SAVONOSKI CRATER, ALASKA: A POSSIBLE METEORITE IMPACT STRUCTURE

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Savonoski Crater, a small basin about 1700 feet in diameter, is located on a ridge of gently-dipping Jurassic sandstone in Katmai National Monument, southwestern Alaska. Reconnaisance geological, geophysical, and petrographic studies suggest that it was formed either by volcanic processes or meteorite impact prior to the end of the latest glaciation in the region. Surface ejecta, if originally present, apparently have been removed by glaciation. No distinctive shock-metamorphic effects were observed in the few rock specimens collected. Final determination of the crater's origin will require more extensive field studies or drilling in the center of the crater.

INTRODUCTION

Savonoski Crater in the provisional name given to a small circular structure located on a ridge of Jurassic sandstone in Katmai National Monument, southwestern Alaska at lat 58° 31′ 48″ N.; long 154° 55′ 31″ W. The structure, which is partly filled by a circular lake, appears on topographic maps issued since 1951 and was first recognized as distinctive during brief aerial observation by one of us (EHM) in 1953.

The appearance of Savonoski Crater from the air, Fig. 1, is strongly suggestive of meteorite impact origin. Particularly noteworthy are its occurrence on a bedrock ridge above two river valleys, Fig. 2, its circularity, the presence of a poorly defined rim, and the large apparent depth.

A reconnaisance geological and geophysical study of the structure in 1964 (Muller and Ward, 1966) included topographic mapping, magnetic and

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Fig. 1. Aerial view of Savonoski Crater from the east, showing its regular shape and generally uniform rim. The rim is incised by two inlet streams on the W and SW sides of the crater (upper left) and by the outlet stream for the crater lake (lower left).

Fig. 2. Low oblique aerial view of Savonoski Crater from the north, showing the location of the structure on sandstone beds whose uniformly gentle dip to the SW controls the topography in the upper left part of the picture.

gravity surveys, and limited sample collection. The field data afforded inadequate basis for conclusion as to whether the crater is of impact or volcanic origin. More recently, the samples were examined petrographically for shock-metamorphic effects, but none was found (French and Muller, 1969). In this paper we summarize available data on the Savonoski Crater in the hope that further field studies, combined with the great increase in information about terrestrial impact craters obtained in the last few years, will allow future workers to establish definitely the origin of the structure.

STRUCTURE AND GEOLOGY OF THE CRATER

Savonsoki Crater is located about three miles south of the confluence of the Rainbow and Savonoski Rivers in Katmai National Monument, southwestern Alaska. The surface of its crater lake is at approximately 1200 feet above sea level, and the enclosing walls rise as much as 200 feet above the lake surface at its west end.

Topographic mapping (Muller and Ward, 1966), Fig. 3, shows the crater to be slightly elliptical. The E-W rim dimension is 1770 feet and the N-S rim dimension is 1575 feet, corresponding to an eccentricity of 1.13. Maximum relief, from the highest point on the western rim to the bottom of the lake, is 350 feet. The ratio of logarithms of apparent depth to apparent diameter of this crater agrees very well with similar ratios from known meteorite craters (Baldwin, 1963). The rim of the crater is well defined by slopes that increase from less than 10° to more than 20° toward the lake. The crater rim is generally regular, but it is incised by three streams, two of which are inlets draining an area of the adjacent ridge. The third stream is the crater lake outlet, incised some 50 to 60 feet across the east rim. Neither superimposed ejecta nor conspicuous structural deformation of the sandstone beds can be clearly associated with the origin of the structure.

The crater lake, when studied in 1964, was 1350 feet (E-W) by 1060 feet (N-S), slightly more eccentric than the crater rim. The maximum depth of the lake, 137 feet, was recorded well to the northeast of the crater center. The bottom of the lake is generally smooth and flat, Fig. 3, and suggests a predominantly depositional surface. A marked irregularity is observed on the north side, where a narrow shelf 3 to 10 feet below the surface extends for a considerable distance along the shore.

Savonoski Crater is thus markedly asymmetric in topography, with both the maximum lake depth and the steepest inner slopes being found on the eastern side. Part of this asymmetry may have resulted from glacial scour and plucking as ice moved in a generally east-to-west direction through the crater.

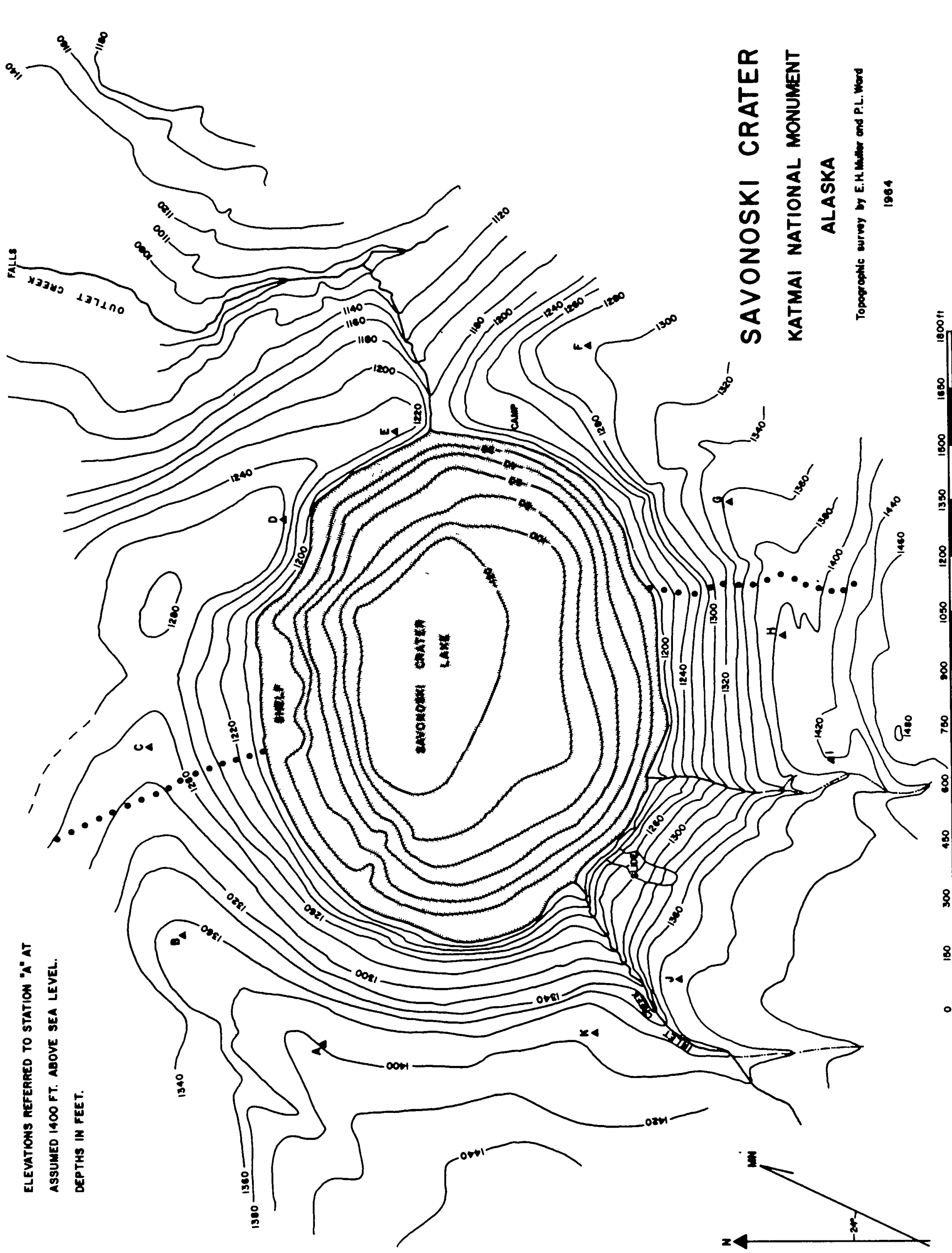

Fig. 3. Topographic map of Savonoski Crater (adapted from Muller and Ward, 1966). The asymmetry of the lake basin and the shallow submerged shelf along the north shore of the lake are well expressed. The line of points trending roughly N-S shows stations for the geophysical profiles across the crater shown in Fig. 4.

Although the crater is in Katmai National Monument, no volcanic landforms occur in the immediate vicinity. The crater is about 16 miles from the imposing northeast-striking alignment of active volcanoes that extends from Martin and Mageik in the southwest through Trident, Katmai, Kukak, and Kaguyak to Douglas in the northeast (Muller *et al.*, 1954; Ward and Matumoto, 1967) and only 13 miles north-northeast of Mt. Griggs (formerly Knife Peak), which has emitted ash and fume historically. On Mt. Ikagluik, only 13 miles southwest of Savonoski Crater in a direction parallel to the main strike of volcanic features in the Katmai area, volcanics on a sedimentary platform are exposed that show no evidence of postglacial activity.

Underlying the crater is the Jurassic Naknek Formation consisting of more than 2000 feet of fine- to medium-grained impure sandstones with interspersed conglomeratic layers (Keller and Reiser, 1959; Muller and Ward, 1966). No soluble rocks (limestones or evaporites) have been observed in the section. The strata dip gently southeast, Fig. 2, but this regional dip is locally reversed on the east side of the crater in a zone that also displays significant fracturing.

The sedimentary rocks around the crater are cut by dikes of fine-grained igneous rocks identified as "andesite porphyry" and "diorite" (Muller and Ward, 1966). Several of these dikes are exposed in the valleys of the inlet and outlet creeks, and others were detected in the course of a magnetometer survey discussed below. The pattern of lineations which shows up on the air photographs appears to be related to regional tectonism rather than to a local source centered on the crater.

No lava flows were observed, nor are any extrusive volcanic rocks clearly identified with the crater. Small exposures of a possible volcanic breccia were observed in the valley of the outlet creek and are described below. The crater is blanketed with ash deposits from distant eruptions, one of which is the distinctive deposit of the 1912 Katmai eruption centered about 18 miles to the south.

Savonski Crater has been glaciated at least once since its formation. Westerly-trending glacial striae were observed on fresh sandstone exposed in a landslide scar some 60 feet above the lake in the southwest part of the crater. Glacial scour by westward-flowing ice may account for the topographic asymmetry of the crater as well as for the apparent absence of associated ejecta around the crater rim. To the extent that glacial erosion decreased the apparent depth of the crater by reduction of the rim and filling of the bottom of the lake, the apparent conformity of depth-to-diameter ratios to Baldwin's curve derived from known impact craters may be misleading.

The reconnaisance gravity survey involved 136 stations distributed around the crater. Problems were encountered in tying the relative readings of the gravimeter to the regional gravity net, and the absolute value of the elevations shown in Fig. 3 may be low by as much as 100 feet. The relative readings, however, are unaffected by these uncertainties. The relative Bouguer anomaly without terrain corrections is shown in Fig. 4 for the longest profile traversing the crater. Elevation corrections are based on a density of 2.55 gm/cm^3, the average of several measurements of wet Naknek sandstones. Bouguer anomalies show no clear decrease over the crater similar to the anomalies of three or more milligals observed over many meteorite impact craters (Innes, 1964). Instead, a small positive anomaly is suggested over the crater and the region to the south. Addition of terrain corretions would reduce the apparent one milligal decrease in gravity at the south edge of the lake. The other gravity data show no significant radial changes in the gravity field around the crater.

A proton-procession magnetometer was used to measure the total magnetic field at several thousand points around the crater. One profile is shown in Fig. 4. A positive 500 gamma anomaly about 40 feet wide and several hundred feet long was found on the west rim of the crater, striking nearly north-south. Excavation uncovered a dike at a depth of a few feet. Two "bullseye" anomalies, one a 50,000 gamma minimum and the other a 54,000 gamma maximum, were found at the west shore of the lake, spaced about 50 feet apart. Excavation again led to discovery of dike rock within a few feet of the surface.

PETROGRAPHY OF THE CRATER ROCKS

A few specimens collected during the 1964 field study of Savonoski Crater were examined petrographically in the hope of detecting definite shock-metamorphic effects that would establish the origin of the crater by metorite impact. Available specimens include the fine-grained glaciated sandstone from an outcrop in the southwest part of the crater and volcanic(?) breccia from the outlet creek valley on the east.

In thin section, Fig. 5, the sandstone is a fine-grained, poorly-sorted graywacke containing grains less than 0.2 mm long and displaying irregular bands and lenses of fine material in the coarser matrix. The detrital grains are dominantly quartz, significant K-feldspar and plagioclase, and minor brown and green mica and/or chlorite. The matrix is an indeterminate mixture of clay-sized material and iron oxide cement. No megascopic crushing or granulation of the specimen is apparent, and no shock effects are observed in the component grains. The quartz grains are clear, commonly contain random fluid inclusions, and display straight to mildly undulose extinction. No kink bands are observed in the mica or chlorite.

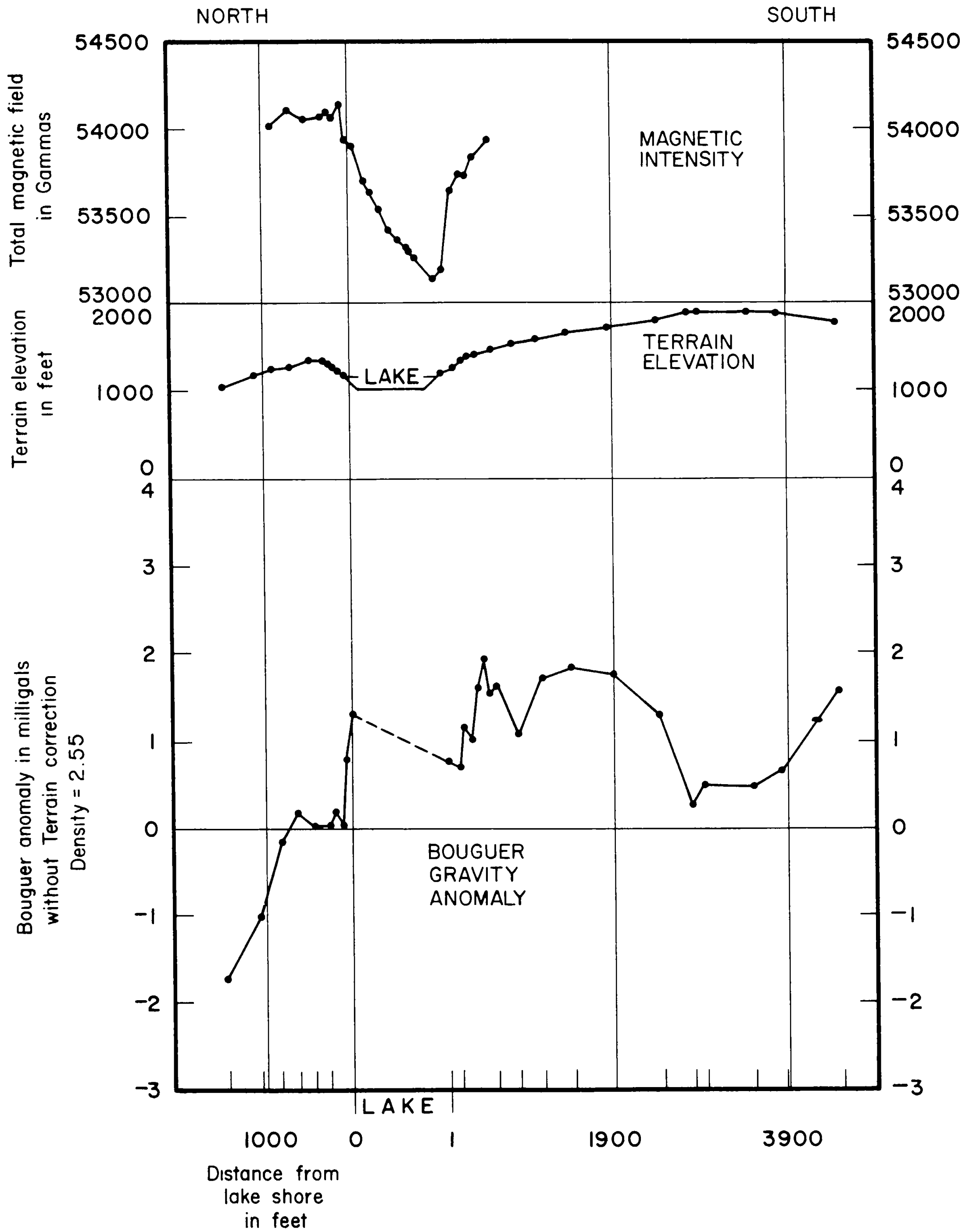

Fig. 4. North-south geophysical profiles across Savonoski Crater, showing terrain elevation, Bouguer anomaly without terrain correction, and total magnetic field. Stations are indicated by points in Fig. 3.

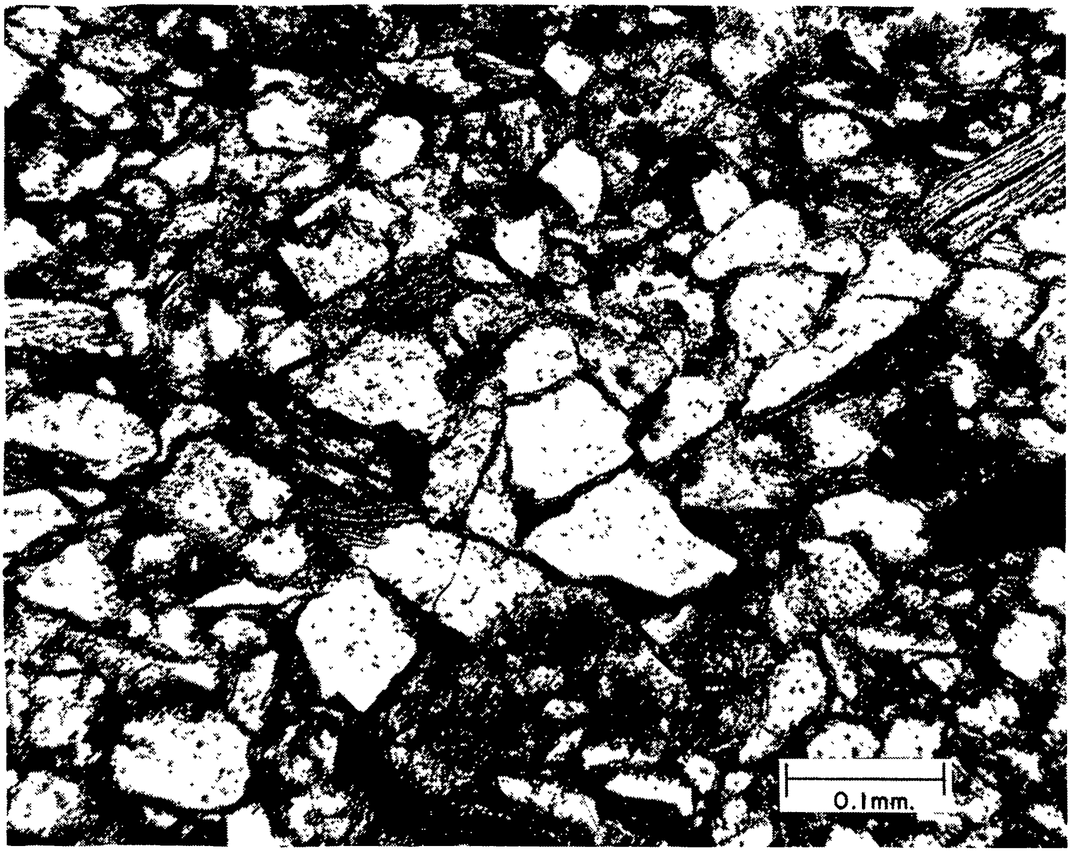

Fig. 5. **Photomicrograph of thin section of fine-grained graywacke, collected from a glacially striated outcrop about 60 feet above lake level on the SW side of the crater. Plane polarized light; largest grains are about 0.1 mm long. The sandstone is composed of angular grains of quartz, feldspars, and minor mica in a clay-rich matrix. Shock effects are absent; the quartz is clear and relatively unstrained, and the detrital mica shows no kink banding.**

The volcanic(?) breccia, collected from the outlet creek, is a poorly sorted fragmental rock with clasts larger than 2 cm in a fine, very friable matrix. The breccia is polymict and contains sedimentary and igneous rocks in about equal amounts. Three distinct types of lithic fragments can be distinguished: (1) Fine- to medium-grained sandstones ranging from graywackes to "grits" and similar to the specimen described above. These fragments are micaceous, poorly sorted, and variable in texture and grain size. They lack both gross deformation features and microscopic shock effects. (2) Fine-grained crystalline volcanic rocks displaying a range of textures. These may be related to the rocks described as "andesite prophyry" (Muller and Ward, 1966). They contain phenocrysts of olivine as much as 0.5 mm across, in some cases grouped in glomeroporphyritic textures, enclosed in a matrix composed of plagioclase and pyroxene crystals as long as 0.1 mm with variable amounts of interstitial glass. The matrix generally shows well developed trachytic textures produced by alignment of feldspar microlites.

No deformation effects are observed, and the textures are typically of igneous origin. (3) Rare fragments of medium-grained igneous rock composed of zoned K-feldspar crystals which sometimes show crude parallel orientation, in a matrix of slightly smaller anhedral quartz, plagioclase, and K-feldspar. This corresponds approximately to the rock type described as "diorite" by Muller and Ward (1966).

No shock-metamorphic effects were observed in clasts in the breccia or in the glaciated sandstone. None of the glass-bearing fragments show textures suggestive of impact origin; rather they appear to be typical volcanic rocks. With the possible exception of the "diorite," all of the breccia fragments may be of strictly local origin.

The origin of the breccia is not clear. It may be a volcanic breccia associated with formation of the crater by a diatreme-like eruption and preserved from glacial erosion in a protected position. However, there is no specific evidence to relate the breccia to the crater-forming event. It may equally well be a breccia from a nearby but unrelated eruption or even a remnant of glacial till or colluvium incorporating primarily volcanic material.

ORIGIN OF THE CRATER

Three hypotheses might account for the origin of Savonoski Crater: a gas-rich volcanic eruption, collapse following diapiric withdrawal, or a meteorite impact. Collapse following solution of underlying rocks is considered untenable in the absence of soluble rock units in the thick sequence of clastic graywackes and conglomerates which underlies the crater.

The location of Savonoski Crater in an area known for recent eruptive activity makes a volcanic hypothesis very attractive. Either a gas-rich eruption or subsidence following diapiric withdrawal is suggested to satisfy the lack of clearly associated pyroclastic material. If the previously described breccia remnant relates to the crater-forming event, the lack of evidence of shock metamorphism and the possibly local source of all the clasts are in accord with a volcanic origin. While the rim of the crater is nearly round, the basin itself is not symmetric. A shelf which extends about 100 yards along the north shore of the lake and a probable rock spur 17 feet below the surface along the northwest shore are the principal departures from regularity of form. Dikes are common around the crater, although none have been shown to be genetically related to it. The gravity data are weak, but they may be interpreted to support a volcanic origin with a body of denser rock at relatively shallow depth beneath and to the south of the crater. Gravimetric evidence for a possible sub-crater brecciated zone or tuff neck is ambiguous.

Origin by metorite impact is suggested by the circular shape of the rim and by the apparently anomalous relation of the crater to the bedrock geology. The apparent existence of a positive gravity anomaly near the crater is not consistent with results from other impact craters, but the data do not appear sufficiently conclusive to rule out the impact hypothesis.

The absence of shock-metamorphic effects in the small number of samples examined is not conclusive. Far too few samples were available for detailed study, and the samples were not ideally suited to the detection of shock effects for several reasons:

(1)Sandstone in any crater wall and rim is subjected to very reduced peak shock pressures which may not be sufficient to produce observable shock effects.

(2) The breccia collected from the east side of the crater could not be definitely related to the crater-forming event.

(3) Studies of other impact craters and of experimentally shocked rocks have indicated that higher peak pressures are required to produce distinctive shock-metamorphic effects in quartz-free mafic rocks (Short, 1969, 1970) and in fine-grained quartz-bearing rocks (De Carli, 1968; Short, 1969) than are needed in coarse-grained quartz-bearing rocks. The lithologies available at Savonoski Crater are particularly unsuitable in this respect, consisting of fine-grained andesitic dikes and fine-grained sandstones. As a result, a smaller portion of ejected material (10 per cent or less; Short, 1969) would show shock effects than would be the case for a crater developed in coarser sandstones or granitic rocks. The chances of finding distinctively shocked material in a few random samples would be correspondingly reduced.

Post-crater glaciation of Savonoski Crater is another complicating factor, since it has apparently removed any surface ejecta associated with formation of the structure. Another possibility (Muller and Ward, 1966) is that the crater formed under an ice cover thin enough to be perforated during the crater-forming event. In such a case, most of the ejecta was probably deposited on the surrounding ice and subsequently dispersed.

At present, both volcanic and impact origins must be retained as working hypotheses. If Savonoski Crater formed by metorite impact, the situation would be closely analogous to that of the New Quebec Crater (Innes, 1964), which has also been subjected to subsequent glaciation and removal of ejecta. Although retention of the impact theory for this structure at one time seemed "heavily dependent on the implausibility of a geologic origin" (Currie, 1966), subsequent fortunate recovery of an isolated "volcanic fragment" from the down-ice glacial drift led to identification of definite shock-metamorphic effects.

Determination of the origin of Savonoski Crater will require further studies. More extensive sampling around the crater is an obvious first step. A related study would be examination of down-ice glacial drift deposits which might contain shocked material excavated from the crater and glacially transported – a method used successfully to establish the impact origin of several Canadian structures (Dence *et al.*, 1968). A definite answer might be obtained by drilling in the center of the crater to determine whether the lake sediments and volcanic ash are underlain by a lens of shocked and melted impact breccia or by volcanic breccias that display no shock effects.

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