SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 608 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 60 NR 3

NILS B. SVENSSON

LAKE HUMMELN

A POSSIBLE ASTROBLEME IN SOUTHERN SWEDEN

I. THE BOTTOM TOPOGRAPHY

STOCKHOLM 1966

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DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1966

CONTENTS

ABSTRACT

A study has been made of an almost circular depression area in Lake Hummeln at approximately lat 57° 22′ N and long 16° 15′ 20″ E of Greenwich. This thesis discusses three specific theories on the origin of the depression *i. e.* the volcanic origin theory, the tectonic origin theory and the meteorite impact origin theory. On the basis of the nature of the lake bottom topography, the regional tectonic pattern, the fissure pattern around the lake, the occurrence of Cambrian-Ordovician boulders south of the lake, and the time span between the development of the tectonic pattern in the area and the formation of the depression, it has been concluded that the meteorite impact origin theory appears to offer the most plausible explanation of the nature and origin of the depression in the lake.

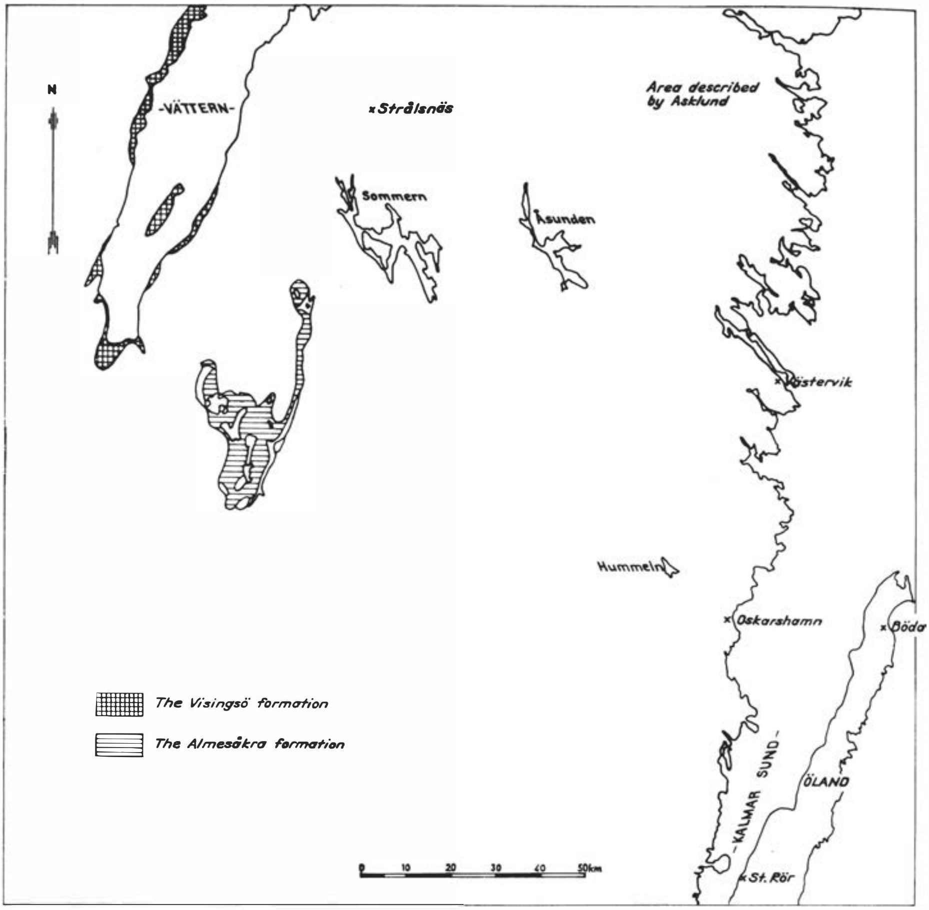

Fig. 1 A. Map showing positions of different areas and places referred to in the description.

Fig. 1 B. Sketch map of Sweden with the area in question.

Previous work

Lake Hummeln is located in the county of Småland, southern Sweden, about 15 kilometers NW of the city of Oskarshamn. (See Fig. 1.) Hisinger (1825) reported the occurrence of boulders of sedimentary rocks on the southern shore of the lake. Linnarsson (1878) subsequently ascertained that those boulders were of Paleozoic age. According to Holm (1892, p. 283) they resemble the Cambrian and Ordovician sequences occurring on northern Öland. In the southern part of Lake Hummeln, Nordenskjöld (1944, p. 77) found a depression about 1,200 meters in diameter with a rather flat bottom and a maximum depth of 61 meters. The center of this depression is located at approximately lat 57° 22′ N and long 16° 15′ 20″ E of Greenwich.

Field work

In the winter 1962 I had an opportunity to sound Lake Hummeln from the ice at about 400 points. A gravimeter survey of the lake was made at the same time. The results of the soundings appeared to be so interesting that the interpretation of the bottom topography has been subjected to a special paper.

A grid in the directions N—S and E—W, was made. (See Fig. 2.) Drilling were made through the ice cover along the lines of the grid for every 100 meters. Where fast changes in the depth of the lake were discovered, drillings were made every 50 meters. A simple plumb-bob attached to a wire was used in making the soundings. In the eastern part of the depression along the profiles A, B, and C (see Figs. 2—5) and the northern section of the depression along profiles D, E and F (see Figs. 2, 6—8), soundings were made with even greater frequencey, i. e., for every 10 meters.

Description and analysis of the bottom topography

In Fig. 2, depth curves have been drawn for every 10 meters.* They show that the depression has a very flat bottom, 61.5 meters at its deepest point.

On the whole the depression has a somewhat elongated, rounded form, its long axis striking NE—SW. The flat bottom of the depression is about 1,000 meters in length when measured along said axis, while the corresponding distance at the rim of the depression is approximately 1,300 meters. The equivalent values along the short axis are 650 and 1,000 meters, respectively.

* A map showing all depth measurements has been deposited in the library of the Geological Survey of Sweden.

From an average depth of 40 to 50 meters the depression rises at an angle of about 12° to a depth of 14 meters in its northern part and to the surface of the lake in its southern part. The fact that the bottom of the depression occasionally continues to rise to a point slightly above the lake bottom outside the depression would seem clearly to suggest that it is surrounded by a rim. Note point "r" in profile C, Fig. 5, whose depth is 13.0 meters whereas the depth immediately west of it is 14.5 meters which also might be the average depth of the lake bottom in this part of the lake. But this point will be treated further below, under "Discussion". The rim thus rises 1—2 meters above the lake bottom. Profile F in Fig. 8 appears

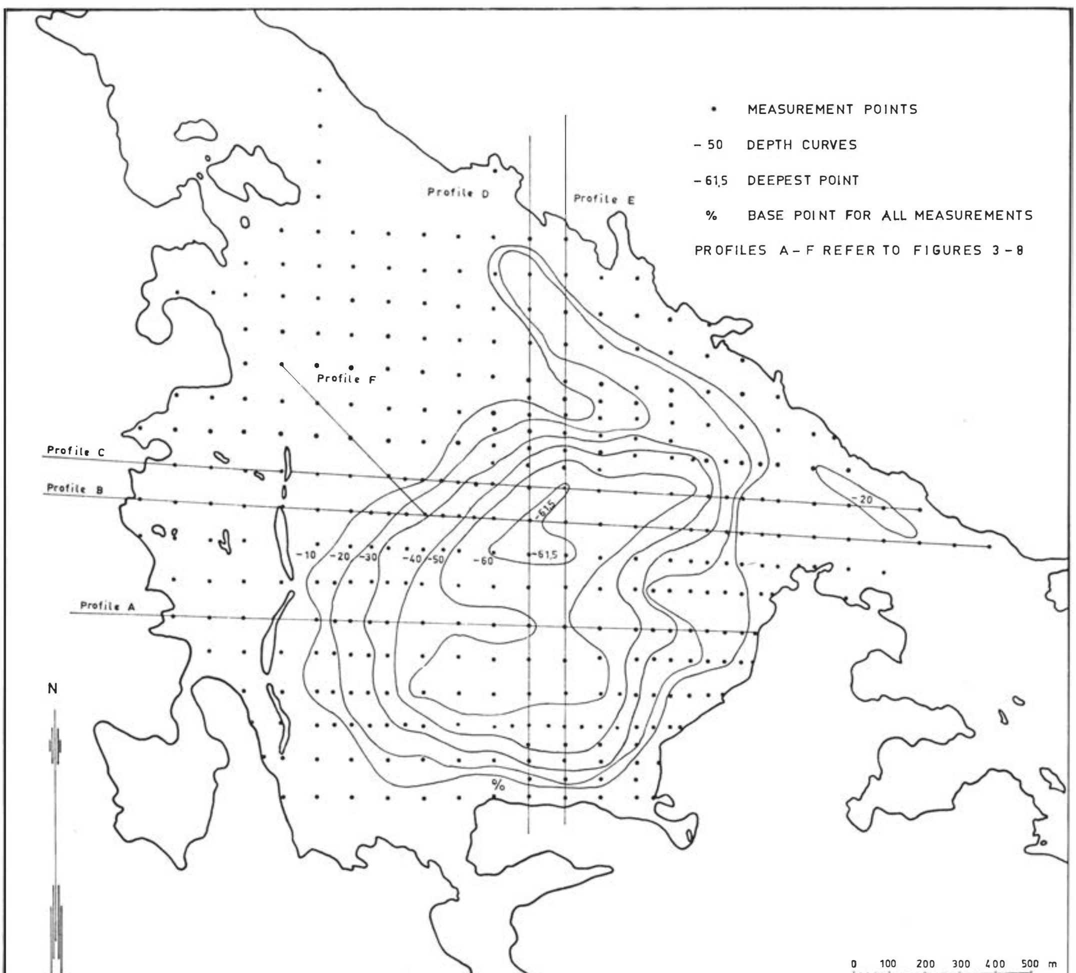

Fig. 2. Map of Lake Hummeln.

to buttress this interpretation. Here the bottom rises rather steeply up to 14 meters and then becomes almost horizontal. The knick-point corresponds to the small rise of the rim in profile 6.

The small island west of the depression (see Fig. 2) represent an esker. Probably sediments from this esker have simply eliminated the difference in height between the top of the rim and the outside lake bottom along the western and southwestern margin of the depression (see Figs. 2—4). In the southern and southeastern parts, the depression rises to the surface of the lake, and the rim may be found on the shore through geophysical investigations, which however have yet to be completed.

A fault line along the northeastern shore of the larger part of the lake is separated from the depression by a narrow ridge (see Figs. 3—7), which has partly disappeared at the point where it hits the long axis of the depression. The question whether or not the top of the ridge corresponds to the above-mentioned rim should be the subject of a special investigation.

Discussion

1. Regional tectonics of the area

Asklund (1923) studied the regional pattern of fissures in an area about 100 kilometers north of Lake Hummeln (see Fig. 1). According to him the pattern can be interpreted as representing Mohr's lines with one system striking about NW—SE and the other one NE—SW. The NW—SE system of fissures is topographically marked through long valleys. Along these lines horizontal movements, in places several hundred meters long, have occurred. In connection therewith tectonic breccias were formed and dolerite dikes intruded along fissures parallel to the valleys. The NE—SW system shows topographically much shorter valleys. Asklund maintains that the movements along this system have been vertical. No dolerite dikes seem to be connected with this system. Where the breccias and mylonites have disappeared through erosion they are often substituted by Cambrian sandstone. (Asklund 1921, pp. 669—670).

S. Gavelin (1931) examined the Almesåkra formation of Jotnian age in Småland, covering an area of about 380 square kilometers and situated about 100 kilometers WNW of Lake Hummeln (see Fig. 1). It is a sedimentary formation with arkoses, quartzitic sandstones and shales. According to Gavelin the tectonic movements started before the sedimentation ended, causing the formation of cracks and fissures in the competent sandstones. The more imcompetent slates have been strongly folded thus indicating that the tectonic movemens were considerable. As a result, the top layer of the formation, a conglomerate, was deposited discordantly, and dolerite dikes and sills intruded. The dolerites, in turn, have been affected by the last phase of the tectonic movements.

Björnsson (1937, pp. 35—63), in his geomorphological studies in the area of

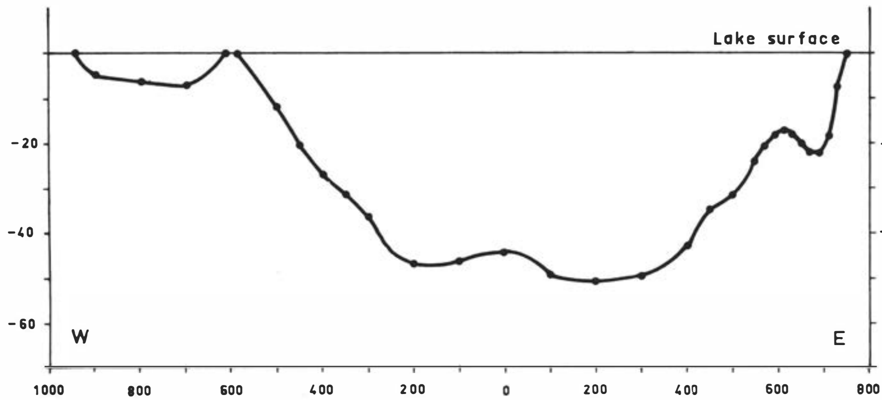

Fig. 3. Profile A. Profile of the bottom topography. Cf. Fig. 2.

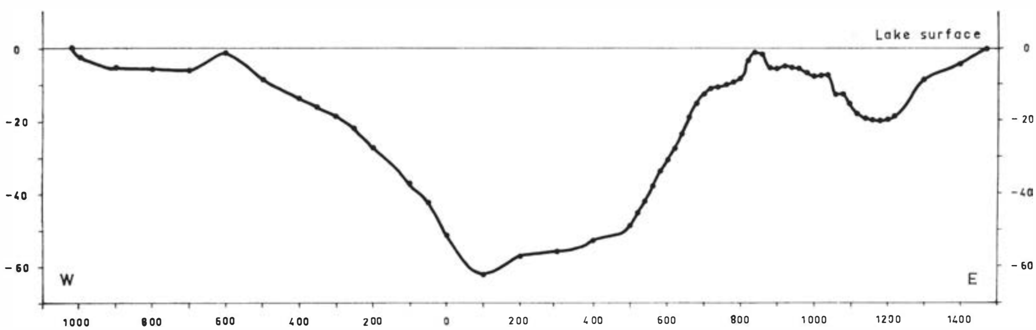

Fig. 4. Profile B. Profile of the bottom topography. Cf. Fig. 2.

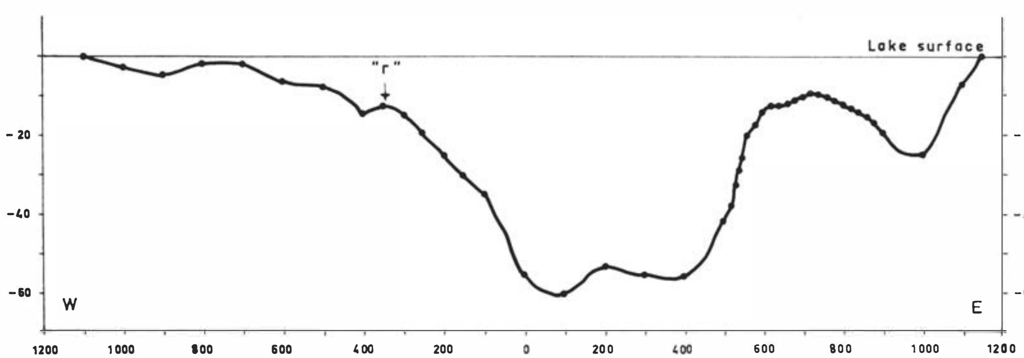

Fig. 5. Profile C. Profile of the bottom topography. Cf. Fig. 2.

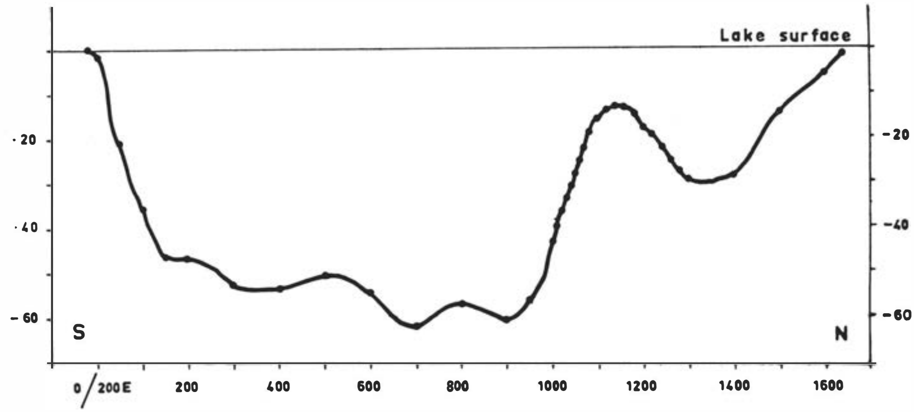

Fig. 6. Profile D. Profile of the bottom topography. Cf. Fig. 2.

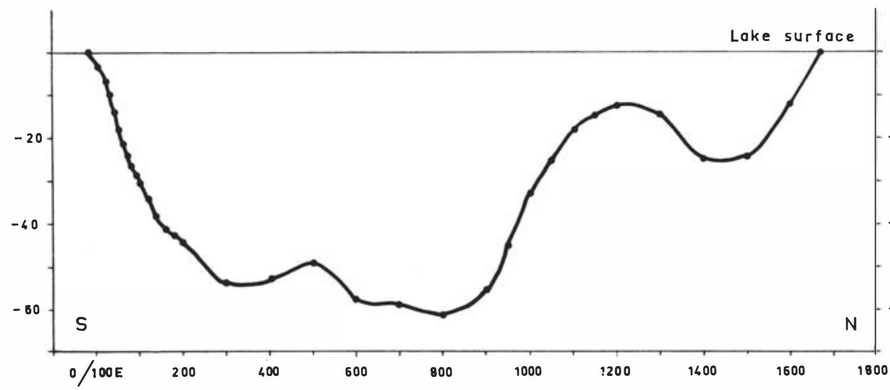

Fig. 7. Profile E. Profile of the bottom topography. Cf. Fig. 2.

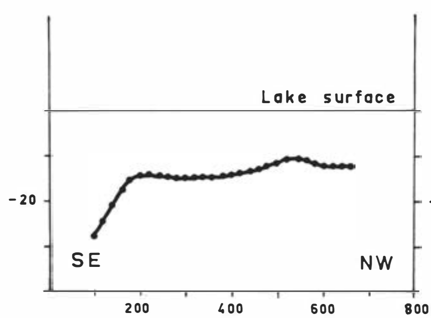

Fig. 8. Profile F. Profile of the bottom topography. Cf. Fig. 2.

Lake Sommen—Lake Åsunden (see Fig. 1) about 80 kilometers NNW of Lake Hummeln, discusses the age of the fissures in that particular area. Of special interest are two systems of fissures which strike NNW and WNW, respectively. He relates their age to the age of the dolerite dikes which intersect some of the valleys. Nothing points, however, to their being dislocated by these valleys. The dolerites are of about the same age as the youngest part of the Almesåkra formation. The NNW and the WNW systems of fissures were thus formed prior to or at the same time as that formation. According to Dahlman (1965), the Kalmarsund sandstone, of Lower Cambrian age, situated only 50 kilometers SE to SSE of Lake Hummeln (see Fig. 1) rests undisturbed on a still older sedimentary formation, which has been strongly affected by tectonic forces.

On the shores of Lake Vättern 140 kilometers NW of Lake Hummeln there occurs the Visingsö formation (see Fig. 1), described by A. Gavelin (1907, pp. 86—91) and Collini (1951, pp. 22—37). It has a thickness of more than 1,000 meters. The bottom conglomerate contains pebbles of quartzitic sandstone from the Almesåkra formation. The pebbles have been affected by tectonic forces in the same way as the *in situ* rock of Almesåkra. The matrix of the conglomerate, however, completely lacks these cataclastic structures. All the above-mentioned geologists agree that considerable tectonic movements appear to have taken place in Precambrian time, though S. Gavelin is more specific by placing them in Jotnian time. Further, according to A. Gavelin and Collini, they seem to have come to an end before the sedimentation of the Visingsö formation.

Welin and coworkers (1966) made age determinations on different rocks in Sweden. Even though but few such determinations have been undertaken, it is possible to ascertain the age of the various formations with a high degree of certainty. In the Strålsnäs area (see Fig. 1) about 20 kilometers N of Lake Sommen the granite is 1,740 million years old, as measured by the Rb/Sr whole rock method (Welin and coworkers, 1966, p. 20), which establishes the maximum age of the tectonic pattern described above, since it is found in that granite. A dolerite from the Nordingrå region about 650 kilometers N of Lake Hummeln is regarded as being of Jotnian age and parallel the dolerites of Jotnian age in southern Sweden. It has been preliminarily dated by the Rb/Sr method (Welin and coworkers, 1966, p. 271) to 1,300—1,400 ± 200 million years and gives at least a rough estimate of the age of the Jotnian dolerites. Magnusson (1960, p. 427) suggests that the K/Ar age of the Almesåkra formation is 964 million years and that the Visingsö formation is 985 million years. These determinations were made on slates from these formations. According to Magnusson the determinations give the age of the mica from the source bedrock and not the age of the sedimentation. The sediments thus should be younger, though still Precambrian. The ages are however dubious (Welin and Blomqvist, 1966, p. 16) because the bedrock in the southern part of Sweden to some extent at least has been regenerated in connection with the formation of the granites and pegmatites in the western part of southern Sweden.

2. The fissure pattern around Lake Hummeln

Nordenskjöld (1944, pp. 53—74) carefully investigated the fissure pattern around Lake Hummeln. In an area reaching from Oskarshamn in the south to Västervik in the north (see Fig. 1) there is a system of thrust planes.

They have all about the same strike of N 50°—60° W and dips of about 10°—30° SW. The long and narrow eastern part of Lake Hummeln and its north-eastern shore are defined by such thrust planes. (See Fig. 9). The western shore of Lake Hummeln is determined by the so called Kristdala fault line stretching N—S. This fault, however, is camouflaged by sediments from the above mentioned esker (see Fig. 2). Another fault system strikes E—W. Topographically it usually appears as narrow, steep valleys. Along these faults the rocks have become brecciated, mylonized and schistose.

3. The occurrence of Cambrian-Ordovician boulders south of Lake Hummeln

Hisinger (1825), Linnarsson (1878), Tullberg (1882, p. 19), Holm (1892, p. 283), and Svedmark (1892, pp. 282—283, 1904, pp. 45—51) have contributed to the study of the Cambrian-Ordovician sedimentary deposits which are revealed through boulders at Humlenäs (see Fig. 9) on the southern shore of Lake Hummeln. They resemble the corresponding strata found on northern Öland, Holm (1892, p. 283), Svedmark (1904, p. 49). Of the latter the following are represented at Humlenäs:

1. Grey Asaphus limestone
2. Red Limbata limestone
3. Planilimbata limestone
4. Stinkstone with *Agnostus pisiformis*
5. Sandy limestone with *Paradoxides Tessini*
6. Green clayey shale with *Paradoxides oelandicus?*
7. Lower Cambrian sandstone

The limestone occurs as big boulders on and near the surface of a narrow moraine ridge stretching NW—SE from the shore towards the Humlenäs farm and further southeast, (Linnarsson, 1878, pp. 4—5). On the eastern part of Kalvnäset and the peninsula W of Humlenäs (see Fig. 9) there are plenty of Cambrian sandstone boulders. To the north, west and east of the lake no limestone boulders and only a few small sandstone boulders have been found. Svedmark (1904, p. 51) concluded from these observations that the sedimentary rocks occur on the bottom of the lake.

4. The breccia

Linnarsson (1878, p. 81) and Svedmark (1892, 1904, p. 45) made field observations on the breccia, which occurs on the shore south of the lake. The bedrock consists of a Precambrian porphyritic granite in which the breccia appears in narrow bands.

The level of the lake has been lowered since these investigations were made, making it possible to investigate a larger area of breccia outcrops (see Figs. 10, 11). Just along the present shore line the breccia consists of angular fragments ranging in size from 50 centimeters in cross section down to sand granules. The fragments consist of porphyritic granite of the same type as the surrounding bedrock. Radially from the center of the depression and within a distance of 12—15 meters this breccia gradually passes over into undisturbed bedrock. Two main jointdirections are present, one radial to the center of the depression, the other tangential to it. Small vertical movements have taken place in association with the latter, and have given rise to a "schuppen" structure. Among the bands defined by these faults,

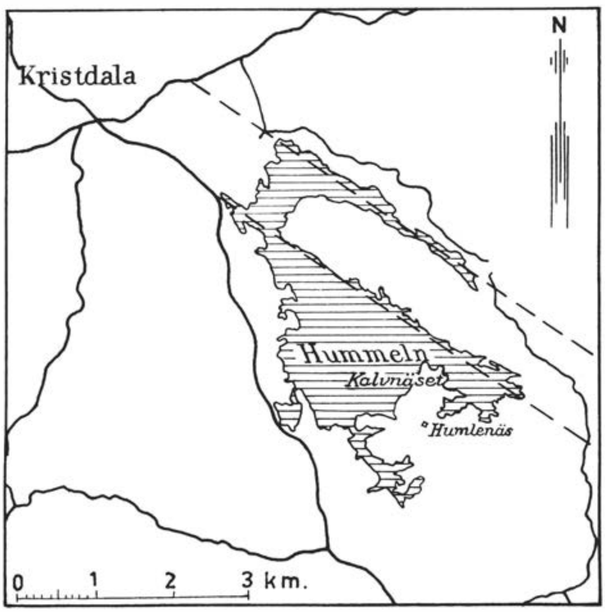

Fig. 9. Map of Lake Hummeln and surroundings.
— — — — — = probable fault line.

those with large fragments of bedrock relatively intact alternate with other bands of heavily crushed bedrock. Wedges of breccia penetrate beyond these bands radially from the center of the depression into fissures in the bedrock. The matrix of the breccia does not show any sign of having been subjected to tectonic forces after the deposition. Thin sections show that the feldspars of the breccia fragments have only been very slightly weathered. Nor has any enrichment of quartz grains taken place in the matrix. The latter seems to be devoid of cement. No tuff structures or other signs of volcanism have been found. The breccia completely differs macroscopically from known Cambrian bottom conglomerates of Sweden.

Fig. 10. The breccia close to the waterline. Vertical photograph from an altitude of about 5 meters. Square sides marked by crosses = 1 meter.

No fragments of sandstone or arkose have been found in the breccia which rests directly in contact with the Archean bedrock.

Some hypotheses regarding the origin of the depression

Cambrian sandstone boulders have been found on the shore. The sandstone most probably can be found on the bottom of the depression and with the breccia forming the base towards the Archean bedrock. The breccia thus must have been formed in Cambrian or Precambrian time. Since the breccia seems to be uncemented, it must have been covered with younger sediments within a com-

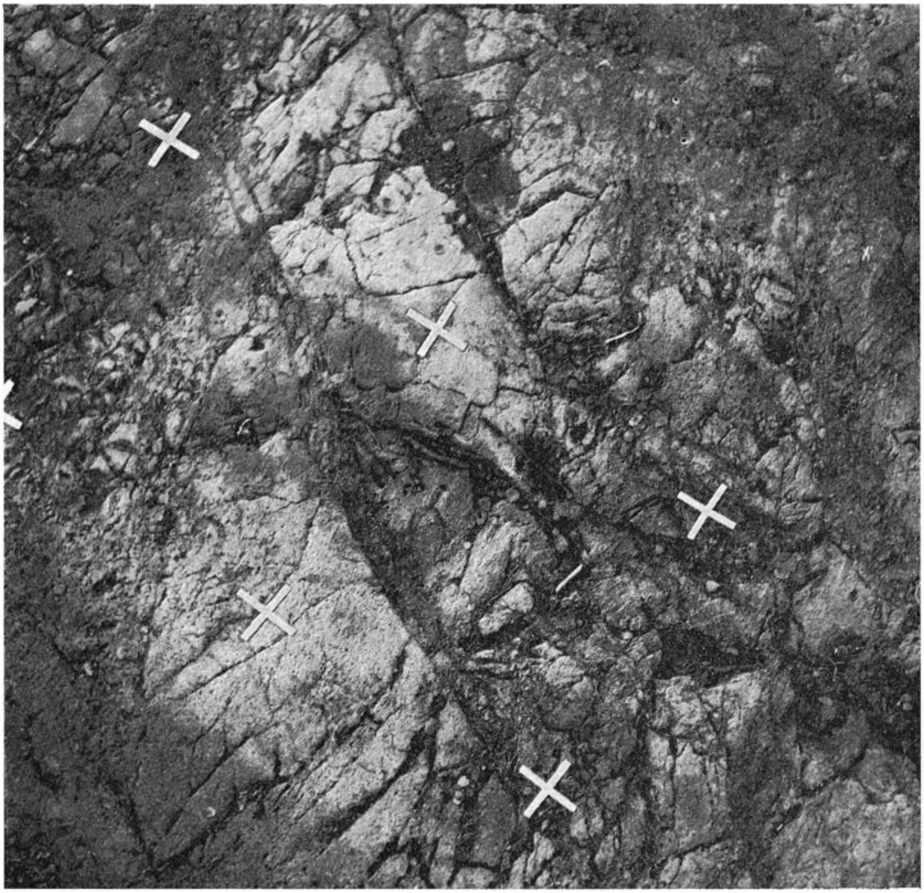

Fig. 11. The breccia 6 meters from the waterline. For explanation, see Fig. 10.

paratively short time span to be protected from erosion. According to current views Cambrium started about 600 million years ago. As mentioned before (p. 10), the tectonic pattern around Lake Hummeln very probably has been established at least about 1,200 million years ago. There is thus a gap of about 600 million years from the formation of the tectonic pattern to the formation of the depression.

Several hypotheses can be advanced in explanation of the origin of the Lake Hummeln depression; *i. e.*, 1. a volcanic origin theory, 2. a tectonic origin theory, 3. a meteorite impact theory and 4. other possible theories.

1. Volcanic origin theory.

Asklund (1944). Under this theory, three different structures have to be considered, *i. e., (a)* a structure caused by ordinary volcanic activity with lavas, pyroclastics and other volcanic products, *(b)* a pure gas explosion, and *(c)* a collapse structure (caldera).

A. A structure caused by ordinary volcanic activity

No volcanic rocks of the correct age have been found in the area. Descriptions of cores from diamond rock drillings at Bödahamn (see Fig. 1) (Waern 1952, Hessland 1955, pp. 52—75), File Haidar on Gotland (Thorslund and Westergård 1938, pp. 16—20, 26—33) and Visby on Gotland (Hedström 1923) do not mention anything about volcanic products. These drillings have penetrated the Paleozoic rocks into the Archean crystalline rocks. Dahlman (1965) reports that volcanic products occur in drill cores from Stora Rör (see Fig. 1) but these products belong to a sedimentary formation which underlies the Lower Cambrian beds and which has been affected by tectonic forces (cf. p. 7). Thus no volcanic products of actual age have been found in the area.

B. Gas explosion

According to Rittmann (1960, p. 51) all known cases of simple gas explosions have occurred within volcanic areas but no regional volcanism is — as mentioned before — known from the actual area.

C. Collapse structure

The rim that surrounds the depression discussed on p. 6 could not have been formed by a collapse structure.

Although the form of the depression with this kind of rim is common among volcanic structures, and there is no evidence of tectonic origin of the breccia along the southern lake shore, there is overwhelming evidence against application of the volcanic theory here. No actual volcanic products have been found in the area, gas explosions simply do not occur in areas not actively volcanic, and the rim could not be caused by a collapse structure.

The volcanic origin theory seems in general also to be contradicted by the fact that the shore line around the larger part of the lake is defined, in the northeast, by a fault line which dips about 20° to the southwest, i. e., towards the depression. Horizontally, the distance from the fault line to the border of the depression is only about 50 meters. In addition, the western shore line of the lake is also defined by a fault, its distance from the center of the depression being about 1,000 meters.

It is difficult to understand why a volcanic activity, which gives rise to a depression structure as large as Lake Hummeln, should form without using the preexisting fault lines or zones of weakness.

2. Tectonic origin theory

A depression area caused by tectonic forces has been suggested by Nordenskjöld (1944, p. 163). There are two possible tectonic patterns which could give rise to a depression structure, i. e. fault lines or fissures running in different directions may form a polygonal pattern, or alternatively, may all intersect approximately at a given point, and weathering and erosion may in both instances cause a depression structure to develop.

It should be noted, however, that, unlike the Lake Hummeln depression, a depression structure of this origin would not be bordered by a rim.

There are two additional factors which also seem to contradict the tectonic theory. First, the considerable outcrop of breccia appearing on the southern shore ought in order to support this theory, to show some evidence of being of tectonic origin, but it appears not to do so.

Secondly, the fact that a narrow ridge lying between one of the area's most significant fault lines and the depression structure (see Figs. 2, 5, Profile C) has been left largely uneffected by weathering and erosive forces would also appear to be inconsistent with the tectonic origin theory. In fact, the only thing that seems to favor the tectonic origin theory is the shape of the depression.

3. Meteorite impact theory

This theory has been suggested by Wickman (1961) as a possibility. The physical phenomena of an impact of this kind produce a geological structure reminiscent of that caused by a volcanic eruption or gas explosion, i. e. it will produce a rim, and cause explosion breccia to form around the depression.

It also offers a clear and simple explanation as to why the fault lines run undisturbed outside the Lake Hummeln depression by merely suggesting that the point of impact of a meteorite, always being a random point, in this case happened to fall exactly between those lines.

4. Other explanations

Of course, the possibility of additional theories as to the origin of the Lake Hummeln depression cannot be excluded, but thus far the meteorite impact theory appears to the author to offer the most plausible explanation to the nature and the origin of the circular depression in Lake Hummeln.

Acknowledgements

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