATERS

Although the number of known impact craters on Earth is small, the preserved craters are an extremely important resource for understanding impact phenomena. They provide the only ground-truth data currently available and are amenable to extensive geological, geophysical and geochemical study. Earth's impact craters also provide important data on the structure of such landforms in all three dimensions. In some cases, the large size of impact craters, up to approximately 150 km in diameter, requires orbital imagery and observation to provide a synoptic view of their structure and large-scale geologic context. Photographs with various look angles, fields of view, and sun angles are all potentially valuable. For example, photographs taken under low sun angles are most useful for defining more subtle structural and geomorphic features.

Orbital observations can also lead to the discovery of additional structures. Based on the number of large (> 20 km in diameter), relatively young (< 20 million years old) impact craters known from the well-mapped regions of North America and Europe, an estimate of the number of craters expected in any region of the Earth's crust can be determined. Applying this estimate to the less-well studied older terrains of South America, Africa and Australia suggests that a dozen 20 km and larger craters await discovery in these areas of the southern hemisphere. Astronauts, with their unique orbital perspective, have an excellent chance of making some of these discoveries. The last section of this guide illustrates a few suspected impact craters for which more orbital and ground data are needed.

ORGANIZATION OF THIS GUIDE

In this guide, we have brought together orbital photographs illustrating the appearance of terrestrial impact craters. Each crater is depicted by two photographs and a map. The map (from Defense Mapping Agency ONC charts) and matching photograph are reproduced (when possible) at a 1:1 million scale, and are meant to aid in locating the crater in a regional context. The locations of craters which are not conspicuous are indicated on the maps by either a circle or an arrow. The second photograph is an enlarged view (commonly from a different photograph) to better illustrate the detailed morphology of the impact crater. Because the craters range in size from 1 to 140 km, the degree of enlargement varies for each crater.

Excellent astronaut photography exists for more than a dozen impact craters; we have used such photographs whenever possible in this guide. The majority of photographs, however, are Landsat MSS images, with occasional use of Landsat TM, SPOT and Large Format Camera data. The sources and numbers for each photograph and map are listed on page 87.

The craters are ordered by geographic location and a few principal facts are given for each crater and the general terrain within which it is located. In most cases, the diameter given for each crater is the estimated original diameter, which may not correspond to the most visible morphologic element seen from orbit. It must be remembered that many terrestrial impact craters have been extensively eroded and their original morphologic elements correspondingly modified. For example, in some cases only an erosionally-resistant remnant of the central uplift remains. This guide includes most terrestrial impact craters which have some surface expression on available orbital imagery. It is not intended to be all inclusive, as some craters are completely buried or otherwise poorly detectable on orbital imagery. With a few exceptions, the craters included are greater than 2.5 km in diameter. This document is intended to serve as a training manual on the appearance of terrestrial impact craters and as an aid in the gathering of future photographs which will be of interest to the geologic community.

ACKNOWLEDGMENTS

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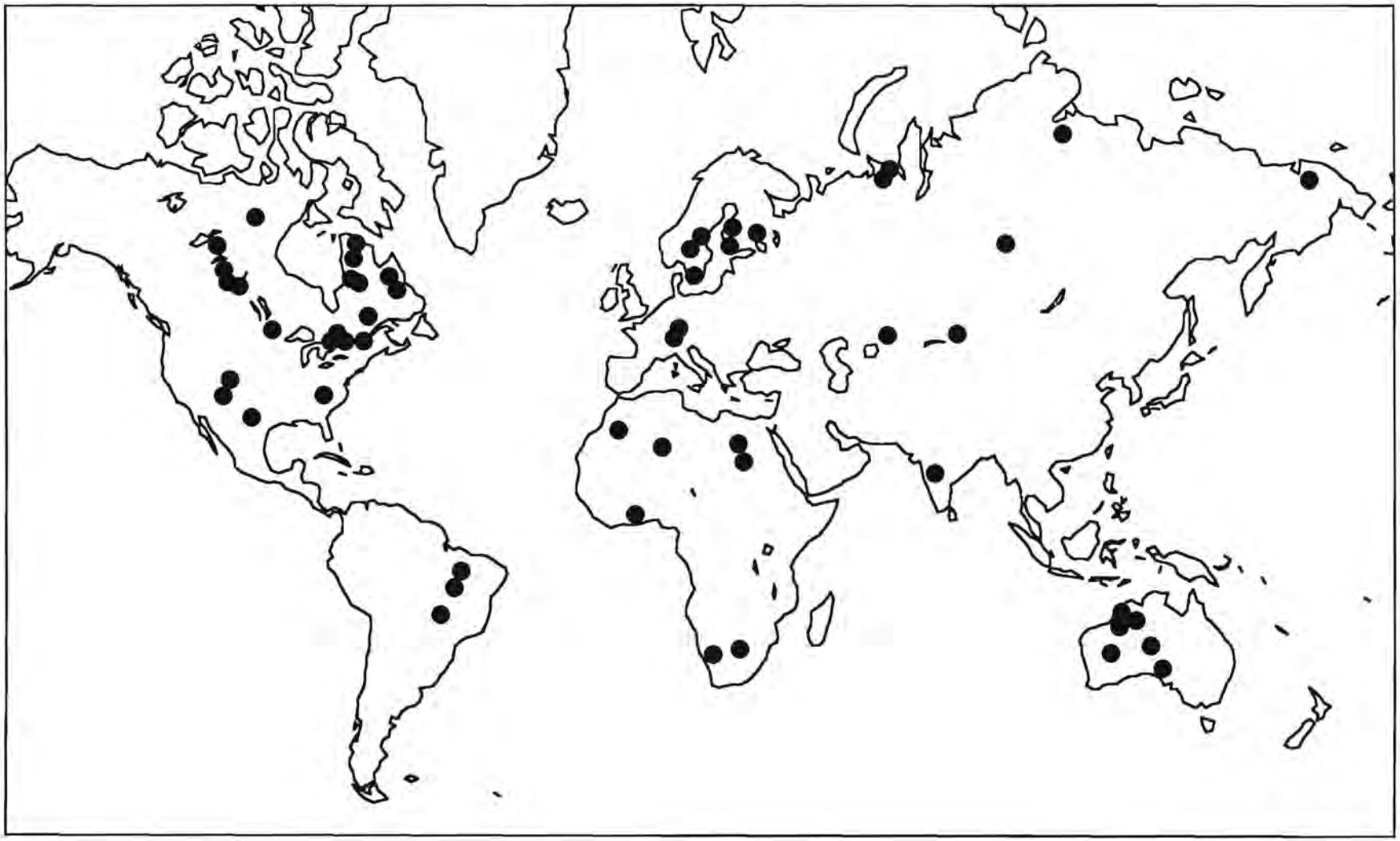
World Map of Impact Craters



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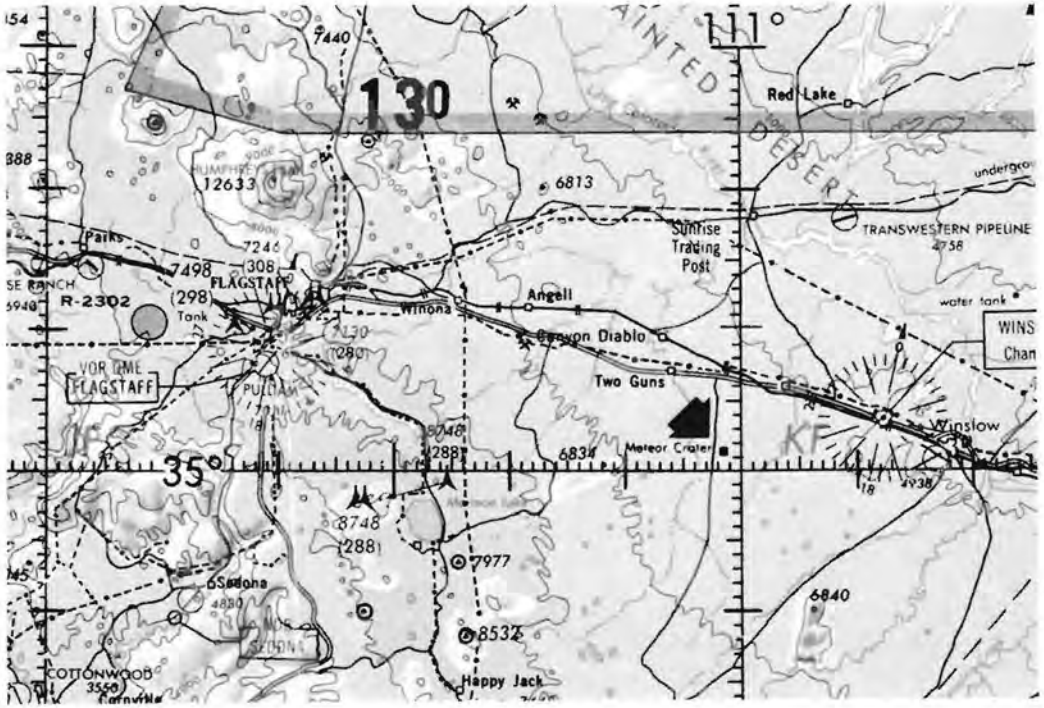
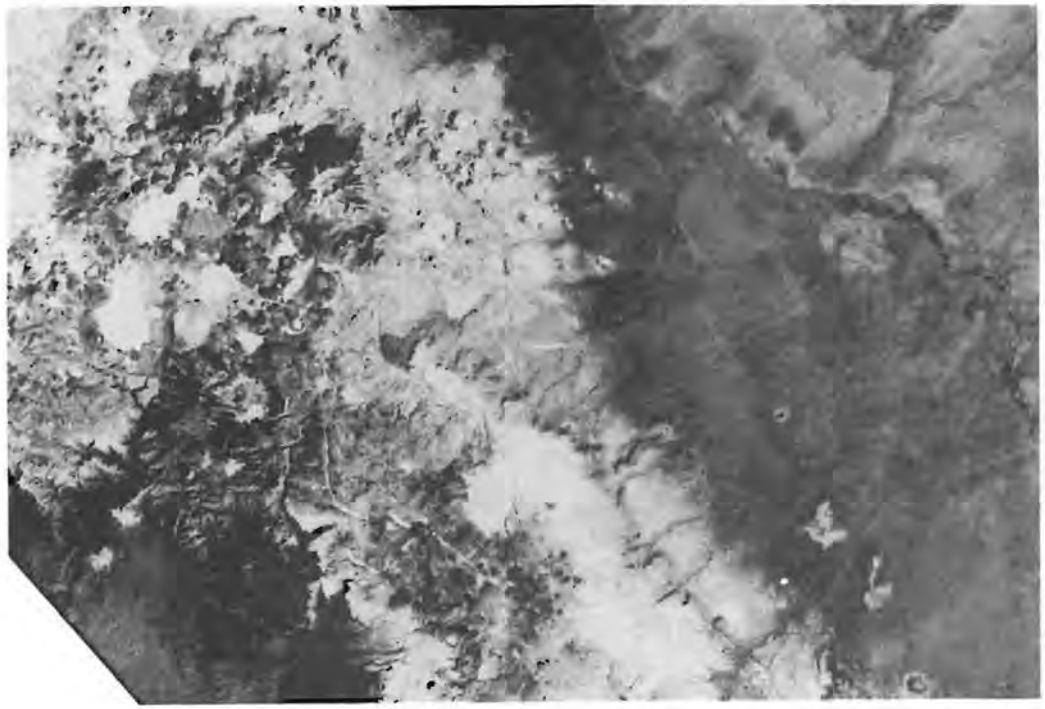


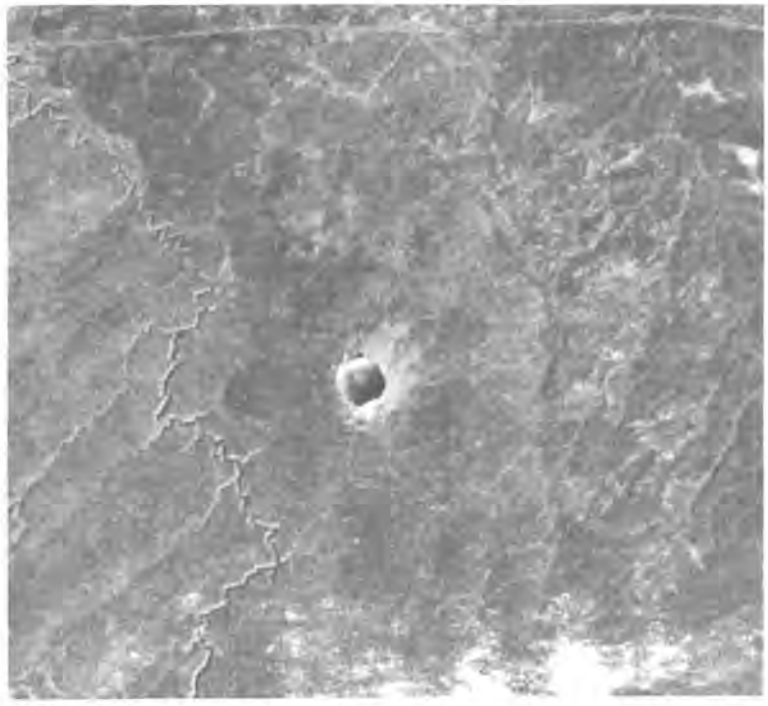
METEOR CRATER
ARIZONA, U.S.A.

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.



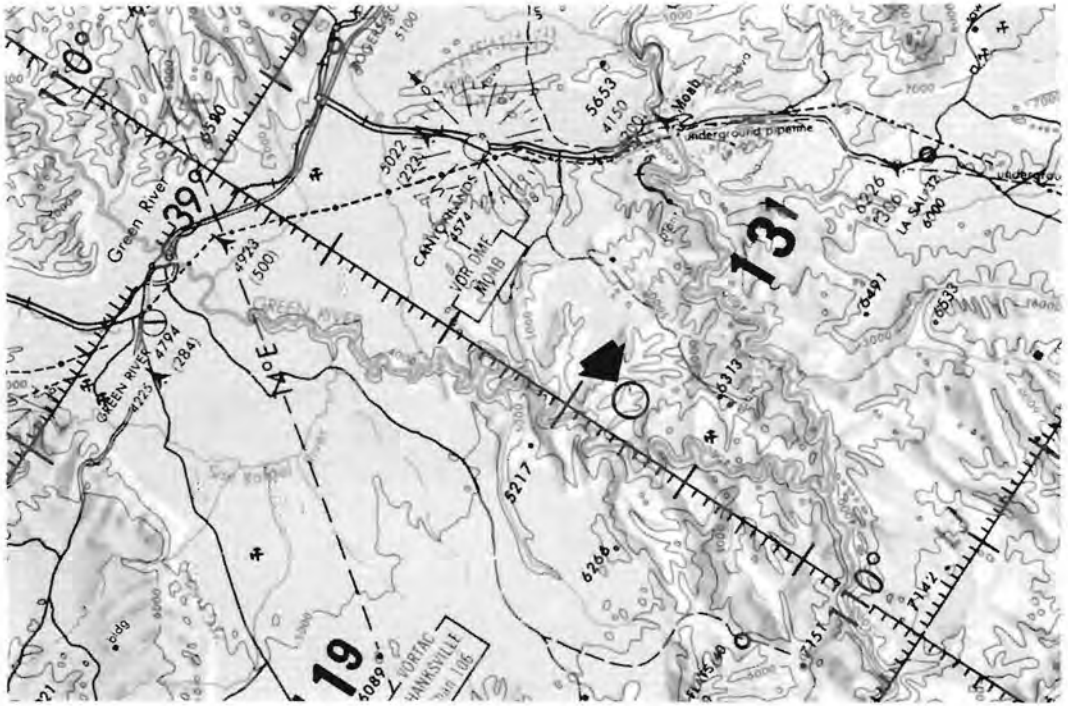


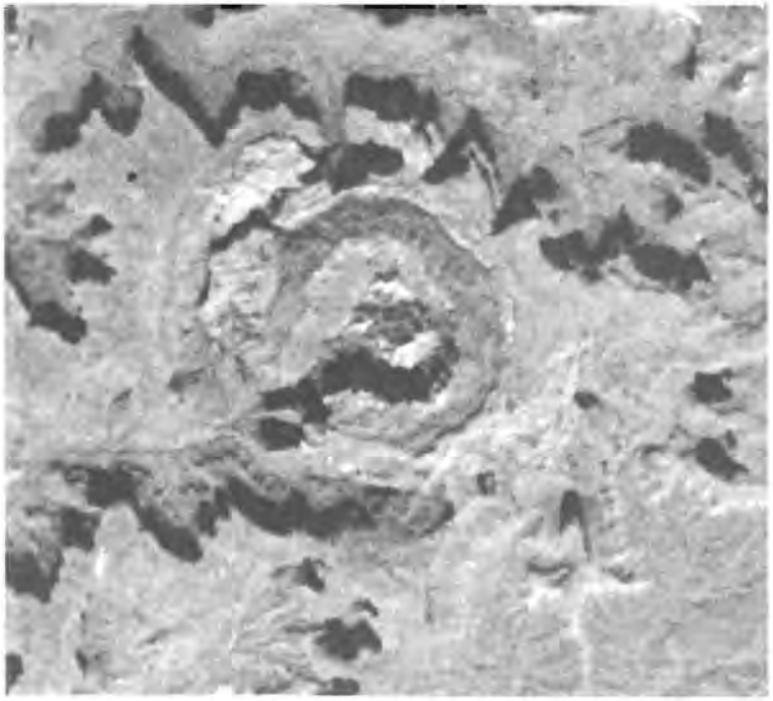
UPHEAVAL DOME
UTAH, U.S.A.

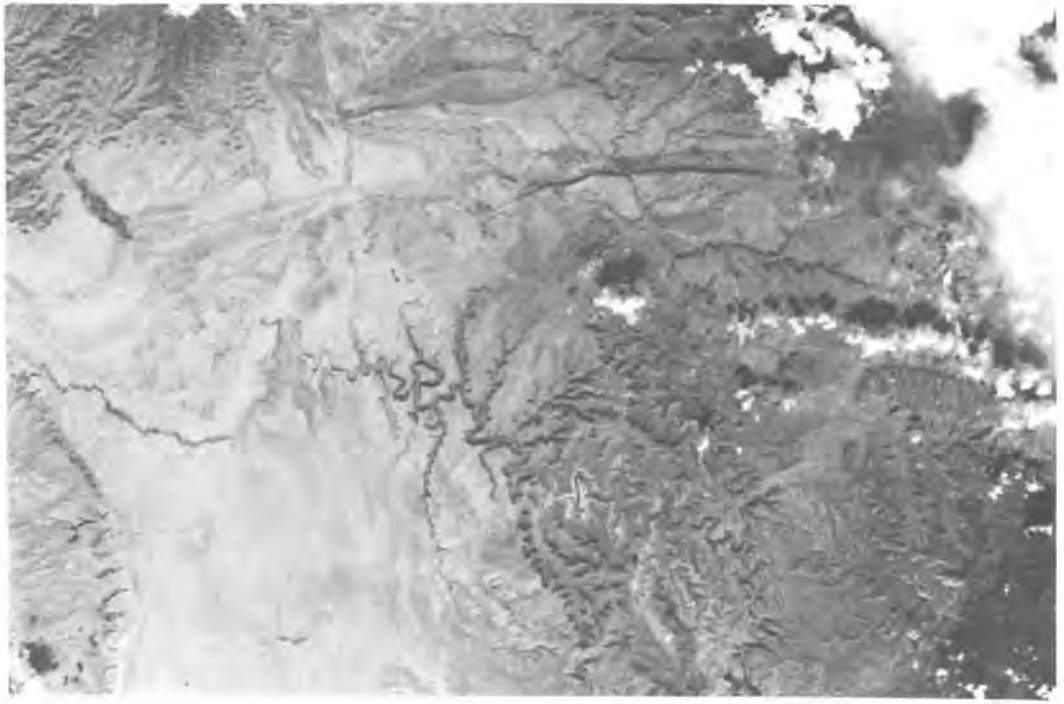
38°26'N; 109°54'W
Diameter: 5 km
Age: Unknown
Discernability: Good, if you can find it
Morphology: "Bull's Eye" pattern of concentric rings

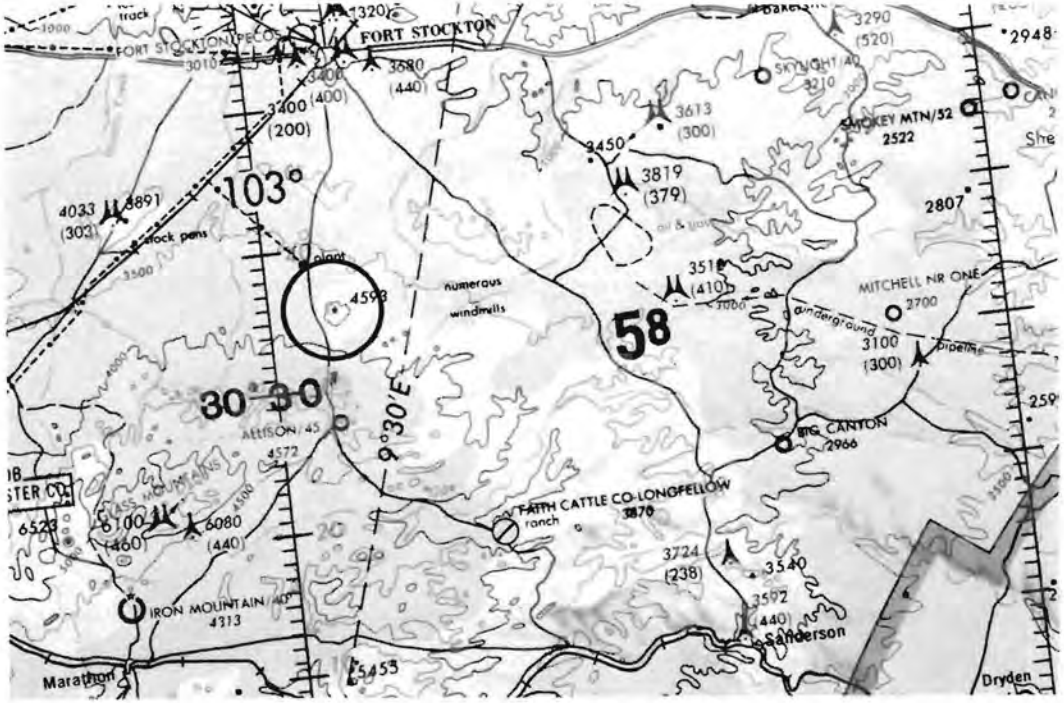
General Area: Upheaval Dome is located between the Green and Colorado Rivers near the northern edge of the Canyonlands National Park in Utah. The crater stands out as an anomalous circular feature in an area dominated by dramatic stream-cut canyons. The target rocks are sedimentary.

Specific Features: The crater appears to be composed of three concentric rings enclosing a central mountainous area. One to two kilometers of erosion has stripped away the surface features revealing the strongly faulted core of the crater. The excellent rock exposures, due to deep canyons, will permit the subfloor structure of this crater to be well-mapped in three dimensions.









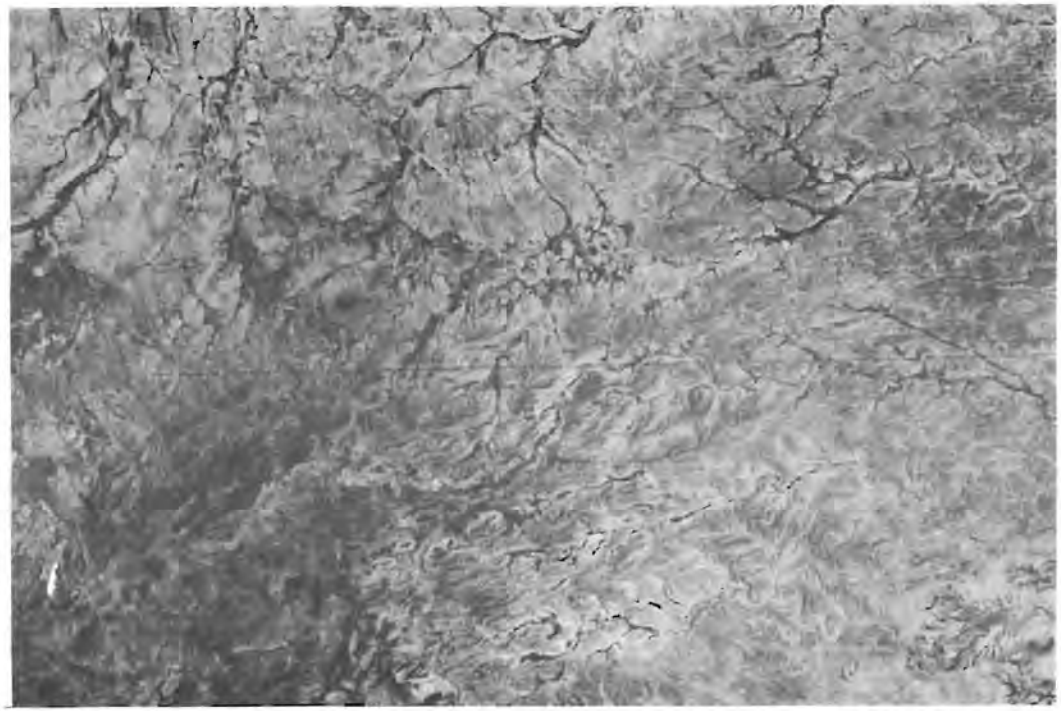
SIERRA MADERA

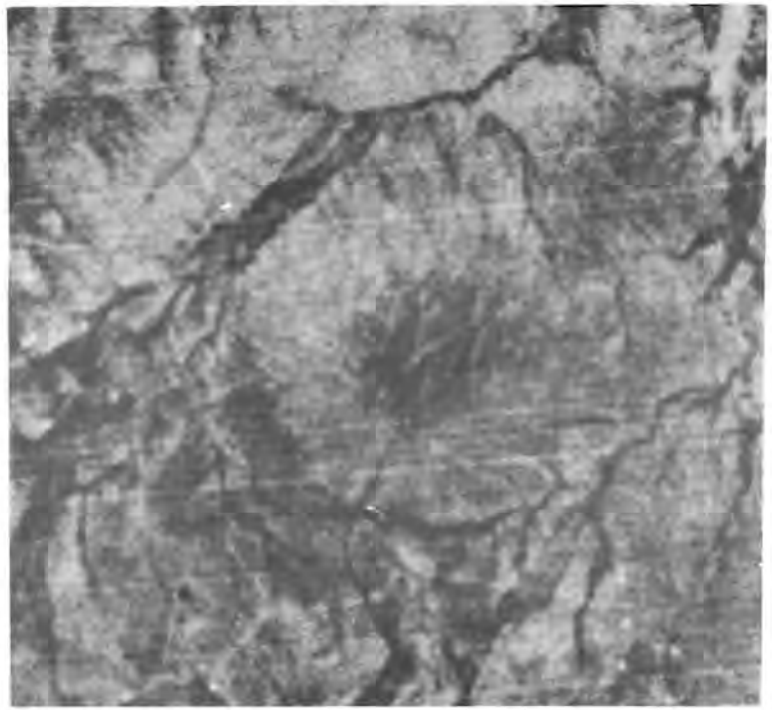
TEXAS, U.S.A.

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.



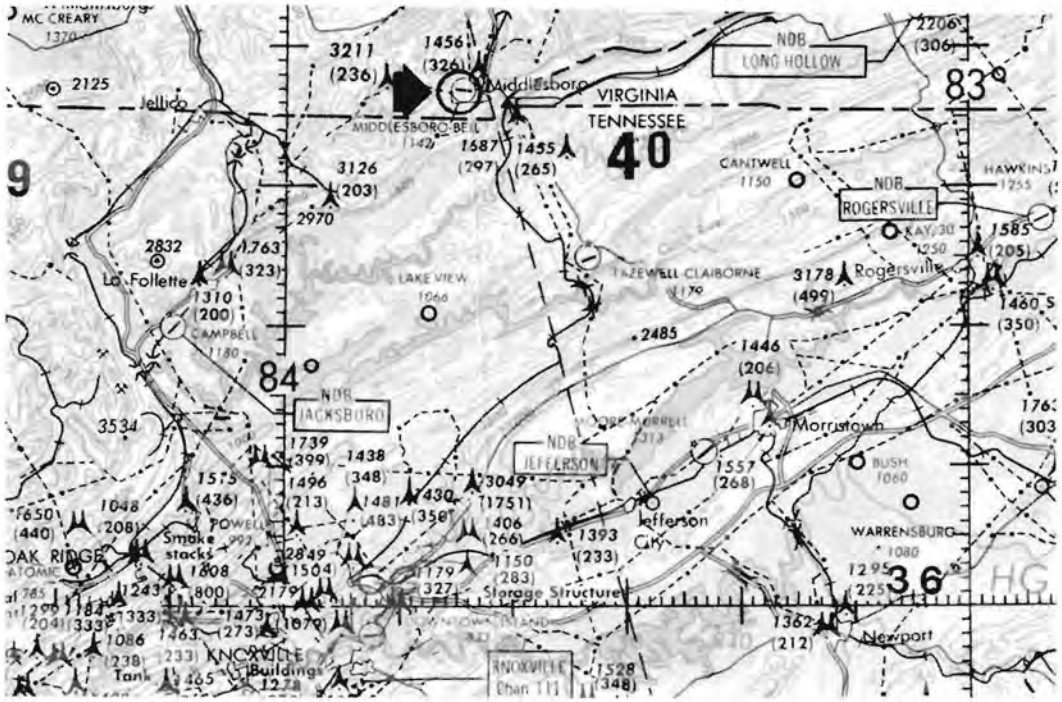


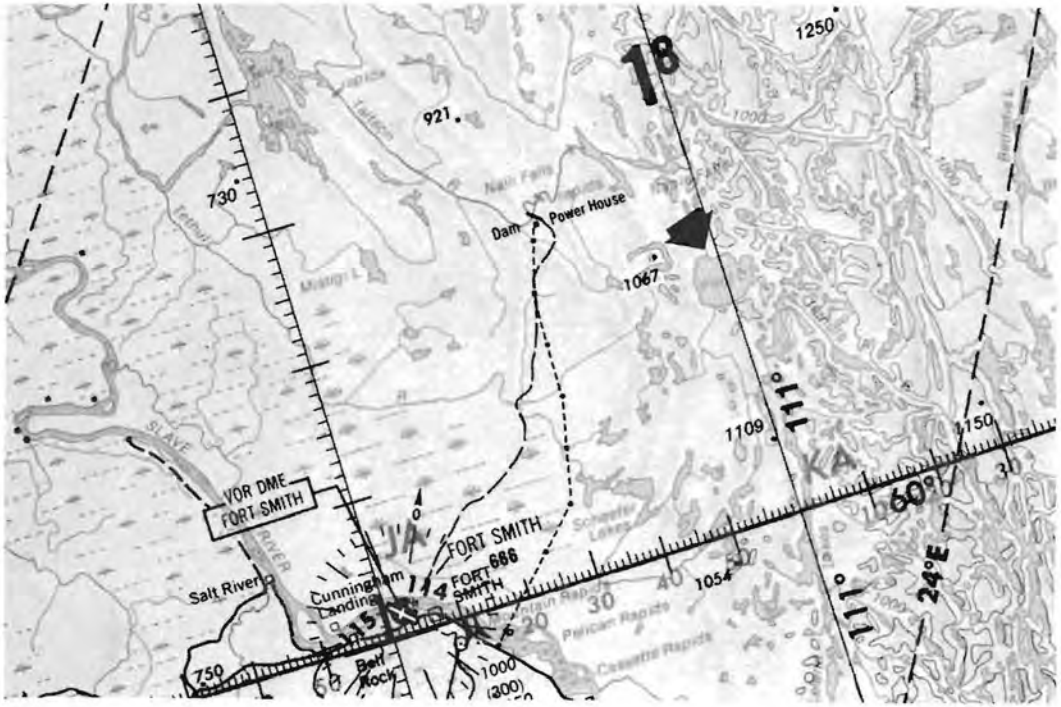
MIDDLESBORO
KENTUCKY, U.S.A.

36°37'N; 83°44'W
Diameter: 6 km
Age: < 300 m.y.
Discernability: Poor
Morphology: Shallow depression

General Area: Dissected plateau region of the westernmost part of the Appalachian Mountains at the junction of Kentucky, Virginia and Tennessee. Middlesboro impact crater is identifiable as a circular patch (occupied by the city of Middlesboro) in otherwise hilly terrain. Knoxville and Norris Lake to the south of Middlesboro are landmarks to help locate the crater. The target rocks are sedimentary.

Specific Features: The 6 km wide crater forms an uncommonly circular depression in a hilly terrain. Although there is a 400 m wide central uplift (exposed in a golf course!), it is not detectable on available high sun angle space photographs. Shatter cones have been found, proving that the feature is of impact origin.





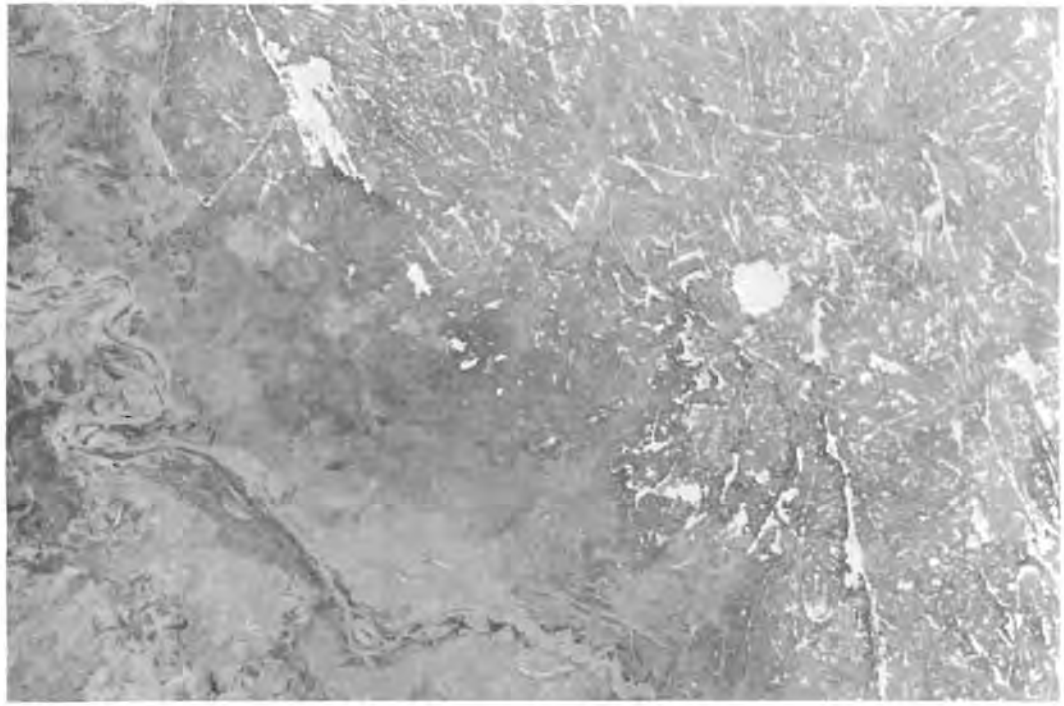
PILOT LAKE

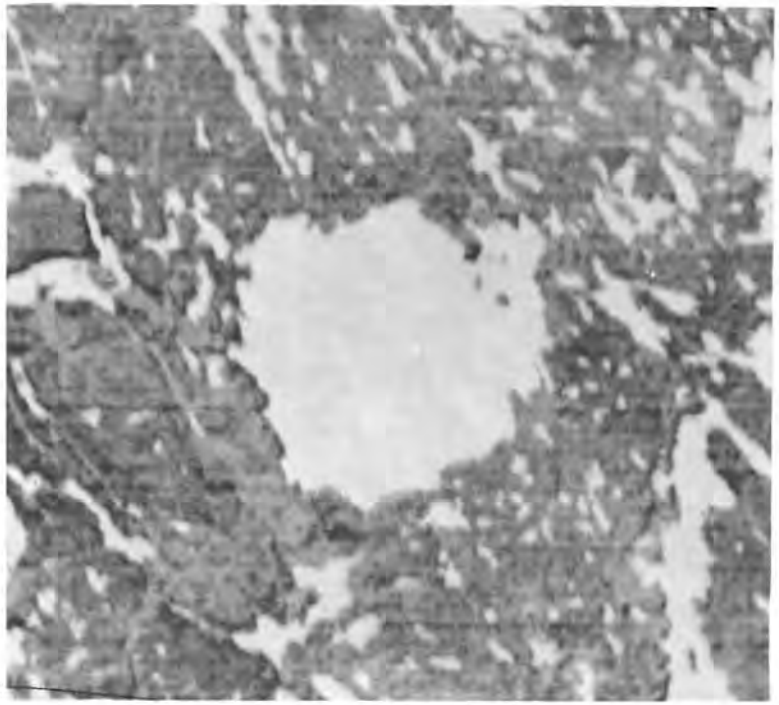
NORTH WEST TERRITORIES, CANADA

60°17'N; 111°01'W
Diameter: 6 km
Age: 440 ± 2 m.y.
Discernability: 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.



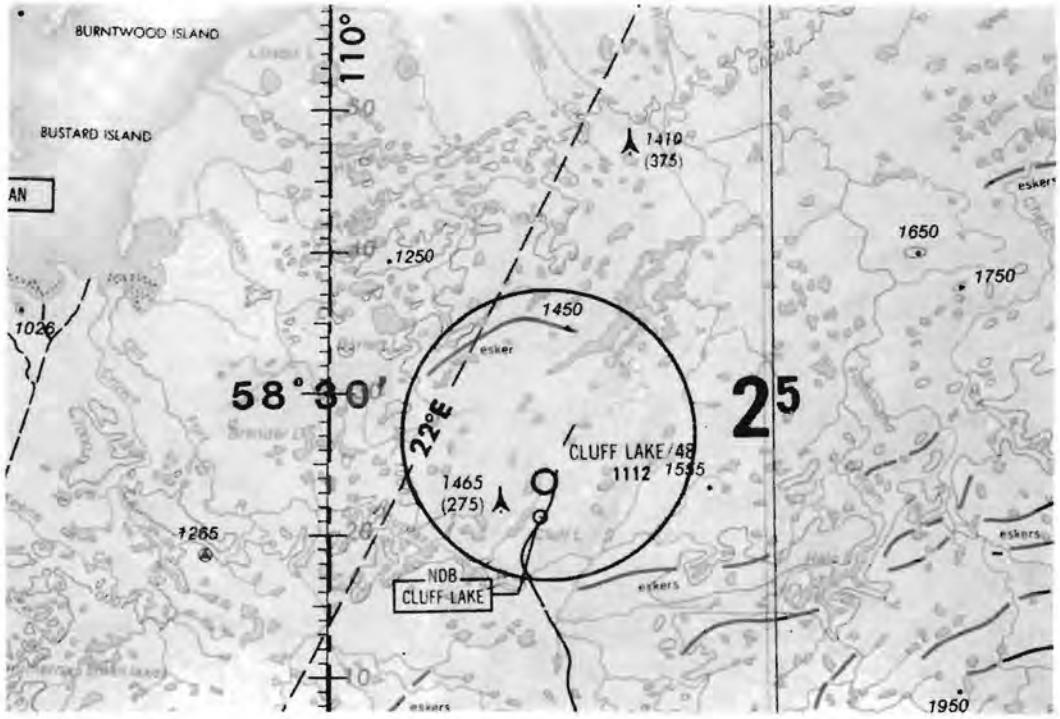


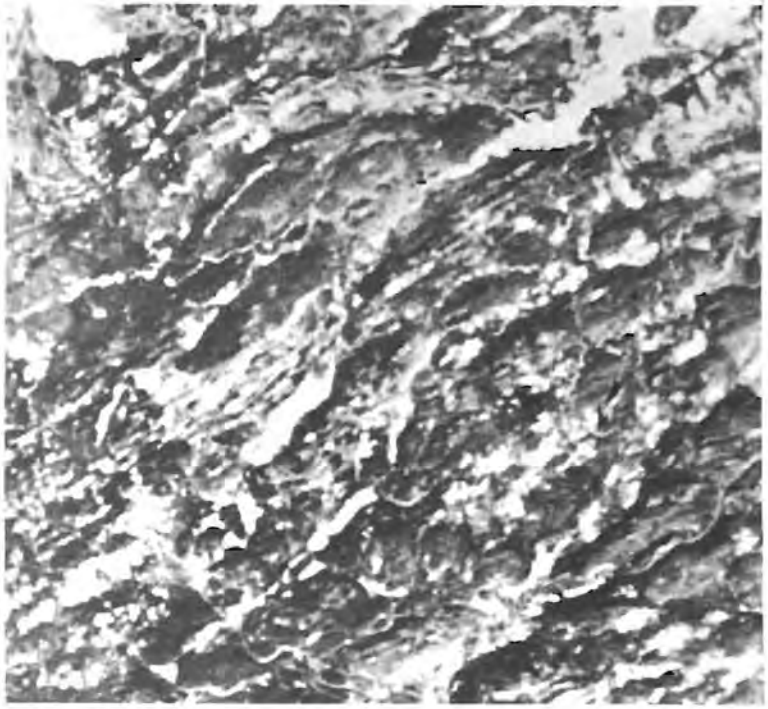
CARSWELL
SASKATCHEWAN, CANADA

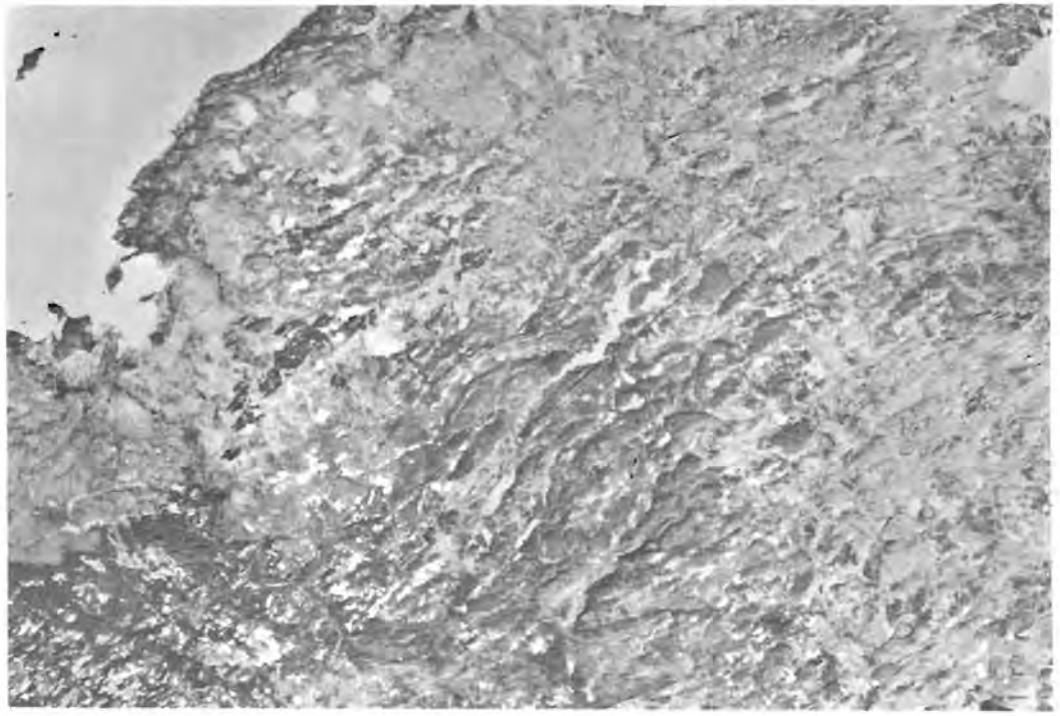
58°27'N; 109°30'W
Diameter: 37 km
Age: 117 ± 8 m.y.
Discernability: Poor
Morphology: Circular geologic structure

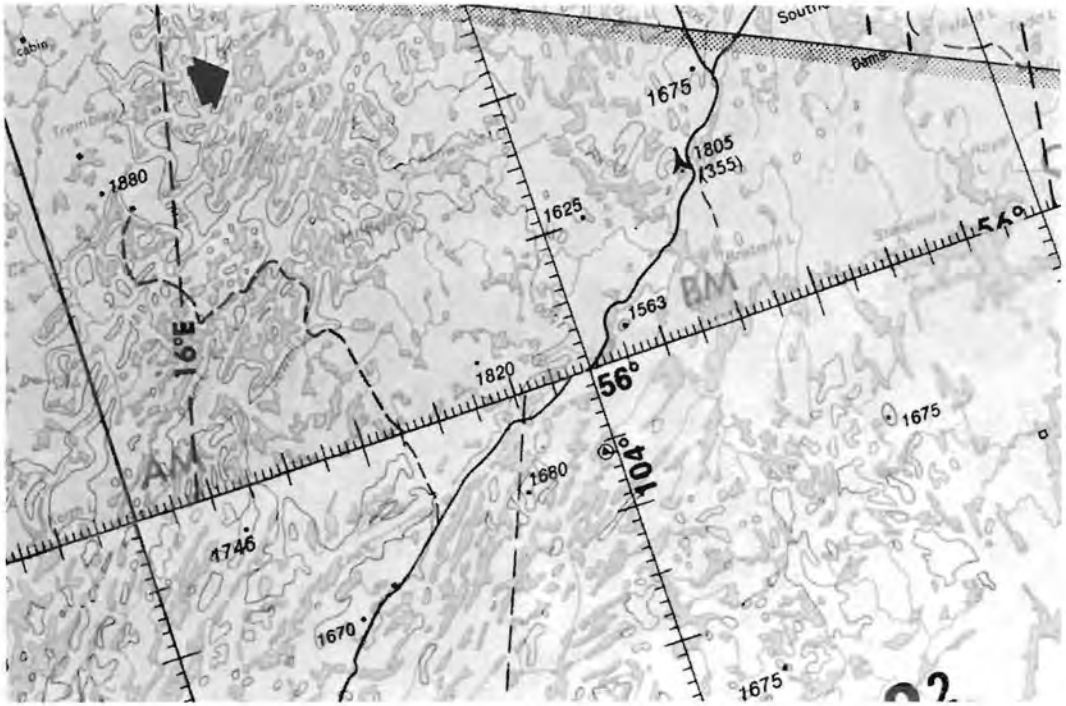
General Area: Low relief area in the Canadian Shield. Area is sparsely forested and has been glaciated. The target rocks are metamorphosed sediments overlying crystalline rocks.

Specific Features: The structure has been highly eroded. The principal morphological element is a ring of small hills ~50 m high, with an inner diameter of 30 km and an outer diameter of ~40 km. These represent upturned beds of erosionally resistant rocks. There is a central core of swampy ground with a diameter of 18 km. At the contact between the crystalline rocks of the core and upturned sediments, uranium deposits are mined.







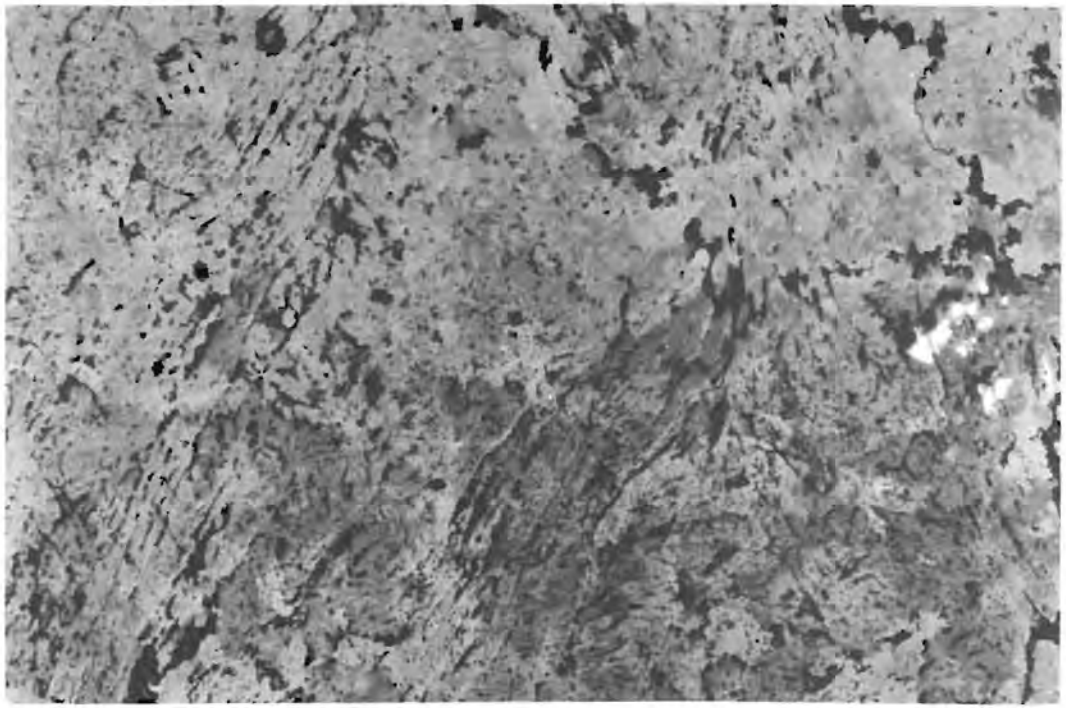


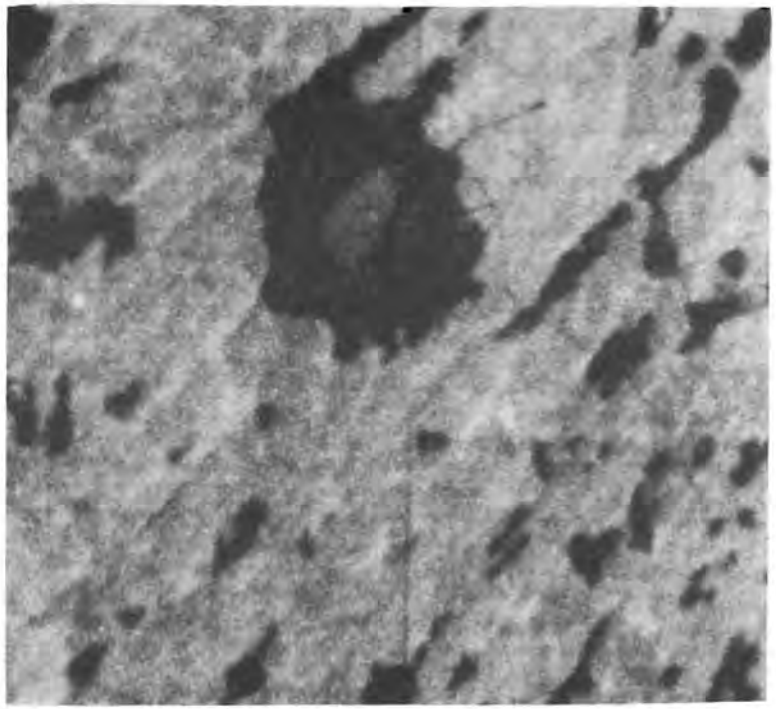
GOW LAKE
SASKATCHEWAN, CANADA

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.



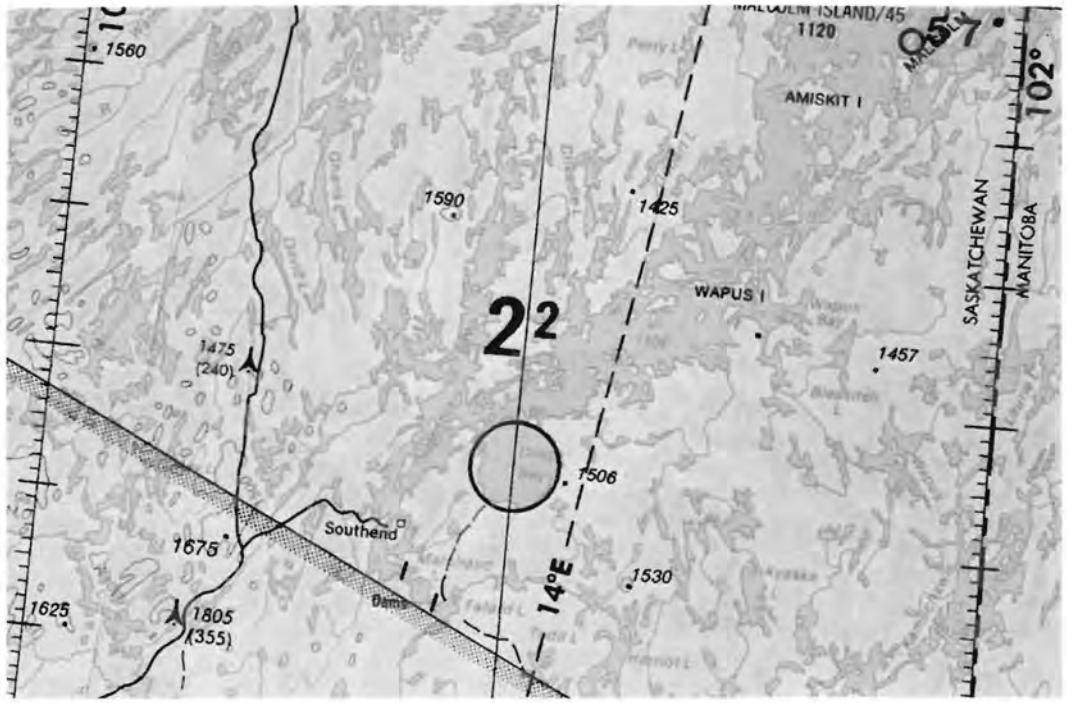


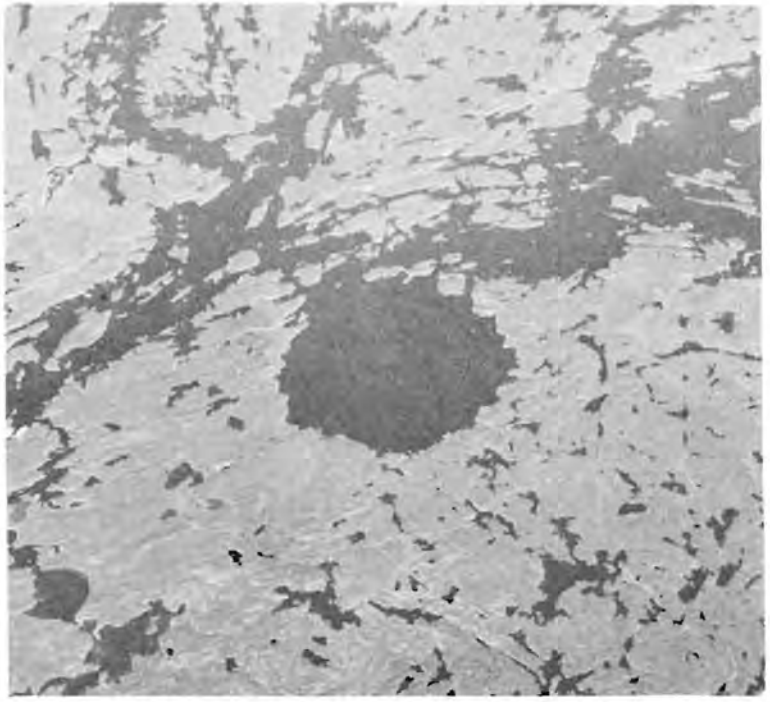
DEEP BAY
SASKATCHEWAN, CANADA

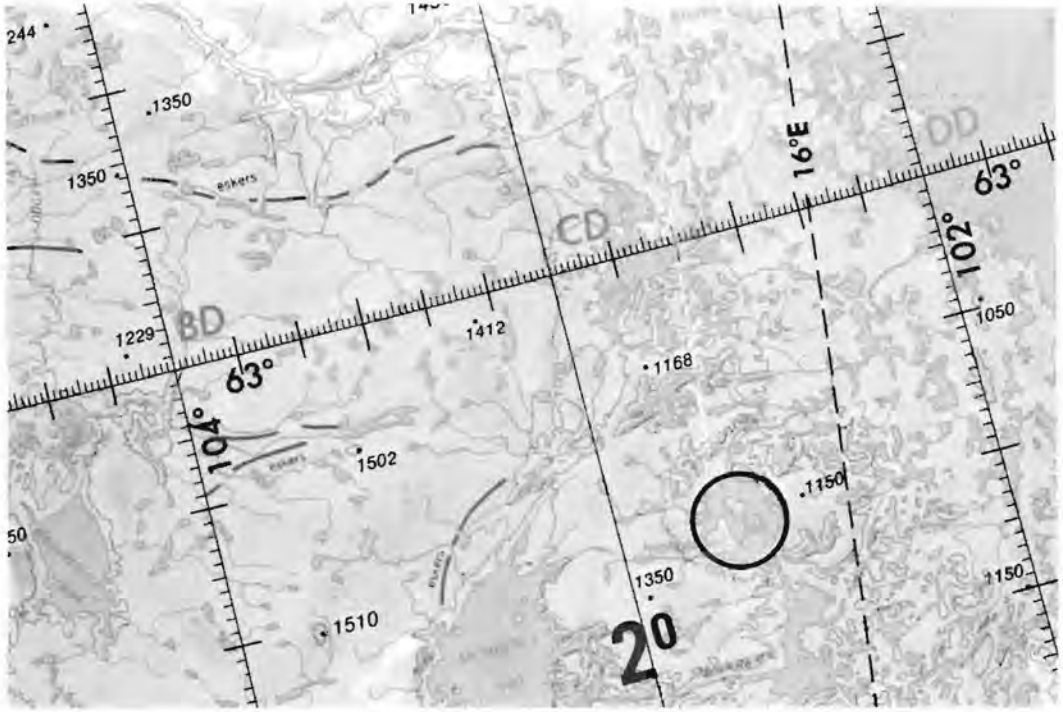
56°24'N; 102°59'W
Diameter: 12 km
Age: 100 ± 50 m.y.
Discernability: Good
Morphology: Circular lake

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

Specific Features: Structure is a circular feature 11 km in diameter, at the south end of Reindeer Lake. The crater is defined by a 220 m deep circular bay in a lake which elsewhere averages only ~50 m in depth. The shape and depth of the bay contrast sharply with other lakes in the area. Local Indian legend has a taboo on fishing in the bay, presumably due to its unusual appearance and depth. A subtle rim ~100 m high surrounds the bay at a diameter of 13 km. Additionally, a faint fracture halo has been mapped from aerial photographs and SIR-B radar imagery.





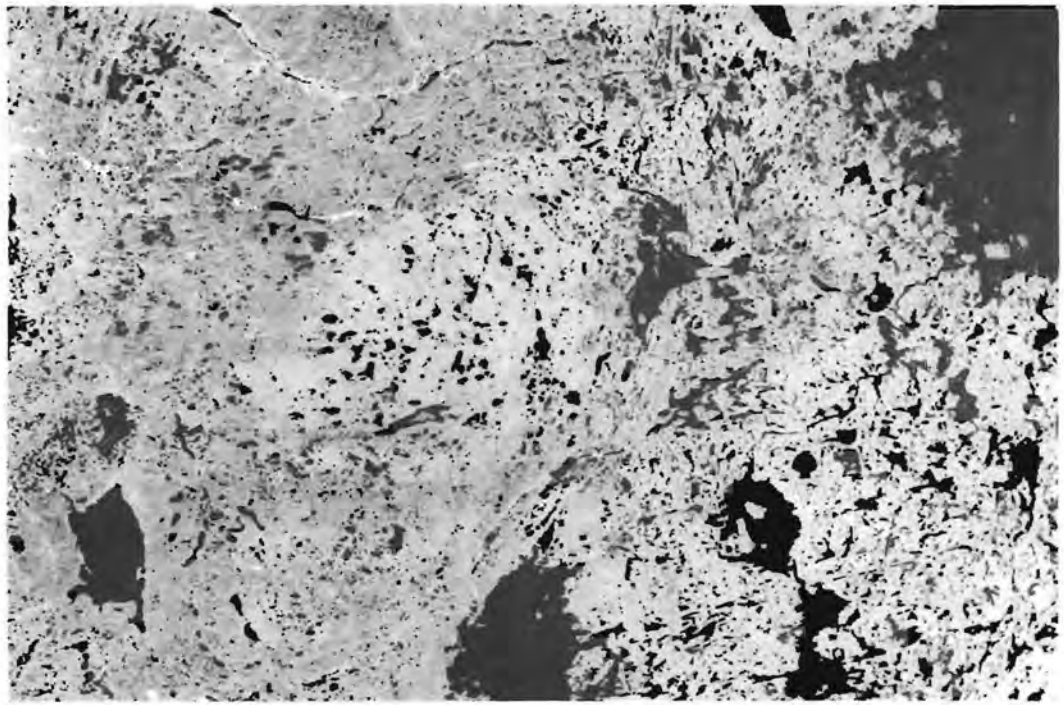


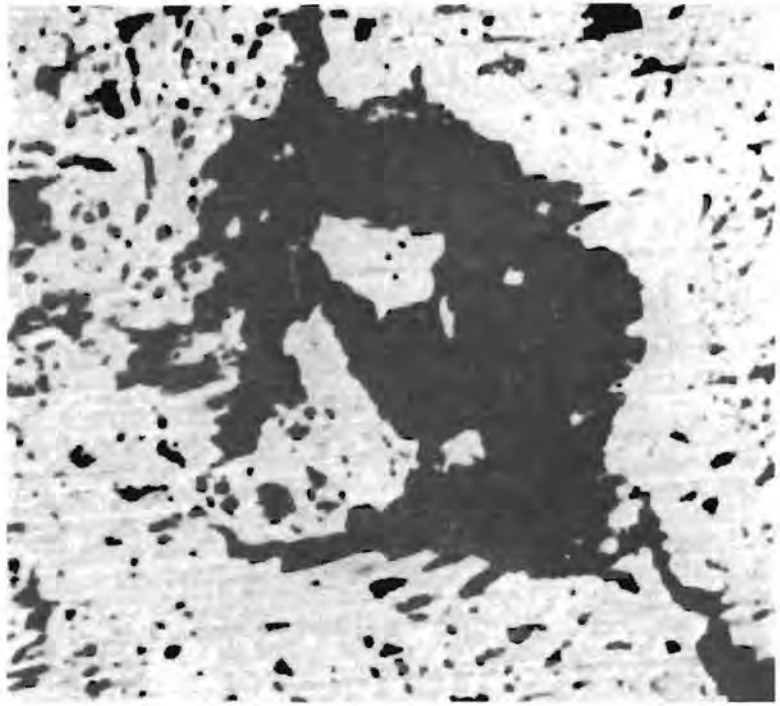
NICHOLSON LAKE
NORTH WEST TERRITORIES, CANADA

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.



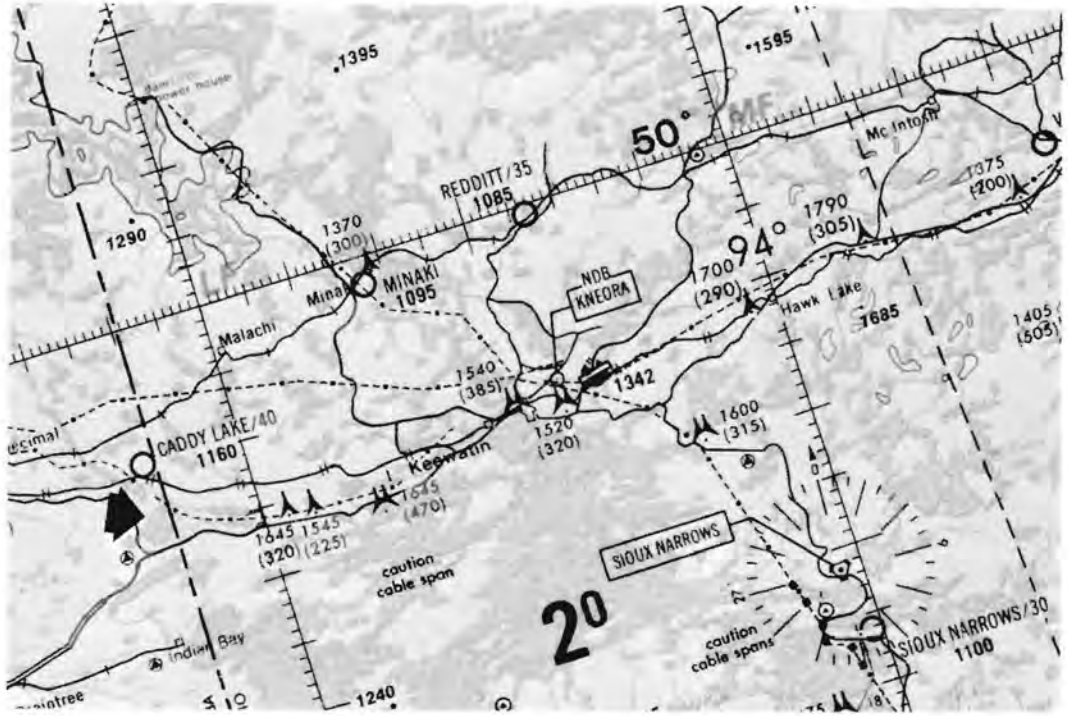


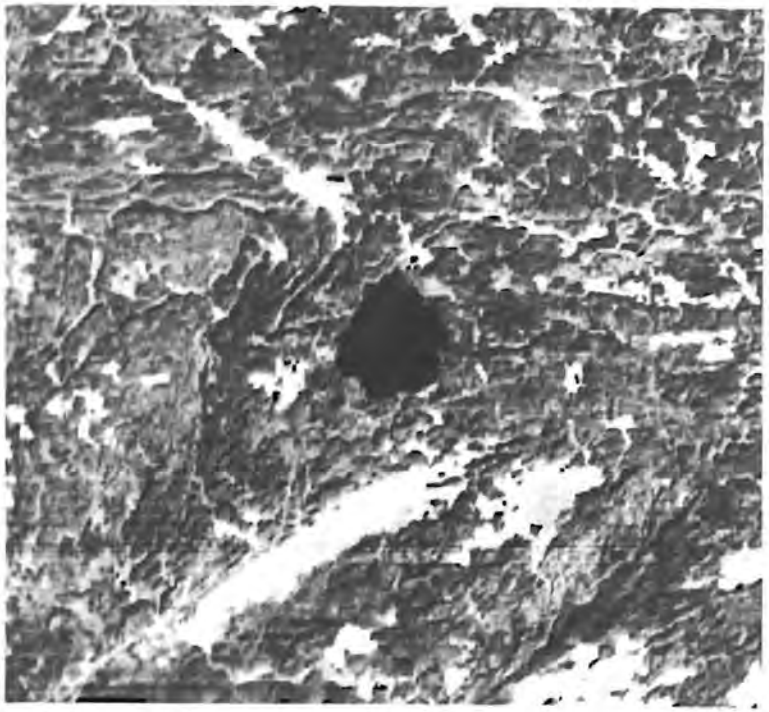
WEST HAWK LAKE
MANITOBA, CANADA

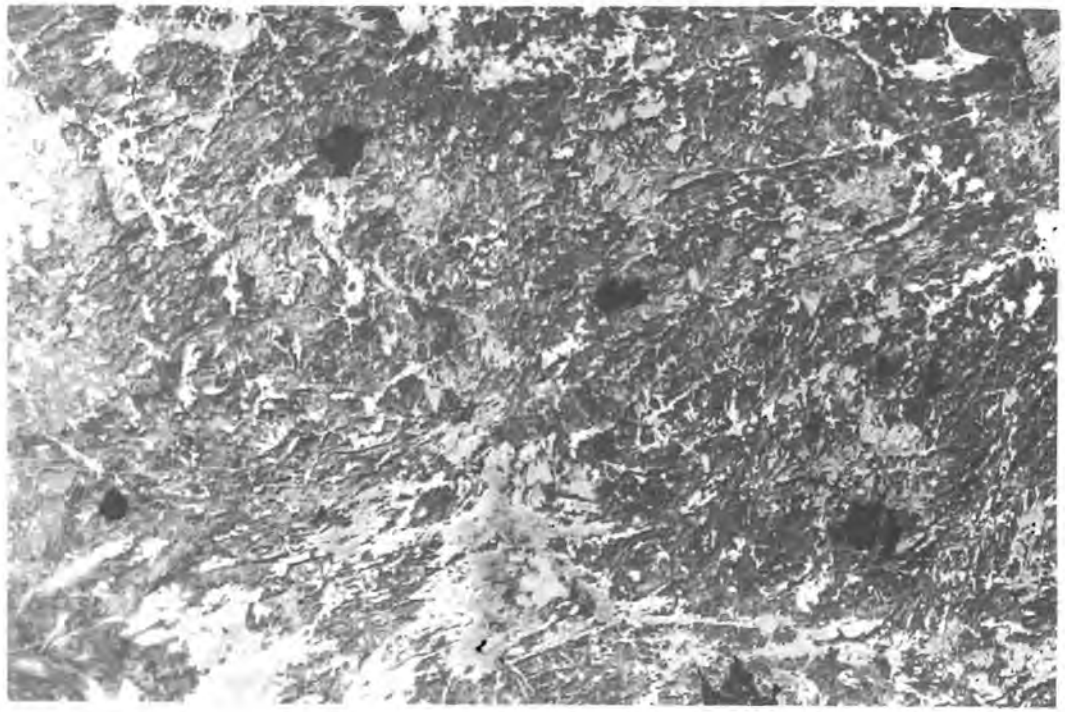
49°46'N; 95°11'W
Diameter: 2.7 km
Age: 100 ± 50 m.y.
Discernability: Average
Morphology: Polygonal lake

General Area: Subdued relief near the southwestern edge of the Canadian Shield. The area is heavily forested and has been glaciated. The target rocks are crystalline.

Specific Features: Structure lies within the polygonal 3.6 km diameter West Hawk Lake. The shape of the lake contrasts with others in the immediate area. There is a partial ring of hills rising ~40 m around the lake. The crater is clearly superimposed upon the structural fabric of the rocks in the area. A major fold can be seen northwest of the crater.





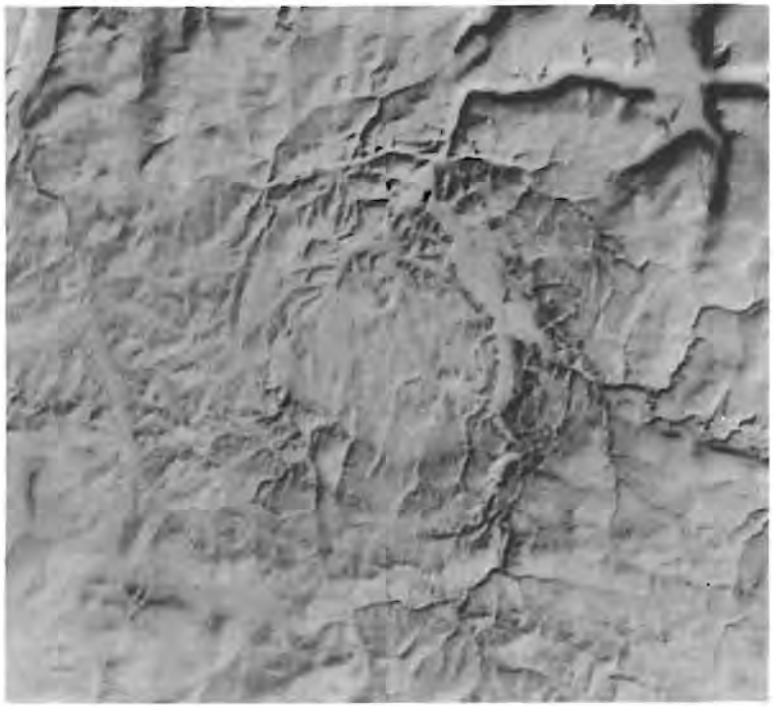


HAUGHTON
NORTH WEST TERRITORIES, CANADA

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.

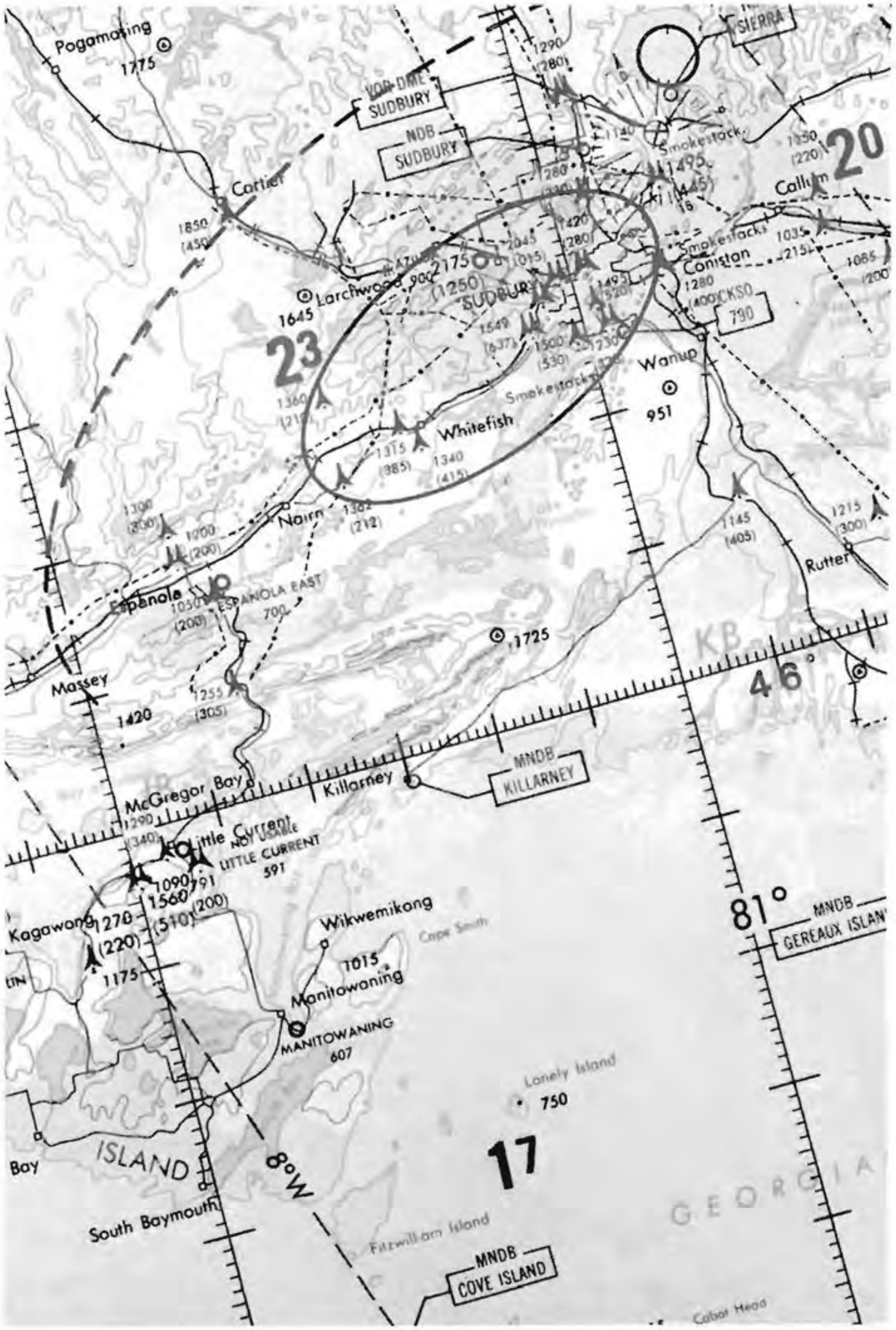


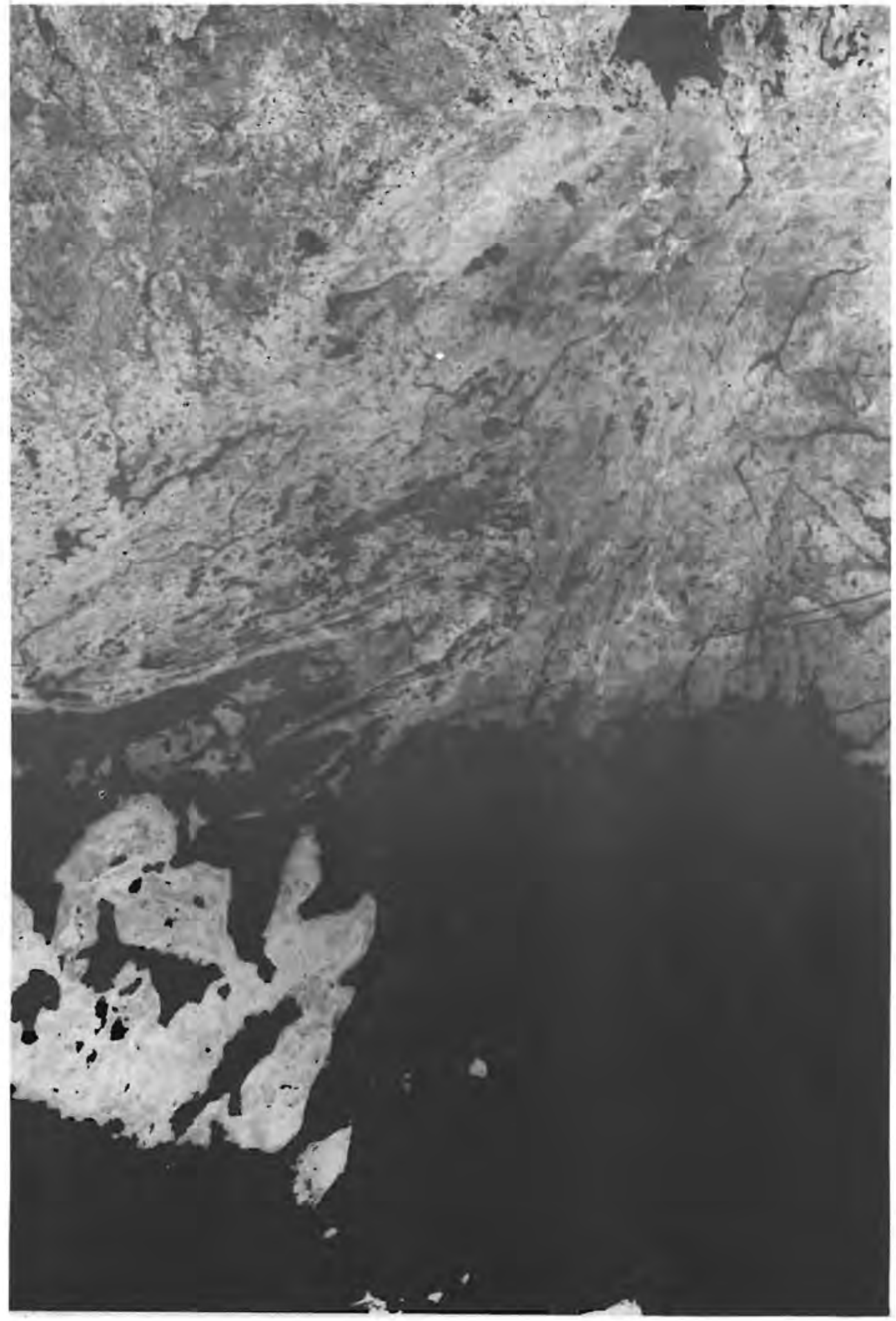
SUDBURY
ONTARIO, CANADA

46°36'N; 81°11'W
Diameter: 140 km
Age: 1850 ± 150 m.y.
Discernability: Average - Poor
Morphology: Elliptical basin with smooth, lake-free interior

General Area: Sudbury lies close to the junction of three major structural provinces of the Canadian Shield. The area has been glaciated and is generally timbered, with agriculture occurring within the Sudbury structure. The target rocks are crystalline.

Specific Features: The Sudbury structure is the oldest and largest impact structure in North America. It is almost completely eroded and is most visible only as the elliptical outline of the Sudbury Igneous Complex, the interior of which is filled by post-impact sediments and appears smooth with few lakes. The original structure extended beyond the Igneous Complex but has no remaining morphologic expression. The elliptical appearance is due to post-impact tectonism, with shortening to the northwest. A weak fracture halo is developed to the north, exterior to the Igneous Complex. The Sudbury Igneous Complex has associated major nickel and copper ore-bodies, which are currently mined, and is outlined on its accompanying map.


Pogamasing
1775
VOR-DME SUDBURY
NDB SUDBURY
SIERRA
Smokestack
1495
(445)
1350
(220)
20
Callum
Cartier
1850
(450)
Larchwood
2175
(1250)
SUDBURY
Smokestacks
Coniston
1280
(400)
CKSO 790
1035
(215)
1085
(200)
1645
23
Wanup
951
Smokestacks
Whitefish
1315
(385)
1340
(415)
Nairn
Espanola
ESPANOLA EAST
700
1725
1145
(405)
1215
(300)
Rutter
KB
46°
Massey
1420
1255
(305)
McGregor Bay
Killarney
MNDB KILLARNEY
Little Current
NOT USABLE
LITTLE CURRENT
591
1560
(510)
Kagawong
1270
(220)
1175
Wikwemikong
Cape Smith
1015
Manitowaning
MANITOWANING
607
81°
Lonely Island
750
17
ISLAND
Bay
South Baymouth
Fitzwilliam Island
MNDB COVE ISLAND
G E O R G I A
Cabot Head

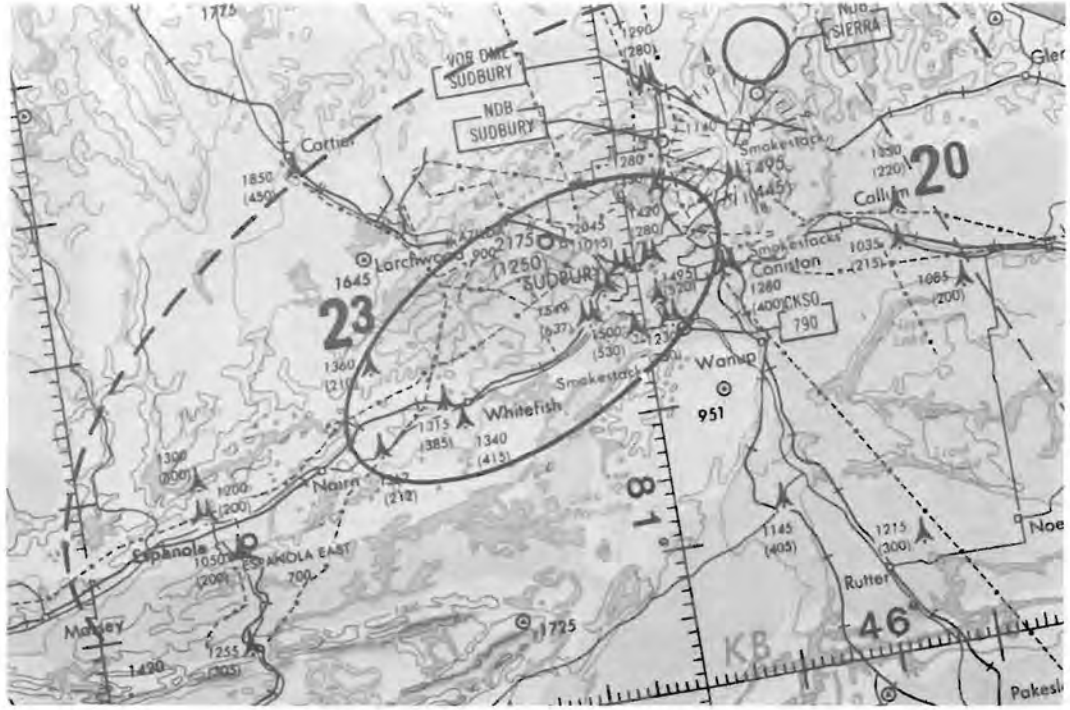


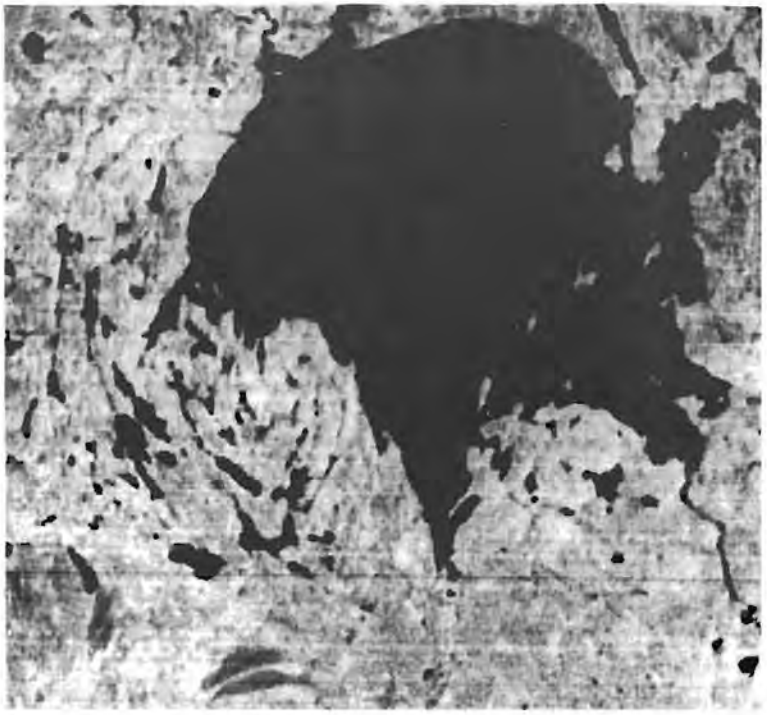
WANAPITEI
ONTARIO, CANADA

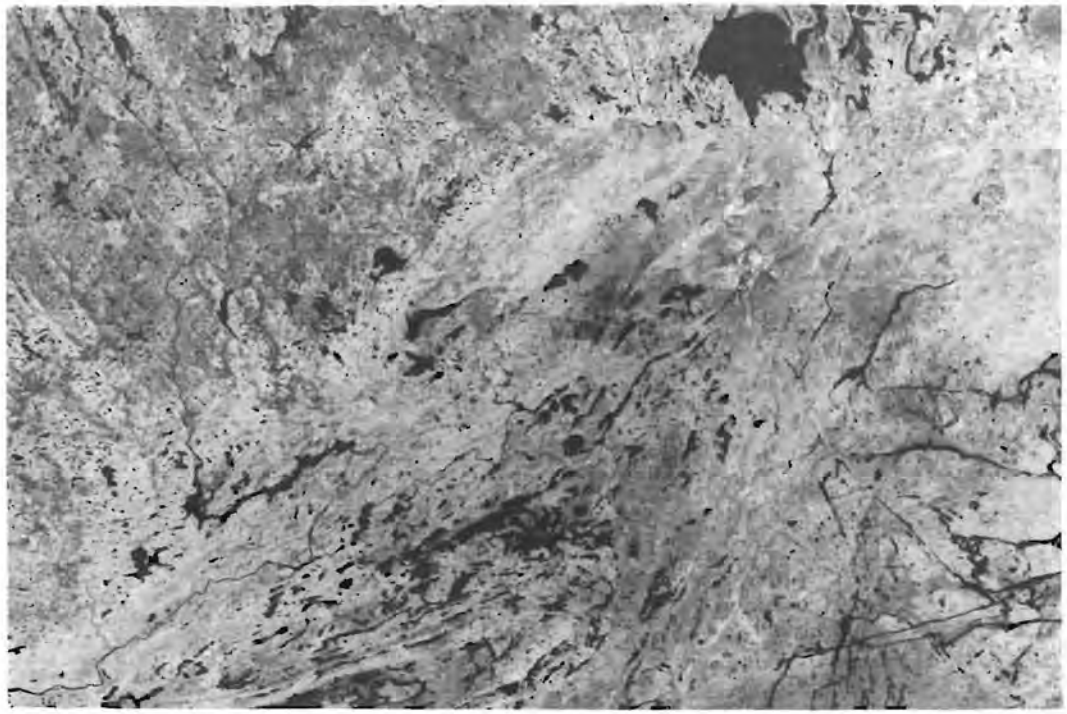
46°44'N; 80°44'W
Diameter: 8.5 km
Age: 37 ± 2 m.y.
Discernability: Good
Morphology: Lake with semi-circular northern shore

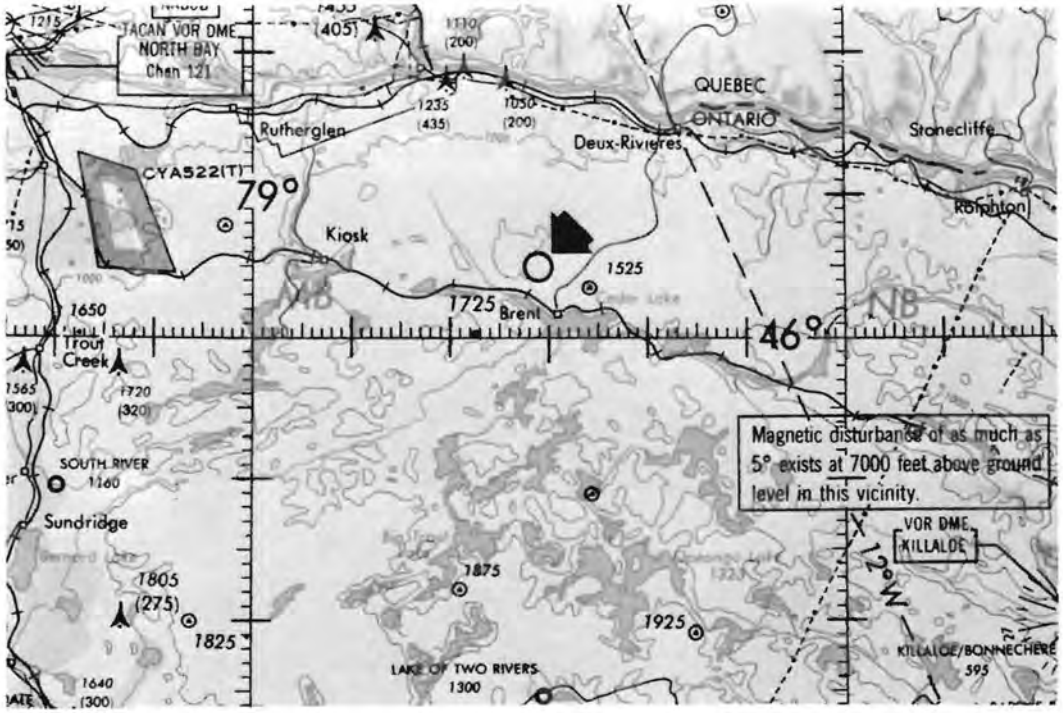
General Area: Wanapitei is superimposed upon the eastern margin of the older, larger Sudbury structure. The area is generally timbered and has been glaciated. The target rocks are crystalline.

Specific Features: The crater is occupied by a lake with a semi-circular north-shore, and defines a circle 8.5 km in diameter. Elongate fingers of the lake to the south are the result of deepening by glaciation. Wanapitei is superimposed on the Sudbury structure and clearly transects pre-existing structural trends. A circular fracture halo is developed to the north and west but is obscured to the south by glacial deposits.







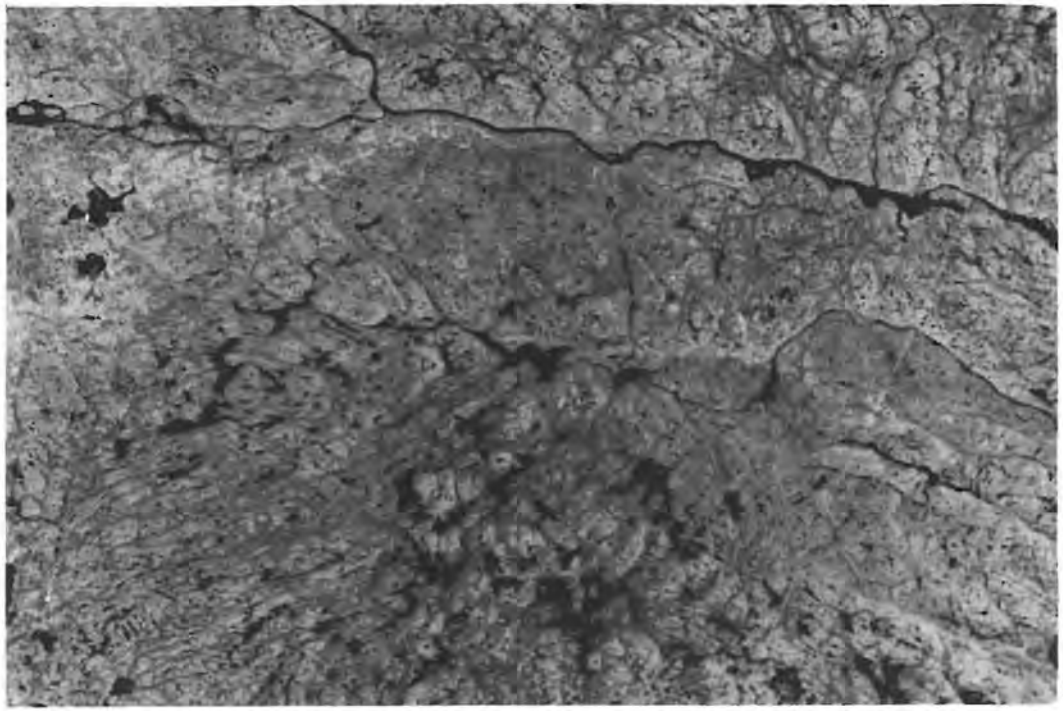


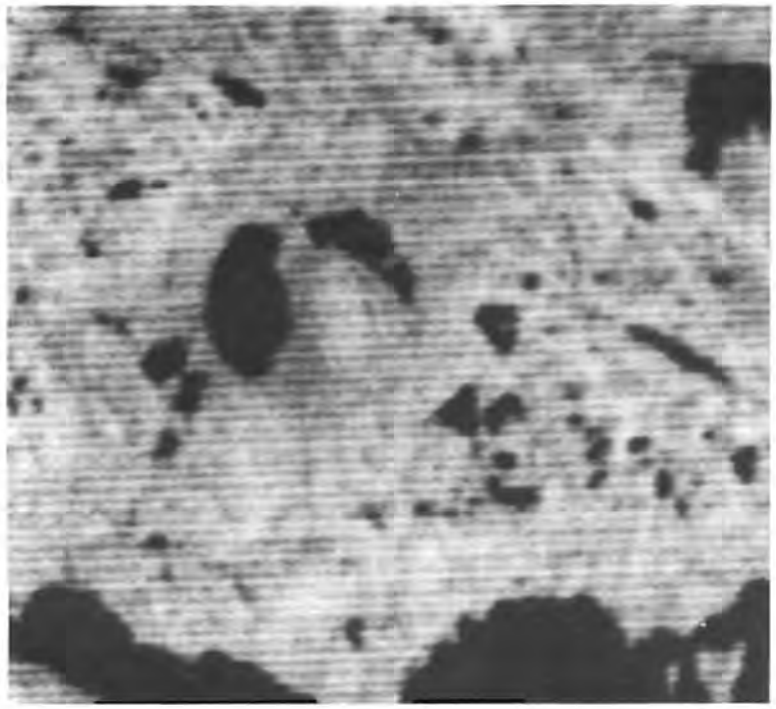
BRENT
ONTARIO, CANADA

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.



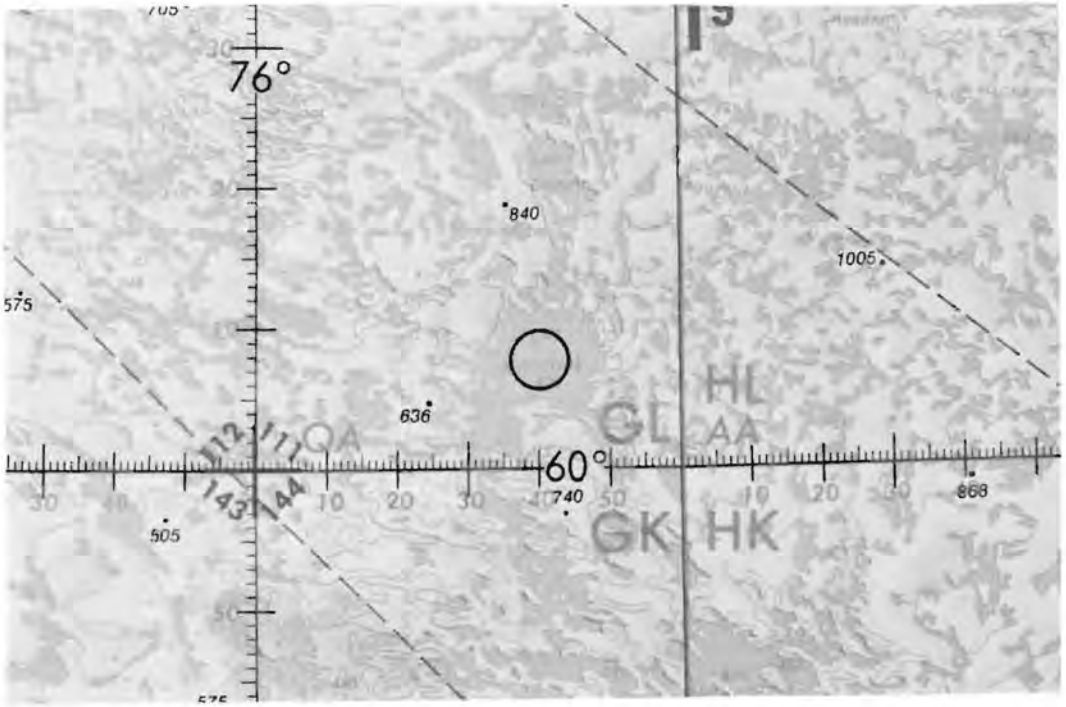


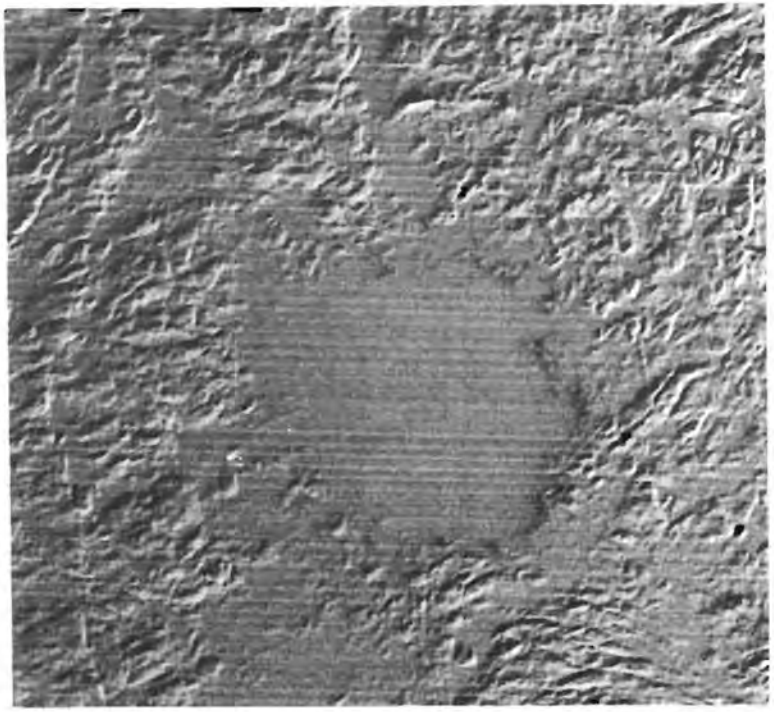
LAC COUTURE
QUEBEC, CANADA

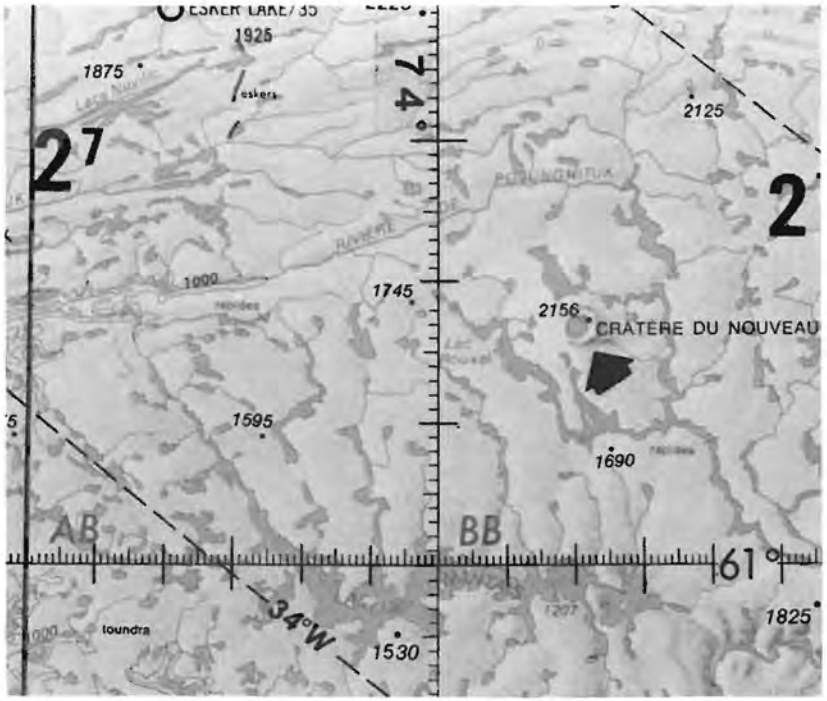
60°08'N; 75°20'W
Diameter: 8 km
Age: 425 ± 25 m.y.
Discernability: Good
Morphology: Circular lakes

General Area: Subdued topography in the Canadian Shield. The area is tundra, with little vegetation, and has been glaciated. The target rocks are crystalline.

Specific Features: Crater occupies a circular lake ~13 km in diameter which contrasts sharply with the linear and irregular lakes in the area. The central, island-free portion of the lake is ~8 km wide and is taken as the diameter of the crater. There is a small central peak which is submerged. Erosion has removed all traces of the rim. There is some indication of increased fracturing in the local bedrock surrounding the structure.





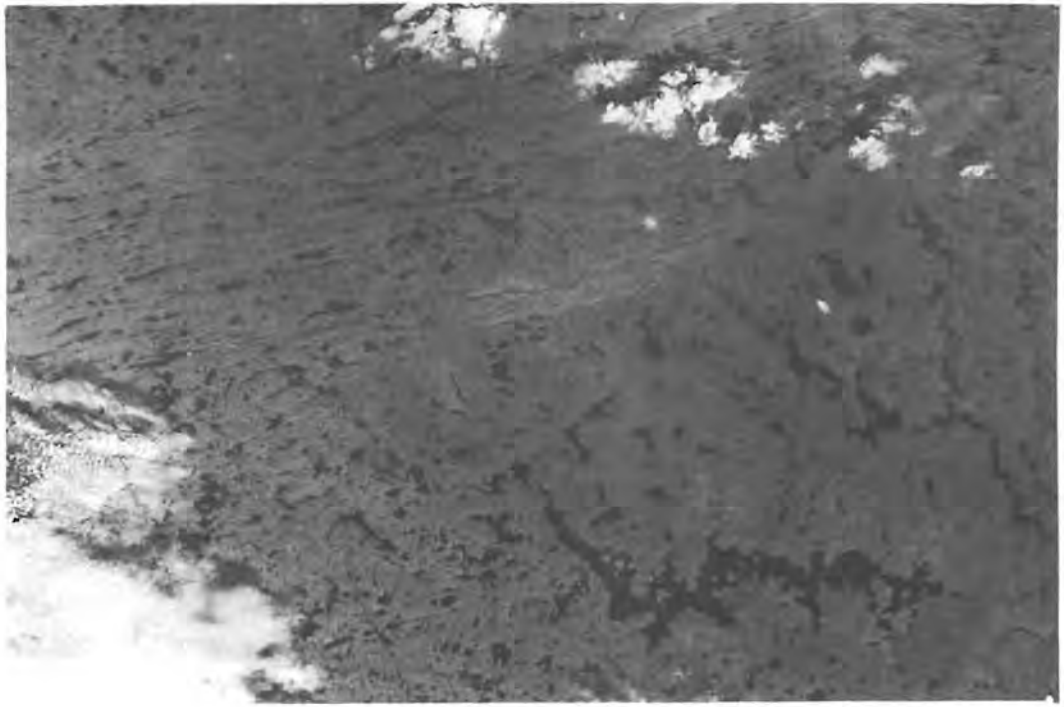


NEW QUEBEC
QUEBEC, CANADA

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.

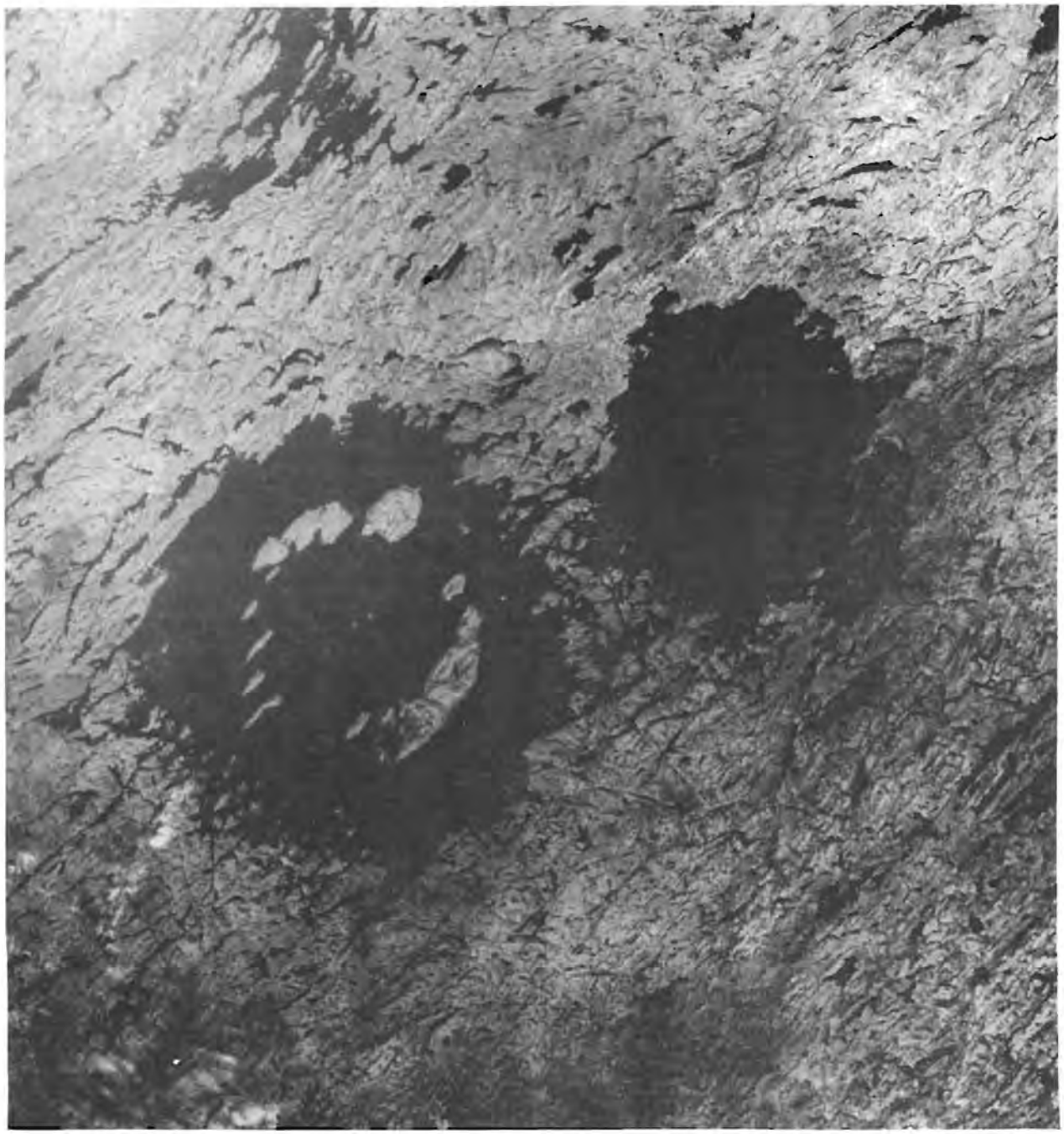


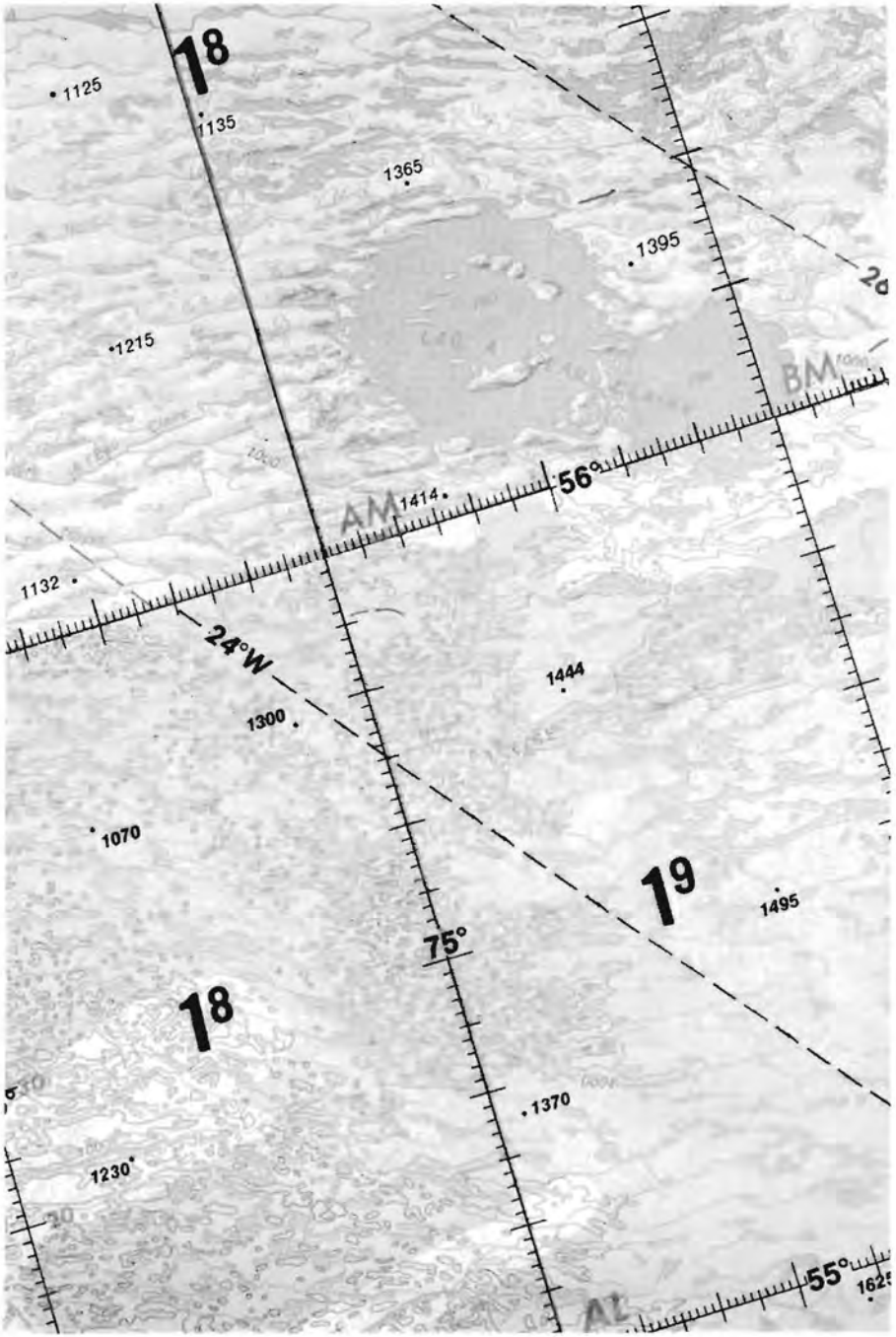
CLEARWATER LAKES
QUEBEC, CANADA

East: 56°05'N; 74°07'W
West: 56°13'N; 74°30'W
Diameter: East 22 km
West 32 km
Age: 290 ± 20 m.y.
Discernability: Excellent
Morphology: Twin circular lakes, one with an interior ring

General Area: The Clearwater Lakes lie within the Canadian Shield, close to the tree-line. Their circular form contrasts sharply with the linear and irregular lakes in this area of generally low relief. The area has been glaciated. The target rocks are crystalline.

Specific Features: Twin craters, formed simultaneously by the impact of an asteroidal pair. The eastern, smaller structure has a submerged central peak. The western, larger structure contains a prominent ring of islands, that are 6-10 km in diameter. This ring is capped by impact melt rocks. A fracture halo extending out 20-30 km from the structures is visible at low sun angles. The lakes are named after their exceedingly clear water.




18
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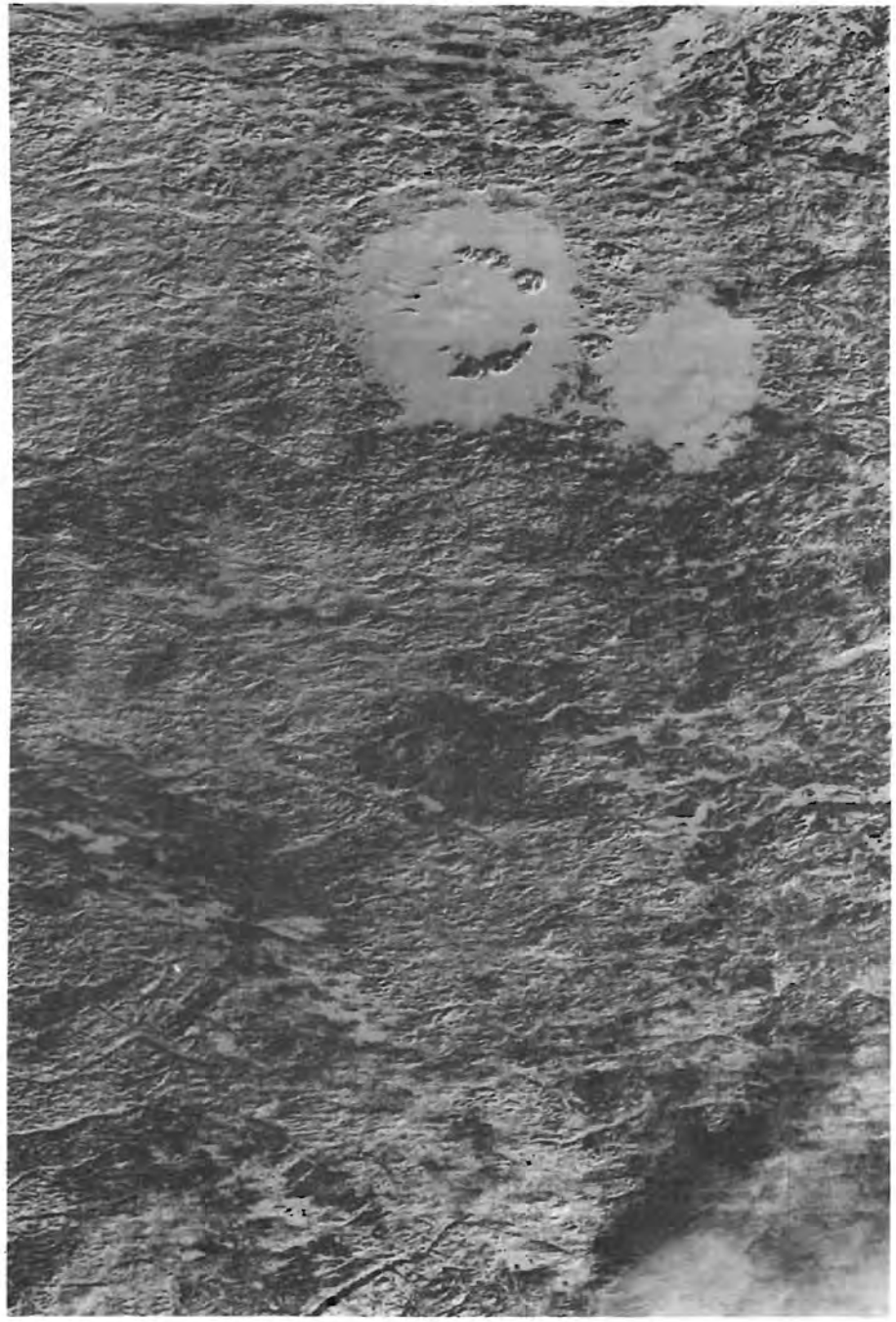
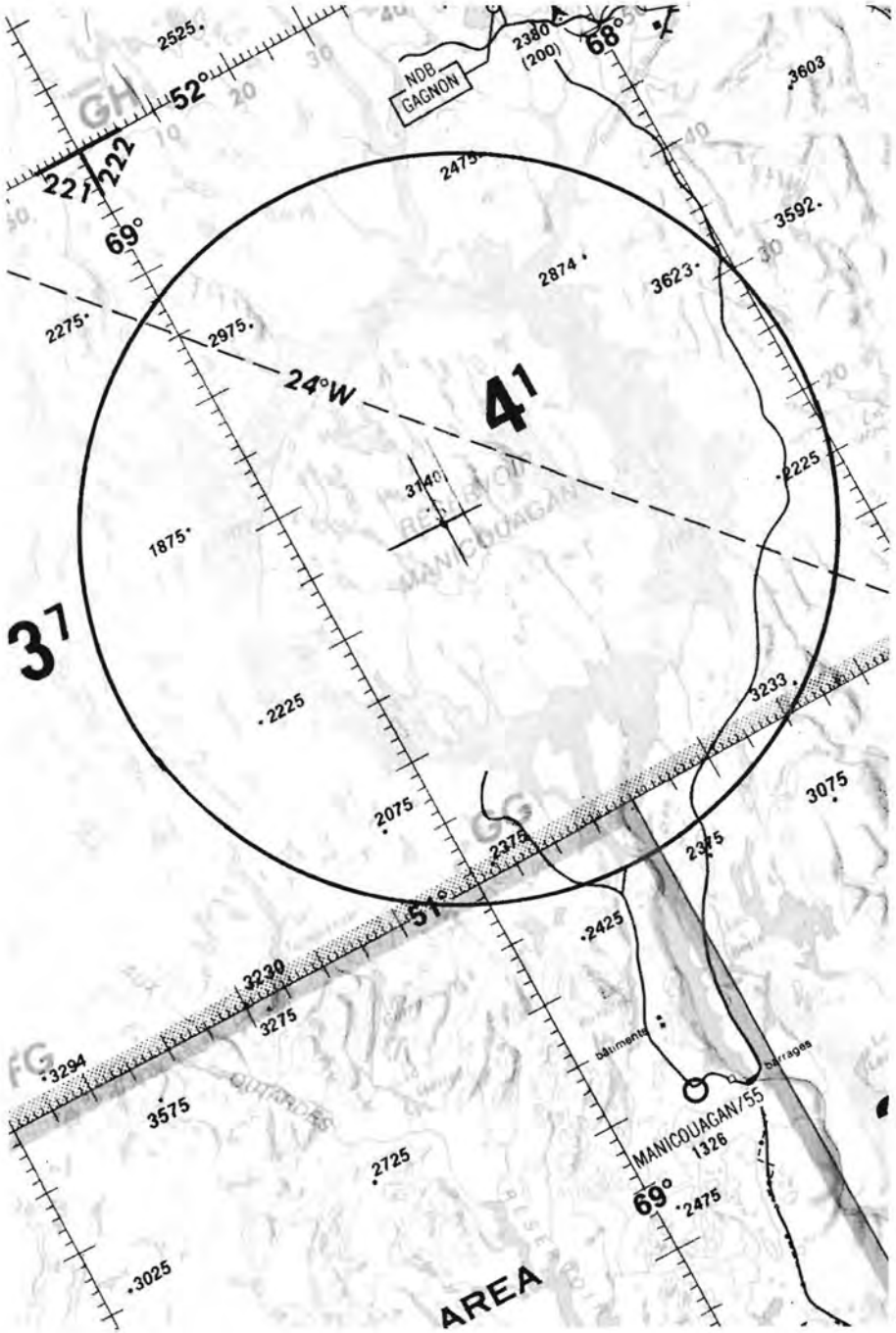


MANICOUAGAN
QUEBEC, CANADA

51°23'N; 68°42'W
Diameter: 100 km
Age: 212 ± 2 m.y.
Discernability: Excellent
Morphology: Large annular lake

General Area: Heavily timbered area of the Canadian Shield. The topography is generally rugged and the area has been glaciated, with north-south ice movement. The target rocks are crystalline.

Specific Features: The structure may be divided into a number of morphologic elements. The most striking is the ~70 km diameter annular depression filled by the waters of the Lac Manicouagan reservoir. The annular depression is interpreted as the glacially overdeepend expression of the interior contact between the crater floor and inner blocks of the original rim. In the middle of the lake is a dissected plateau capped by ~200 m of impact melt rocks and a series of uplifted peaks ~5 km north of the center. Of particular interest is a fracture halo, which extends out to ~150 km from the center. First noted on Skylab photography, this halo is best developed in the west and south.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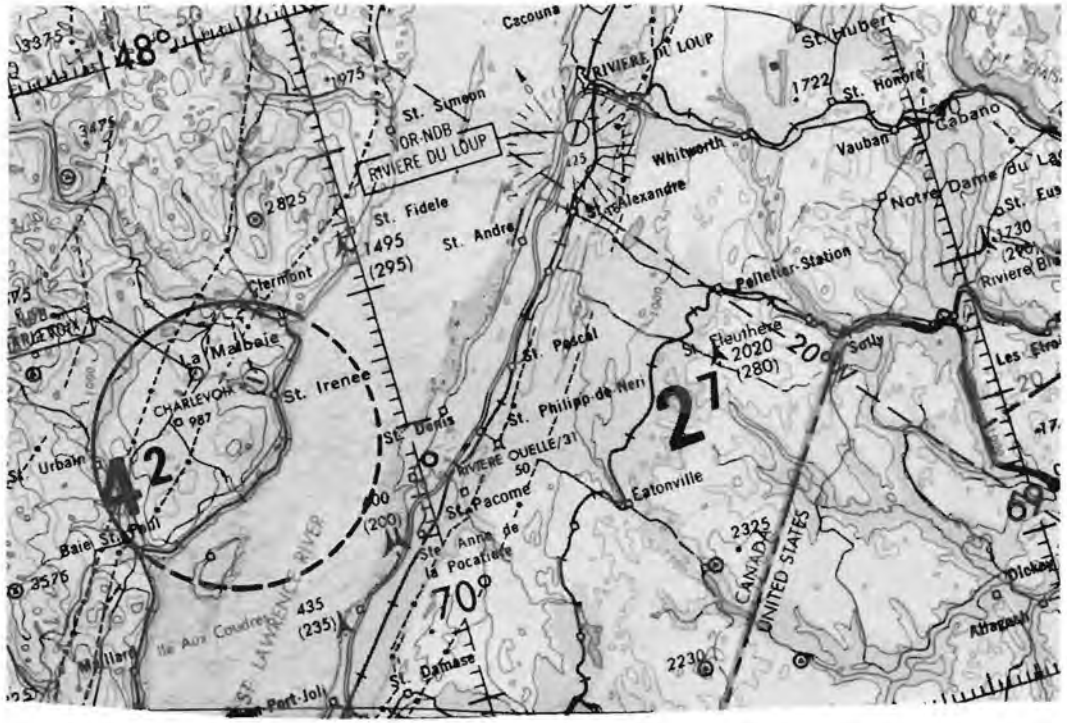
MANICOUAGAN/55
1326
bâtiments
barrages
AREA

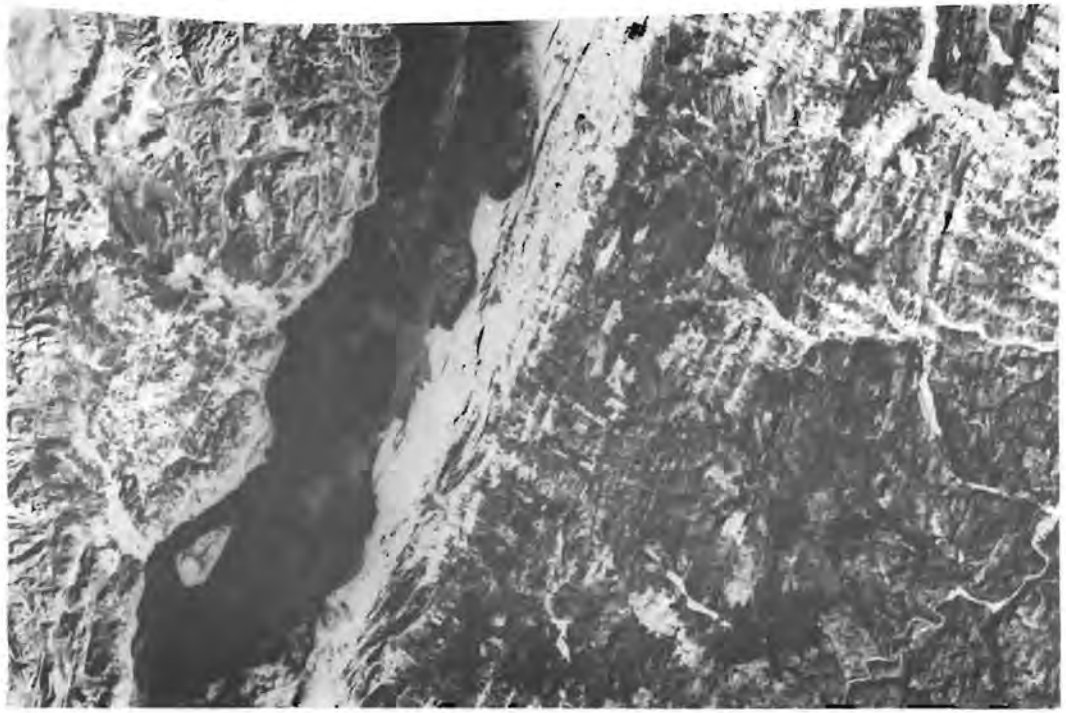
CHARLEVOIX
QUEBEC, CANADA

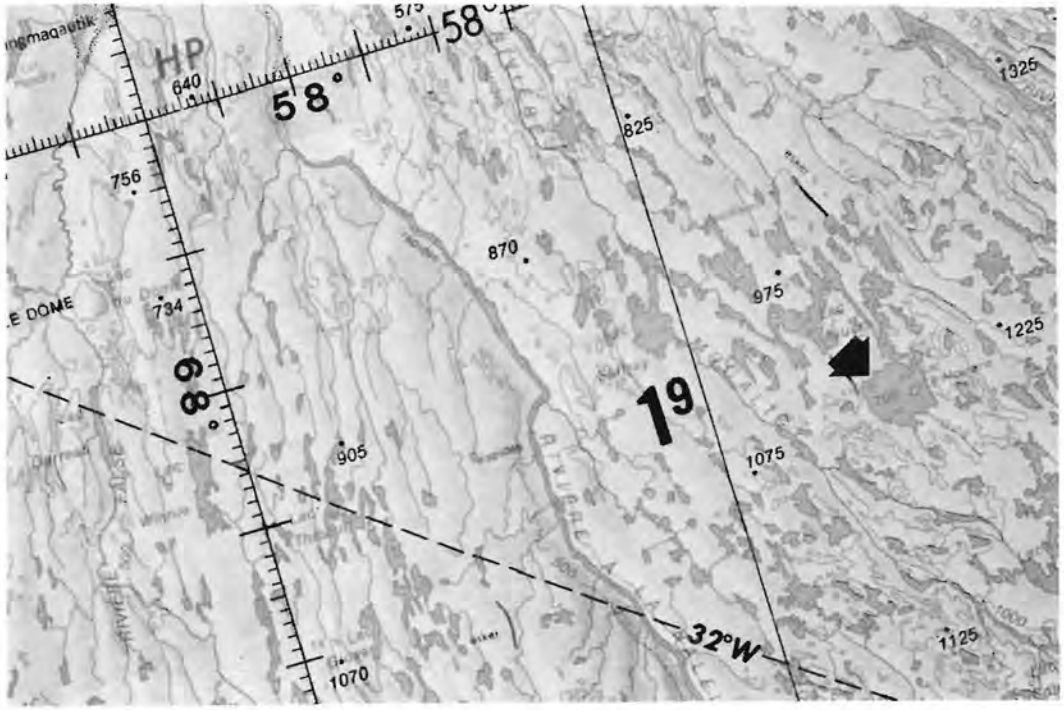
47°32'N; 70°18'W
Diameter: 46 km
Age: 360 ± 25 m.y.
Discernability: Average
Morphology: Annular, semicircular valley with central peak

General Area: Charlevoix lies on the southern edge of the Canadian Shield and intersects the north shore of the St. Lawrence River. The annular valley and interior plateau are farmed. Target rocks are crystalline.

Specific Features: Structure is dominated by a 1.5 km wide semi-circular peripheral valley, which lies interior to a ring of hills defining a diameter of ~46 km. Interior to the valley lies a plateau and a central peak which rises to ~750 m above sea level. The western half of the crater has been tectonically removed by a major fault system which runs down the St. Lawrence Valley. The structure coincides with the most seismically active area in eastern Canada. It is not known whether there is a physical connection between the impact deformation and seismic activity.





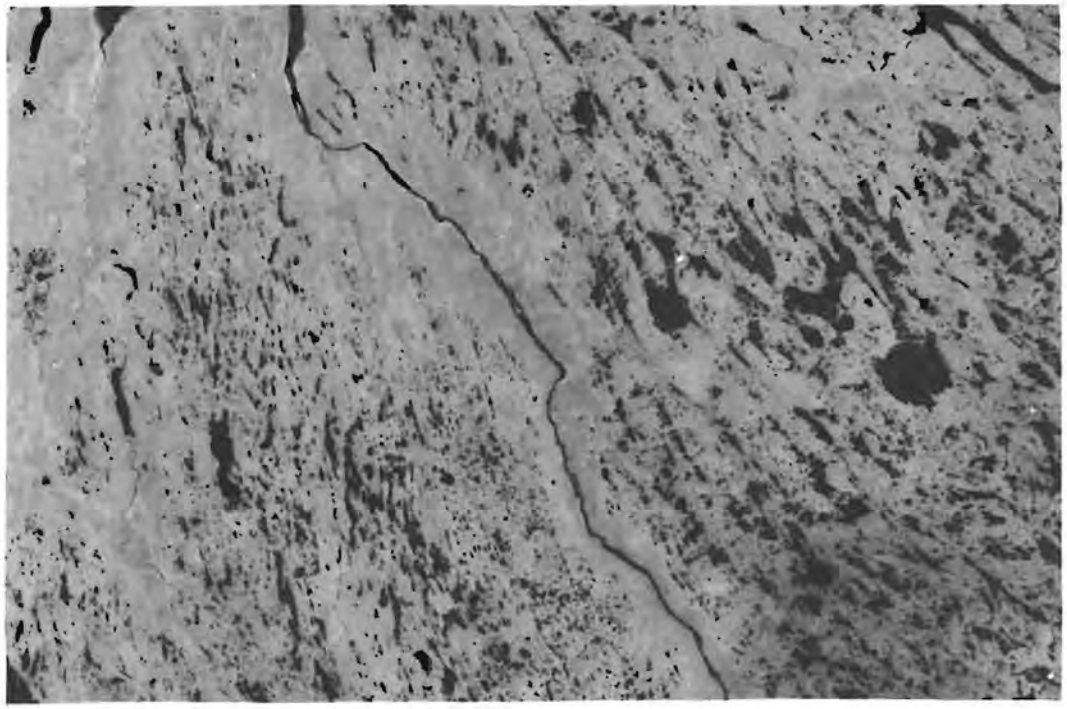


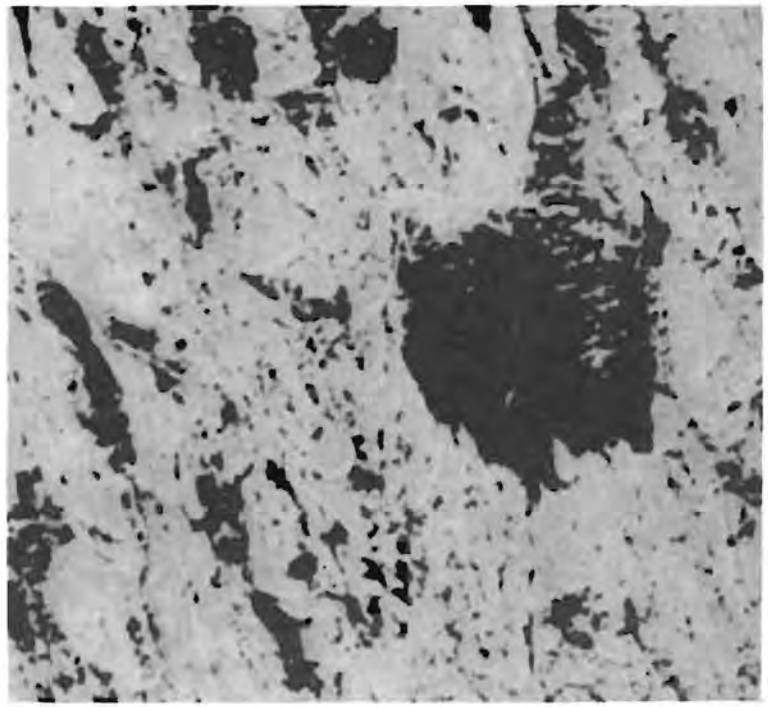
LAC LA MOINERIE
QUEBEC, CANADA

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.



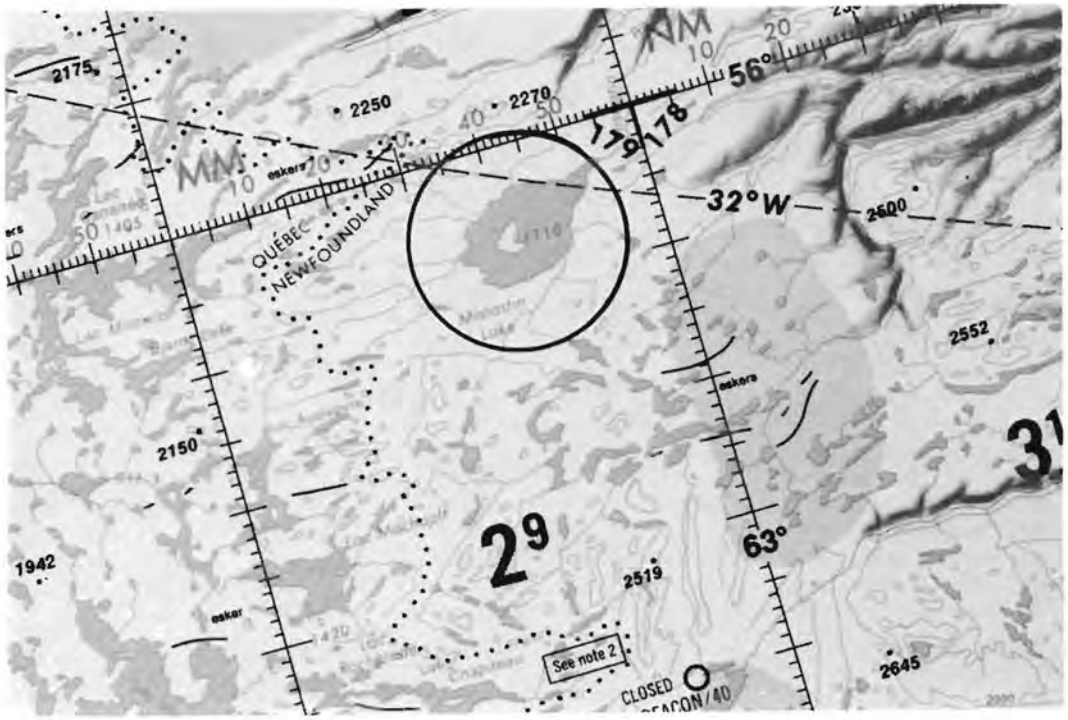


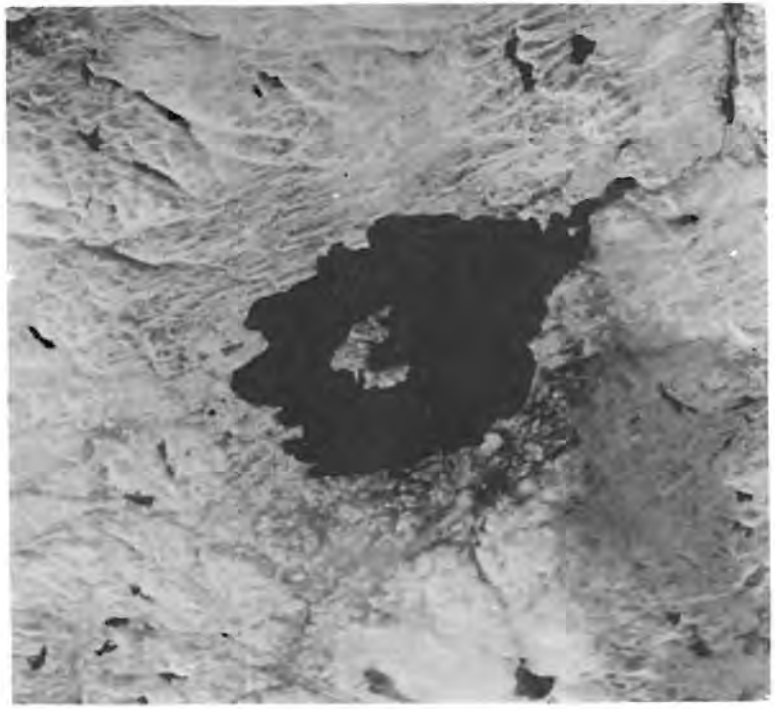
MISTASTIN
NEWFOUNDLAND AND LABRADOR, CANADA

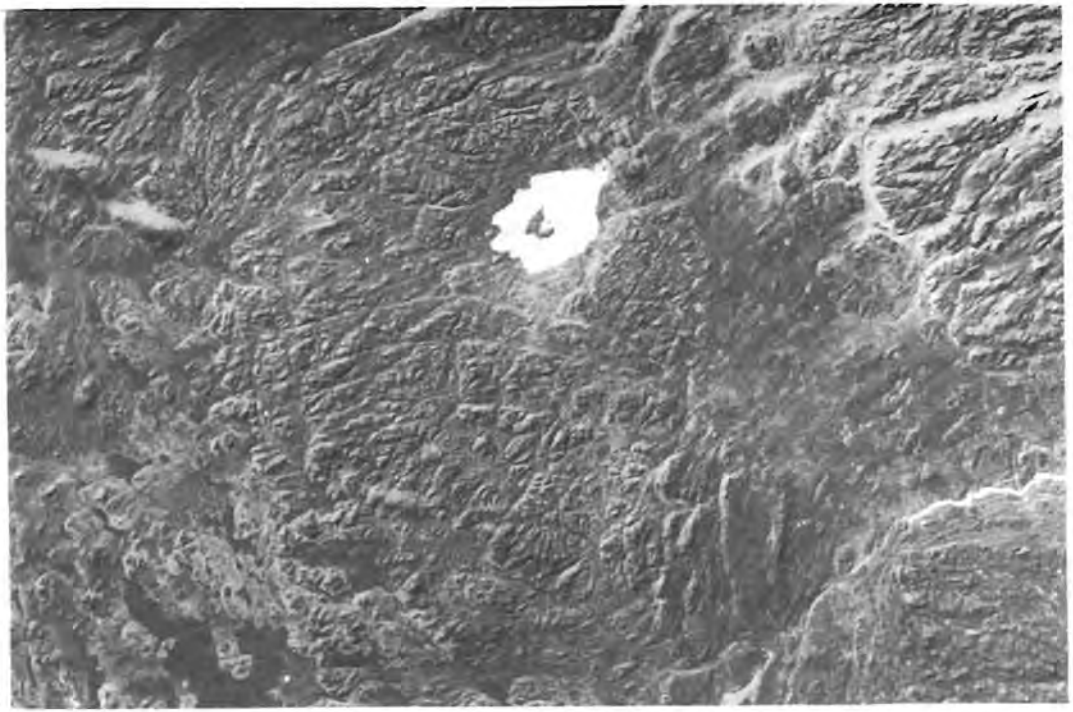
55°53'N; 63°18'W
Diameter: 28 km
Age: 38± 4 m.y.
Discernability: Excellent
Morphology: Roughly circular lake with central island

General Area: Moderate relief, 200-300 m, close to the tree-line in the Canadian Shield. Area has been glaciated, with ice moving west to east. The target rocks are crystalline.

Specific Features: Structure is defined by a ring of low hills, 28 km in diameter, surrounding a depression filled by Lake Mistastin. A horseshoe-shaped island, rising 130 m above the lake and ~3 km in diameter represents a central uplift. Although this is a fairly young crater, much of the original topography has been removed by glacial erosion. A weak fracture halo surrounds the crater in the target rocks and is best expressed in the west.







Impact Craters in SOUTH AMERICA

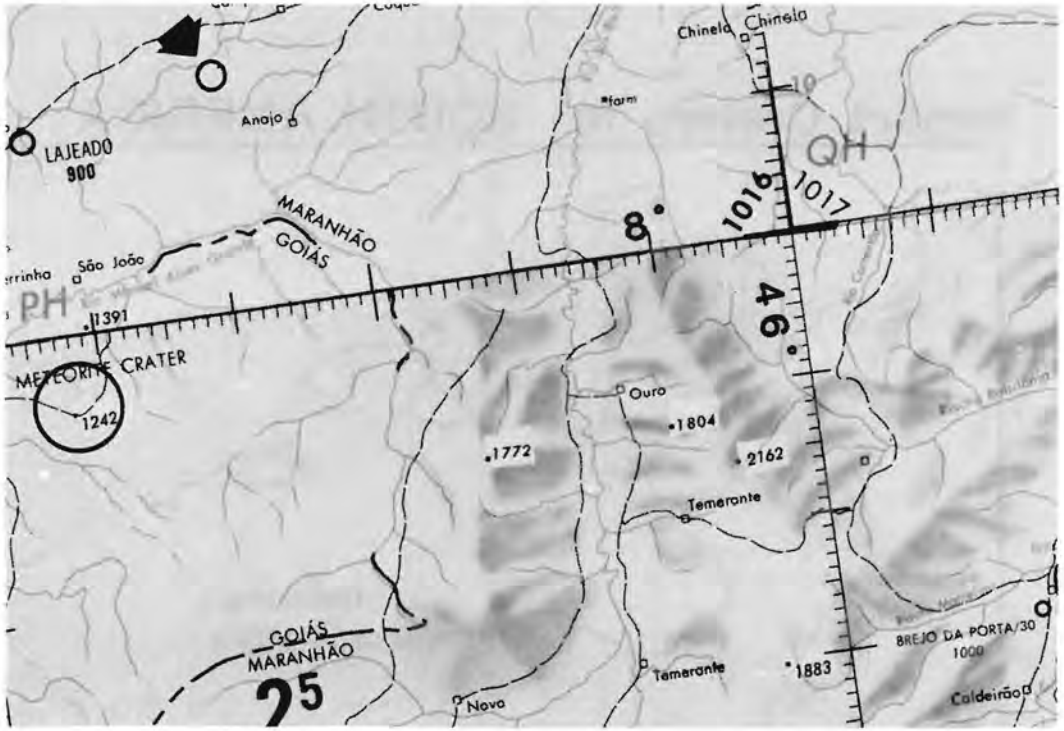
Serra da Cangalha	36
Riacho Ring	37
Araguainha Dome	38

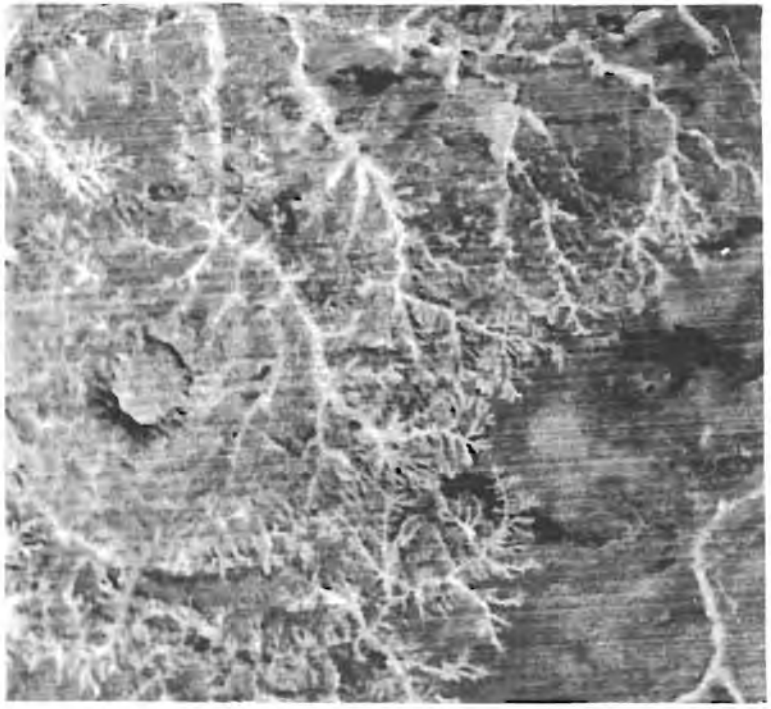
SERRA DA CANGALHA
BRAZIL

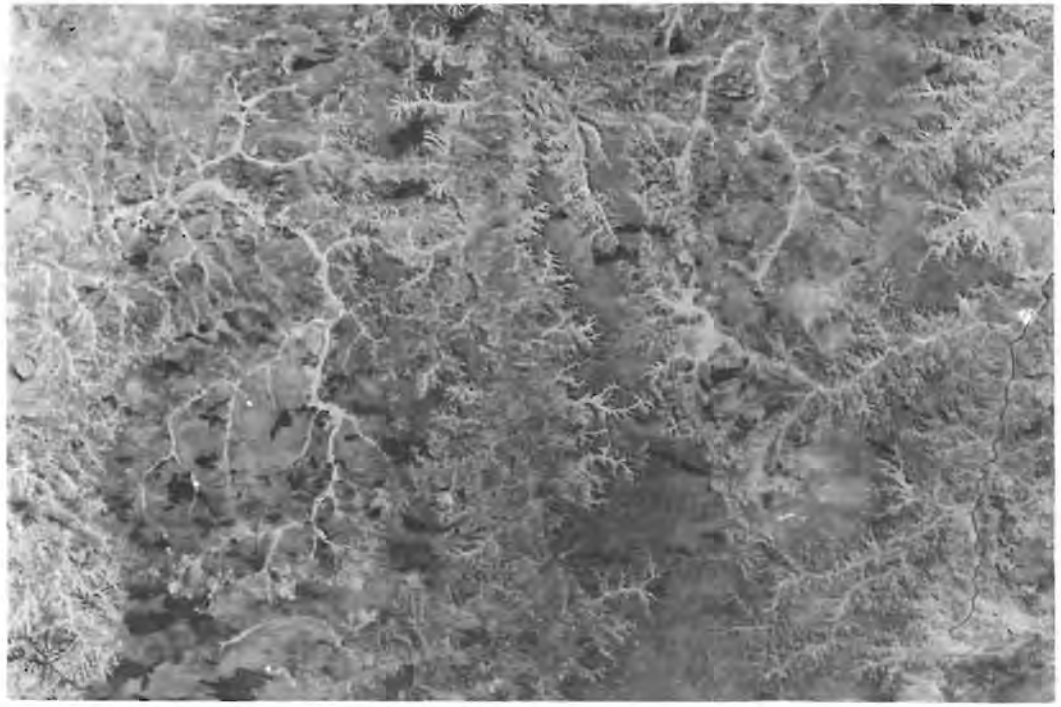
8°05'S; 46°52'W
Diameter: 12 km
Age: < 300 m.y.
Discernability: Average
Morphology: Circular ring of hills

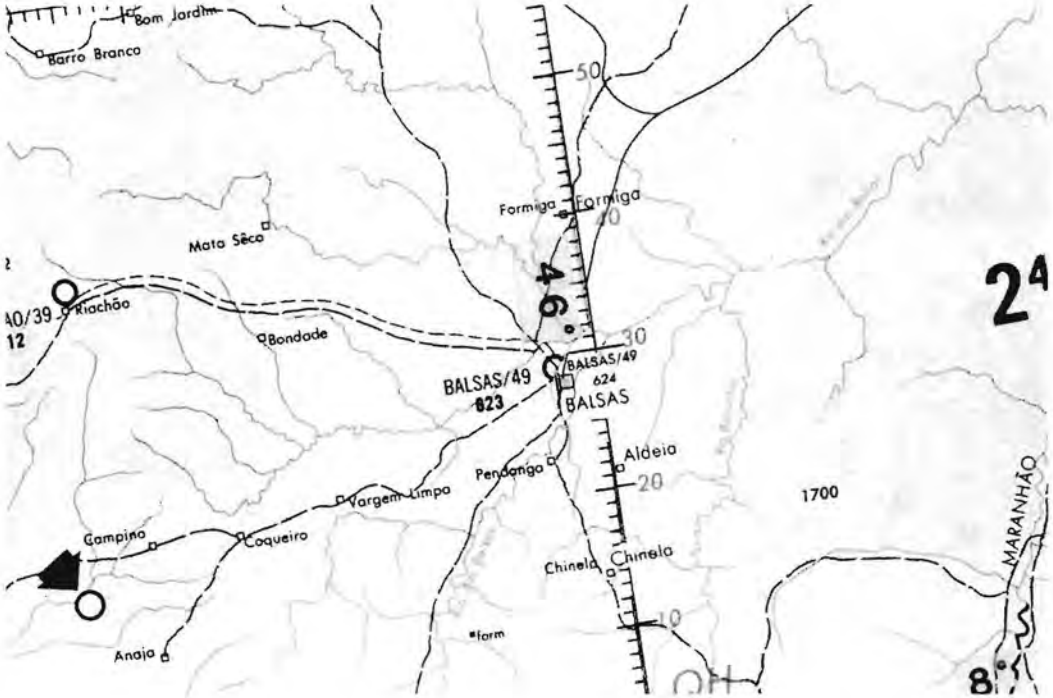
General Area: Southern portion of the Amazon Basin. The area is relatively featureless, apart from a well-developed dendritic drainage system. Target rocks are sedimentary overlying crystalline.

Specific Features: Structure is most obvious as a ring of hills 5 km in diameter. Interior to the hills is a basin. The hills represent the erosionally resistant portion of a central uplift and are similar to the occurrence at Gosses Bluff, Australia. The hills are surrounded by an annulus 12 km in diameter, apparent in the circumferential and radial drainage. This is taken to represent the original rim diameter.









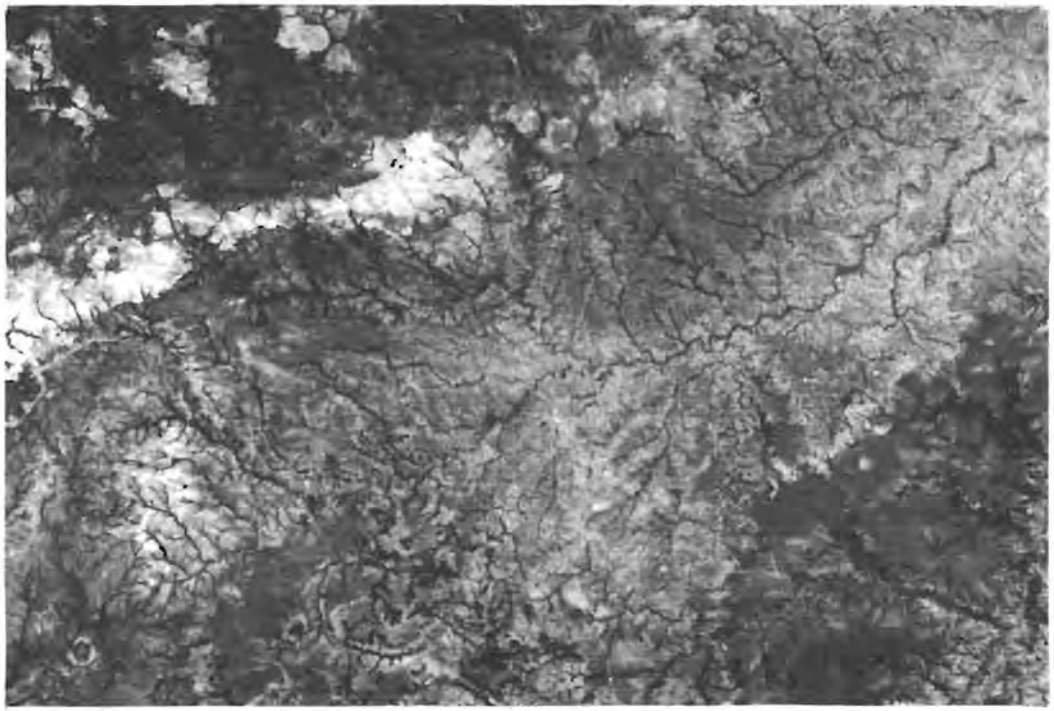
RIACHO RING

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.

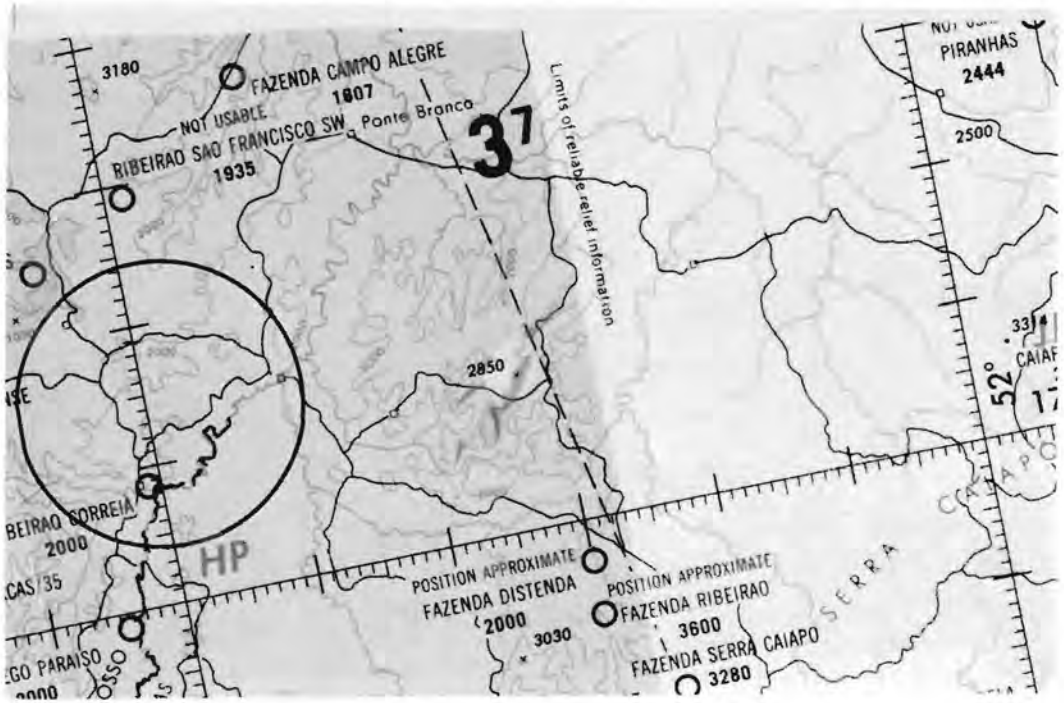


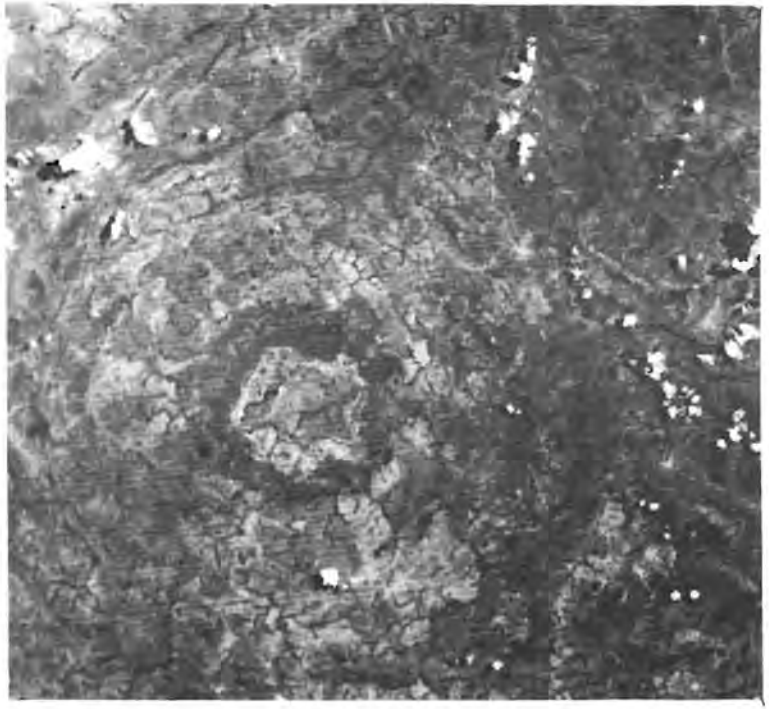
ARAGUAINHA DOME
BRAZIL

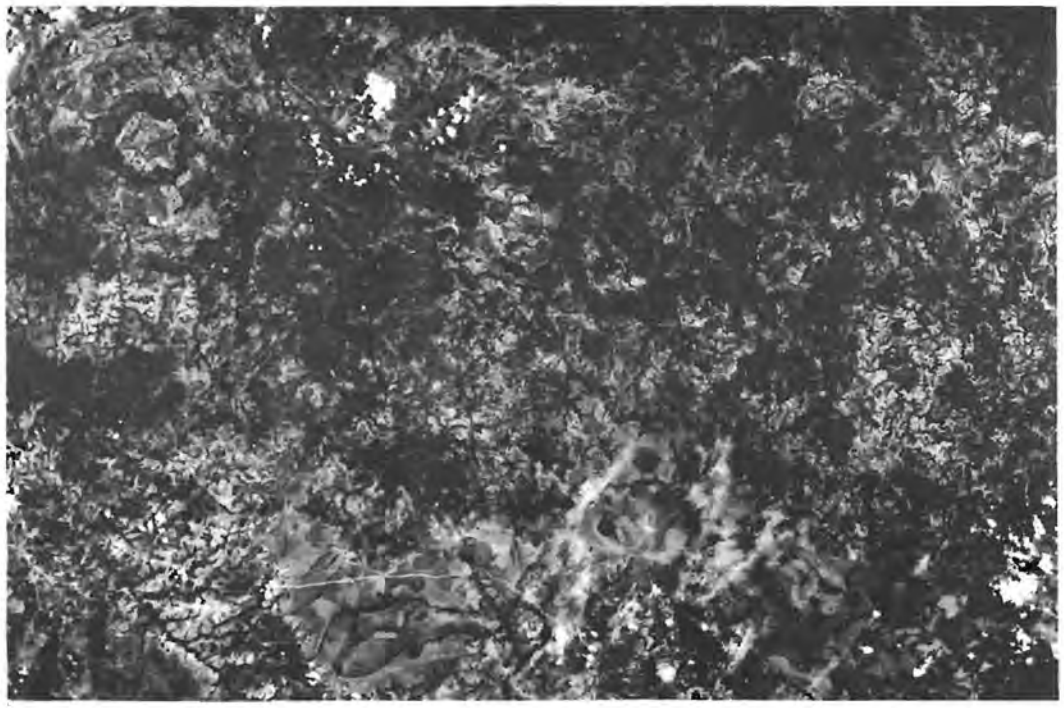
16°46'S; 52°59'W
Diameter: 40 km
Age: < 250 m.y.
Discernability: Average
Morphology: Circular feature in otherwise featureless area

General Area: Tropical forest of the Matto Grosso of Brazil. With the exception of the structure, the area is relatively featureless. The target rocks are mostly sedimentary with some buried crystalline.

Specific Features: Structure is most obvious as an annular ring of uplifted rocks 10 km in diameter. Ground studies estimated the diameter of the structure at 20 km. Orbital imagery, however, indicates a circular pattern extending out to a diameter of 40 km. Within the area of the structure, there is a tendency for drainage to follow circumferential or radial patterns.







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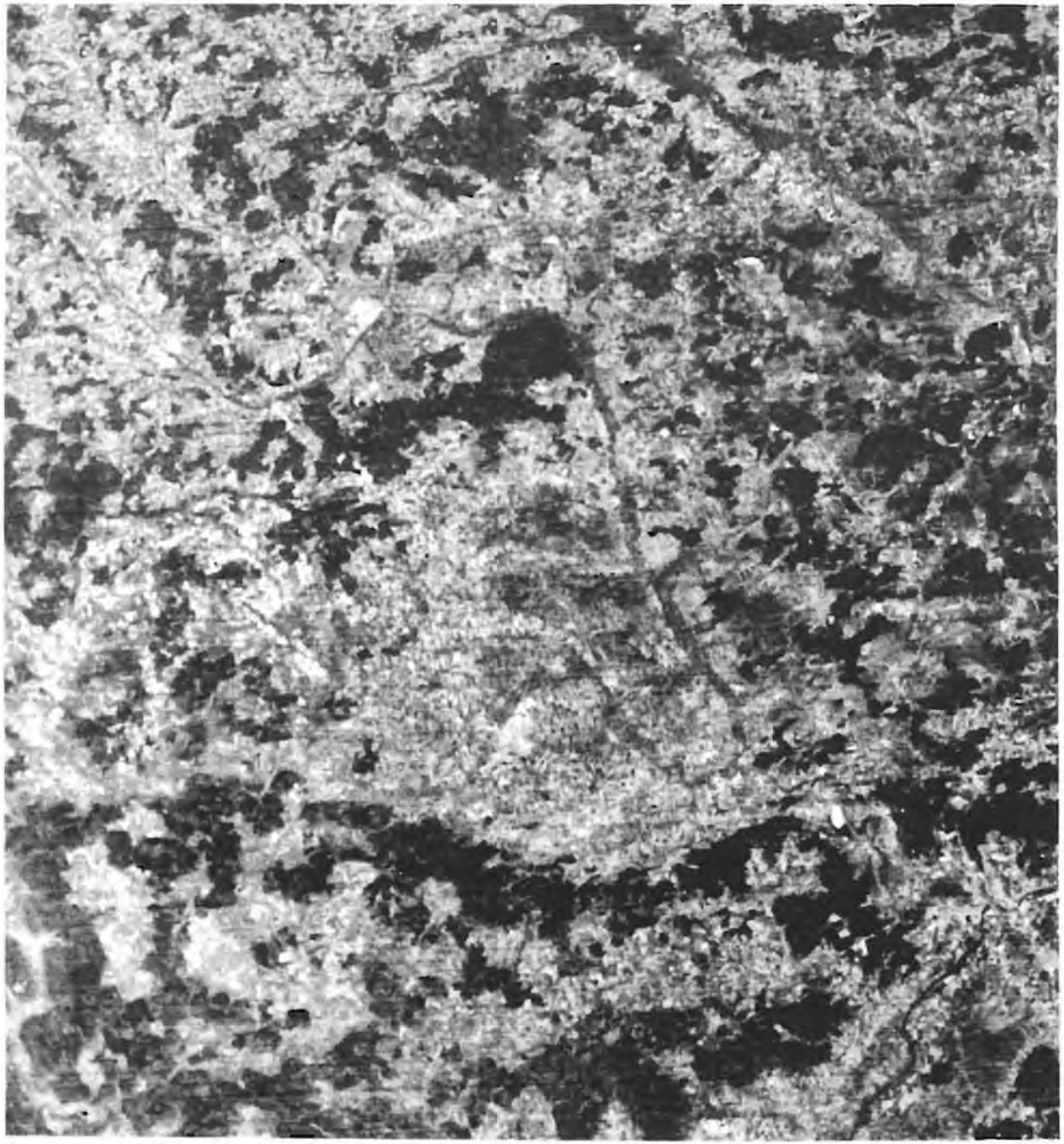
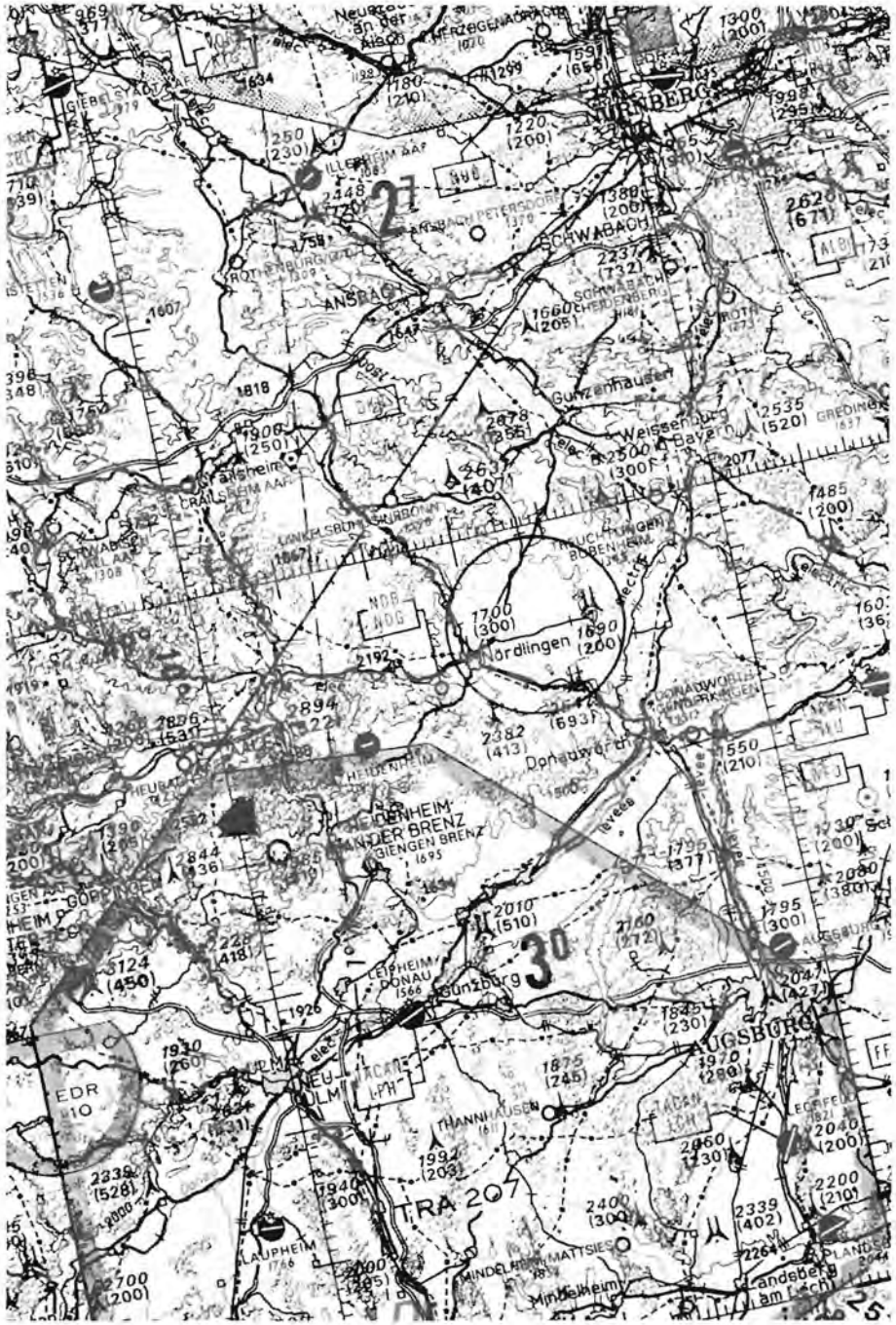
RIES
FEDERAL REPUBLIC OF GERMANY

48°53'N; 10°37'E
Diameter: 24 km
Age: 14.8 ± 0.7 m.y.
Discernability: Poor
Morphology: Circular feature

General Area: The area is rural, with extensive farming inside the crater, and includes a number of small urban centers. Structure lies in flat-lying sediments overlying crystalline rocks. The area has not been glaciated.

Specific Features: The crater is outlined by a circular rim ~ 24 km in diameter and 100-200 m high. There is a broken inner ring of small 50 m hills with a diameter ~ 11 km. Post-crater sediments partially fill the structure and support excellent farming. The Ries is the most extensively studied impact structure in Europe and is the type site for many impact-related features. As the structure has not been glaciated, parts of the ejecta are preserved and can be found up to 50 km from the rim. The Ries is also the source of the so-called Moldavite tektites found several hundred kilometers to the east in Czechoslovakia. The church in the village of Nördlingen, within the Ries, is constructed of impact-derived rocks; specifically, building stones cut from the ejecta deposits containing impact melt clasts.



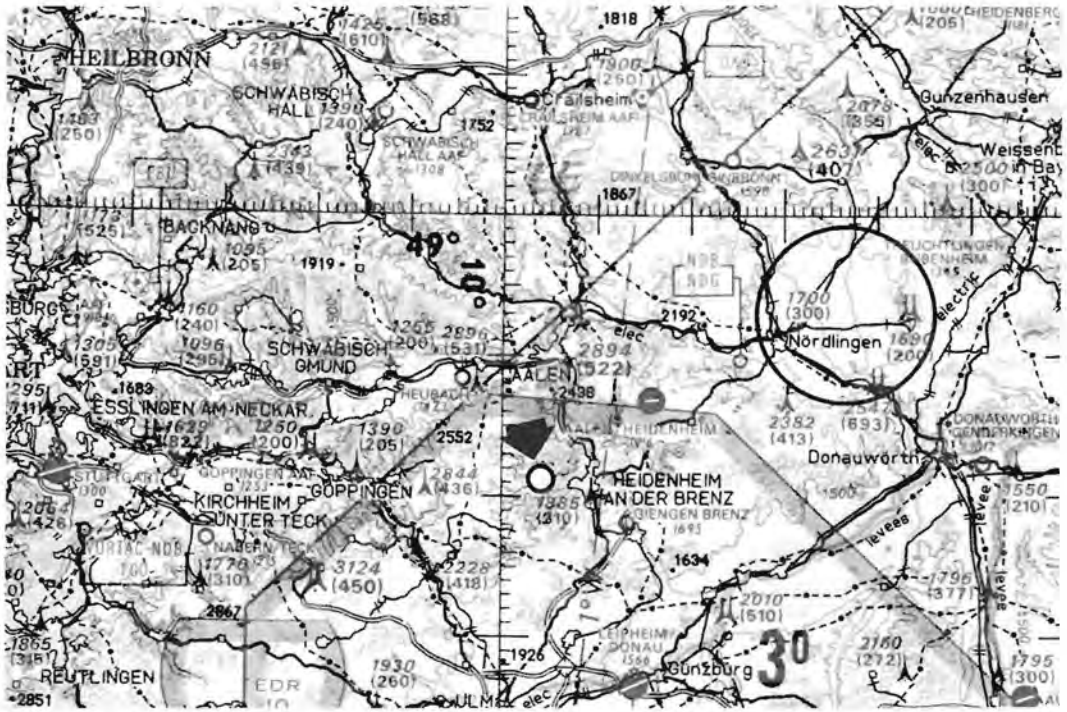

NÜRNBERG
ANSBACH
SCHWABACH
Gunzenhausen
Weissenburg i. Bayern
Nördlingen
Donauwörth
DINKELSBÜHL
HEIDENHEIM
GIENGEN BRENZ
Günzburg
LEIPHEIM
DONAU
AUGSBURG
NEU-ULM
THANNHAUSEN
LAUPHEIM
MINDELHEIM
MATTSIES
Mindelheim
EDR
110
TRA 207
27
30
25

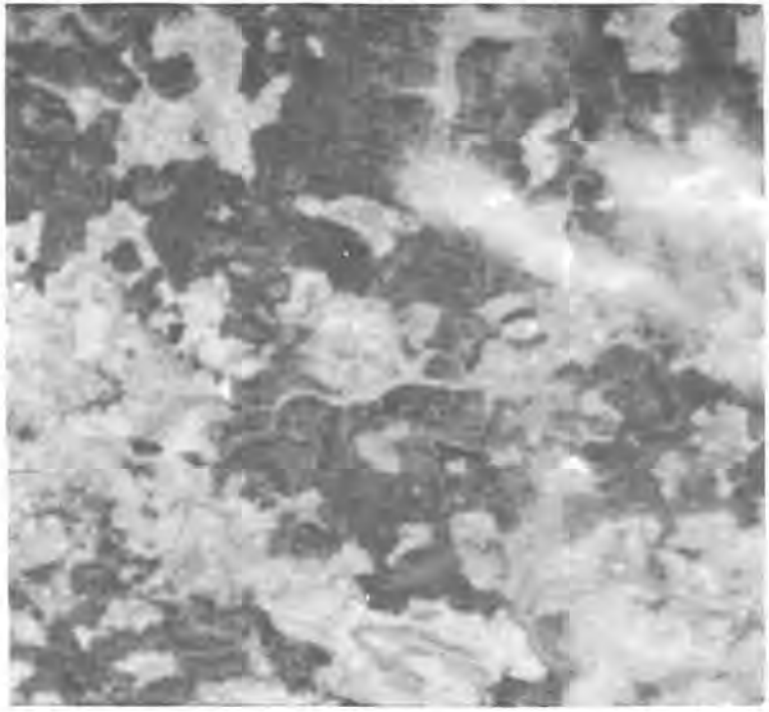
STEINHEIM
FEDERAL REPUBLIC OF GERMANY

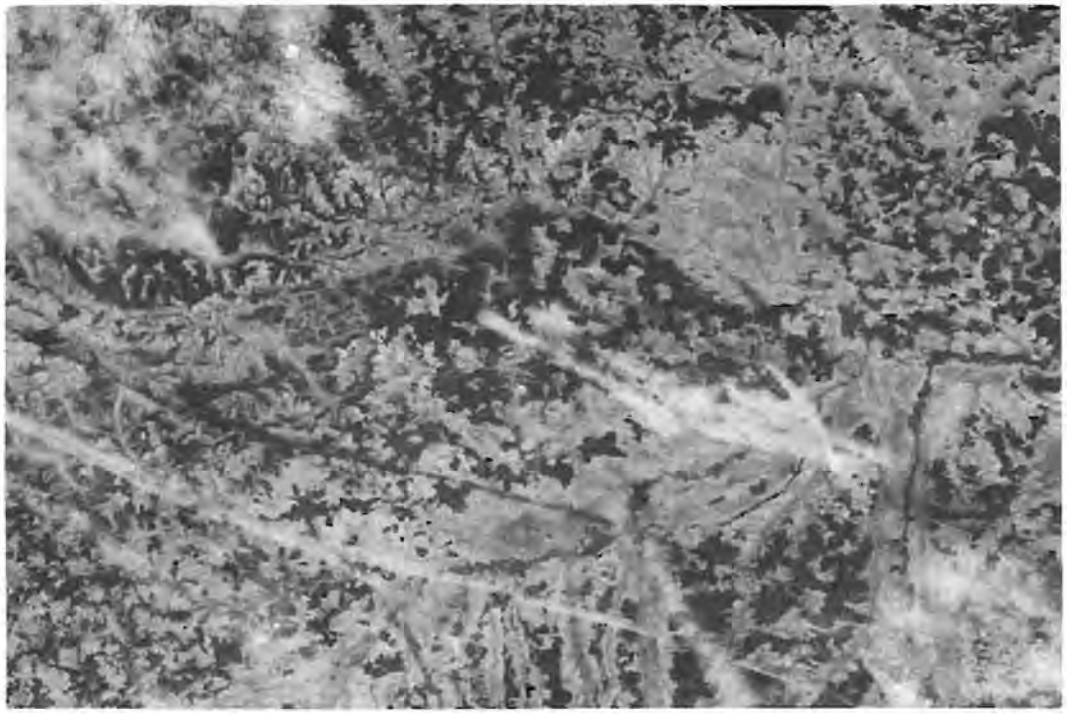
48°41'N; 10°04'E
Diameter: 3.4 km
Age: 14.8 ±0.7 m.y.
Discernability: Poor
Morphology: Circular depression with central hill

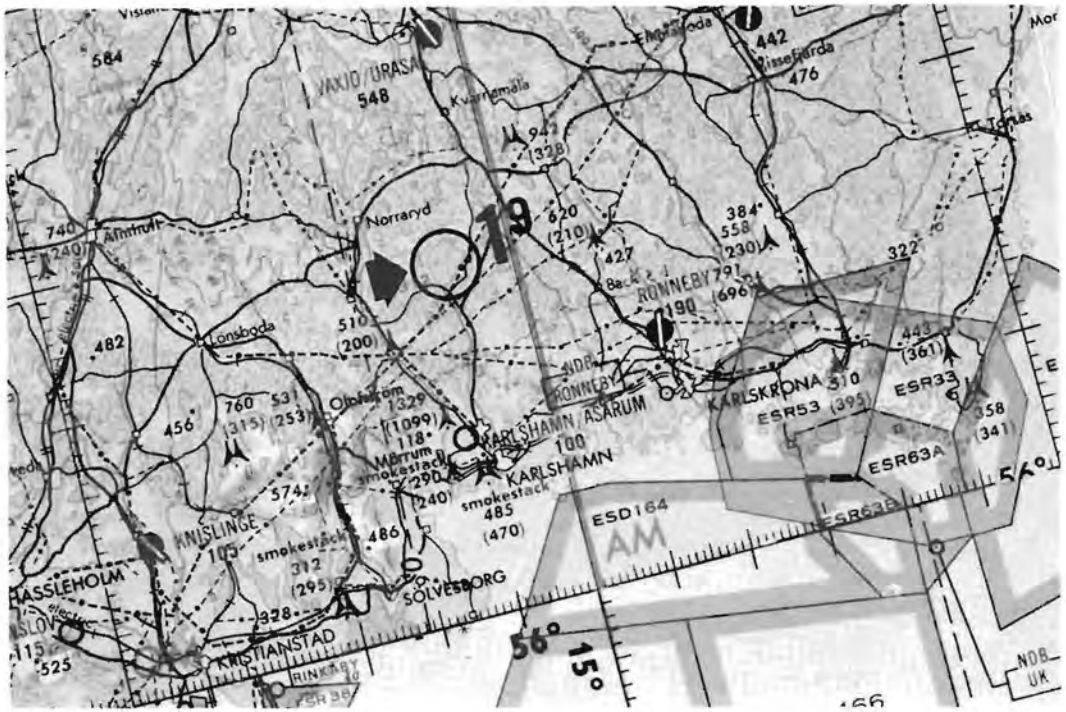
General Area: The crater occurs in an area strongly modified by human activities; farm land and forested hills create a mottled patchwork of bright and light surfaces without any conspicuous landmarks. The target rocks are flat-lying sediments.

Specific Features: This crater is only 40 km west of the center of the Ries impact crater and is generally believed to have formed at the same time (a double impact like the Clearwater Lakes in Canada). Steinheim is a nearly circular depression nearly 100 m deeper than the surrounding plains. The central peak rises 50 m above the floor, which is covered by radiating agricultural fields.







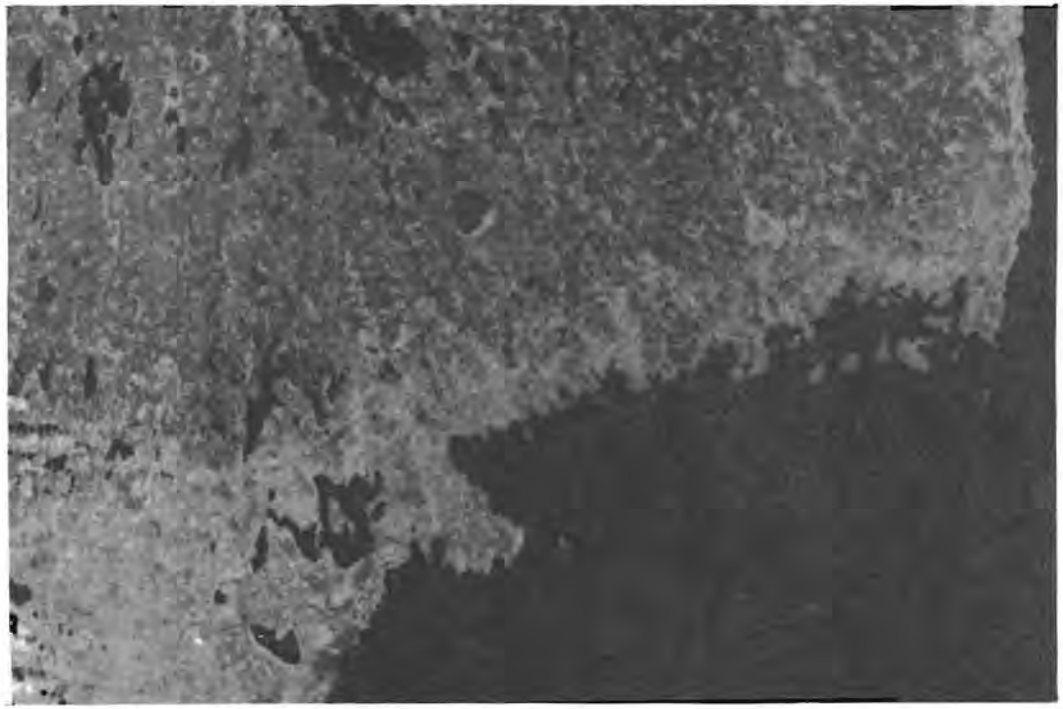


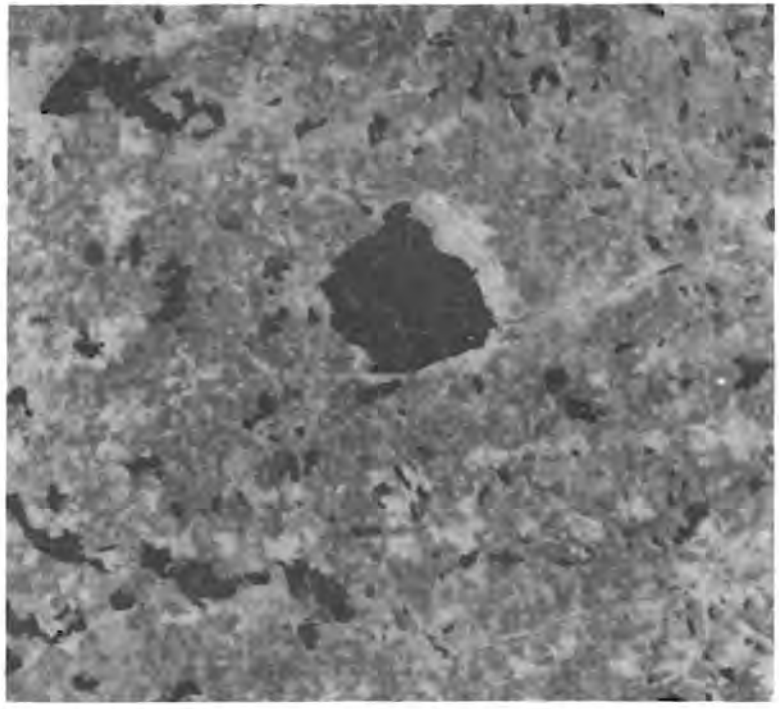
MIEN
SWEDEN

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.



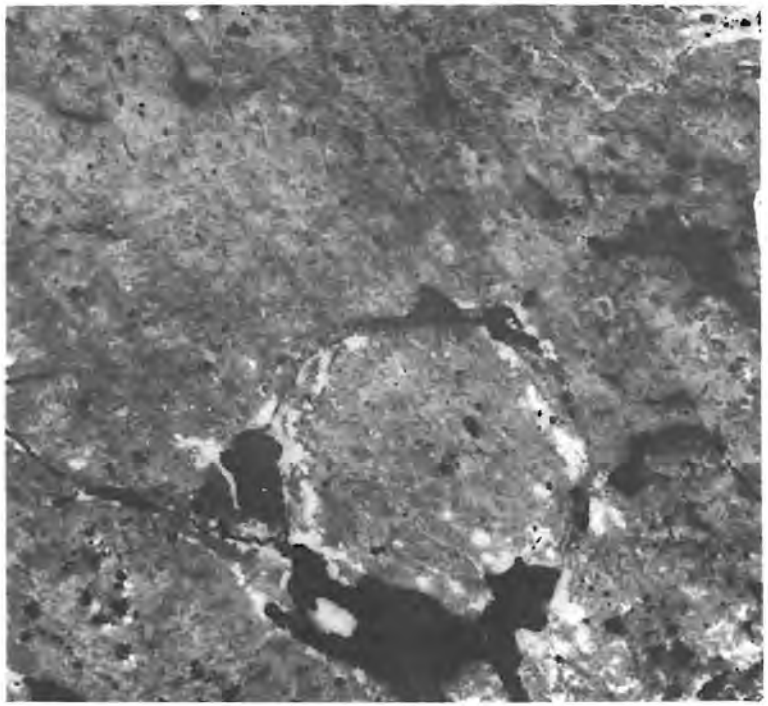


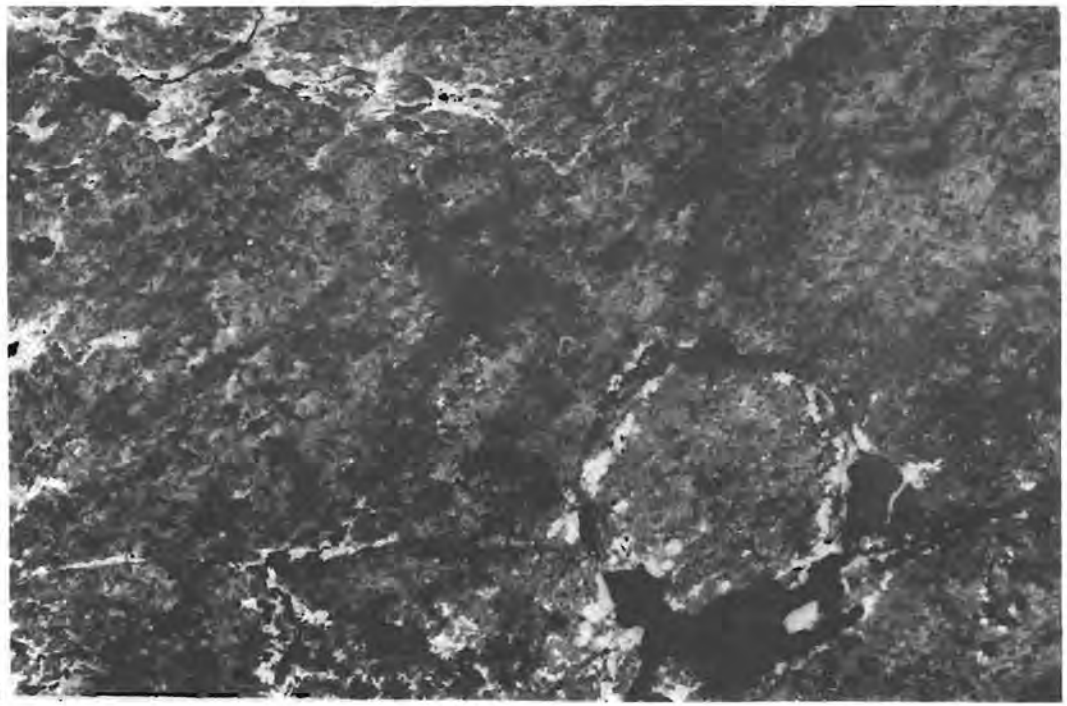
SILJAN
SWEDEN

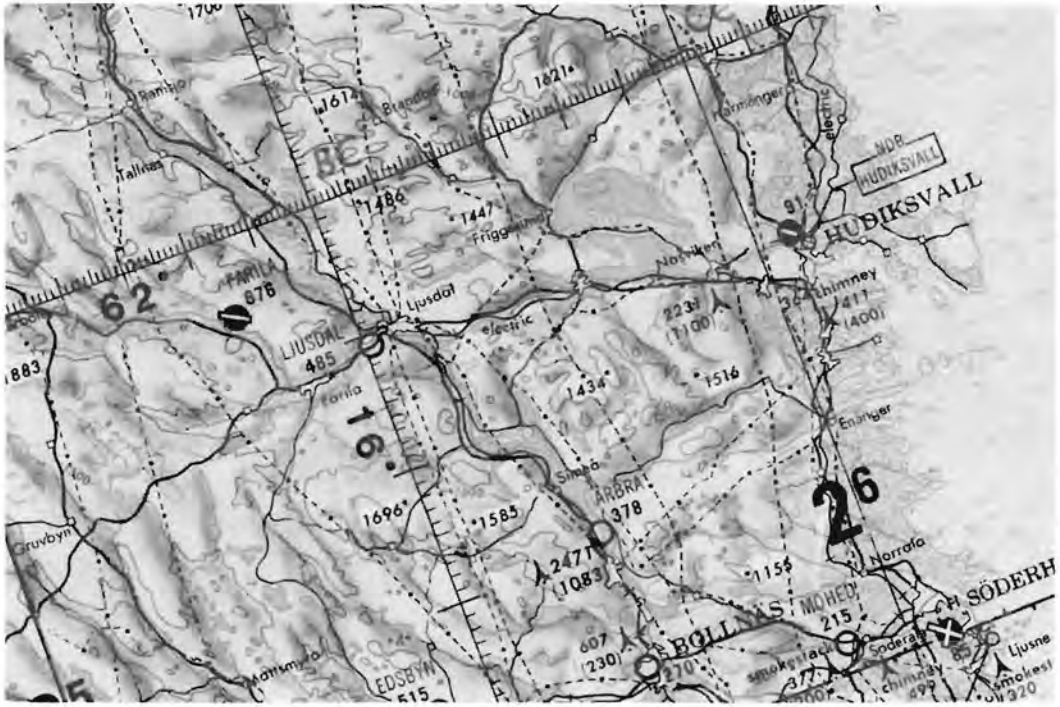
61°02'N; 14°52'E
Diameter: 52 km
Age: 368 ± 1 m.y.
Discernability: Good
Morphology: Circular annulus of lakes

General Area: Subdued topography in the Baltic Shield in Central Sweden. The area is lightly forested, is farmed in places, and includes small rural communities. The area has been glaciated. The target rocks are mostly crystalline, with minor sediments.

Specific Features: Siljan is the largest impact structure in Europe. Its present expression is an annular trough up to 10 km wide, with a number of partially encircling lakes, and it contains down-faulted sediments surrounding a 40 km diameter core of uplifted crystalline rocks. The structure has been highly eroded, so that little remains of the crater lithologies. A low ring of exterior hills defines an original diameter of 52 km. Siljan is the site of a controversial drilling project for deep gas.





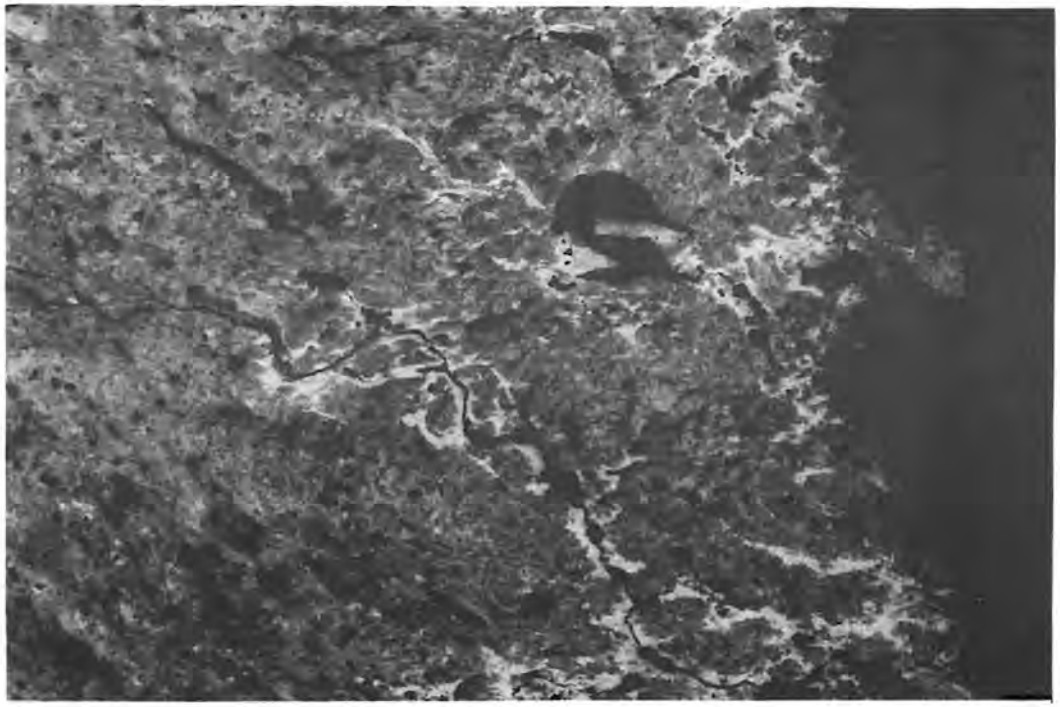


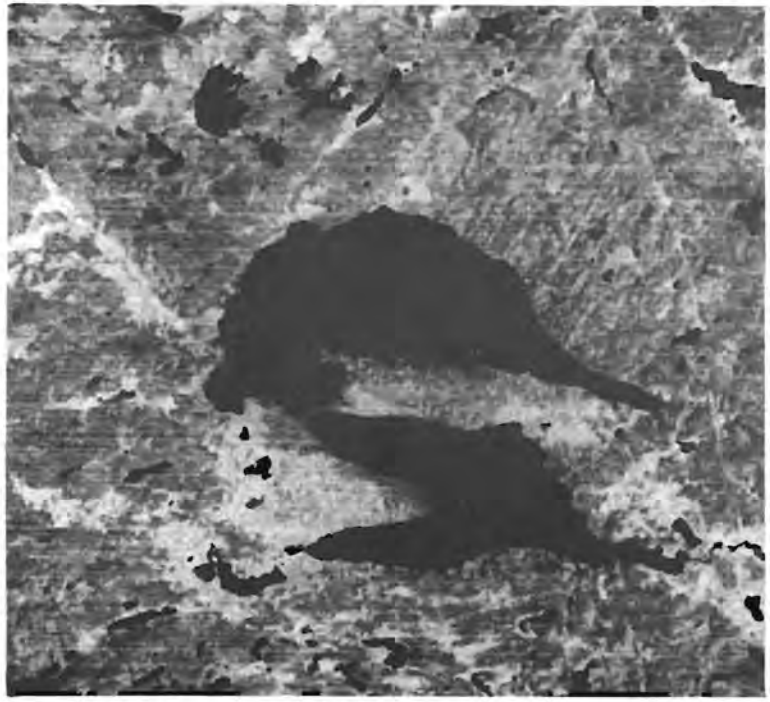
DELLEN
SWEDEN

61°55'N; 16°39'E
Diameter: 15 km
Age: 109.6 ± 1 m.y.
Discernability: 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 northern most 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.



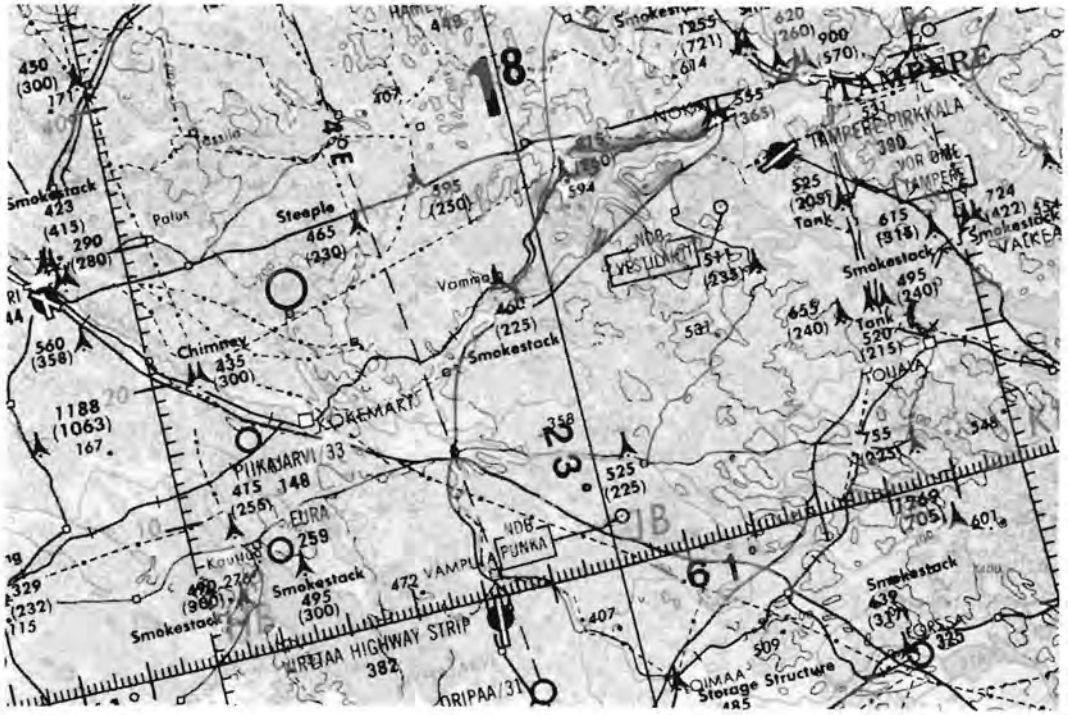


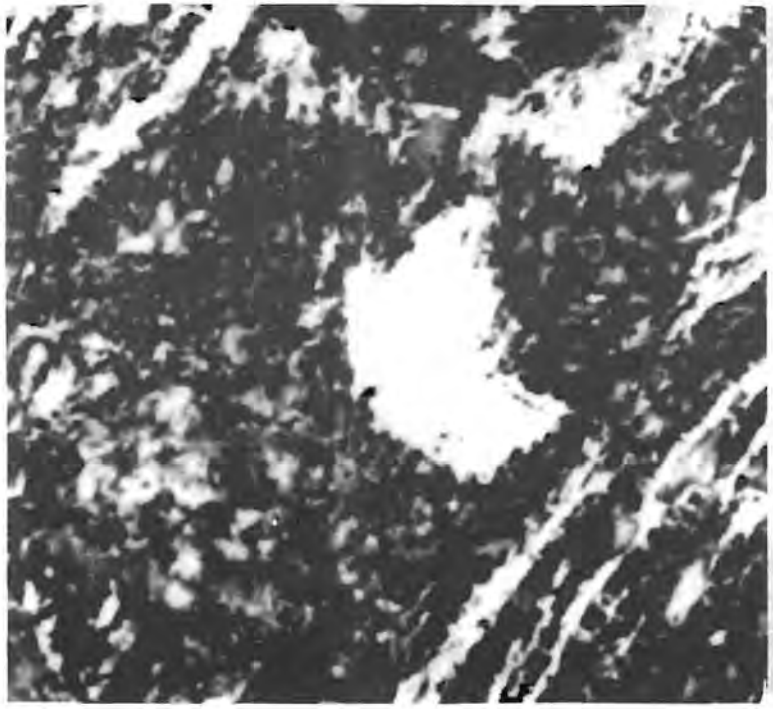
SÄÄKSJÄRVI
FINLAND

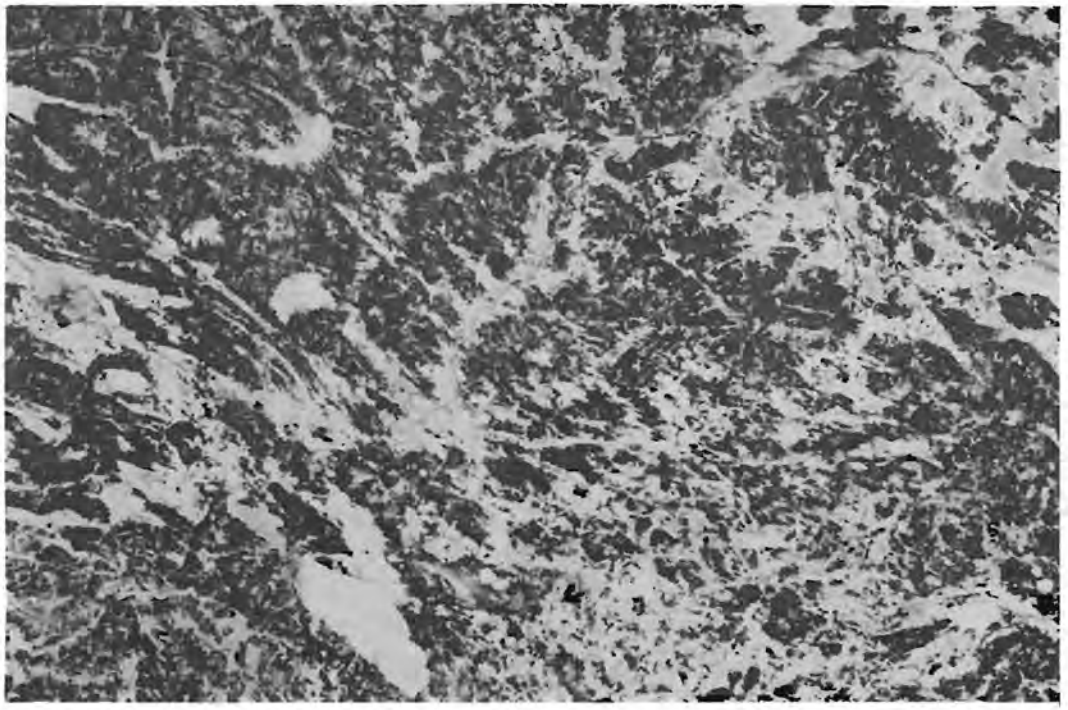
61°25'N; 22°23'E
Diameter: 5 km
Age: 514 ± 12 m.y.
Discernability: Average
Morphology: "Pac-man" shaped lake

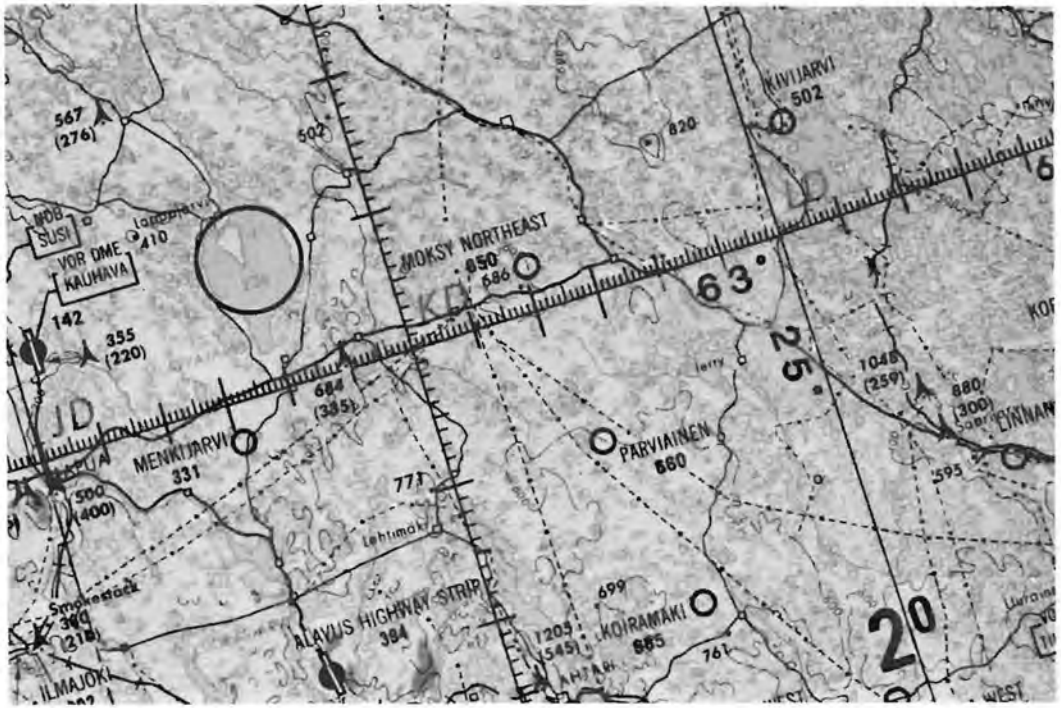
General Area: Generally low relief area in the Baltic Shield of Finland. It is forested and has been glaciated. Target rocks are crystalline.

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. Impact-modified rocks from the floor of the crater are common in glacial deposits to the southeast and have been found as far away as 25 km.







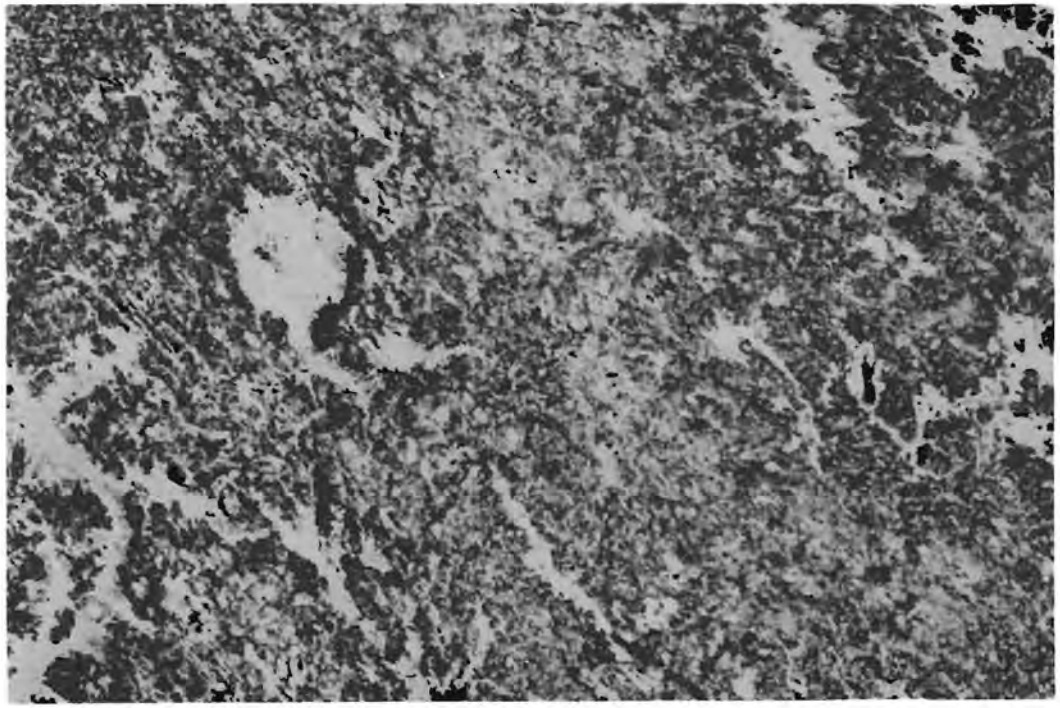


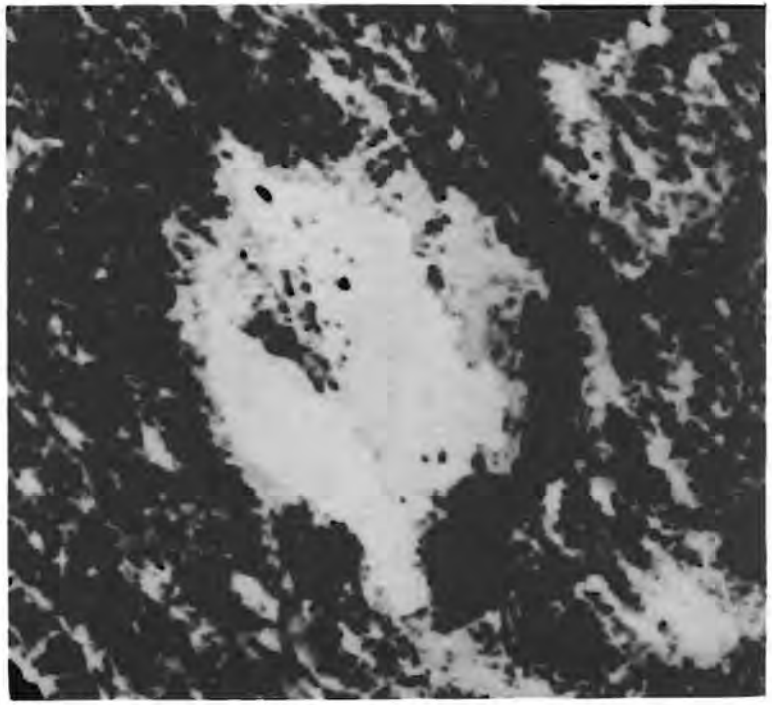
LAPPAJÄRVI
FINLAND

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.



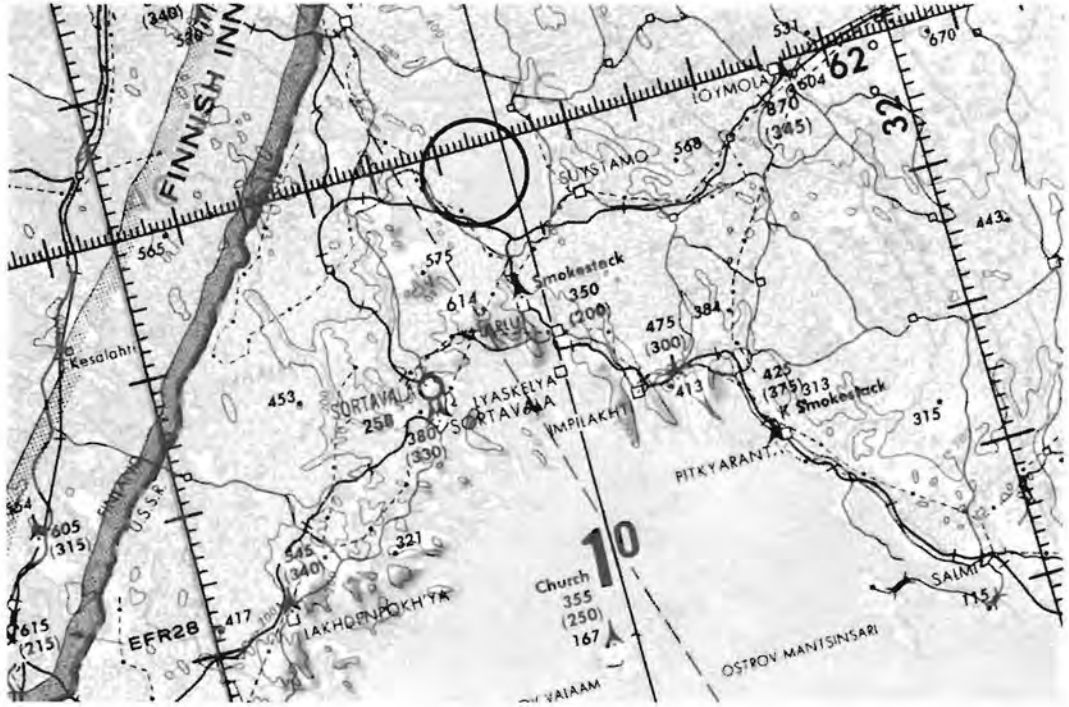


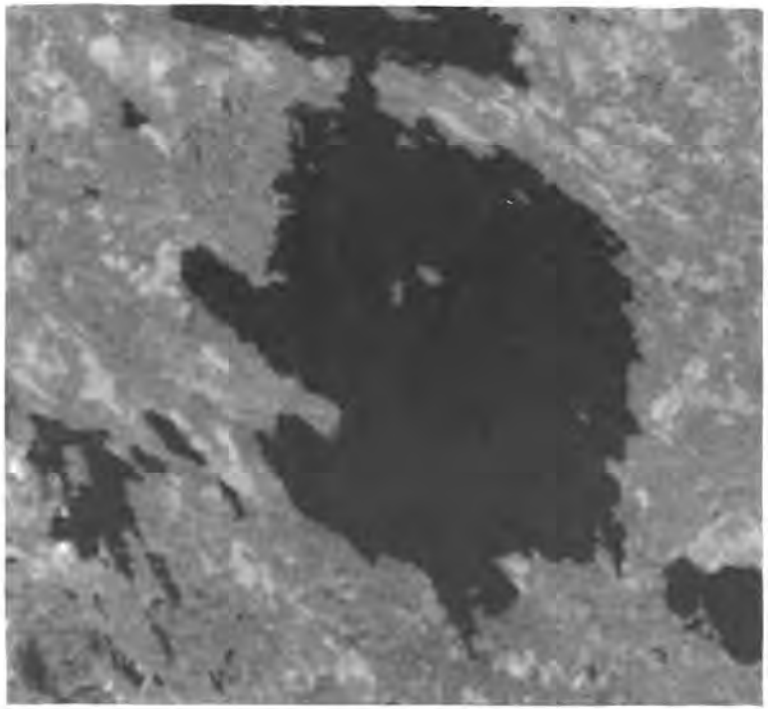
JANISJÄRVI
U.S.S.R.

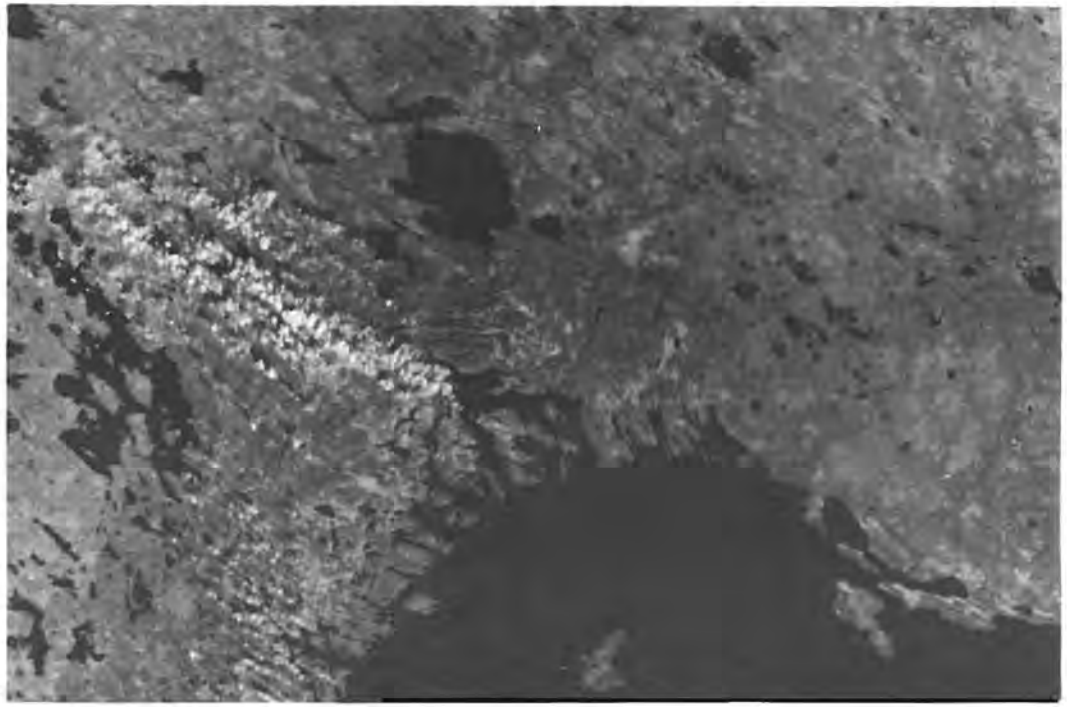
61°58'N; 30°55'E
Diameter: 14 km
Age: 698 ± 22 m.y.
Discernability: Average
Morphology: Irregular oval lake

General Area: Low relief area in the Baltic Shield of the Karelia area in the U.S.S.R. The area is forested and has been glaciated. The target rocks are crystalline.

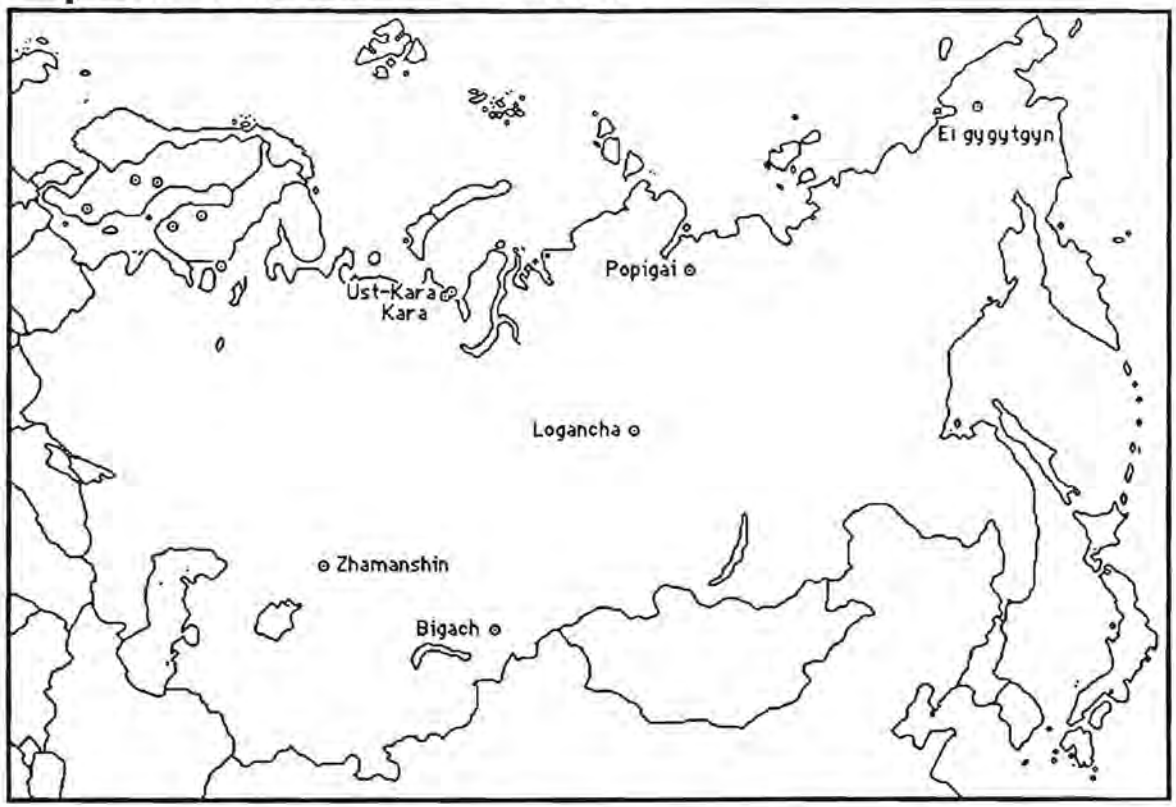
Specific Features: The structure has been highly eroded and appears as an isolated, slightly oval lake, 30 km north of Lake Lagoda. The lake has been elongated by glaciation from the northwest and measures 17 km by 13 km. There are a few small islands almost at the center which represent a central peak.







Impact Craters in ASIA

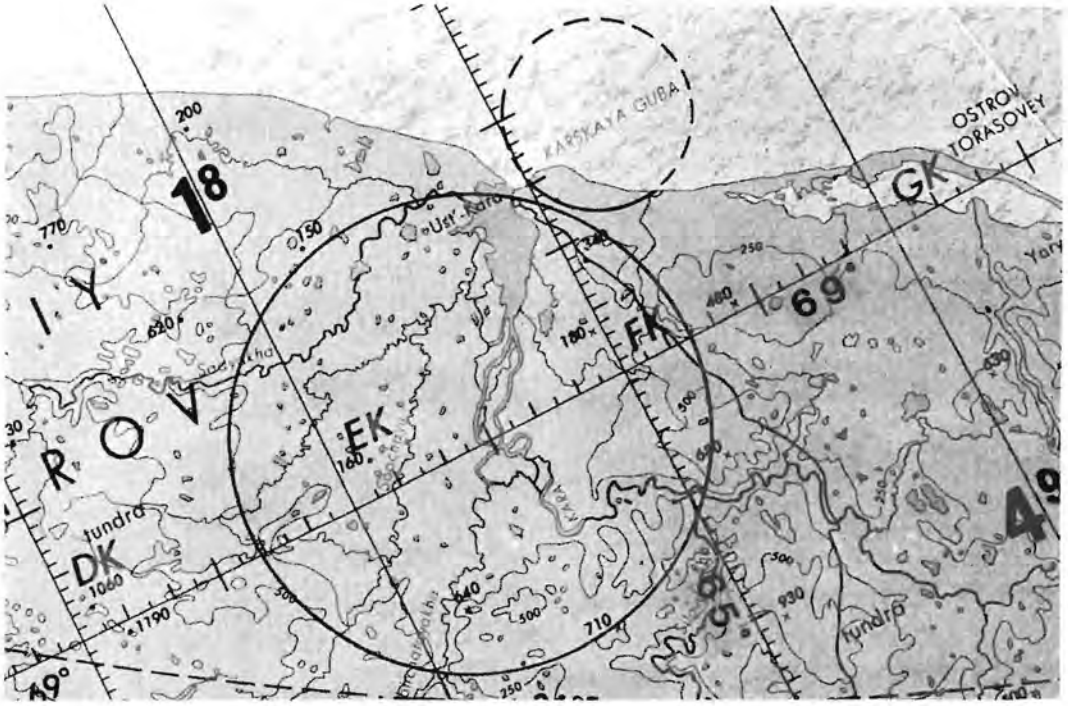


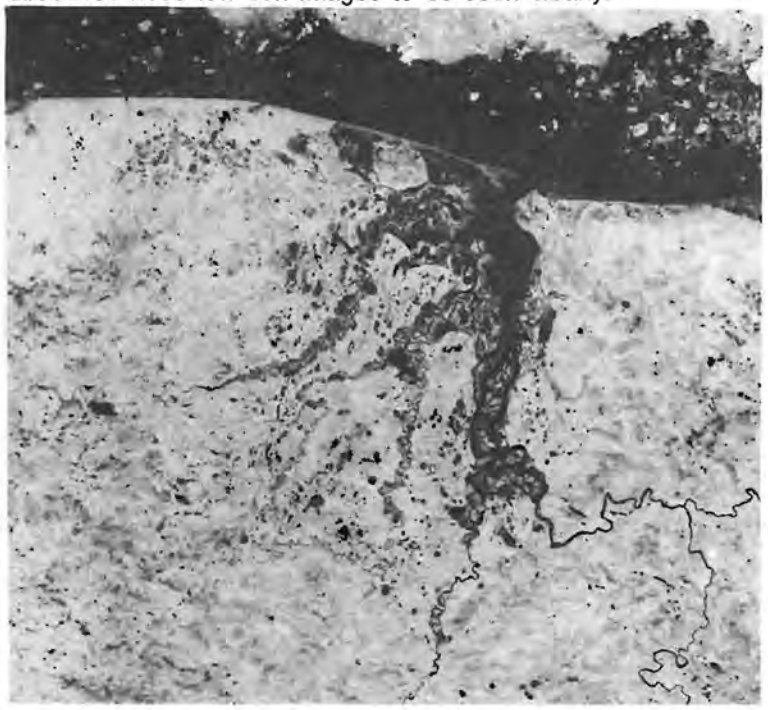
KARA AND UST-KARA
U.S.S.R.

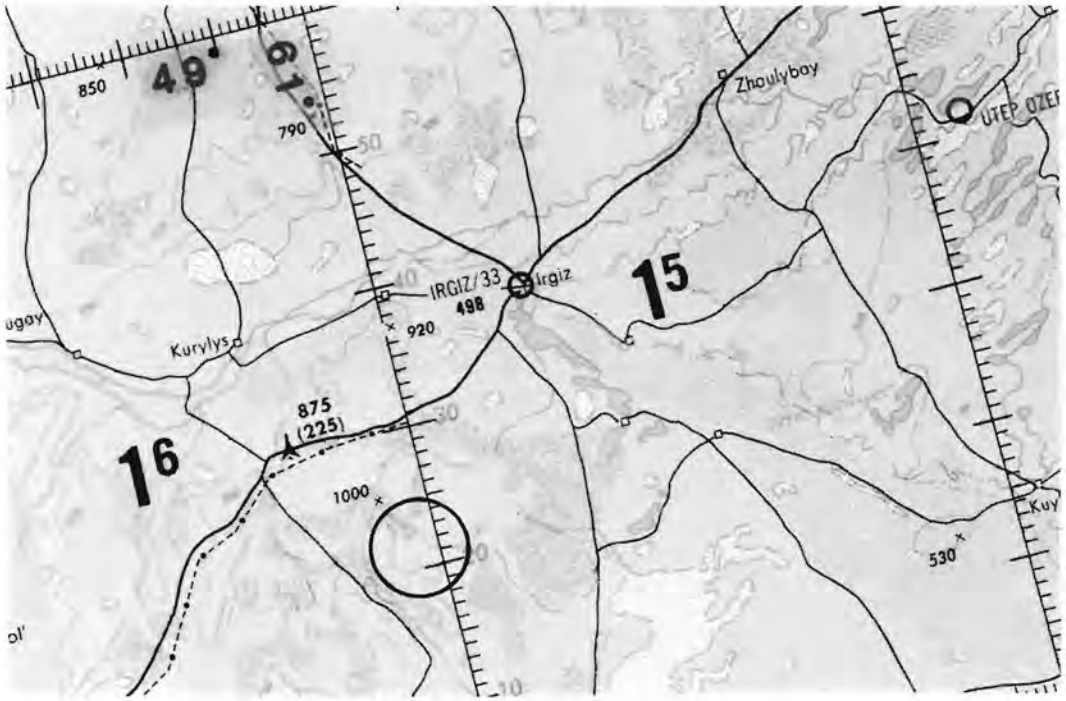
Kara: 69°01'N; 64°25'E
Ust-Kara: 69°18'N; 65°18'E
Diameter: **Kara** 60 km
Ust-Kara 25 km
Age: 57 ± 9 m.y.
Discernability: Very poor
Morphology: Very vague area with many small lakes.

General Area: Low relief area near the mouth of the Kara River which empties into the Kara Sea. Area ranges from coastal swamps and lagoons to low foothills of the northern Urals. Area is tundra. Target rocks are sedimentary.

Specific Features: This is a twin structure. Kara is an elongated depression 60 km in diameter and open to the sea to the north. The swampy floor, with many small lakes, is partially filled by alluvium and forms a relatively flat plain surrounded by low hills. Ust-Kara is mostly submerged beneath the sea; its southern rim appears as a semi-circular band of low relief, 50 m high, 5 km wide and 20 km long. These structures need low sun images to be seen clearly.







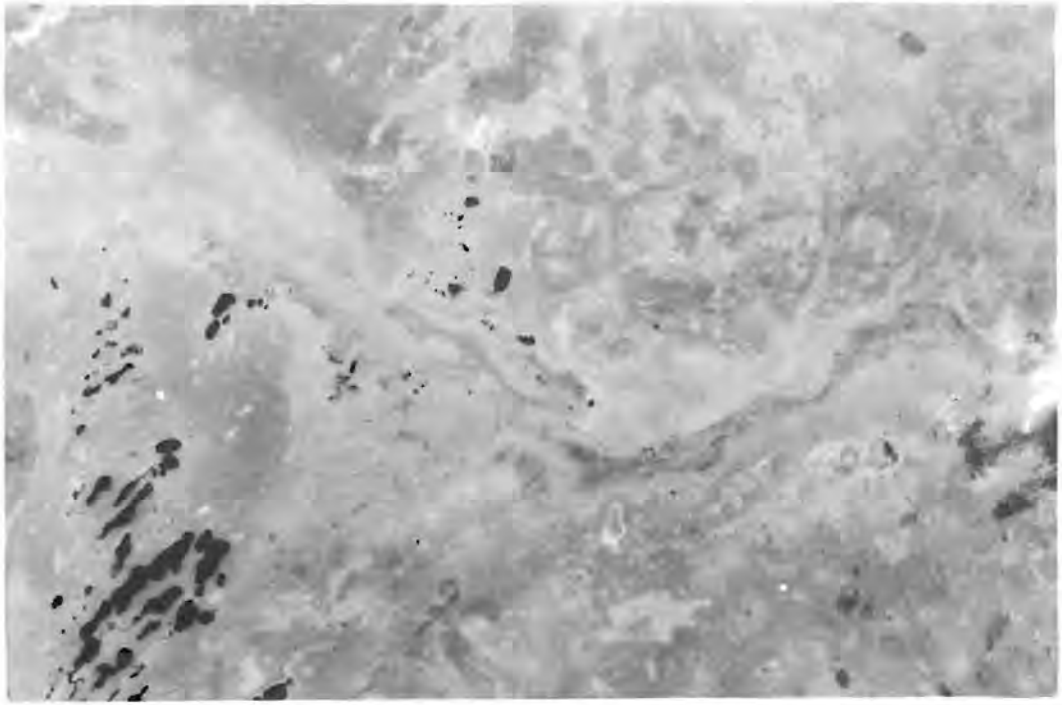
ZHAMANSHIN

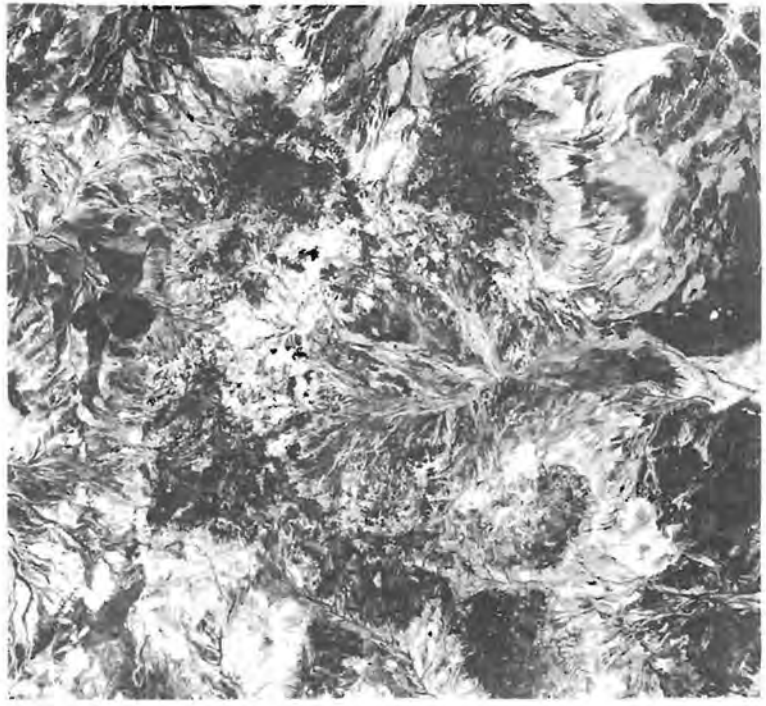
U.S.S.R.

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.



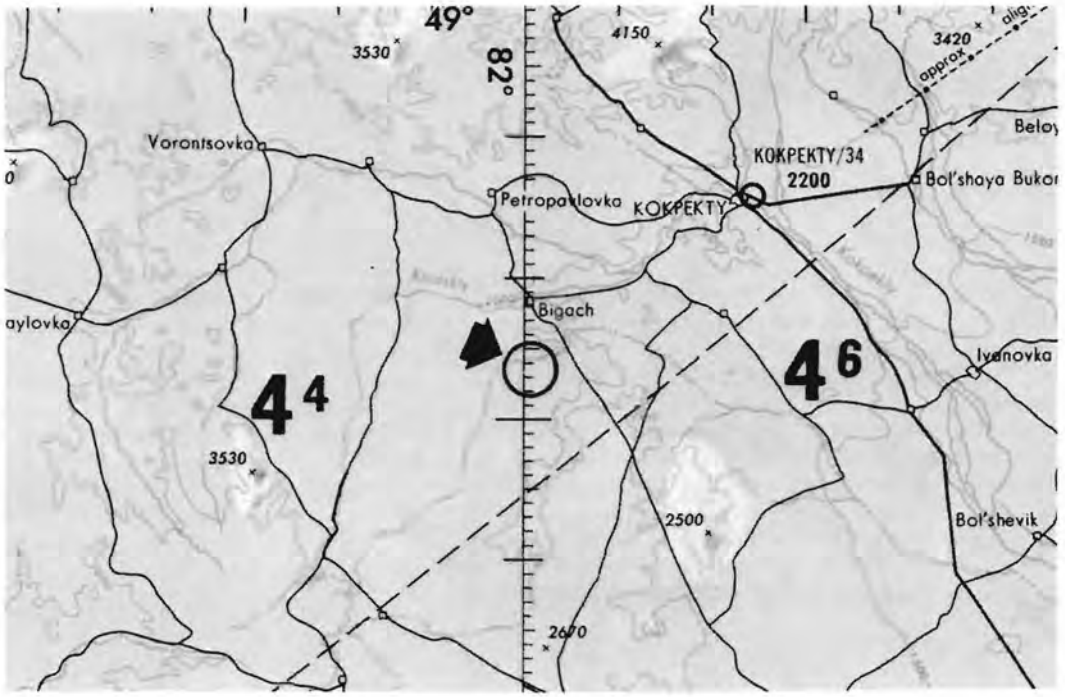


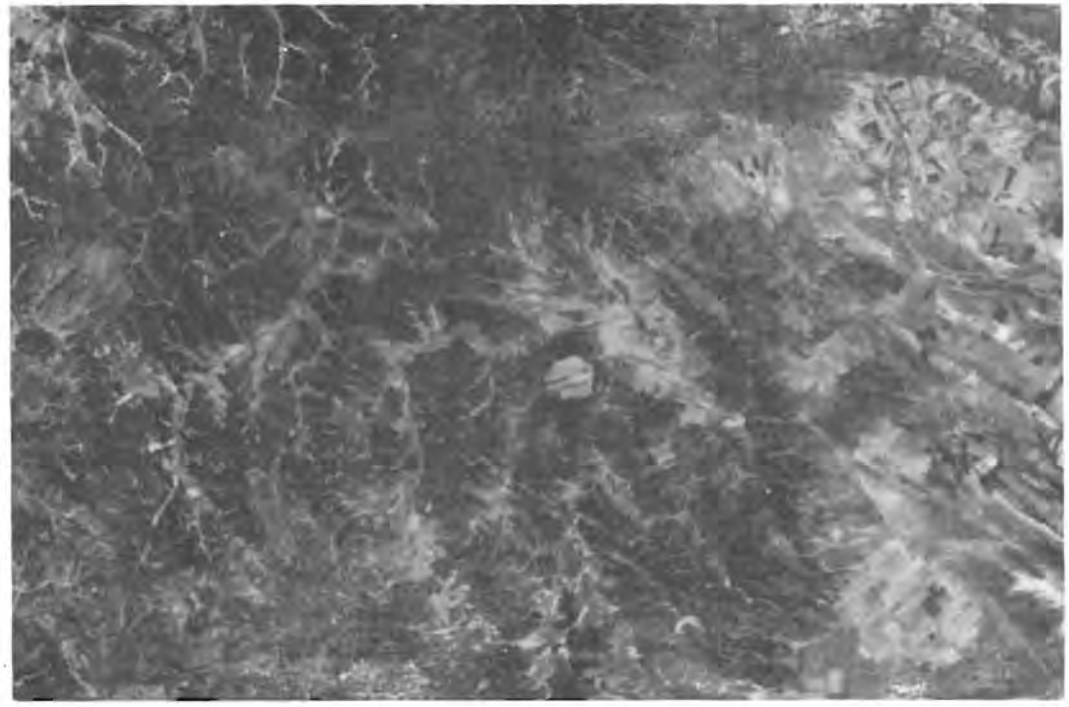
BIGACH
U.S.S.R.

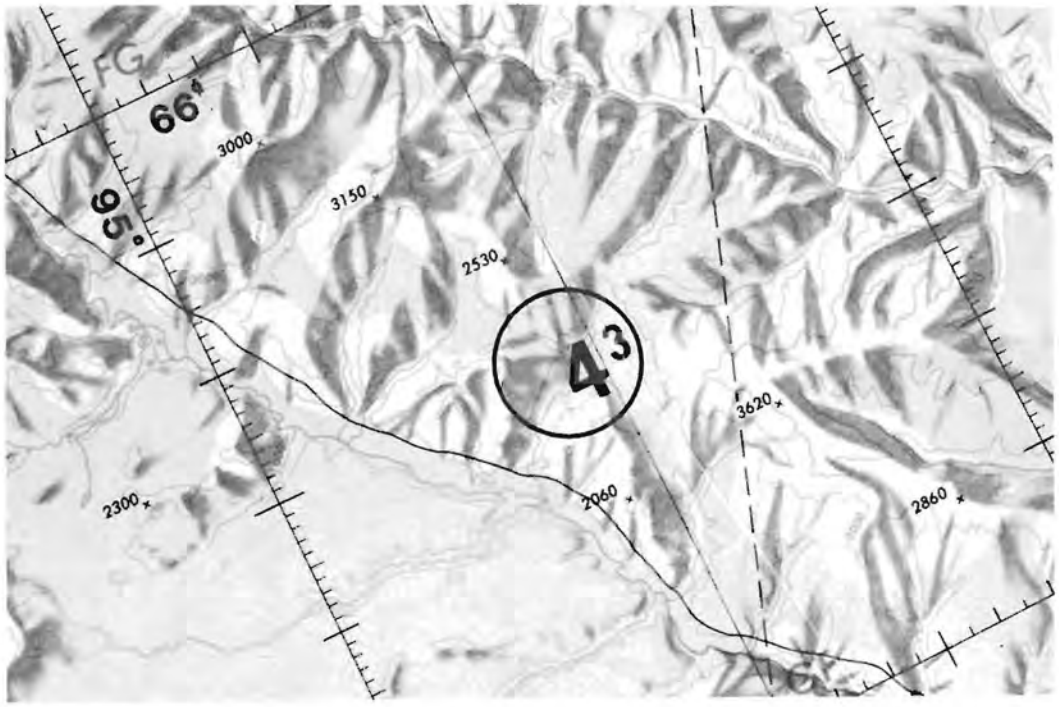
48°34'N; 82°01'E
Diameter: 7 km
Age: 6 ± 3 m.y.
Discernability: Good
Morphology: Polygonal rimmed structure

General Area: Area is hilly and is semi-arid in the eastern Kazakhstan uplands. The target rocks are crystalline.

Specific Features: Structure appears as a polygonal rimmed area 7 km in diameter in otherwise hilly relief. Interior of structure is in-filled by post-crater sediments, is farmed, and contrasts with the surrounding terrain. The rim is ~50 m high and ejecta has been discovered up to ~10 km from the crater. Much of the ejecta, however, is buried beneath a layer of recent alluvial deposits, which fill the inter-mountain areas and river valleys.





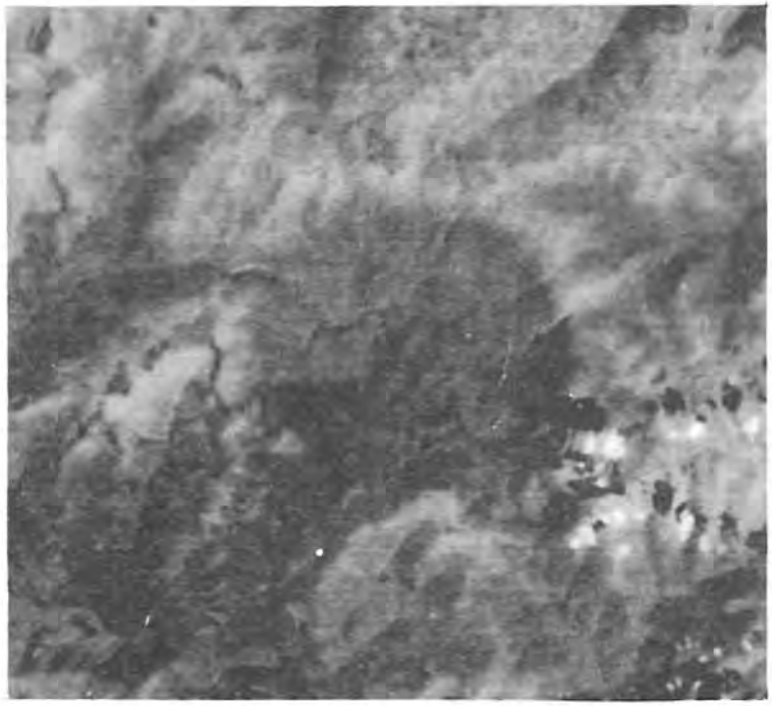


LOGANCHA
U.S.S.R.

65°31'N; 95°56'E
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.



POPIGAI
U.S.S.R.

71°35'N; 111°00'E
Diameter: 100 km
Age: 39 ± 9 m.y.
Discernability: Poor
Morphology: Vague circular feature outlined by rivers

General Area: In the northern portion of the Anabar Shield in Siberia. The area is tundra and has little forestation. It has not been heavily glaciated. The target rocks are sedimentary overlying crystalline.

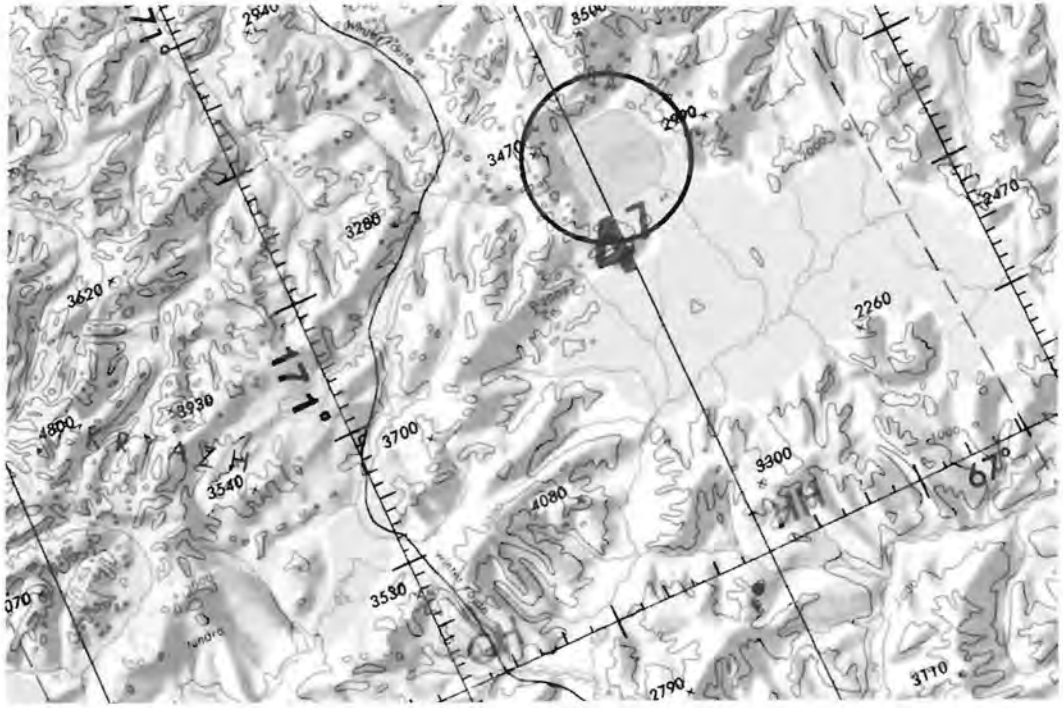
Specific Features: Popigai has an inner basin 75 km in diameter and ~100 m deep. The interior of the basin is relatively flat and swampy, particularly in the north. Surrounding the basin is a 200 m high plateau, with broken chains of circumferential ridges and tablelands up to 150 m high occurring 50 km from the center. These are taken to represent portions of the original rim. Popigai is the largest impact structure in the U.S.S.R.; its poor visibility on orbital imagery, compared to the similar-sized Manicouagan crater in Canada, is due to the absence of glacially overdeepening of the circumferential rivers inside the rim. No fracture halo has been observed but it should be looked for under low sun angles.

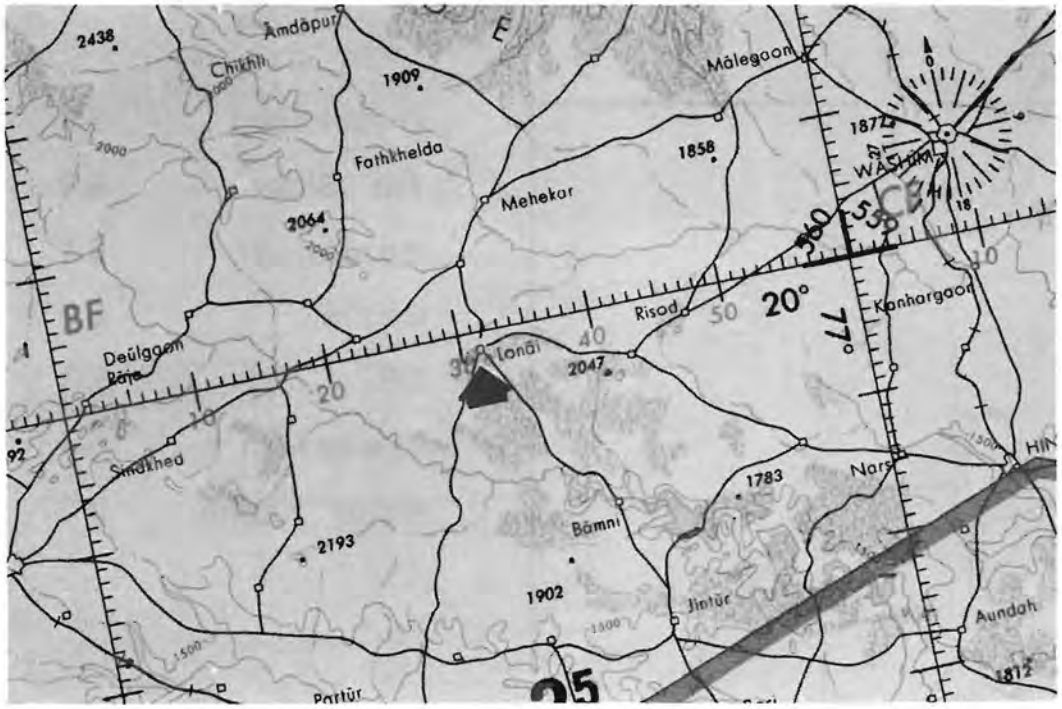
ELGYGYTGYN
U.S.S.R.

67°30'N; 172°05'E
Diameter: 23 km
Age: 3.5 ± 0.5 m.y.
Discernability: Excellent
Morphology: Isolated polygonal lake

General Area: Moderately mountainous relief in the Chukotka area of Siberia. Area is above the tree-line and has been glaciated. The target rocks are crystalline.

Specific Features: Structure is partially occupied by an isolated polygonal lake ~15 km in diameter and ~200 m deep. Although ejecta has been largely removed by erosion, the original rim forms a circular range of hills up to 400 m above the lake and ~23 km in diameter. A fracture halo has been mapped from aerial photographs and extends out ~20 km from the structure. Subtle indications of this halo are apparent on some orbital imagery. The native name means large isolated lake.



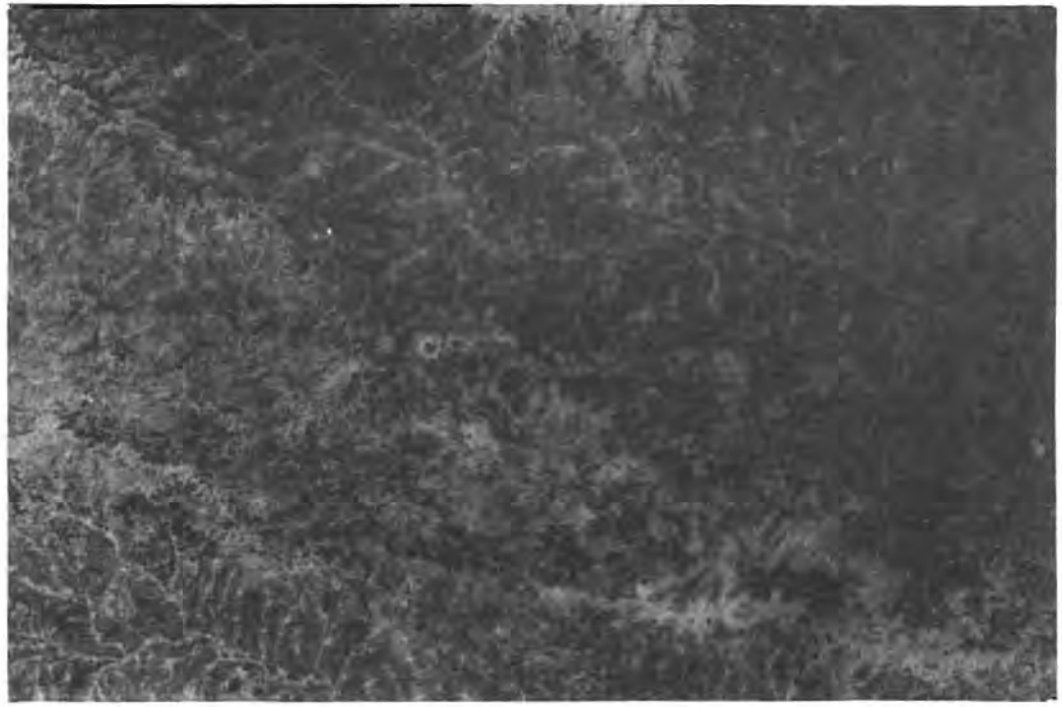


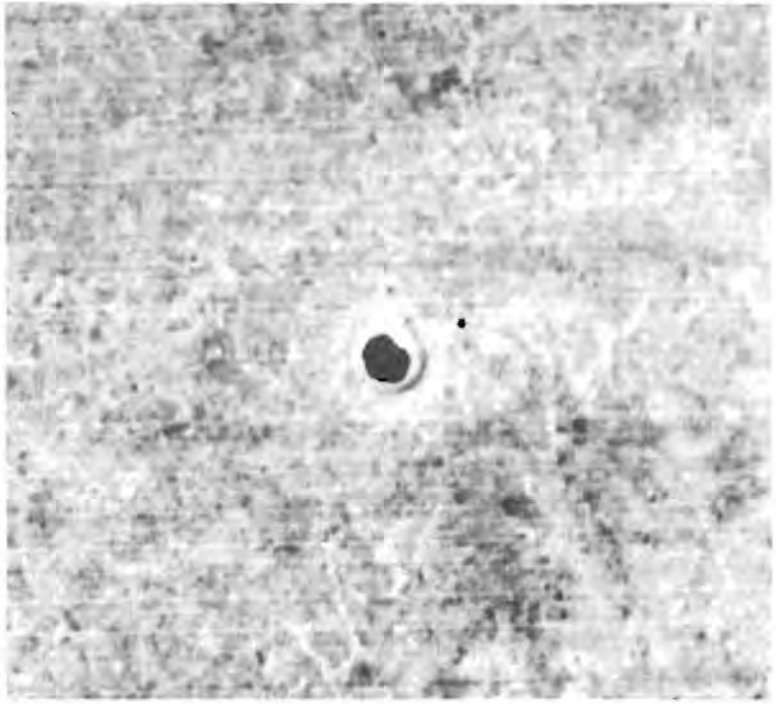
LONAR
INDIA

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

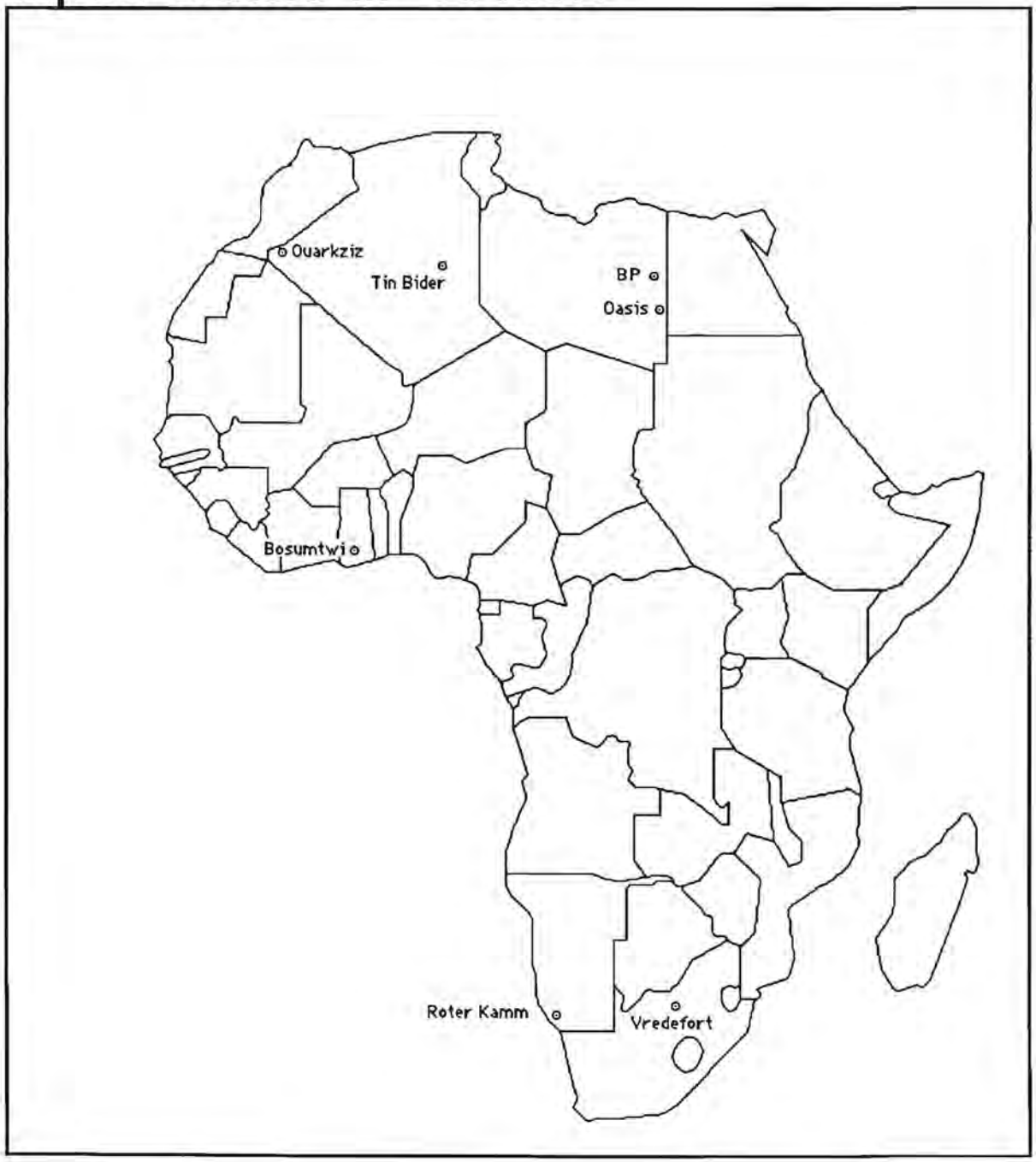
General Area: Flat relief in the volcanic Deccan Plateau of west central India. The area is relatively dry with sparse vegetation in a farmed area. The target rocks are volcanic.

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.





Impact Craters in AFRICA



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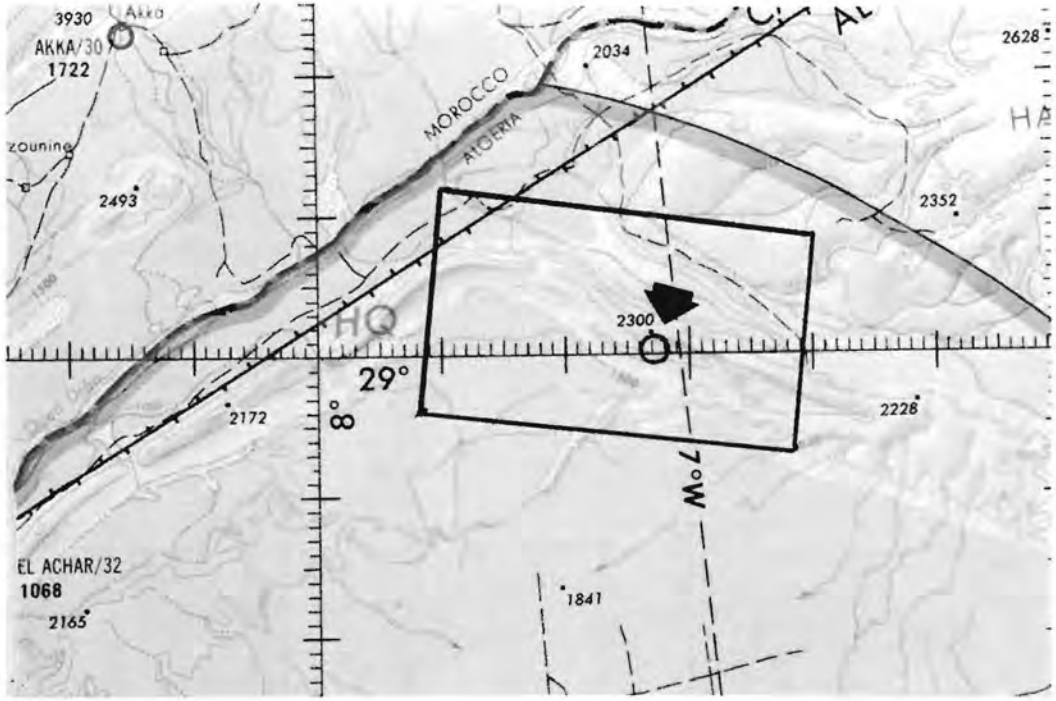


OUARKZIZ
ALGERIA

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.

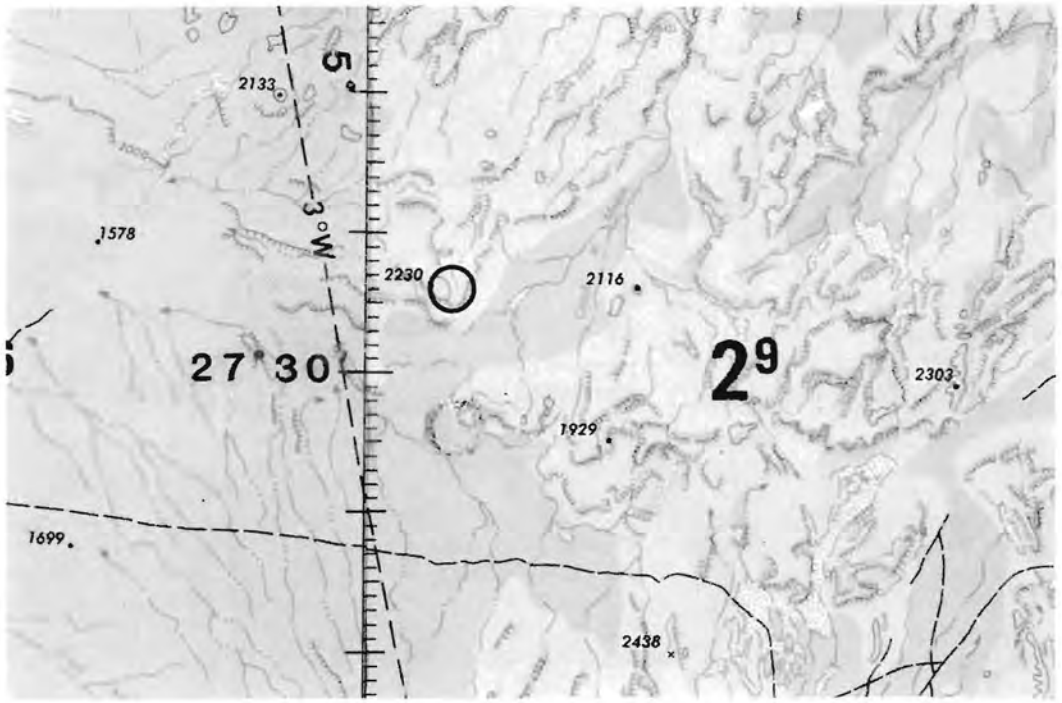
Specific Features: Structure has the form of a well-defined ring open to the south, with interior drainage and walls 100 m high. The crater clearly cuts into local structure, which has a large arcuate form. A ring, 30-40 m high, occurs at the base of the main ring escarpment which may be the result of 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?

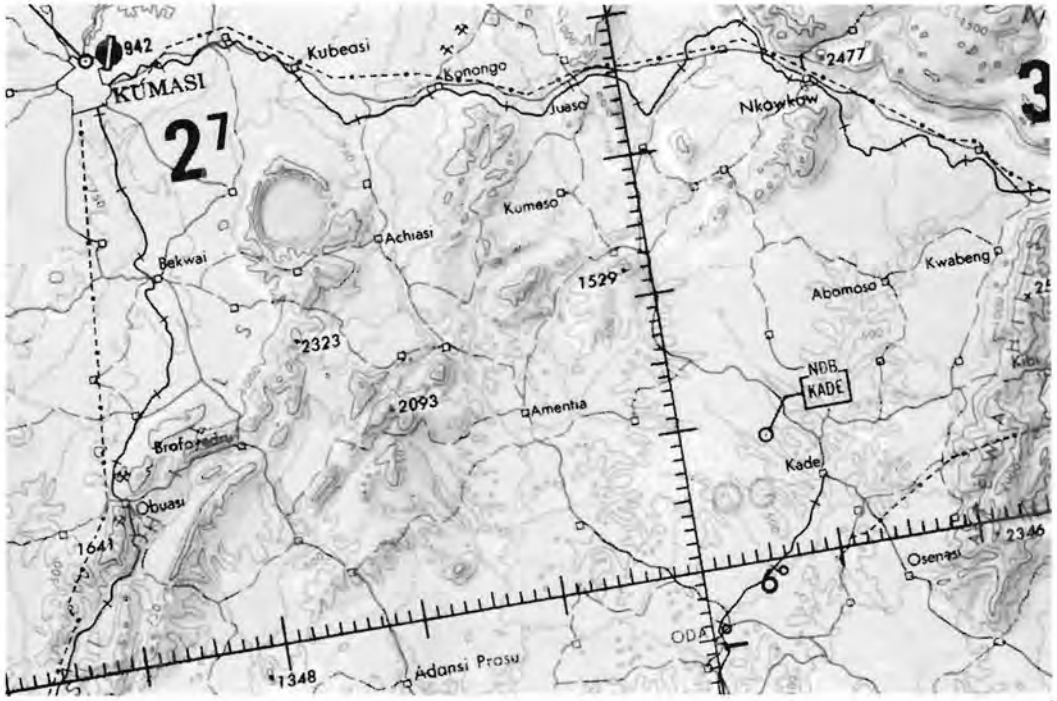
TIN BIDER
ALGERIA

27°36'N; 05°07'E
Diameter: ~7 km
Age: < 70 m.y.
Discernability: Poor
Morphology: Swirl-like circular feature.

General Area: On the southeasternmost extension of the high Tademait Plateau in east-central Algeria. The plateau is partially covered by wind-blown sand from a desert basin to the southwest. Target rocks are sedimentary.

Specific Features: Tin Bider is defined by at least three concentric rings and an outer depression. It has a morphology unlike typical impact features in its size class (5 to 10 km diameter) in similar targets. Tin Bider may represent a section through a multi-ringed impact feature formed in a "soft target" (wet clays?). A sinuous stream within the structure is apparently controlled by radial and concentric fractures, and there is evidence for radial faulting. Erosion has apparently cut below the original crater floor; we are looking at the "roots" of an impact crater.





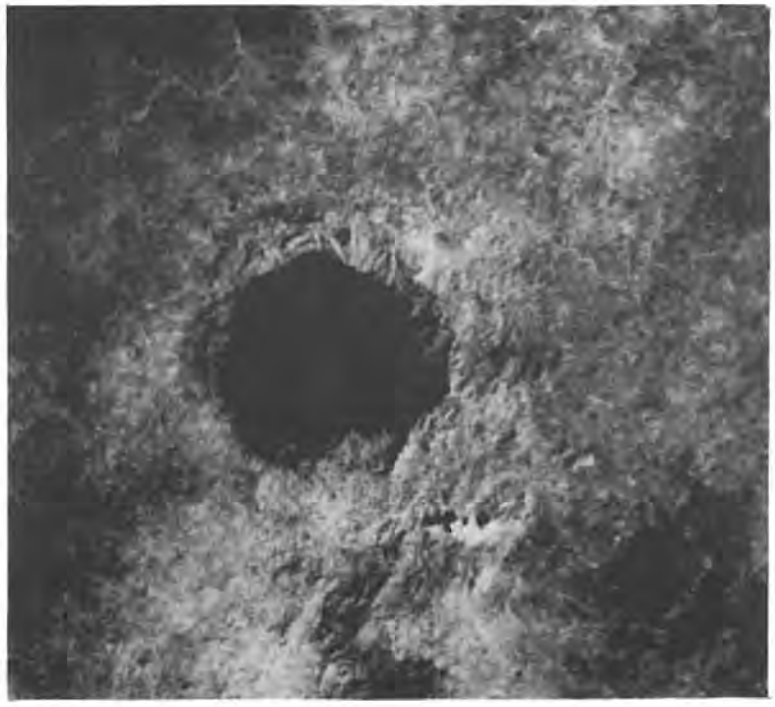
BOSUMTWI

GHANA

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.

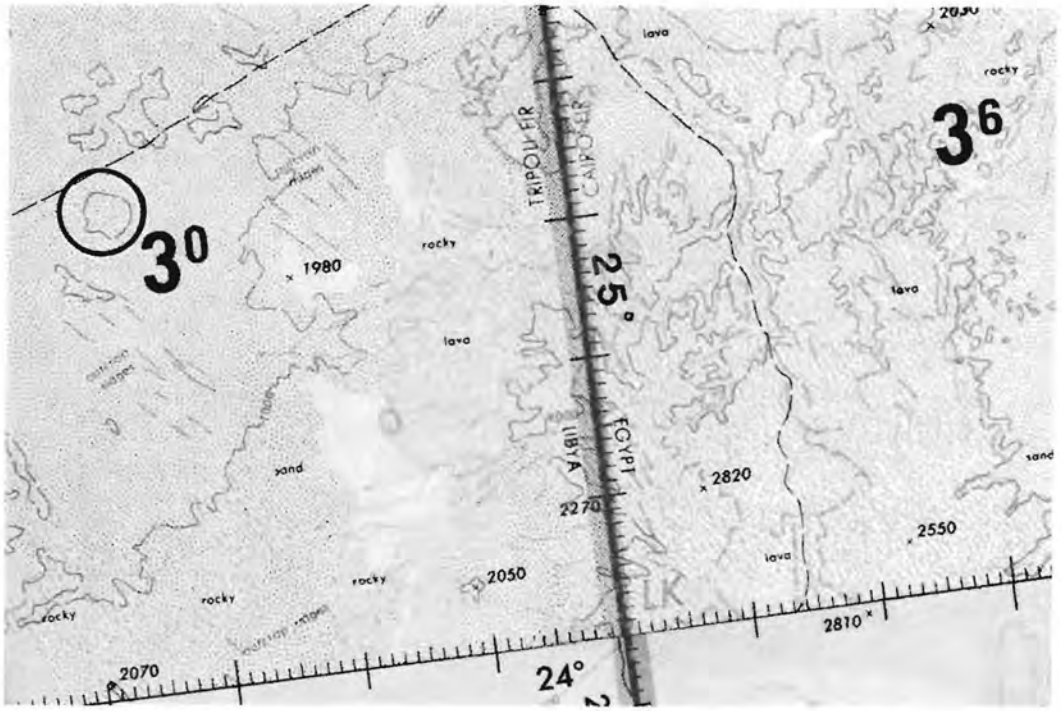


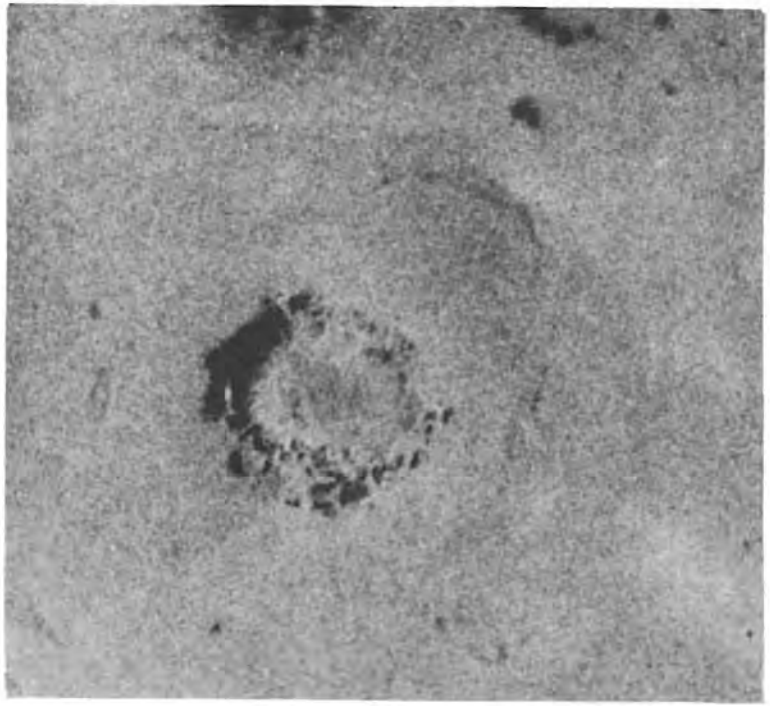
OASIS
LIBYA

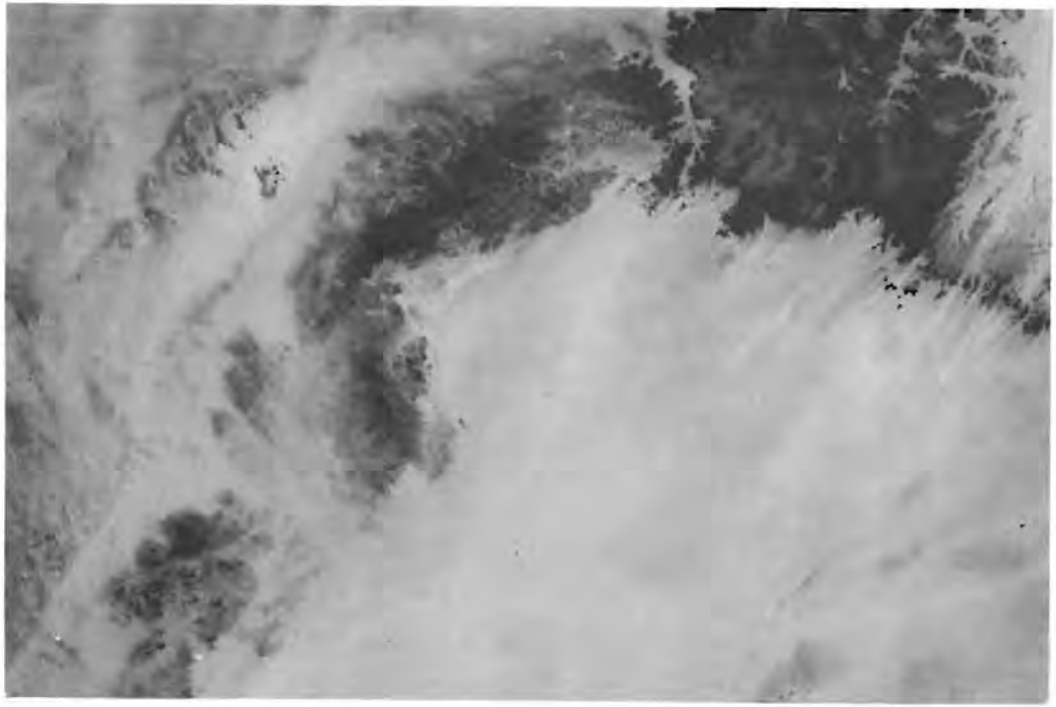
24°35'N; 24°24'E
Diameter: 11.5 km
Age: <100 m.y.
Discernability: Average
Morphology: Circular feature in otherwise featureless area.

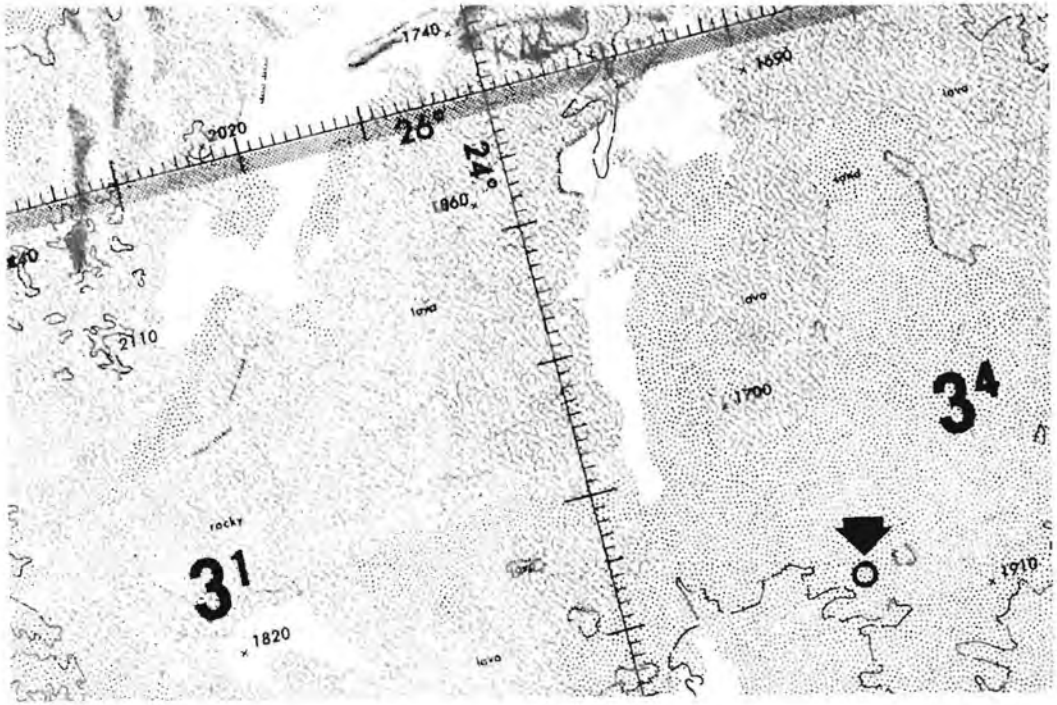
General Area: The area is a bright desert in southeastern Libya, west of the dark Gilf Kebir plateau, and is relatively featureless with respect to bedrock structure. Target rocks are sedimentary.

Specific Features: The most prominent feature of Oasis is ring of discontinuous hills 5 km in diameter and 100 m high, probably representing a central uplift. This central peak ring is surrounded by a weakly expressed outer rim 11.5 km wide. Oasis is thus similar to Gosses Bluff in Australia It has been suggested that Oasis and the ~2.8 km wide BP structure to the north may represent a double impact.







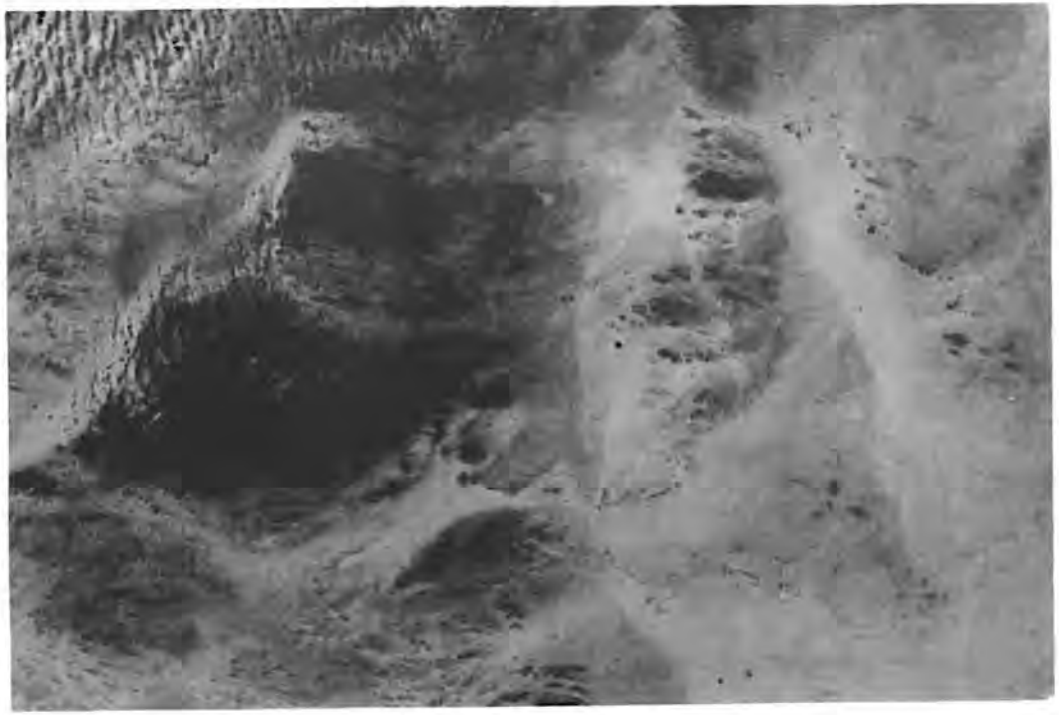


BP
LIBYA

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.

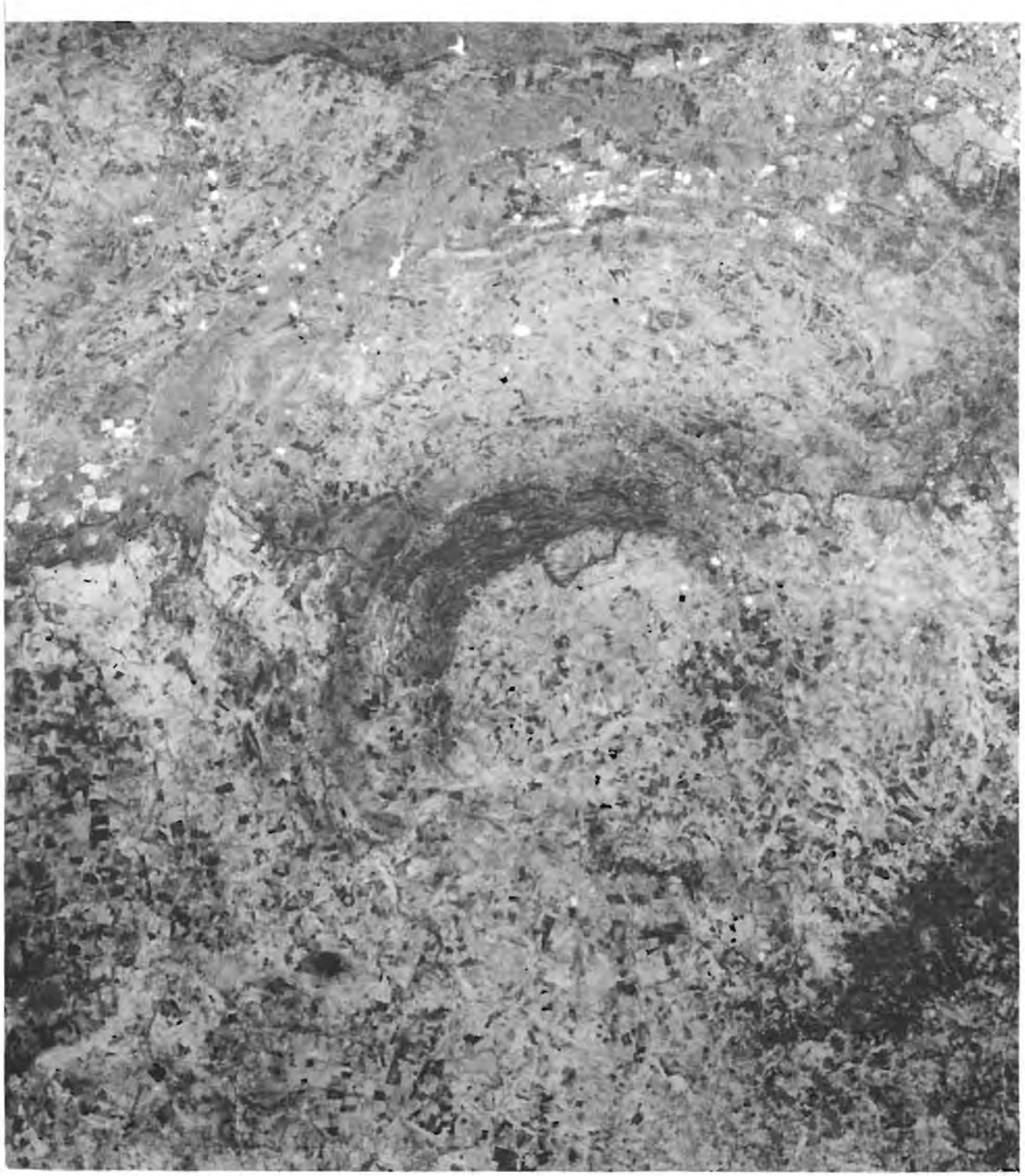


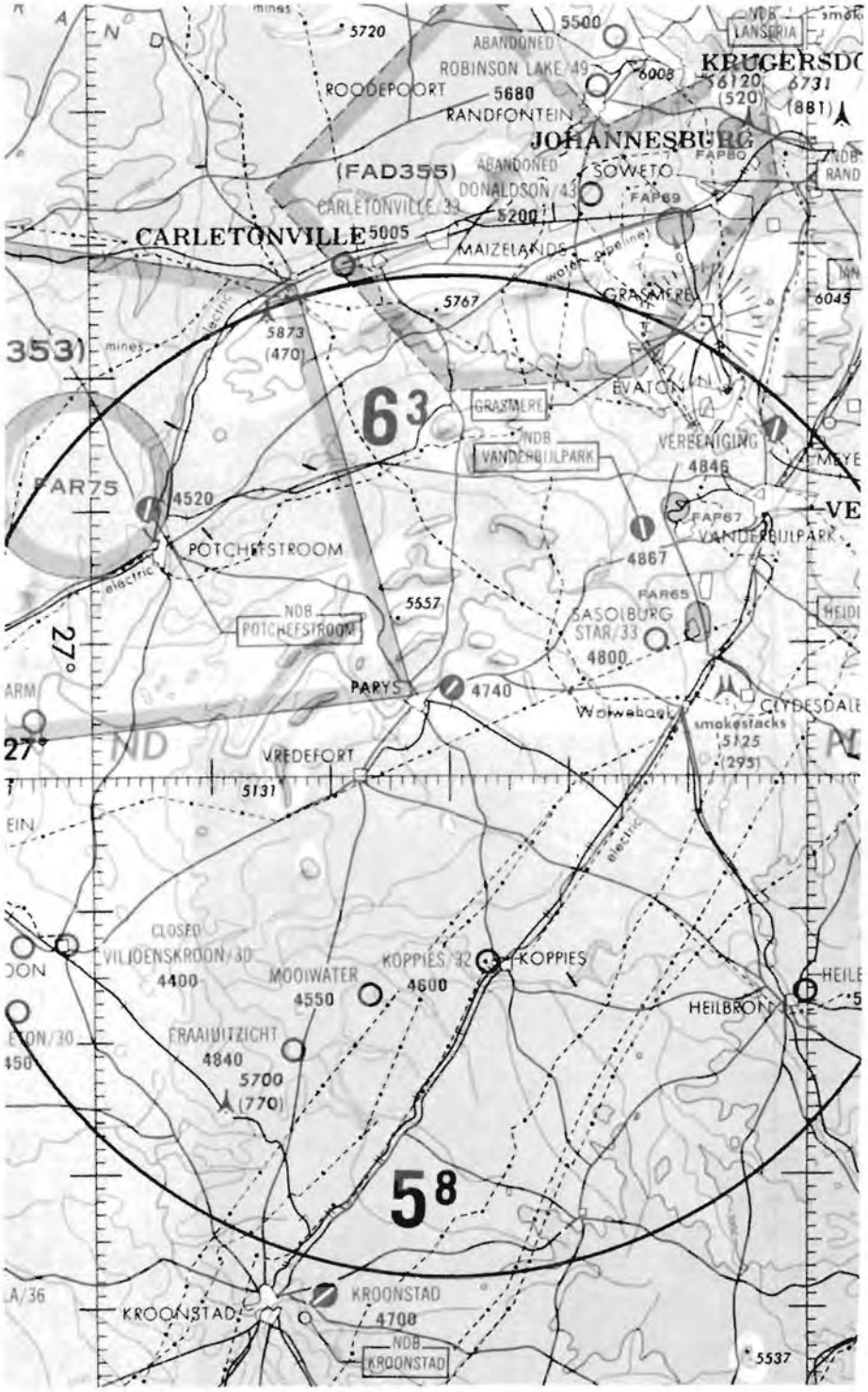
VREDEFORT
SOUTH AFRICA

27°00'S; 27°30'E
Diameter: 140 km
Age: 1970 ± 100 m.y.
Discernability: Good
Morphology: Semi-circular ring

General Area: Structure is located in an area of relatively featureless savannah and farmland in the hinterland of South Africa. Target rocks are crystalline and sedimentary.

Specific Features: Vredefort is outlined by a central core 40 km in diameter of uplifted crystalline rocks. Surrounding the core is a ring or collar 60 km in diameter of uplifted and overturned sedimentary strata. This collar, which covers 200° of arc, is obscured in the south and west, where it is covered by younger rocks. This crater is the oldest known terrestrial impact structure and may be an eroded analog to lunar multi-ringed basins.



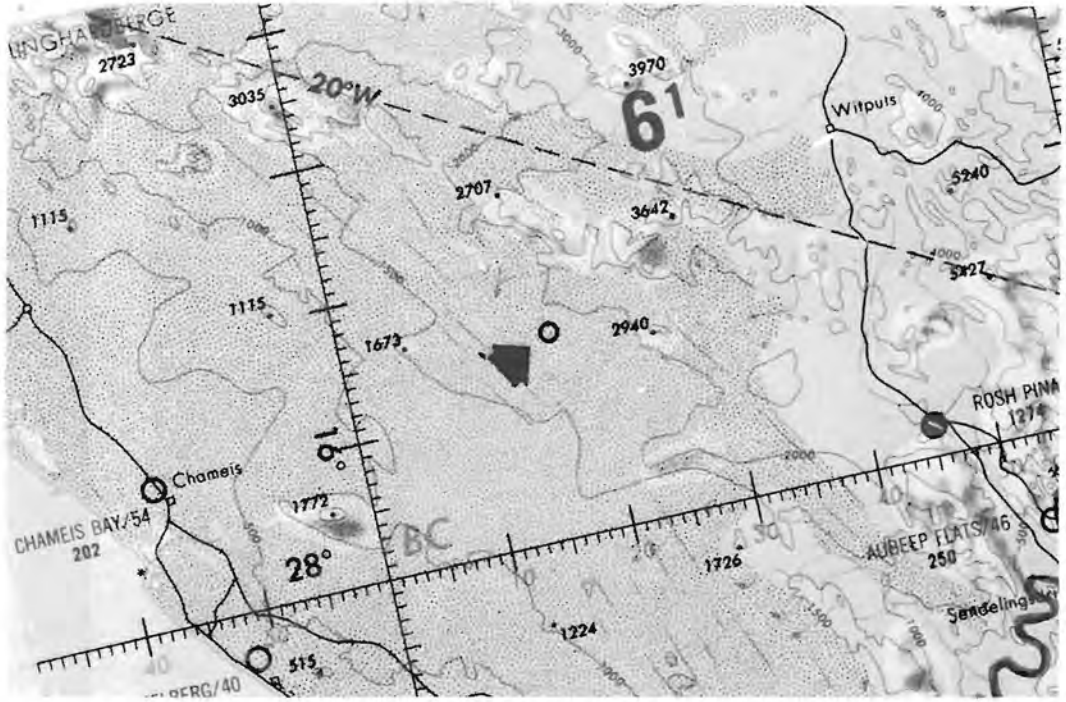

5720
ABANDONED
5500
ROBINSON LAKE 49
6008
KRUGERSDO
6120
(520)
6731
(881)
ROODEPOORT
5680
RANDFONTEIN
JOHANNESBURG
(FAD355)
ABANDONED
SOWETO
FAP69
DONALDSON 43
CARLETONVILLE 33
5200
CARLETONVILLE 5005
MAIZELANDS
GRASMERE
5767
6045
5873
(470)
353)
6 3
EVATON
GRASMERE
NDB
VANDERBIJLPARK
VEREENIGING
4846
PAR75
4520
POTCHEFSTROOM
FAP67
VANDERBIJLPARK
4867
5557
NDB
POTCHEFSTROOM
PAR65
SASOLBURG
STAR 33
4800
27°
PARYS
4740
Wolwebaai
CLYDESDALE
smokestacks
5125
(295)
VREDEFORT
5131
CLOSED
VILJOENSKROON 30
4400
MOOIWATER
4550
KOPPIES 32
4600
KOPPIES
HEILBRON
FRAAIUITZICHT
4840
5700
(770)
5 8
KROONSTAD
KROONSTAD
4700
NDB
KROONSTAD
5537

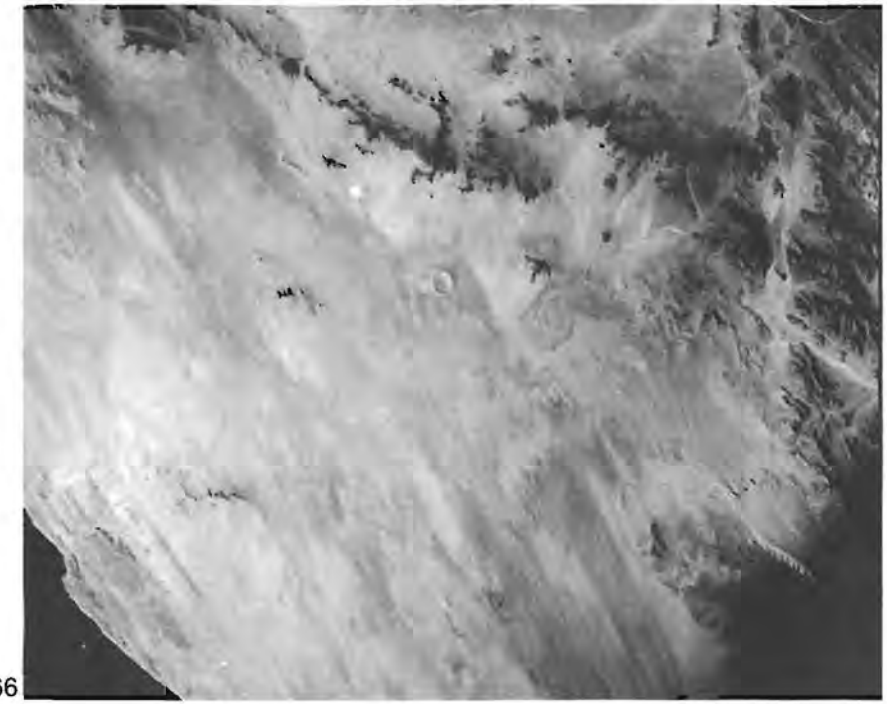
ROTER KAMM
NAMIBIA

27°45'S; 16°17'E
Diameter: 2.5 km
Age: Unknown but young
Discernability: Excellent but small
Morphology: Circular crater

General Area: West of the Hans Mountains in the desert of Namibia. Linear dune formations are evident in the area. The target rocks are sedimentary and crystalline.

Specific Features: Roter Kamm clearly cuts across pre-existing formations and is superimposed on the landscape. It has the form of a bowl-shaped depression 2.5 km in diameter. An outer, uplifted and disturbed zone can be seen extending out from the rim. The structure is very similar in appearance to Meteor Crater, Arizona.





Impact Craters in AUSTRALIA

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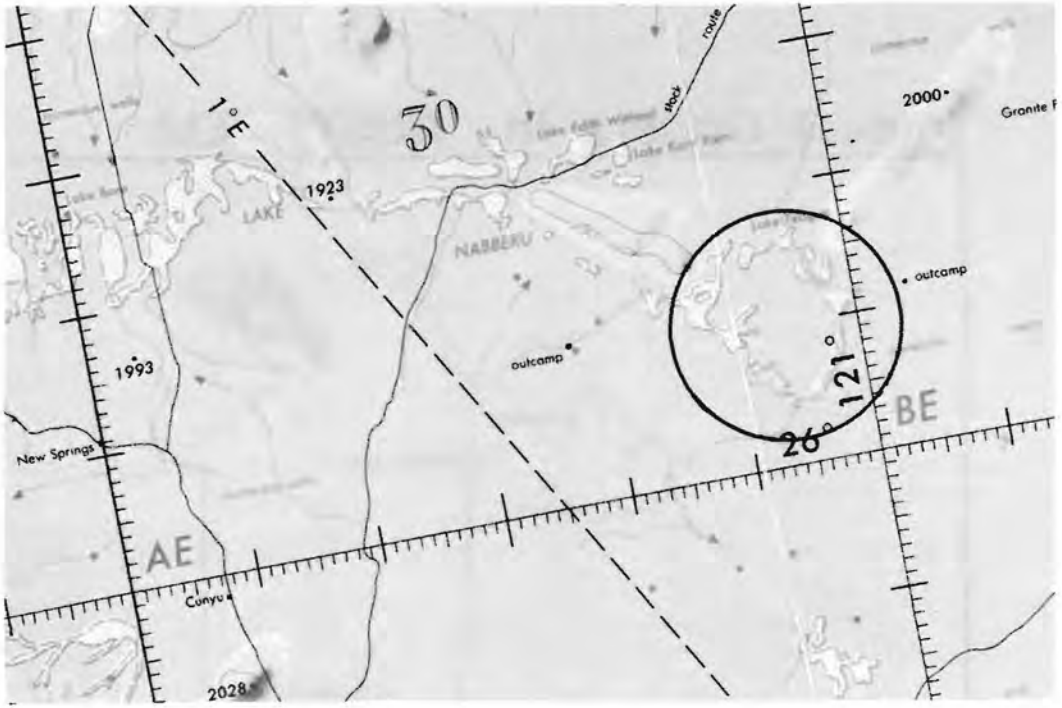
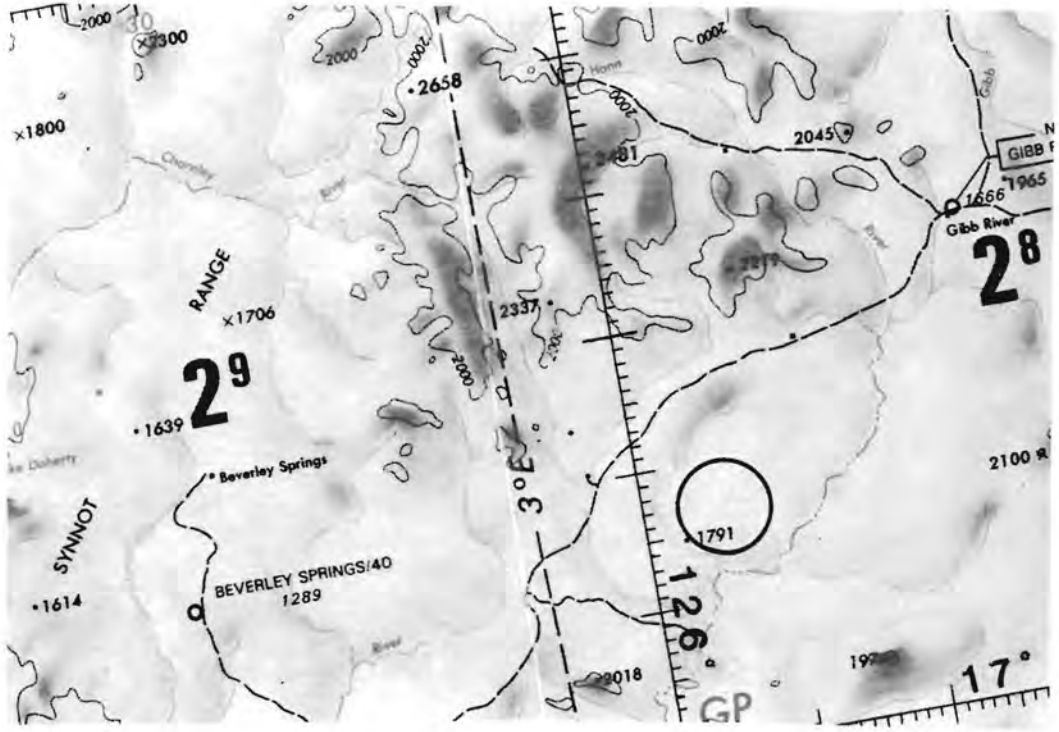
TEAGUE
WESTERN AUSTRALIA, AUSTRALIA

25°50'S; 120°55'E
Diameter: 28 km
Age: 1685 ± 5 m.y.
Discernability: Average
Morphology: Arcuate ridge

General Area: Structure is arid Western Australia. Area is relatively featureless with temporary lakes and salinas. Target rocks are sediments overlying crystalline.

Specific Features: Structure consists of an uplifted core of older granite 10 km in diameter surrounded by a ring 20 km in diameter of younger Precambrian sediments. Outcrop is poor and many of the rocks are covered by lake deposits and wind-blown drift. There is a well-developed internal drainage system and the interior of the structure contains shallow annular lakes, particularly in the area of the ring and ring-core contact.



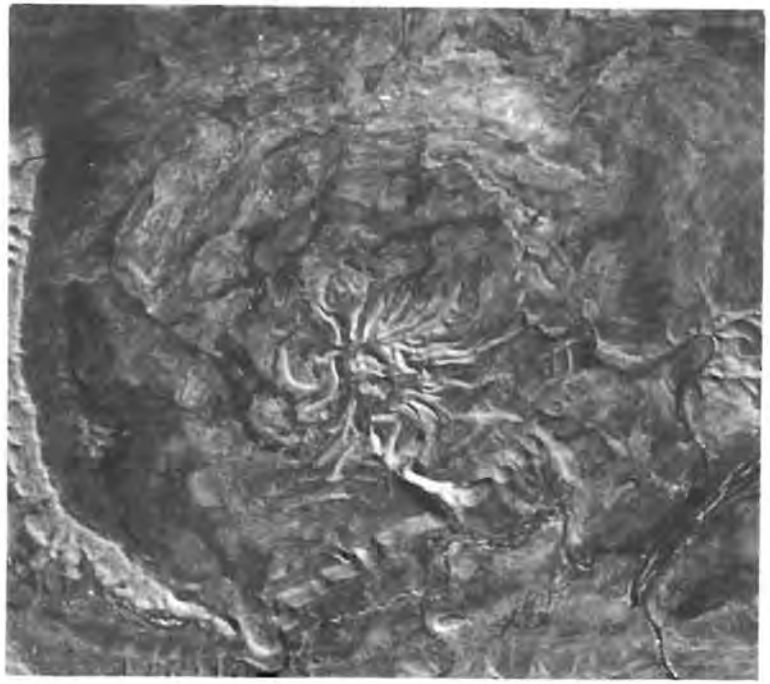


SPIDER
WESTERN AUSTRALIA, AUSTRALIA

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.

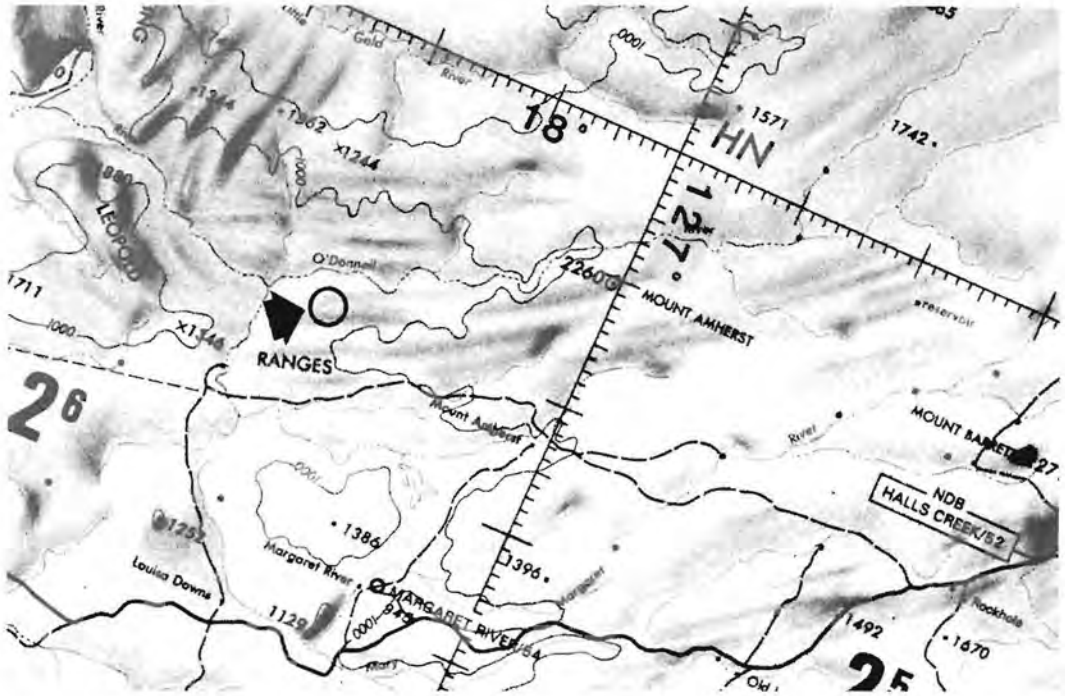


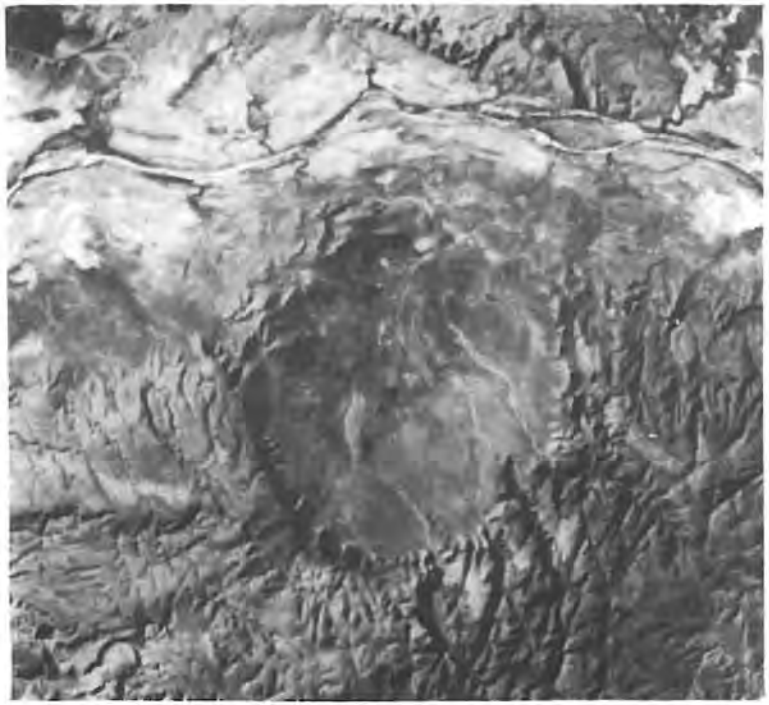
GOAT PADDOCK
WESTERN AUSTRALIA, AUSTRALIA

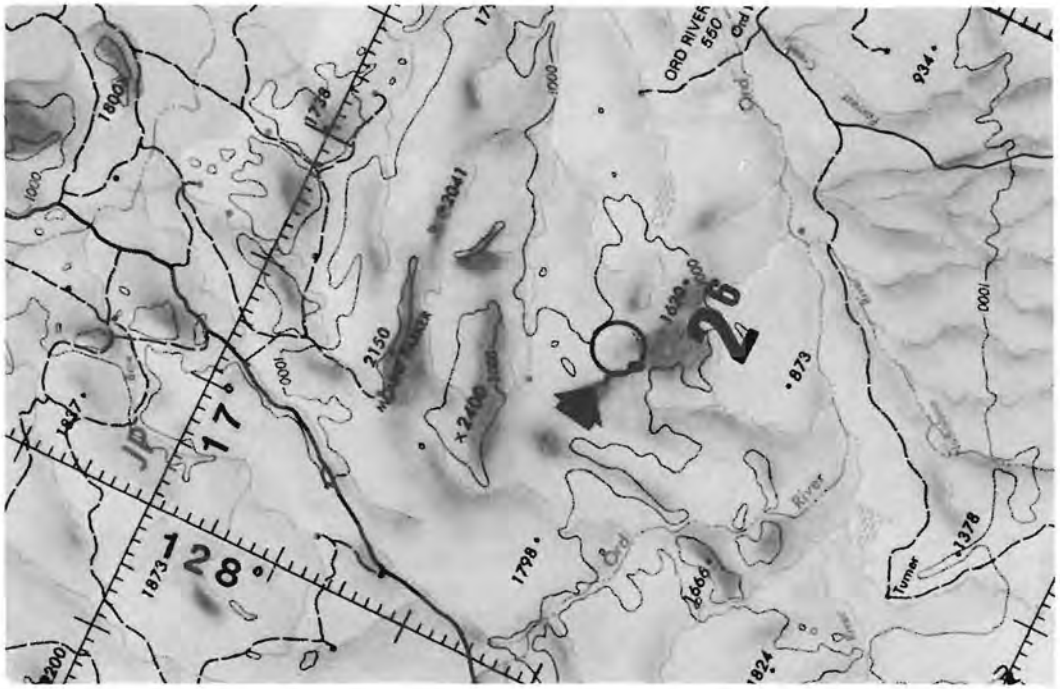
18°20'S; 126°40'E
Diameter: ~5 km
Age: < 55 m.y.
Discernability: Good
Morphology: Oval depression

General Area: In the semi-desert plains south of the Kimberley plateau of northwestern Australia. Target rocks are sedimentary.

Specific Features: Goat Paddock consists of a nearly circular depression open to the north, and clearly cutting the regional geologic structure. The crater's name reflects its natural capacity as a paddock for livestock. A possible slump terrace can be seen to the northeast. Goat Paddock might represent the best example of a crater transitional in morphology from a simple bowl-shaped depression to a more complex form with slump terraces and central mounds or uplifts. Further investigations of this interesting impact feature are warranted.







PICCANNINY
WESTERN AUSTRALIA, AUSTRALIA

17°25'S; 128°26'E
Diameter: 7 km
Age: < 360 m.y.
Discernability: 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.

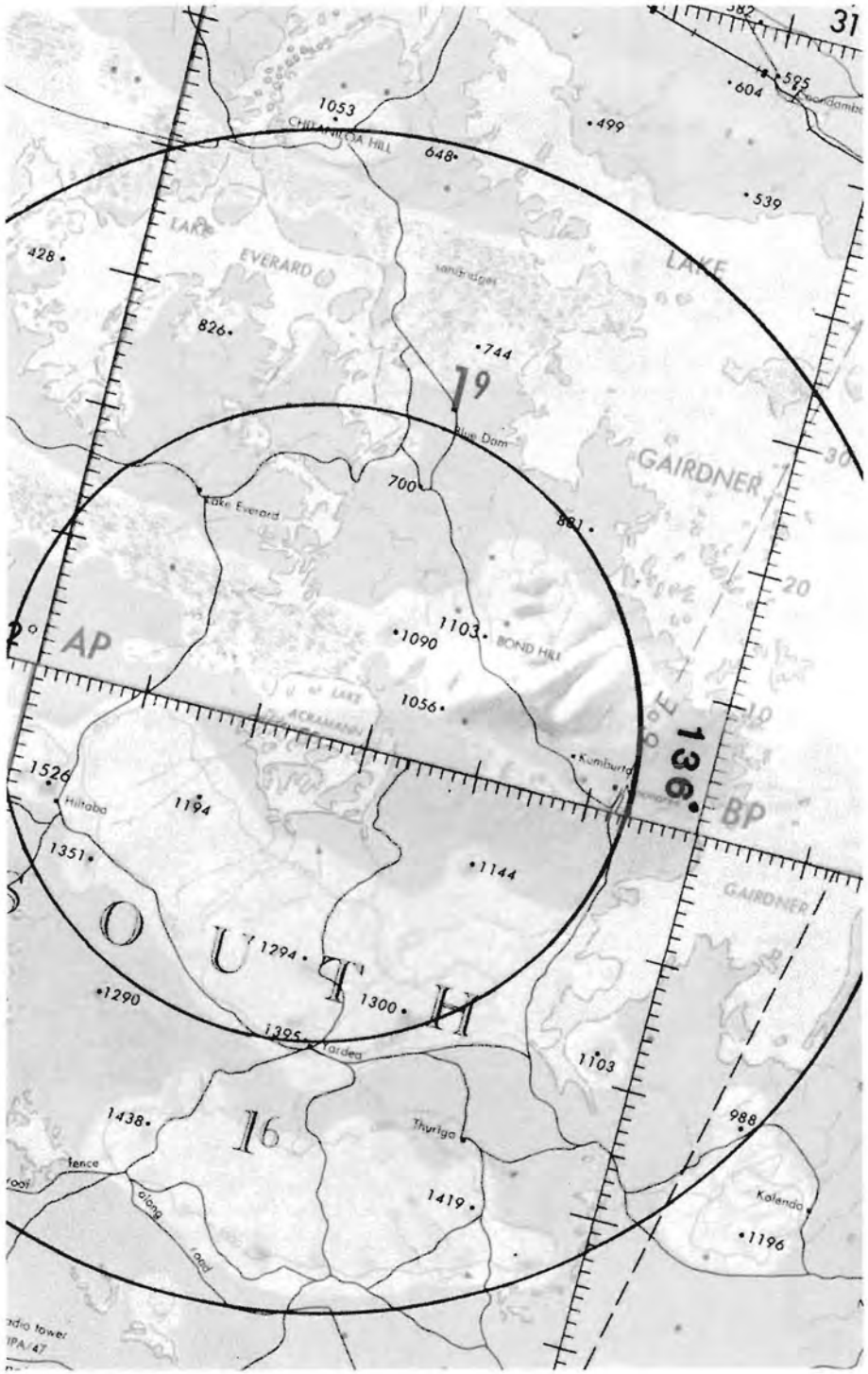
Specific Features: The structure consists of an elliptical zone of anomalous deformation within essentially undeformed sediments. A radial joint pattern is well-defined around the periphery of the structure, and the central region of Piccanniny consists of an eroded gentle dome. A subtle central peak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

ACRAMAN
AUSTRALIA

32°01'S; 135°26'E
Diameter: 90 km (or 160 km)
Age: ~600 m.y.
Discernability: Good
Morphology: A hexagonal shaped 20 km wide salt lake

General Area: Within the semi-desert Gawler Range of South Australia, east of coastal farmland and south and west of Lake Gairdner. Target rocks are crystalline.

Specific Features: Acraman consists of at least two obvious structural elements. The first is represented by Lake Acraman, a dry salt lake about 20 km in diameter. The second element is a crudely circular depression which surrounds the lake like a moat; this region is about 35 km across. An outer zone forms the high-ground that defines the horseshoe shape of the 90 km diameter of the impact structure. Some questions remain regarding the size of the structure and whether it includes the crudely semi-circular Lake Gairdner. A layer of ejecta has been observed 300 km to the east, which may have its source as the Acraman impact. If so, it is likely that Acraman has an outer ring diameter of 150 km to 160 km, which would make it the largest preserved impact crater on the Earth. Astronaut photography of this region can help identify subtle features associated with the outer ring of the crater.

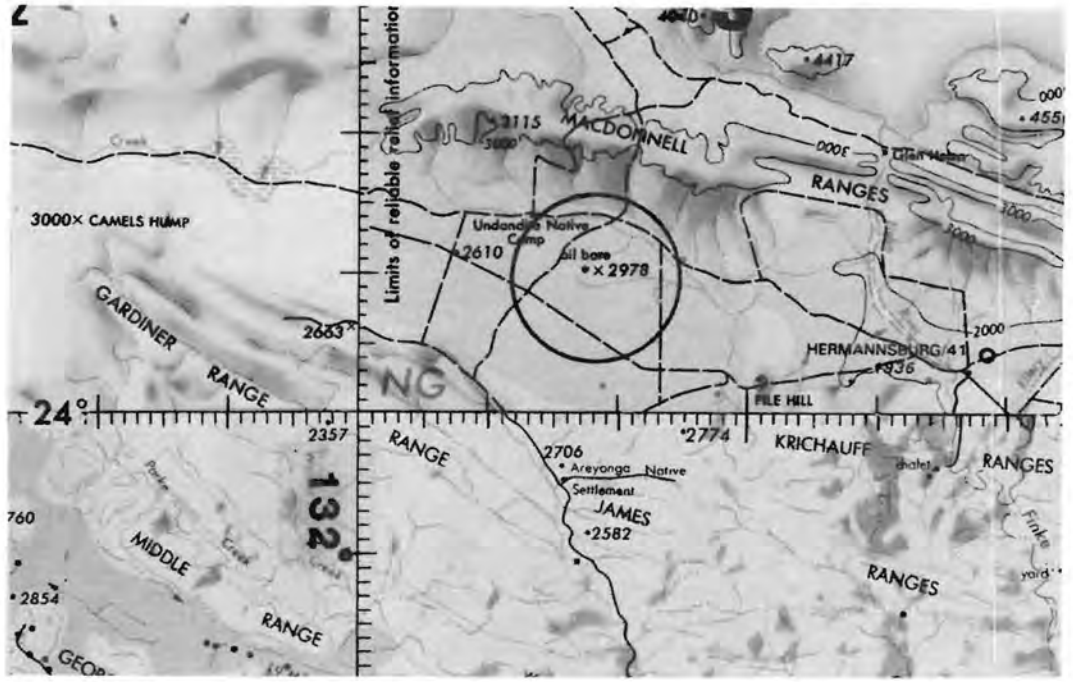

LAKE EVERARD
GAIRDNER
Lake Everard
Blue Dam
BOND HILL
Kumburgo
Hillaba
Yardea
Thurlga
Kalenda
AP
BP
136
19
16
1053
648
499
604
539
428
826
744
700
861
1103
1090
1056
1526
1194
1351
1144
1294
1300
1290
1395
1103
988
1438
1419
1196

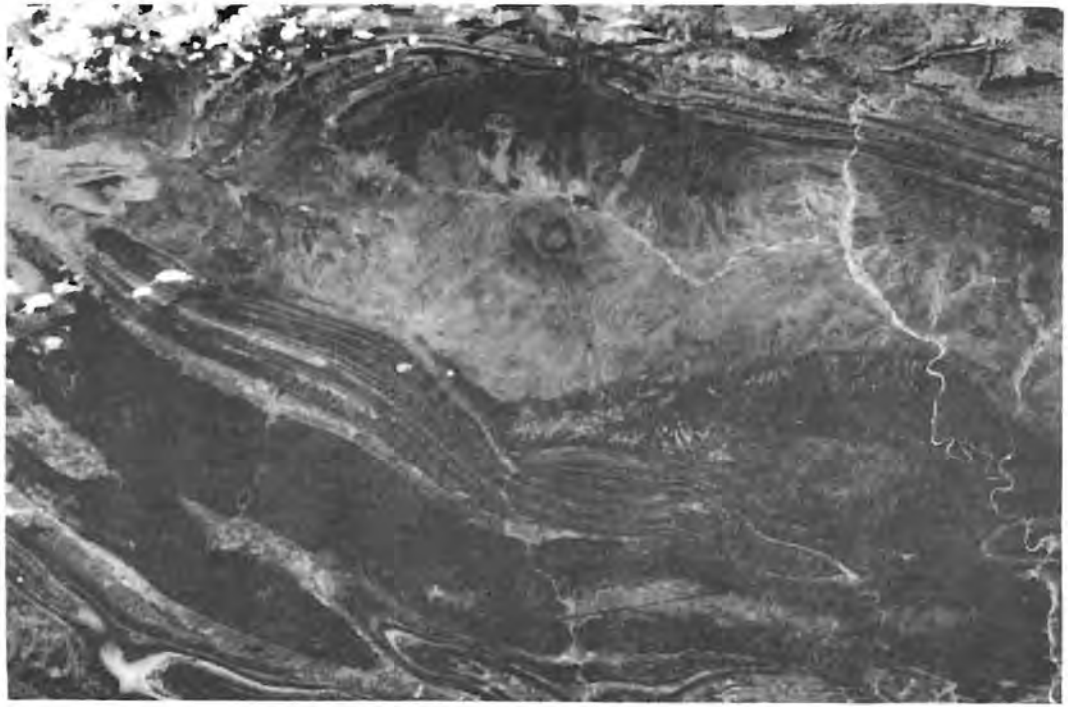
GOSSES BLUFF
AUSTRALIA

23°50'S; 132°19'E
Diameter: 22 km
Age: 142.4 ± 0.5 m.y.
Discernability: Good
Morphology: Isolated ring of hills ~ 5 km in diameter

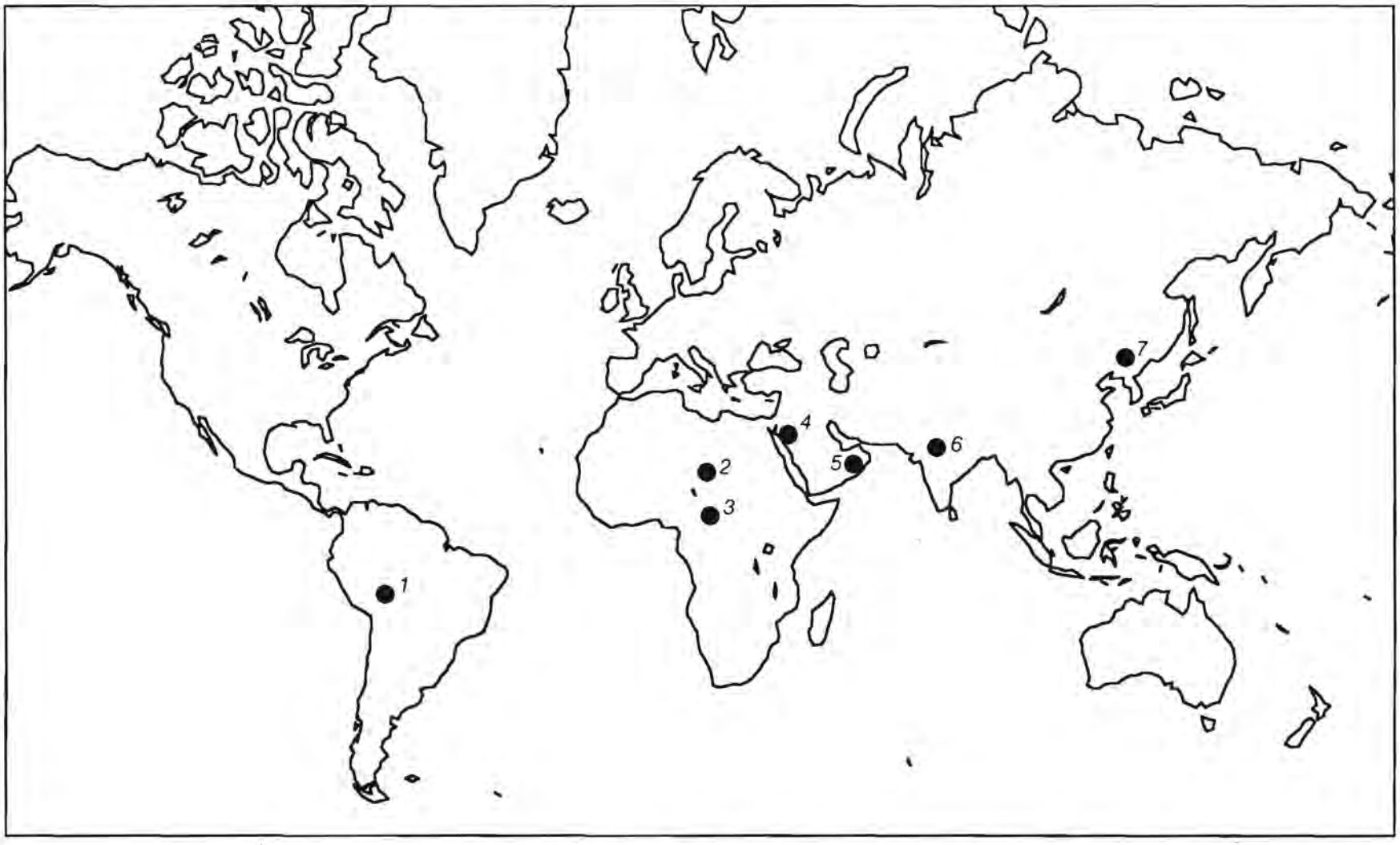
General Area: The structure lies in the arid, semi-desert of the flat Missionary Plain between the MacDonnell Ranges to the north and the James Ranges to the south in the Northern Territory, Australia. Folding of the MacDonnell and James Ranges is very apparent from space. Target rocks are sedimentary.

Specific Features: Highly eroded structure; in fact, the polygonal ring of hills which defines the feature on space images is a consequence of differential erosion. The 5 km wide ring of 250 m high bluffs is all that remains of an intensively uplifted central region of a complex impact feature. Small isolated hills lie outside the ring of bluffs, and control of drainage some 20 km from the center of the structure suggests the approximate location of the original crater rim.





Possible Impact Craters



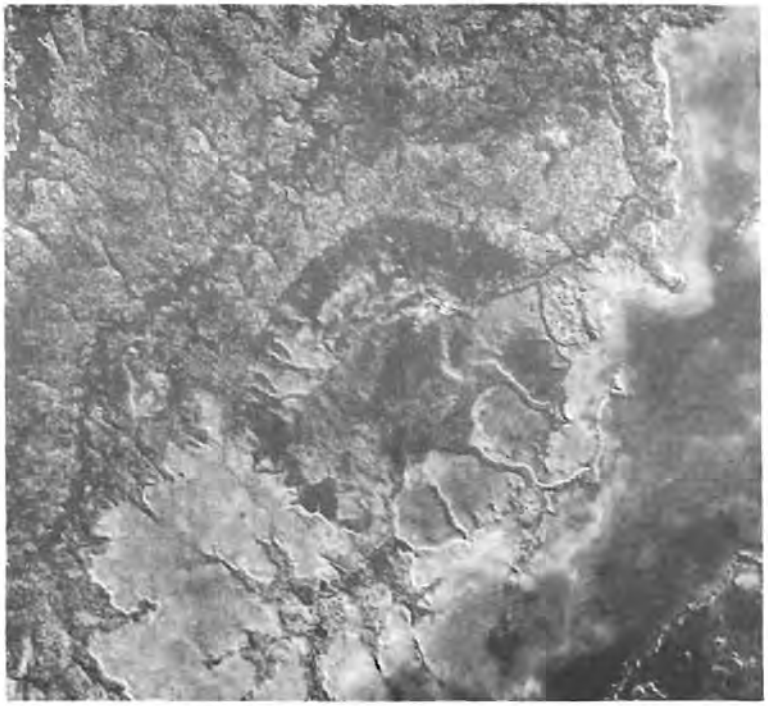
1—Itturalde, Bolivia 2—Aorounga, Chad 3—Lac Iro, Chad 4—Al Madafi, Saudi Arabia
5—Habhab, Oman 6—Ramgarh, India 7—Shanghewan, China

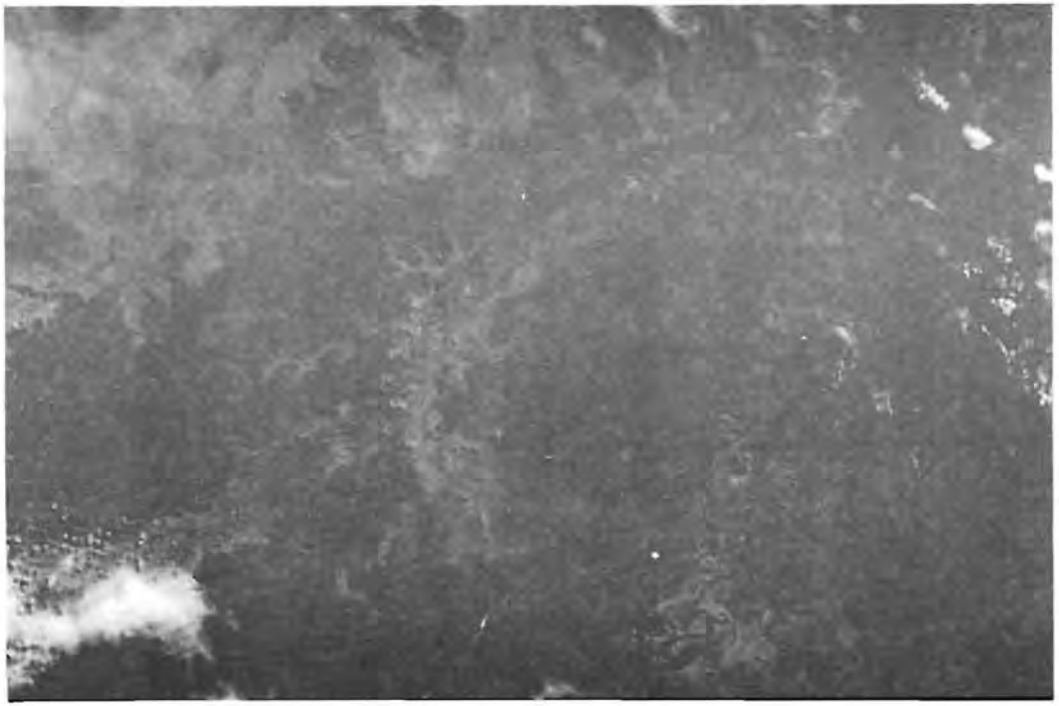
ITTURALDE
BOLIVIA

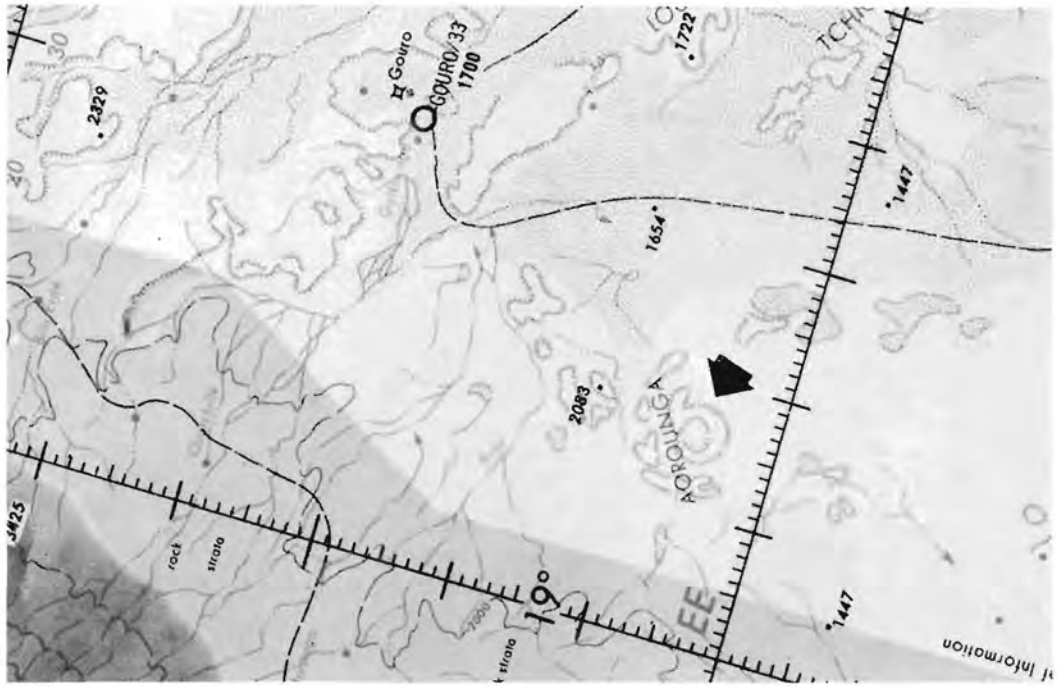
12°30'S; 67°30'W
Diameter: 8 km
Age: 11,000 - 32,000 yrs
Discernability: Very Poor
Morphology: Roughly circular area

General Area: Flat area, partly jungle and partly pampas in the western Amazon basin of Bolivia. The target rocks are sedimentary.

Specific Features: Structure is a roughly circular low area superimposed upon an old delta. There are some indications of a central peak. In this area, higher areas are jungle and lower areas are pampas. If this is an impact structure, it formed in wet unconsolidated sediments and may be a good analog to some types of Martian craters.





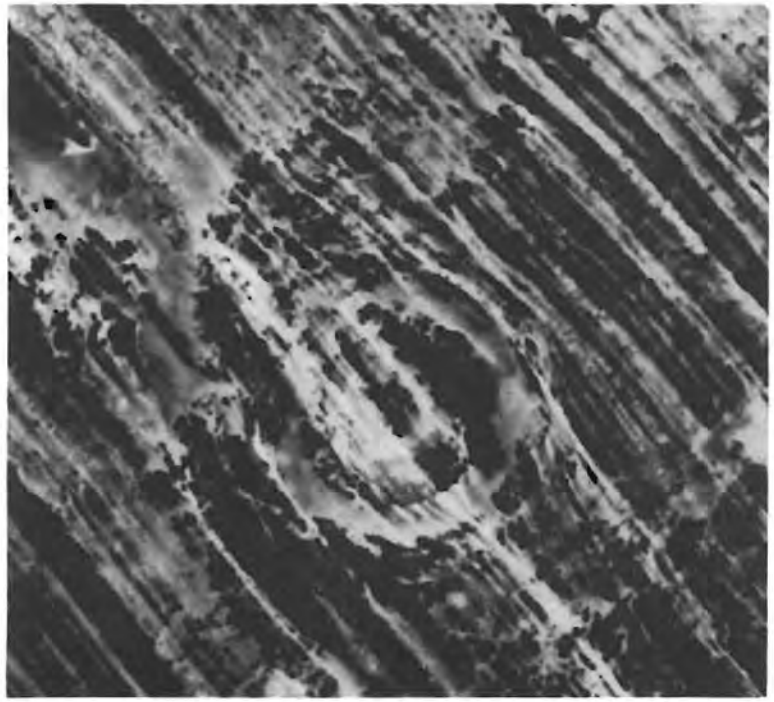


AOROUNGA
CHAD

19°6'N; 19°15'E
Diameter: 12 km
Age: unknown
Discernability: 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 morpholoogy is very much like a multi-ringed impact crater.

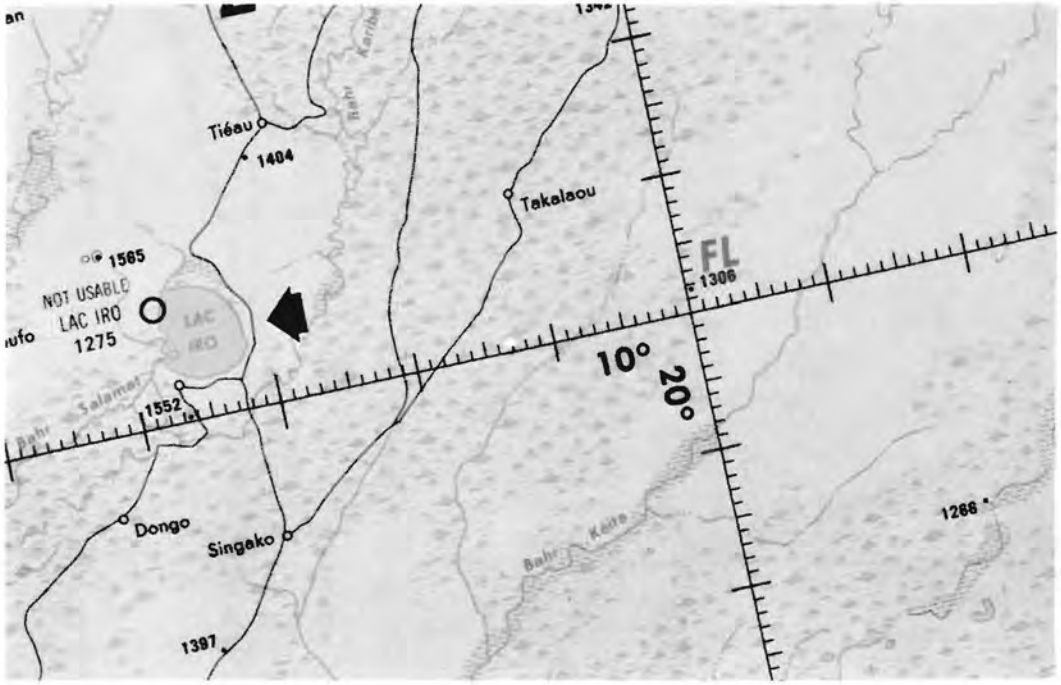


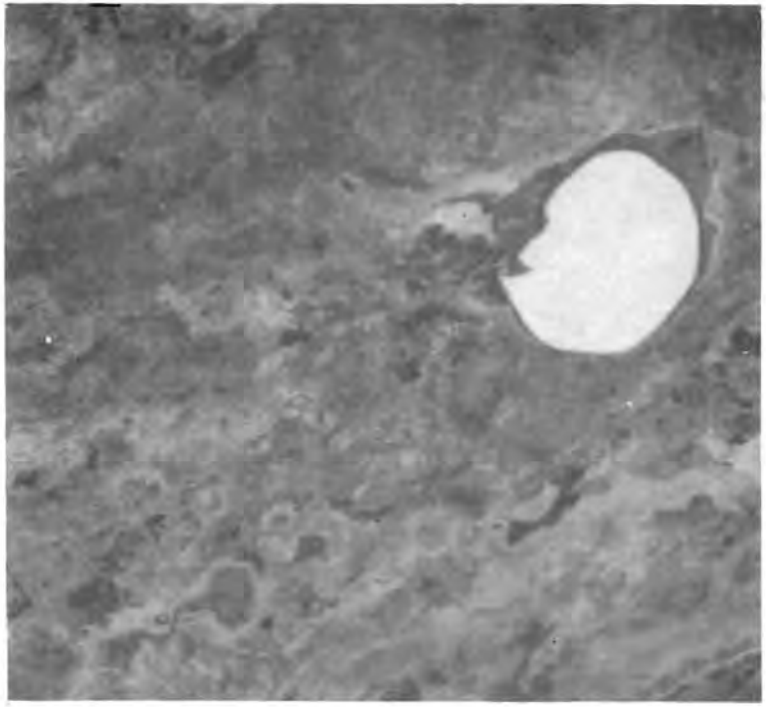
LAC IRO
CHAD

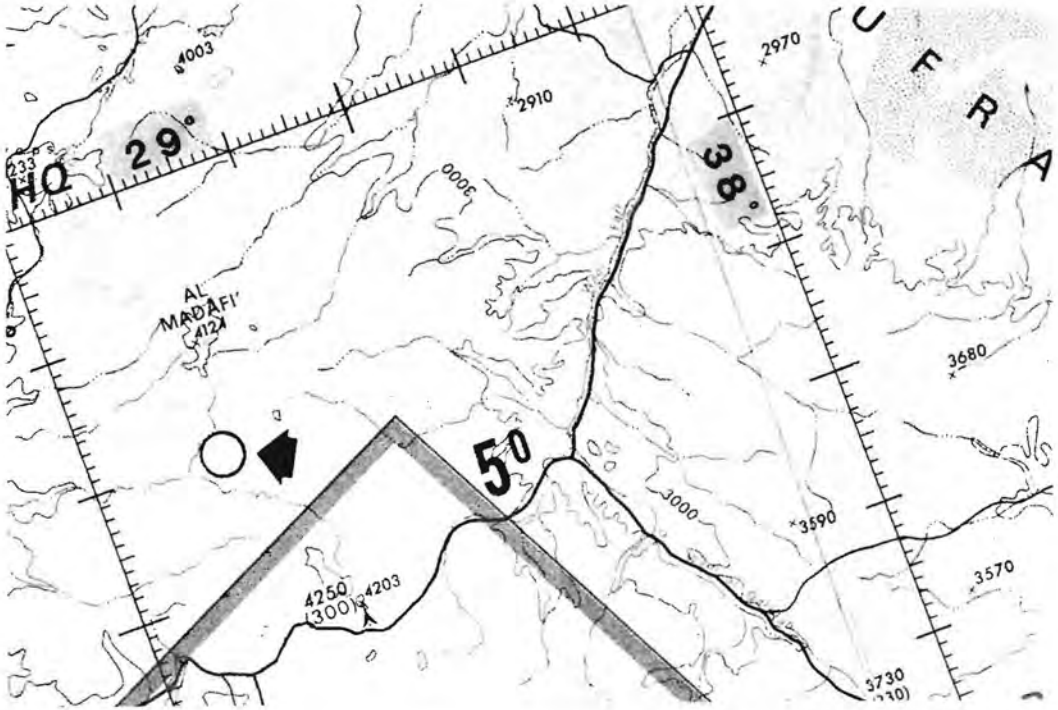
10°6'N; 19°25'E
Diameter: 12 km
Age: unknown
Discernability: Excellent
Morphology: Isolated, nearly circular lake

General Area: Lac Iro occurs in the savanna region of southern Chad. To the east are swamps, now being used to grow sugar cane. Target rocks are probably sedimentary.

Specific Features: As one of the few circular lakes in northern Africa, the origin of Lac Iro is uncertain. If it were caused by solution of limestone terrain, additional lakes would be expected. An impact could create an isolated circular lake (e.g. Lake Bosumtwi), but there is insufficient evidence to do more than speculate at this time.







AL MADAFI
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.

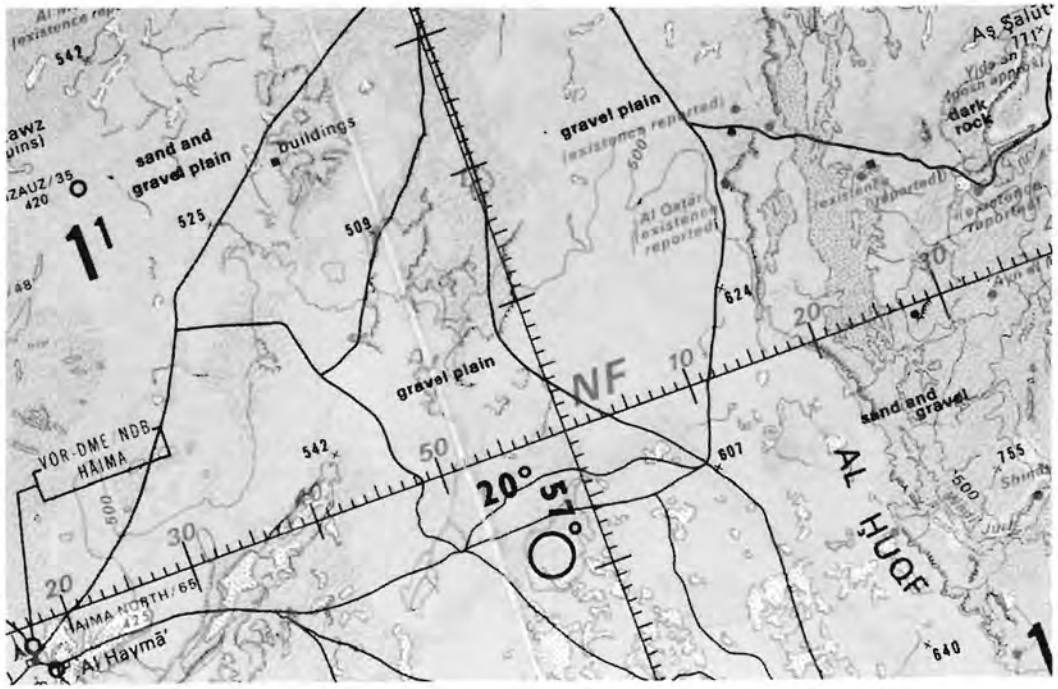
Specific Features: The suspected impact structure is defined by a remarkably circular ridge, about 6 km in diameter, open to the south. The ridge may be upturned sedimentary rocks, with terraces or slumps on the inner walls. There is no sign of a central peak. Al Madafi is morphologically unlike most 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 and nearly vertical bedding.

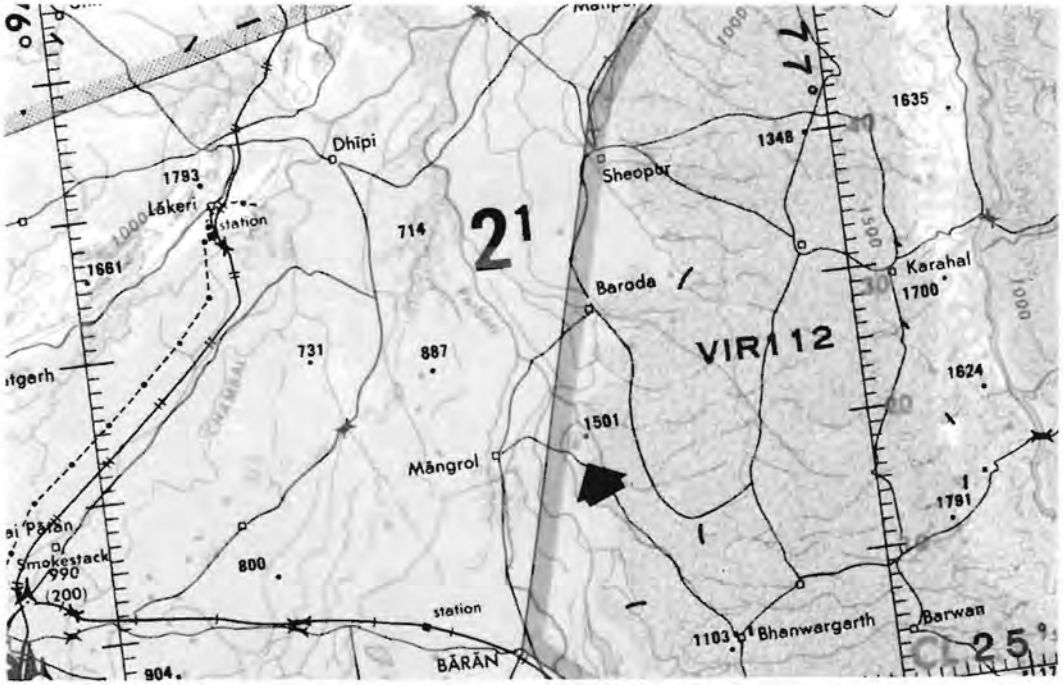
HABHAB
OMAN

19°52'N; 56°56'E
Diameter: ~6 km
Age: unknown
Discernability: Good
Morphology: Two concentric dark rings

General Area: The suspected crater lies in a non-descript desert west of a major dry river bed (wadi) and east of sand dune fields.

Specific Features: On Landsat images Habhab appears as two concentric dark rings, 6 and 2 km in diameter. There appears to be little topographic relief, and the dark hue probably represents vegetation. No volcanics are known for hundreds of kilometers from this site, and the concentric ring pattern is reminiscent of multi-ring impact craters. Both ground observations and better spacecraft images are needed to improve understanding of this enigmatic feature.



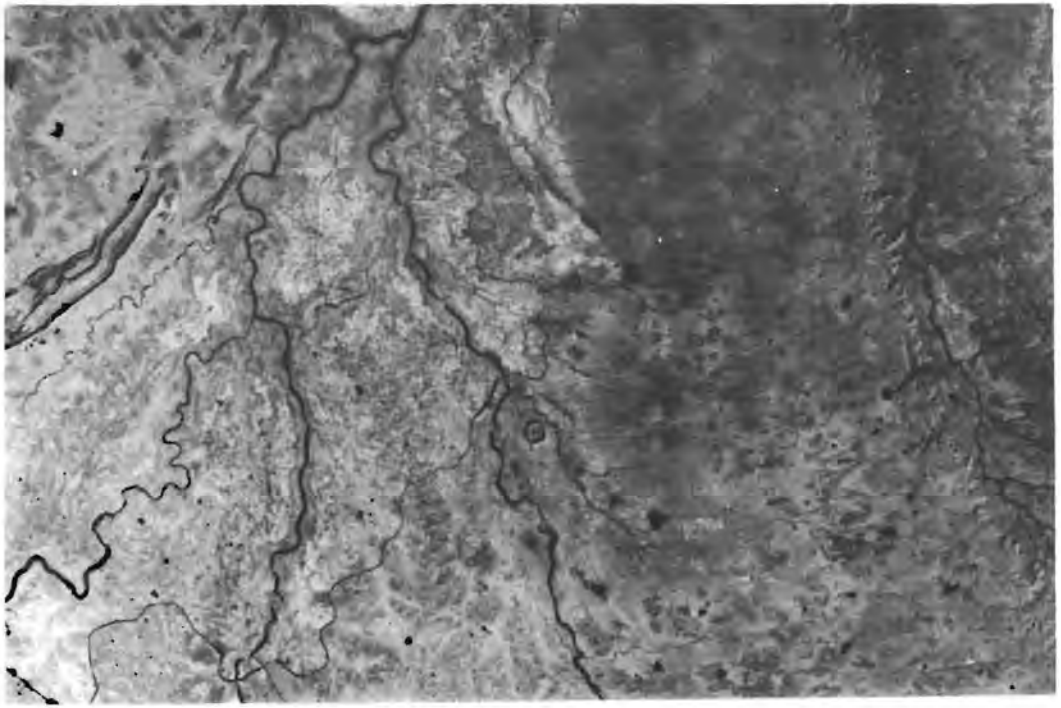


RAMGARH
INDIA

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.

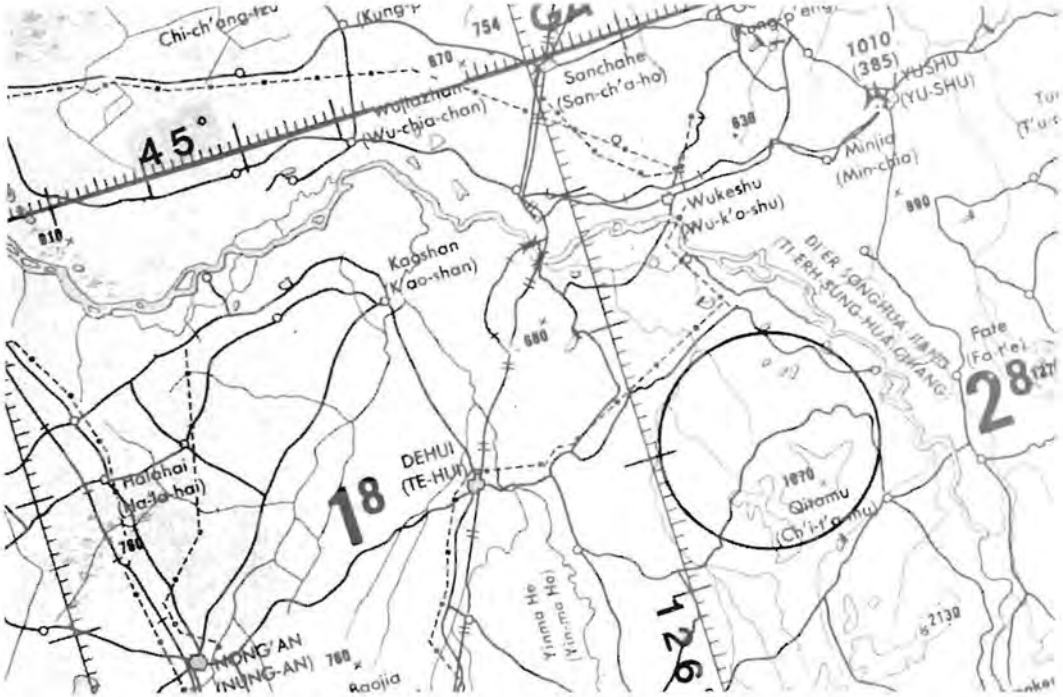


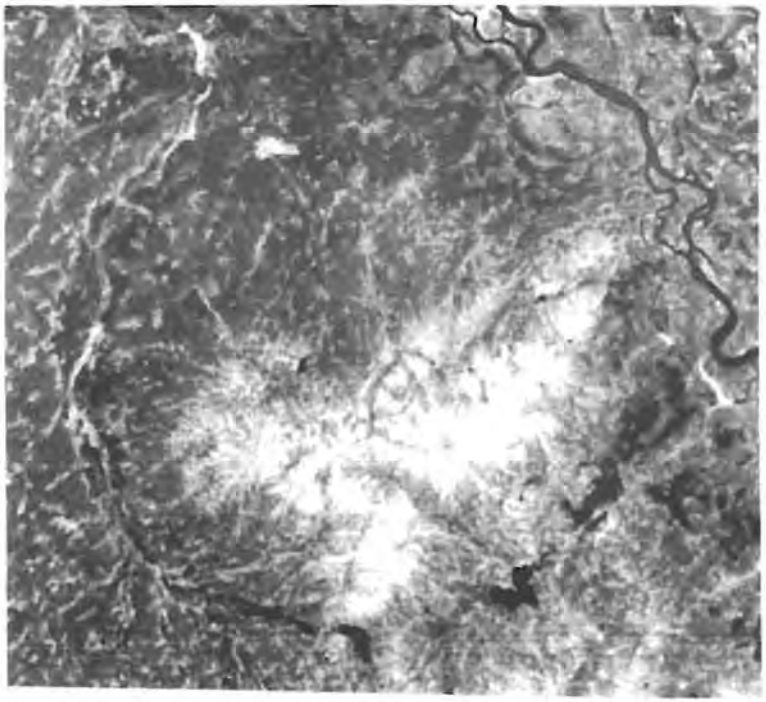
SHANGHEWAN
CHINA

44°29'N; 126°11'E
Diameter: 30 km
Age: unknown
Discernability: Poor
Morphology: Circular outline of lakes and rivers

General Area: 85 km NE of city of Ch'ang Ch'un in the forest-steppe region of the Northeast China Plain. Peaks within Shanghewan appear to be outliers of the Changbei Mt. range to the SE.

Specific Features: China must possess many impact craters, but none are known with certainty. One suspected crater, based upon recognition of a circular pattern of lakes and rivers in Landsat images, is Shanghewan. This feature is remarkably circular - and impact craters are among the most circular landforms that exist - but otherwise there is insufficent evidence to prove or refute the impact proposal.





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NOTES: Maps are from the Defense Mapping Agency's 1:1,000,000 Operational Navigational Chart series. Photographs come from a variety of sources; the form of the photo number provides a means of identifying which spacecraft acquired the image. Numbers beginning with "E" are Landsat MSS and TM frames; those marked with an * are used with the permission of the Earth Observations Satellite Co., Lanham, MD. "CCRS" means that the Landsat scene was recorded by the Canadian receiving station. "LFC" refers to Large Format Camera images. "SL..." are Skylab photographs; AS are pictures from the Apollo mission; AST are pictures from the Apollo-Soyuz mission; and frame numbers starting with "S" or a two digit number followed by a letter (e.g. 61C) are Shuttle handheld pictures.

IMPACT CRATER INDEX

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