Manitoba Crater Revealed

by Barry Bannatyne and Hugh McCabe

Geological detective work identified it. The crater explains anomalous features noted as early as 1859

Barry Bannatyne and Dr. Hugh McCabe have worked for many years with the Geology Section of the Government of Manitoba as industrial minerals geologist and stratigrapher, respectively. Their overlapping interests were focused on the recognition of the Lake St. Martin crater in the late 1960s. They cooperate informally with EMR's Earth Physics Branch researchers in continuing study of the crater.

The earth has often been hit by meteorites, but its highly mobile surface has erased the scars through erosion and sedimentation, volcanism, and even plate tectonics. However, cratering events probably had far-reaching effects on the earth's early evolution, and later possibly even affected the environment enough to kill off the dinosaurs (see GEOS, Summer 1981).

Understanding the processes involved in impact cratering events is hampered by the lack of well preserved craters to study. Modelling crater formation is difficult because these catastrophic cosmic collisions are over in minutes, with many physical and chemical processes happening simultaneously and interacting. As well, the larger the impacting meteorite, the more complex the geological structure it creates. It takes years of investigation to unravel the processes involved in its creation.

Canada is a natural crater laboratory because our large area of ancient stable Shield rocks has preserved evidence of numerous craters. At least 23 structures have been recognized here, and we have, in fact, more than a third of the world's known impact craters over 1 km in diameter. Nevertheless, earth scientists were surprised by the identification, in 1968, of a well preserved major crater in

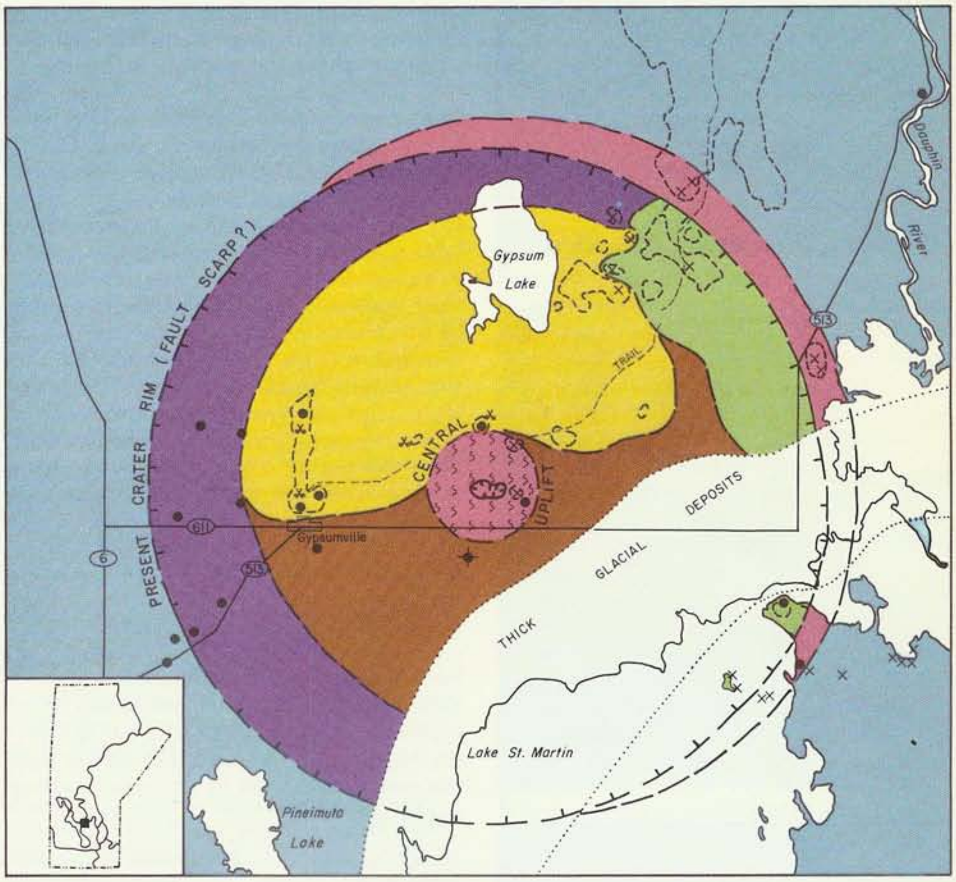


Figure 1 Lake St. Martin crater

Cratère du lac Saint-Martin

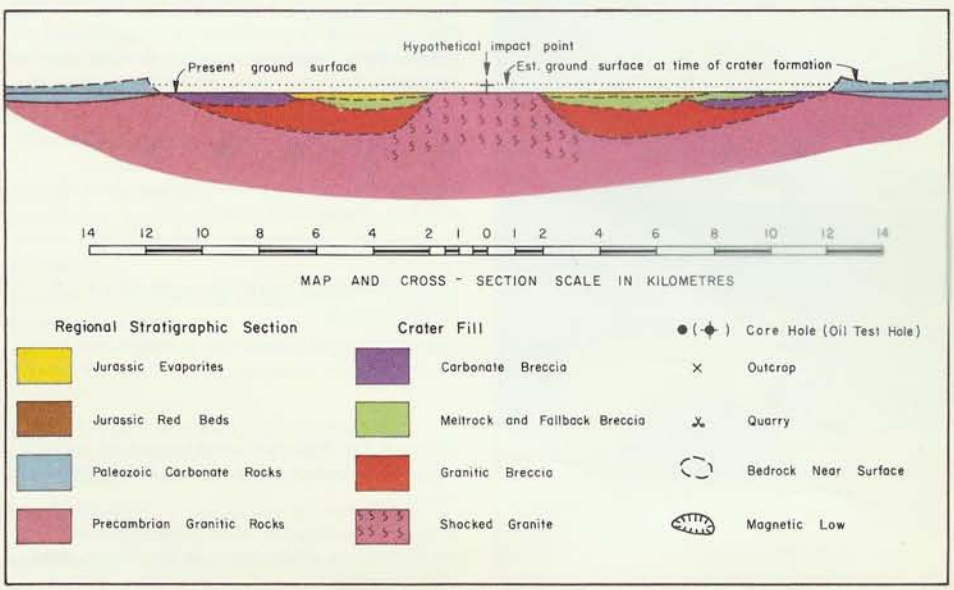


Figure 2 Postulated true-scale cross-section of Lake St. Martin crater

Coupe transversale présumée, à l'échelle, du cratère du lac Saint-Martin

Figure 3 Core samples of meltrock containing inclusions of granite (bar scale: 1 cm)
Carottes de roches fondues contenant des inclusions de granite (échelle: 1 cm)

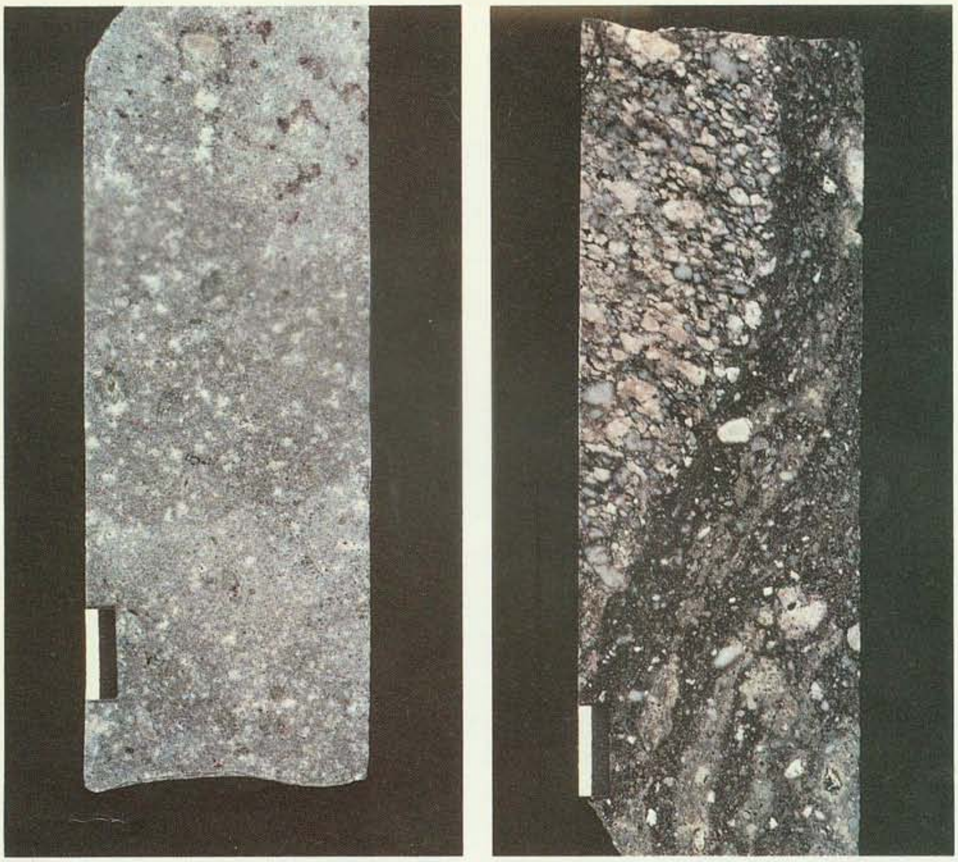


Figure 4 Shock-metamorphosed granitic gneiss (a) and pegmatite (b) of the central uplift (bar scale: 1 cm)
Gneiss granitique a) et pegmatite b) de la saillie centrale métamorphisés par le choc (échelle: 1 cm)

the Gypsumville–Lake St. Martin area 230 km northwest of Winnipeg. With a 24 km diameter, it is filled with a thick sequence of unusual rock types, including a central uplift of basement rocks (Fig. 1). It is surrounded by a ring of fractured Paleozoic limestones 10 km wide and Precambrian granites that have been tilted up as much as 220 m. Because of the overlying cover of Jurassic sediments, 190 million years old (Ma), the crater fill (200 to 250 Ma) suffered little erosion (Fig. 2), making the Lake St. Martin structure probably one of Canada's best preserved large crater structures, and one of the two or three best preserved large craters in the world.

Years of geological detective work led to identification of the Lake St. Martin structure. Aerial photographs and aeromagnetic maps do not reveal any obvious circular structures — commonly the first sign of an impact event. In fact, the significance of some clues, such as an intense magnetic low that occurs east of Gypsumville, was not clear until after the structure was identified.

The Interlake region of Manitoba, with Lake Winnipeg to the east and lakes Manitoba and Winnipegosis to the west, is underlain by a thin sequence of Paleozoic sedimentary rocks, mainly carbonates, that dip gently southwestward toward Williston Basin and overlie ancient Precambrian (2600 Ma) granitic rocks. The crater explains a number of anomalous features noted during early geological work around Lake St. Martin and Gypsumville. S.J. Dawson reported gneissic islands in the Lake St. Martin area during his geological travels in 1859, and Joseph B. Tyrrell of the Geological Survey of Canada mapped a granite ridge north of Lake St. Martin in 1887. Another granite ridge occurs northeast of Gypsum Lake. All these Precambrian rocks are about 220 m above their expected level, and at first were interpreted as hills on the Precambrian erosion surface that were almost buried by younger sediments. Now they are considered part of the crater's rim.

GSC's Tyrrell also discovered gypsum ridges rising approximately 15 m above the surrounding wetlands and plains. This gypsum has been quarried since 1901. It was deposited during Jurassic time within the isolated low area formed by the crater. Large folds and overthrusts in the gypsum probably were formed by ice-drag at the base of Pleistocene ice sheets and are not related to the cratering event.

Another anomalous feature is the occurrence of purplish lavalike rock which, near the top, contains large vesicles or cavities formed by trapped gas bubbles. The outcrop east of Gypsum Lake, for instance, has vesicles filled with jasper. These rocks were at first classified as vesicular andesite. Reported traces of native copper suggested that the rocks were possibly related to the Lake Superior copper-bearing volcanics of late Precambrian age. When their age was determined to be between 200 and 250 Ma, that theory had to be jettisoned. They are, in fact, meltrocks or impactites formed during the meteorite impact (Fig. 3).

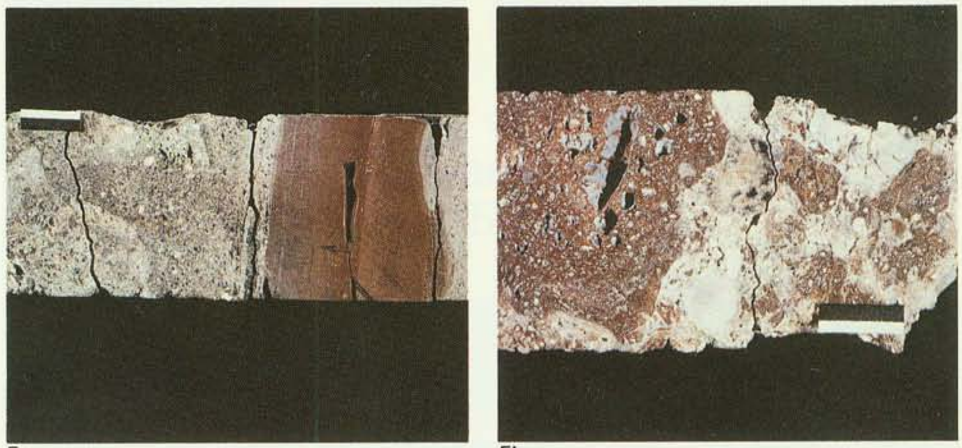
Outcrops of granite gneiss south of Gypsum Lake have a distorted texture and contain abundant bright red hematite (Fig. 4). In places, veinlets of red glossy material called pseudotachylite cut through the gneiss. These outcrops form part of a large central uplift within the crater (Fig. 2). Such central peaks are typical of terrestrial impact craters with a diameter of more than 5 km, and are also well documented in photographs of many lunar and planetary craters.

More evidence pointing to a crater was uncovered during an oil exploration program in 1966 near the flanks of Tyrrell's postulated "Precambrian hills". One drill hole, just 7 km east of Gypsumville, intersected Jurassic sedimentary strata composed largely of red sandstone, siltstone and shale. These red beds are underlain by 265 m of fallback breccia and finely brecciated granitic material, which enclose fragments of granite and the purplish lavalike rock (Figs. 5, 6). Fractured and faulted granite, possibly from a megabreccia or from Precambrian basement, was found at the bottom of the hole, 100 m below its normal depth. This find proved conclusively that the granite outcrops are not simply erosional features. Subsequent microscopic examination of thin sections of the breccia provided the first solid evidence that the Lake St. Martin feature is a meteorite impact structure. Studies launched in 1968 later confirmed this.

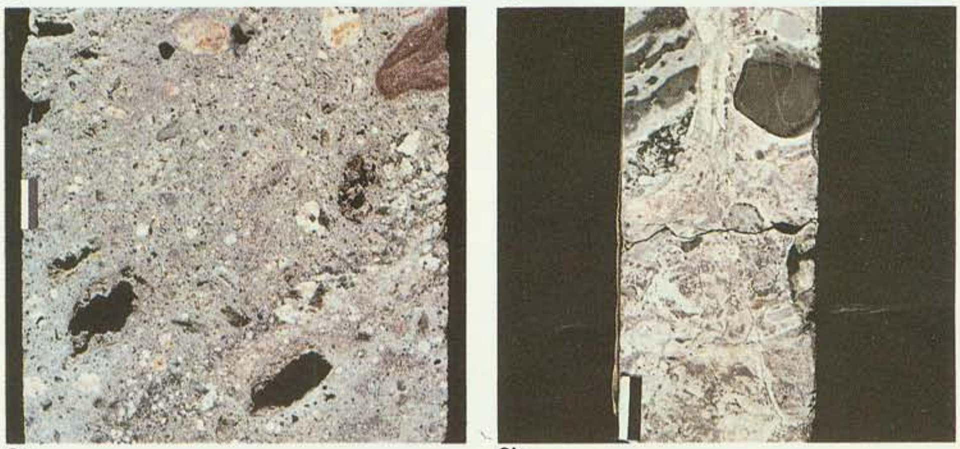
Samples and thin sections from the initial holes of an extensive diamond-drilling program were submitted to Michael Dence of EMR's Earth Physics Branch, a specialist in the study of terrestrial impact structures. He documented the widespread occurrence of shock metamorphic features in breccia, meltrock and the central uplift. These features are:

- extremely fine grained to glassy veinlets called pseudotachylite
- kink-banded biotite, a form of mica showing deformation bands
- partially decomposed mafic minerals (biotite and hornblende)
- disordered quartz and feldspar showing planar deformation features resulting from disruption of the crystal lattice (Fig. 7)

Figure 5 Jurassic red shale overlying fallback breccia (a), which contains blobs (b) of vesicular meltrock (bar scale: 1 cm)
Shiste argileux rouge du Jurassique recouvrant une brèche retombée a) qui contient des taches b) de roches fondues vésiculeuses (échelle: 1 cm)



5a **5b**



6a **6b**

Figure 6 Complexly brecciated granitic (a) and carbonate (b) rocks (bar scale: 1 cm)
Roches granitiques a) et carbonatées b) bréchifiées complexes (échelle: 1 cm)

All these features result from shock waves of 50 to 500 kilobars or more passing through the rock at the time of impact.

Microscopic features that are the result of melting include reaction rims of clear quartz and dark pyroxene around granitic inclusions in the meltrock (Fig. 8), and ameboid, rimmed, glassy to partly devitrified rock fragments in fallback breccias (Fig. 9), some of which show development of frostlike iron oxide crystallites (Fig. 10).

Most researchers now believe that naturally occurring shock metamorphic features such as those described above are the unique fingerprint of meteorite impact structures. However, some scientists, especially those skeptical of the impact theory, await identification of actual meteorite material before accepting this origin.

Unravelling the Impact

A cosmic collision releases thousands of megatons of kinetic energy, which form the major crater structures within minutes. The meteorite that struck the Lake St. Martin area was at least 1 km in diameter and was probably an Apollo asteroid. These asteroids orbit close to Earth and occasionally collide with it. The following scenario is based on evidence from the Lake St. Martin area as well as various cratering models (see GEOS, Fall 1982).

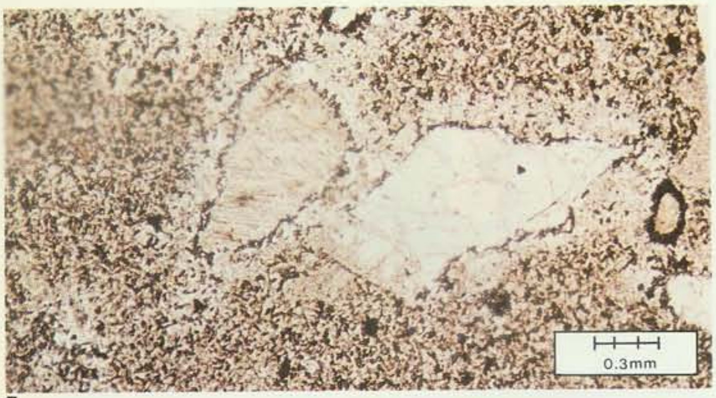
The initial impact generated extreme pressures and temperatures, which disintegrated and vaporized the meteorite. Some fragments of the original body or particles condensed from rapidly cooled vapour may have survived, but as yet no particles have been found. The target rock also was partly melted or vaporized as the meteorite penetrated 400 to 500 m of sedimentary cover and several hundred metres into Precambrian basement rock. The resulting meltrock is similar in chemical composition to the Precambrian target rock. Initial crater excavation was accompanied by a radial outward movement of a mixture of broken rock, meltrock and large volumes of gas. The gas comprised vaporized

Figure 7 Thin section of meltrock with feldspar (clear) and quartz fragments that show several sets of planar features (bar scale in mm)

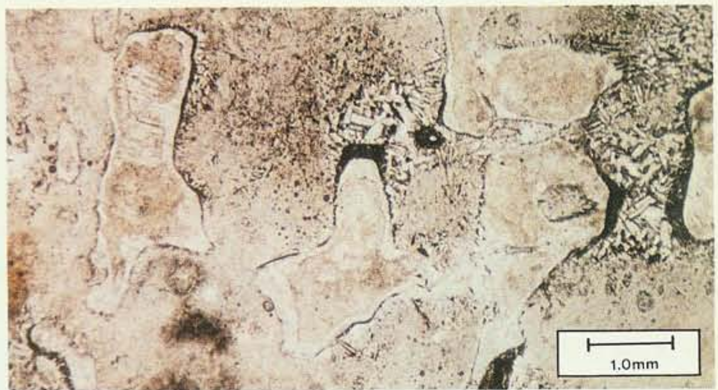
Mince plaque de roche fondue contenant des fragments de feldspath (clair) et de quartz qui présentent plusieurs séries d'éléments planaires (échelle en millimètres)

Figure 8 Shock-metamorphosed, partially melted inclusions of granite in meltrock (bar scale in mm)

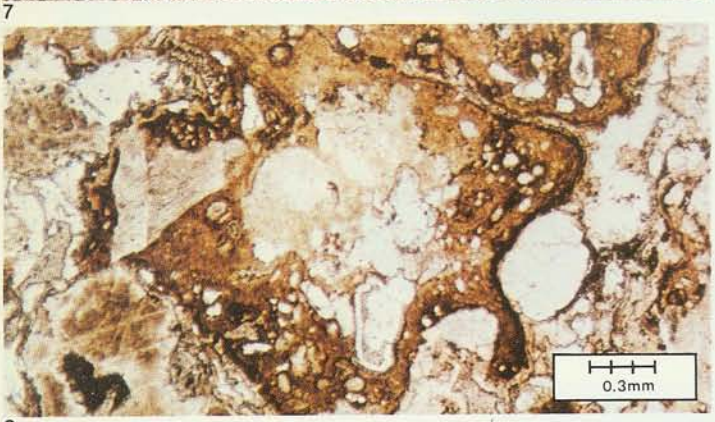
Inclusions de granit partiellement fondues et métamorphisées sous le choc dans la roche fondue (échelle en millimètres)



7



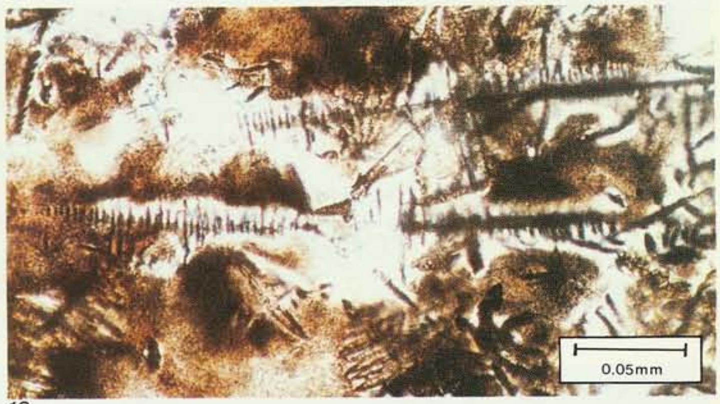
8



9

Figure 9 Fragments of melted rock in fallback breccia; note planar features (bar scale in mm)

Fragments de roche fondue dans une brèche retombée; à noter les éléments planaires (échelle en millimètres)



10

Figure 10 Glassy to partly devitrified fragments with skeletal crystals (bar scale in mm)

Fragments allant de vitreux à partiellement dévitrifiés, à cristaux squelettiques (échelle en millimètres)

water and carbon dioxide derived from carbonate rock. Although some of this material was ejected beyond the crater and has since been eroded, part of it remained, falling back into the crater and mixing with breccias and meltrock both during and after the excavation stage.

The initial crater was unstable because of its large size, and because of rebound following the initial stage of shock compression. Large blocks of massive to intensively brecciated carbonate rock (Fig. 6) slumped from the crater rim, particularly on the west side of the crater, where blocks have been identified as Ordovician to Upper Devonian. Rebound, together with the effects of excavation unloading and weakness of the disrupted target rocks, formed a central uplift, approximately 4 km in diameter, of granitic rocks that show fracturing and various degrees of shock metamorphism. In addition, much granitic debris slumped from both the crater rim and the central uplift.

Most of these processes occurred simultaneously with crater excavation and movement of meltrock within the crater. The end result was a complex crater structure 24 km in diameter. More work should show how these Lake St. Martin features relate to proposed models of the cratering process. Indeed, some features, such as shatter cones, meteorite contamination, and high-pressure forms of silica known as coesite and stishovite, have yet to be found here. Additional drilling is planned to determine rock type distribution within the crater, particularly the extent of the meltrock.

It is worth nothing that another small but well preserved crater occurs near High Rock Lake, less then 50 km southeast of the Lake St. Martin crater. It is only 2.5 km in diameter, but geological exploration has shown that interesting contrasts and similarities exist between the two craters. The High Rock Lake crater is probably of Silurian age (400 Ma), and hence is not directly related to the Lake St. Martin crater.

Le cratère du lac Saint-Martin, à Gypsumville (Manitoba), identifié en 1968, est l'un des cratères d'impact complexe les mieux préservés au monde. Il mesure 24 km de diamètre et est rempli de roches de type inhabituel. L'étude de ce cratère aidera à élucider le processus de formation d'une structure complexe. Il est difficile d'établir un modèle de la formation des cratères, car ces bouleversements ne durent que quelques minutes au cours desquelles de nombreuses actions et interactions se produisent.

Cet article est aussi disponible en français.