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# CAVES INDICATING NEOTECTONIC ACTIVITY IN SWEDEN

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**ABSTRACT.** Several caves formed within gigantic boulders have been researched in Sweden. Many facts suggest a neotectonic origin for these bouldercaves, meaning that they were formed by earthquakes during the melting of the Weichsel-glaciation about 10.000 years B.P., when the isostatic uplift of the region could have reached 0.2–0.5 m per year.

The author proposes a three-fold classification of such caves, into 1. Caves in split roches moutonnées, 2. Caves in collapsed mountain-slopes, and 3. Caves in sub-horizontally displaced mountain-tops.

The most prominent evidence of neotectonic origin regarding these caves is that (a) the boulders forming many of these caves are striated, which proves that they were formed after the advance of the inland ice; (b) huge talus blocks forming caves of type 2 are situated in a manner which indicates a momentary collapse of the mountain-slope; and (c) scarcely any weathering products are found on the floors of the caves; this indicates a recent date for cave formation.

## Introduction

As a part of the Baltic Shield Sweden is believed to be a tectonically stable region, with traces only of older tectonic events such as the Caledonian orogeny (0.4 Ga) (Ga = Gigayears  $\cdot 10^9$  radiometric years), the Dalslandian (1.0 Ga) and the Sveco-karelian (1.9 Ga), (Strömberg 1978). However, there are several indications that this stability is just apparent. In the last 50 years several authors have described phenomena that reveal the occurrence of 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 explains his assumption that these moraines were caused by an earthquake in five points, where nr. 4 is: "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 nr. 5. is: "Here occurs a very marked, almost straight small vertic-

al wall along a quite open fissure in the bed-rocks, only concealed by moss and growing herbs. – This fissure seems to have been formed by an earthquake after the adjacent moraine", (De Geer 1940, p. 119). In northern Sweden, on the coast of the Bothnian Sea, De Geer also found traces of younger tectonics: "The bed-rocks 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", (ibid., p. 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 K-E Bergsten (1943) describes the cave Torekulla Kyrka, in the province of Östergötland, southern Sweden. This fairly big cave is formed within a heap of giant boulders. These boulders once formed a perfectly rounded roche moutonnée, and Bergsten suggested that this little hill was split by local tectonics released by the fast isostatic movement at the margin of the melting inland ice.

After this period the discussion about neotectonics came out of fashion until 1973, with the start of Section B of the Swedish GDP-project called "Postglacial Earth Movements (Mörner 1977).

At about the same time a very recent, several tens of kilometers long fault, the Pärvie-fault, was discovered in the northern inland of Sweden. This fault had disturbed the sediments in a couple of eskers crossing the fault, and it was obvious that the fault was formed after the eskers (Lundqvist and Lagerbäck, 1976).

Very soon two schools developed – for and against neotectonism. The discussion can be summarized in these two statements:

"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, p. 66).

"In view of these rates of isostatic uplift and the

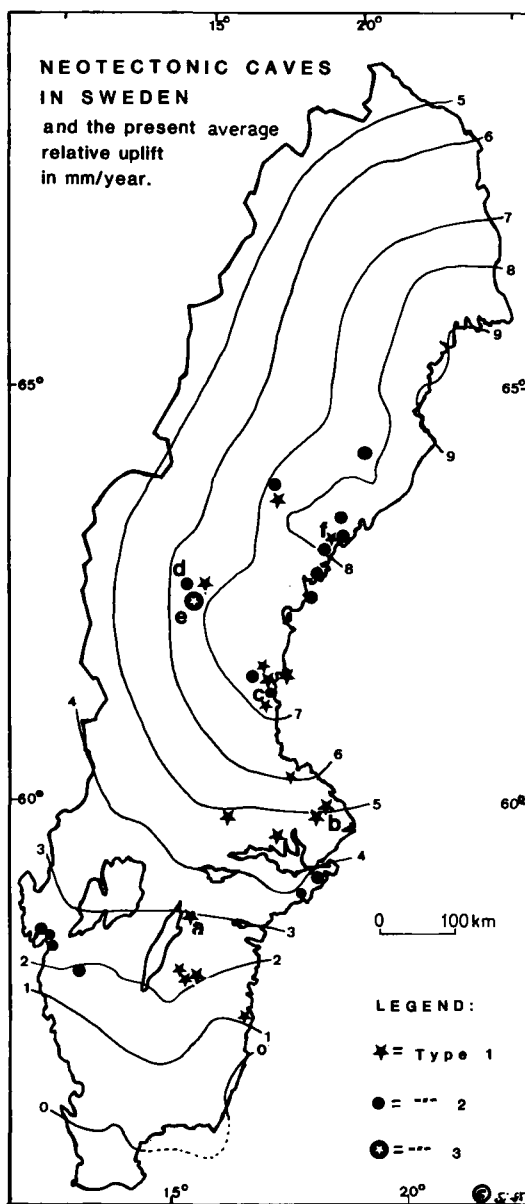


Fig. 1. Neotectonic caves in Sweden and the present mean relative uplift in mm per year. a. the cave Torekulla Kyrka, b. the cave Gillberga Gryt, c. the Boda caves, d. the Källberg cave, e. the Strångberg cave, f. the Degerfjällegrottan, Rövarlippan and Slätt-dal's cave.

Table Neotectonic caves in Sweden (from N to S).

Name of the cave	County	Type	Length in m.
Lobergsgrottan	AC	2	75
Kalbergsgrottan	Y	2	10
Degerfjällegrottan	Y	2	c. 150
Jättingstuga	Y	1	c. 20
Stora Slättdalsgrottan	Y	2	c. 40
Rövarlippan	Y	2	76
Nässjögrötan	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 gryt	AB	1	110
Vällnora kyrka	AB	1	c. 100
Pukbergsgrottan	C	1	c. 60
Rudtjärnsgrottan	U	1	c. 100
Klövbergsgrottan	AB	2	c. 275
Smedstorpsgrottan	D	1	c. 50
Frubergsgrottan	D	2	?
Torekulla kyrka	E	1	c. 60
Solltorp cave 1.	E	1	28
Solltorp cave 2.	E	1	?
Trollegator	E	1	c. 150
Hällers grotta	O	2	14
Borrefjällsgrottan	O	2	?
Friskas Urd	O	2	c. 40
Sjögaredsgrottan	P	2	c. 100

corresponding changes in stress and strain rates in the bedrock, faulting and seismic activity are in fact, to be expected" --- and "are quite common (and may be, rather the rule than the exception)" (Mörner 1979, p. 282).

Mörner's statement was based partly on shoreline bends and isobase irregularities (Mörner e.g. 1978) and partly on minor faults, heavily fractured bedrock and details and structures of certain bouldery moraines in the Stockholm area (Mörner 1977). He also demonstrated that the Fennoscandian uplift is caused by two different mechanisms, the first being the adjustment of a low-viscosity asthenosphere, and the second, which is responsible for the present uplift, having uncertain origin. At the centre of the uplift in the northern Bothnian Sea (Fig. 1) the maximum rate of uplift is related to the Younger Dryas Stadial and the final deglaciation and amounts to as much as 0.2–0.5 m per year (Mörner 1977a, b, 1978, 1979). The present uplift is 0.8 cm per year in this area.

In 1981, Agrell studied a boulder cave in Archean rocks north of Stockholm, namely Gill-

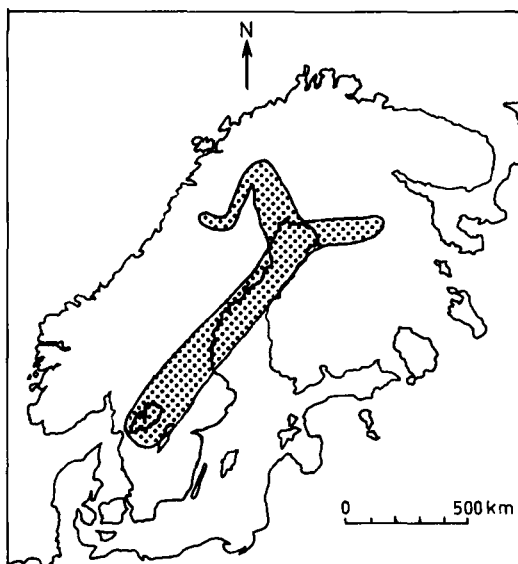


Fig. 2. The seismic belt through Sweden, after Mörner (1977).

berga Gryt, and found that it had developed within a perfectly formed and striated roches moutonné. "It seems like the whole mountain has been blasted", he writes (Agrell 1981). The same year he studied the biggest cave in noncalcareous rocks in Sweden, Bodagrottorna, a boulder cave system more than 2800 m long, situated on the coast of the Bothnian Sea, and found that it was of the same

type. The splitting of the mountain must have occurred during the deglaciation of the area about 10 000 years ago, and after that the striae were formed by the receding ice (Agrell 1982, Agrell and Sidén 1982).

#### Different types of neotectonic caves in Sweden.

In recent years several caves presumably formed by neotectonic activity have been studied in Sweden, and we can now discern three types of neotectonic caves, here proposed by the author:

1. Caves in split roches moutonnées.
2. Caves in collapsed mountain-slopes.
3. Caves in sub-horizontally displaced mountain-tops.

The location of these caves can be seen in Fig. 1, which also shows the present rate of average relative uplift. A list of the most important neotectonic caves is shown in table 1. A seismic belt through Sweden is shown in Fig. 2.

As shown in Figs. 1 and 2 most caves in split roches moutonnées are found within the tectonic belt. They are characterized by labyrinthic cave passages joining fairly big grottos in angular boulders, formed by the vertical and horizontal jointing of the bedrock. On the top of the former mountain the boulders are wedged together, so that the shape of the mountain can be restored. Striae can occur on the tops of the boulders and sometimes on the sides, showing that the boulders have turned during the earthquake. Typical exam-

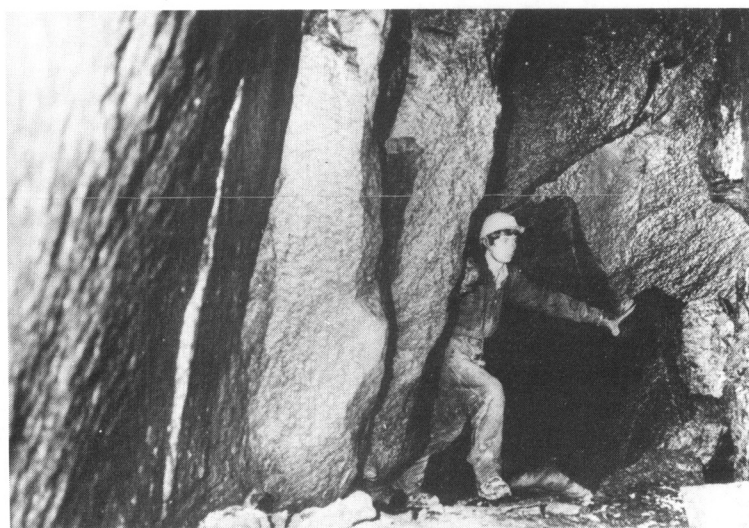


Fig. 3. A grotto in the Boda caves. The rectilinear faces of the floor and the walls show the horizontal and vertical jointing of the bedrock. Photo: J. Wagner 1984.



Fig. 4. The split roches moutonné above the Boda caves. Photo: R. Sjöberg 1984.

ples are the caves at Boda (Figs. 3 and 4), and at Gillberga Gryt.

Most of the caves in collapsed mountain-slopes are also found within the tectonic belt, Fig. 1. The boulders forming a sort of voluminous talus (Ahlin, 1983) create more or less vertical caves with big grottos connected by narrow passages. The total length of these caves can exceed one hundred meters. Even in this case the neotectonic formation can be traced by abruptly broken striae, but the most prominent clue is that the boulders are stuck together in a way that indicates a momentary collapse of the whole mountain-side. In one case, the Källbergsgrottan, in the province of Jämtland, the cave is formed by rock-falls on the slope of a very deep canyon-like melt-water channel (Isacsson, 1982). Ahlin (1983) tries to explain the formation of voluminous talus as a result of the recharge of strain in the bedrock, occurring during the final phase of the glaciation, where the load-gradient of the bedrock could have produced minor brittle tectonism.

Several boulder caves, researched by the author, along the coast of the Bothnian Sea, e.g. Degerfällgrottan, Rövarklippan and Slättdalsgrottan (Fig. 5), belong to this type and all of them are situated within what Mörner (1979) calls the centre of isostatic uplift in Sweden.

As for the third type, "caves in sub-horizontally displaced mountain-tops", only one cave is

known, Strångbergsgrottan in the province of Jämtland. This 510 m long cave has been studied by Isacsson (1982). The northern part of this maze-cave has a dip of 15-20° eastwards. Vertical opposite joints in the roof and the floor of the cave indicate that the 110×50×10 m big top of the mountain has slipped fairly intact about 2-3 m in a SE-E direction along subvertical joints. An indication pointing towards a neotectonic origin of the cave is that the southern part of the cave has rounded forms indicating weathering processes and contains supposed sediments from a minor ice-dammed melt-water lake around the top of the mountain. As no weathering is found on the fresh rectilinear faces of the walls of the northern part of the cave and no sediments are found within this part, it is considered to be very much younger than the southern part of the cave. Thus, the only cave forming process in this part of the cave must be neotectonic.

The indications of a neotectonic origin of several boulder caves in Sweden can be summarized as follows:

1. Glacial striae are in many cases found on the sides and on the tops of boulders forming the caves. This proves that the boulders were formed after the last glaciation of the area.
2. The amount of boulders in the talus forming some of these caves is too great to be formed by frost weathering after the deglaciation, as we

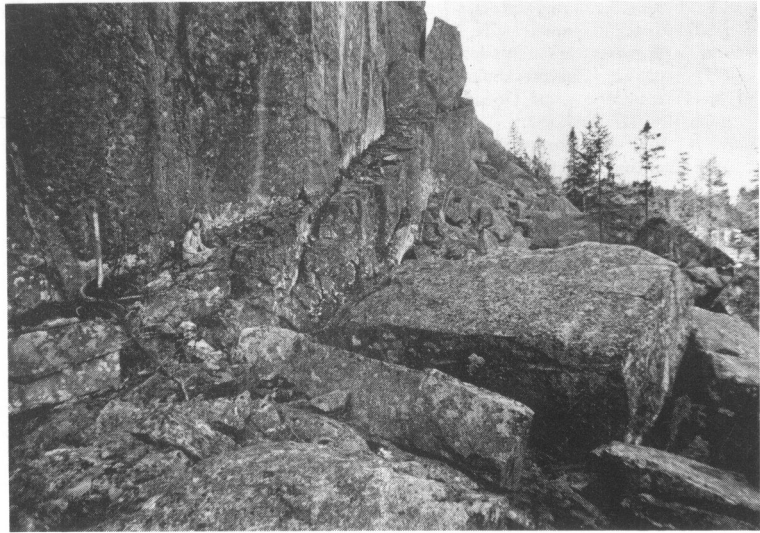


Fig. 5. The collapsed mountain-slope above the Slåttdal's cave. To the left a sitting person as a scale. Photo: R. Sjöberg 1984.

can assume that all previous talus of these areas were removed by the Weichsel glaciation.

3. The position of big, often angular boulders forming the caves in this voluminous talus indicate a sudden, momentary collapse of the whole mountain-side.
4. The small amount of freeze-thaw debris within the caves indicates a fairly recent date for cave formation.

### Conclusion

By recent studies of caves in the Precambrian bedrock in Sweden it seems quite clear that the neotectonic activity during the deglaciation phase of the Weichsel glaciation must have been very great. According to Mörner (1985) the corresponding earthquakes may have reached magnitudes of up to about 7 on the Richter Scale.

Further studies most probably will reveal that these phenomena are much more common than indicated on the map accompanying this paper.

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R. SJÖBERG

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