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Caves as indicators of neotectonics in Sweden

by

R. SJÖBERG, Umeå

with 2 figures, 3 photos and 1 table

Summary. Several caves formed within accumulations of huge boulders have been investigated in Sweden. Many facts suggest a neotectonic origin for these boulder caves, suggesting that they were formed by earthquakes during the melting of the Weichselian glaciation about 10,000 years B.P., when isostatic uplift of the region may have reached rates of 20–50 cm per year. The present maximum rate of uplift in Sweden is 0.9 cm per year. The author proposes a three-fold classification of these caves: (1) Caves in split *roches moutonnées*, (2) Caves in collapsed mountain slopes, and (3) Caves in sub-horizontally displaced mountain summits. The strongest evidence for a neotectonic origin for some of these caves is that (a) the boulders forming many of these caves are striated, which proves that they accumulated after advance of the inland ice; (b) the huge talus blocks forming caves of type 2 lie in such a way that points to sudden collapse of the hill-slope; (c) the amount of blocky talus is too great to have been formed by frost weathering in post-glacial time; and (d) scarcely any weathering has affected the faces of the boulders forming the caves, and no weathering products are found on the floors of the caves.

Introduction

As part of the Baltic Shield, Sweden has usually been regarded as a tectonically stable region, bearing only traces of older tectonic events such as the Caledonian (400 M years), the Dalslandian (1000 M years) and the Svecokarelian orogeny (1900 M years) (STRÖMBERG 1978). However, there are several indications that this stability is more apparent than real. In the last 50 years, several authors have described phenomena that point towards neotectonic activity in Sweden.

Previous research

The father of the Swedish varve chronology, GERARD DE GEER, described what he called 'tectonic moraines' from Bromma, a suburb west of Stockholm (DE GEER 1940). He explained his assumption that these moraines were caused by an earthquake by using five

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arguments, of which the fourth was "At its southern end the boulder train begins quite abruptly with most remarkable masses of big blocks, heaped upon each other almost without any material of morainic soil", and the fifth was "Here occurs a very marked, almost straight small vertical wall along a quite open fissure in the bedrocks, only concealed by moss and growing herbs. ... This fissure seems to have been formed by an earthquake after the adjacent moraine" (DE GEER 1940: 119).

Also in northern Sweden, on the coast of the Gulf of Bothnia, DE GEER found traces of recent tectonics: "The bedrocks are splitted ..., often with open fissures, sometimes forming grottos and such masses of angular boulders that they seem likely to be caused by considerable earthquakes" (DE GEER 1940: 203). He continues: "The whole appearance seems to make it probable that this pronounced headland has been uplifted at a relatively late date and thereby splitted by severe earthquakes". A couple of years later, BERGSTEN (1943) described the cave of Torekulla Kyrka in the province of Östergötland, southern Sweden. This fairly large cave is formed entirely within a pile of huge boulders. These once formed a perfectly rounded *roche moutonnée*, and BERGSTEN suggested that this small hill was split by local tectonics released by rapid isostatic recovery at the margin of the melting inland ice.

Since that time, discussion of neotectonics went out of fashion until the mid-1970s, when talks began on the problems of the disposal of nuclear waste in Sweden. The natural solution for most engineers was that this waste should be stored deep inside the supposed very stable bedrock. At about the same time, a very recent fault several tens of kilometres in length was discovered in the northern interior of Sweden. This fault disturbed the sediments in a couple of eskers crossing it, and it was clear that the fault had been formed after the eskers (LUNDQVIST & LAGERBÄCK 1976). Soon, two schools of thought developed, for and against neotectonism. The differences of opinion may be illustrated by quoting two statements: (1) "The results of the analyses seem to imply that no alarming tectonic movements in Fennoscandia can be traced from the records now studied" (BJERHAMMAR 1977: 66). (2) "In view of these rates of isostatic uplift and the corresponding changes in stress and strain rates in the bedrock, fracturing and seismic activity are quite common (and may be rather the rule than the exception)" (MÖRNER 1979: 282).

MÖRNER's statement is based on studies which show that the Fennoscandian uplift is caused by two different mechanisms, the first operating through adjustment in the low-viscosity asthenosphere and the second, which is responsible for the present uplift, having an uncertain origin. At the centre of uplift in the northern part of the Gulf of Bothnia (fig. 1), the maximum rate of uplift was related to the end of the Younger Dryas stadial and the final deglaciation, and amounted to as much as 20–30 cm per year (MÖRNER 1977a, 1977b, 1978, 1979). The present rate of uplift in this area is 0.8 cm per year. In 1981, AGRELL studied a boulder cave named Gillberga Gryt in Archaean rocks north of Stockholm, and found it was developed within a perfectly formed and striated *roche moutonnée*. "It seems as though the whole mountain has been blasted", he wrote (AGRELL 1981). The same year he studied the largest cave known in non-calcareous rocks in Sweden – Bodagrottorna, a boulder cave system more than 2800 m long, situated on the coast of the Gulf of Bothnia, finding it to be of the same type. The splitting of the mountain must have occurred during the deglaciation of the area about 10 000 years ago, after the striae had been formed by the receding ice (AGRELL 1982; AGRELL & SIDÉN 1982).

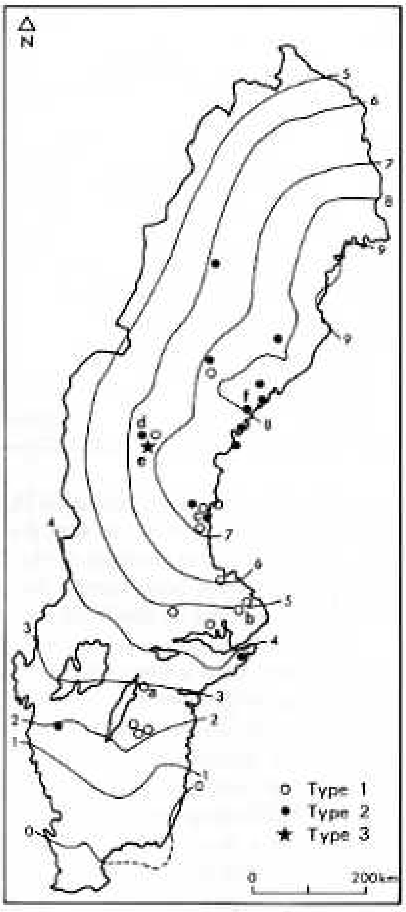

Fig. 1. The distribution of neotectonic caves in Sweden and the present mean relative rate of uplift (mm per year). a – Torekulla kyrka cave; b – Gillberga Gryt cave; c – the Boda caves; d – Källberg cave; e – Strångberg cave; f – the Degerfälle, Rövarklippen and Slåttdals caves

Different types of neotectonic cave in Sweden

In the last few years, several caves presumably formed by neotectonics have been studied in Sweden, and we can now distinguish three types:

(1) Caves in split *roches moutonnées*

(2) Caves in collapsed mountain slopes

(3) Caves in sub-horizontally displaced mountain summits.

The distribution of these caves and their types can be seen on fig. 1, which also shows the present mean rate of uplift. The location of a seismic belt through Sweden, according to MÖRNER (1977) is shown on fig. 2. Table 1 provides a list of the locations of known neotectonic caves, their types and lengths. As comparison of figs. 1 and 2 shows, most caves of the first type are to be found within the seismic belt. They are characterised by labyrinthine cave passages joining fairly big grottos in angular boulders, formed by the

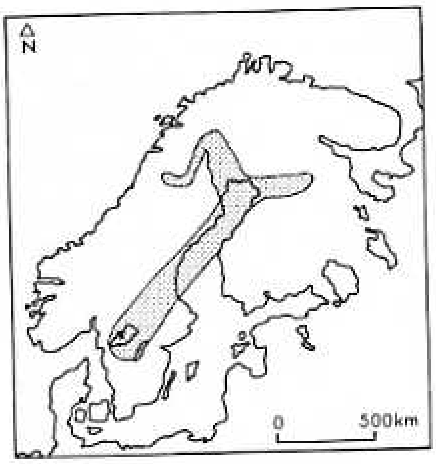

Fig. 2. The seismic belt through Sweden, after MÖRNER (1977)

vertical and horizontal jointing of the bedrock. On the tops of some mountains the boulders are wedged together, so that the former shape of the mountain can be restored. Striae can occur on the top surfaces of the boulders and sometimes on their sides, showing that such boulders have been turned during the earthquake. Typical examples are the caves at Boda (photos 1 and 3) and Gillberga Gryt.

Most of the caves in collapsed mountain slopes (type 2) also lie in the seismic belt. The boulders form a sort of huge talus (AHLIN 1983), creating more or less vertical caves in which larger grottos are connected by narrow passages. The total length of one of these caves can reach several hundred metres. Even in this case a neotectonic origin can be demonstrated by abruptly broken striae, but the most prominent clue is that the boulders are jumbled together in a way that indicates sudden collapse of the whole hillside. In one case, the Källbergsgrottan in the province of Jämtland, the cave is formed by rockfalls on the slope of a deep canyon-like meltwater channel (ISACSSON 1982). AHLIN (1983) has attempted to explain the rock disturbance and talus formation as a result of the release of accumulated strain in the bedrock, occurring during the final phase of deglaciation when the stress gradient in the bedrock produced minor brittle fractures. Several boulder caves investigated by the author along the coast of the Gulf of Bothnia, for example Degerfällegrottan, Rövarklippan and Slättdalsgrottan (photo 2), belong to this second type and all of them are situated within what MÖRNER (1979) identifies as the central zone of isostatic uplift in Sweden. Of the third type, caves in sub-horizontally displaced mountain summits, only one example is known, Strångbergsgrottan in the province of Jämtland. This cave, which is 510 m long, has been studied by ISACSSON (1982). Its northern part slopes down at an angle of 15–20° towards the east. Study of vertical joints in the roof and in the floor of the cave indicate that the top slice of the mountain, measuring 110×50×10 m in size, has slipped as a single intact unit for about 2–3 m in an easterly or south-easterly direction along fracture planes. An indication of the neotectonic origin of this cave is given by the fact that its southern part possesses rounded forms that have originated by weathering, and also some supposed sediments from a minor ice-dammed meltwater lake around the top of the mountain. As the fresh rectilinear faces of the walls of the northern part of the cave are unweathered and no sediments are found here, this

Table 1. Neotectonic caves in Sweden (from north to south).

Name of cave	County*	Type	Length in metres
Lobergsgrottan	AC	2	75
Kalbergsgrottan	Y	2	10
Degerfällegrottan	Y	2	c. 150
Jättingstugan	Y	1	c. 20
Stora Slättdalsgrottan	Y	2	c. 40
Rövarklippan	Y	2	76
Nässjögrottan	Y	2	9
Snöskallegrottan	Y	1	57
Källbergsgrottan	Z	2	c. 120
Strångbergsgrottan	Z	3	510
Klätthålet	X	1	40
Hölickgrottorna	X	1	907
Bodagrottorna	X	1	2606
Örnnästet	X	2	503
Mehedeby gryt	C	1	?
Gillberga gryta	AB	1	110
Vällnora kyka	AB	1	c. 100
Pukbergsgrottan	C	1	c. 60
Rudtjärnsgrottan	U	1	c. 100
Klövbergsgrottan	AB	2	c. 275
Frubergsgrottan	AB	2	c. 100
Smedstorpsgrottan	D	1	c. 50
Torekulla kyrka	E	1	c. 60
Solltorp cave 1.	E	1	28
Solltorp cave 2.	E	1	c. 30
Trollegator	E	1	c. 150
Hällers grotta	O	2	14
Borrefjällsgrottan	O	2	c. 50
Friskas Urd	O	2	c. 40
Sjögaredsgrottan	P	2	c. 100

* AC=Västerbotten, Y=Västernorrland, Z=Jämtland, X=Gävleborg, C=Uppsala, U=Västmanland, AB=Stockholm, D=Södermanland, E=Östergötland, O=Göteborg and Bohuslän, P=Älvsborg.

northern section of the cave is considered to be very much younger than the southern part. It is concluded that neotectonic disturbance was responsible for the formation of this part of the cave.

Summary of the evidence for a neotectonic origin of the boulder caves

The evidence in favour of a neotectonic origin for the Swedish boulder caves can be summarised as follows:

(1) Glacial striae are in many cases found on the sides and tops of the boulders forming the caves. This proves that the boulders were emplaced after the last glaciation of the area.

Photo 1. The split roche moutonnée above the Boda caves (photo: R. SJÖBERG)

Photo 2. The collapsed mountain slope above the Slåttdals cave. Scale is given by the person seated at the left (photo: R. SJÖBERG)

Photo 3. The straight sides of the boulders forming the walls in the Boda caves, representing fissures in the bedrock (photo: J. WAGNER)

(2) The quantity of boulders in the talus forming some of these caves is too great to have been formed by frost weathering after the deglaciation, and it is also likely that all previous talus of these areas was removed by the Weichselian glaciation.
(3) The positions of large, often angular boulders forming the caves in the voluminous talus indicates a sudden, catastrophic collapse of the whole mountain side.
(4) The small quantity of freeze-thaw debris inside the caves indicates a fairly recent date for their formation.

Conclusion

From recent studies of caves in Archaean rocks in Sweden, it seems quite clear that neotectonic activity during the period of the last deglaciation must have been high and that the earthquakes, according to MÖRNER (1985), must have had a magnitude of up to 7 on the Richter scale.

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Address of the author: RABBE SJÖBERG, Department of Physical Geography, University of Umeå, Sweden.