# DISCOVERY OF UNKNOWN ASTROBLEMES IN SWEDEN:
# 1. Mullsjö near Hjo

Version 1.1

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## Summary
The site of Lake Mullsjö, about 4 km west of Hjo (Vättern), is the site of a complex astrobleme, established between Ordovicium and Upper Devon. This can be deduced from the existence of petrified cystoidé, which are found here and likewise at the border between shocked and un-shocker rock in the Siljan astrobleme and at the same border in another, which exists in Gästrikland, (will be published in 2017).

## Location
The centre of Lake Mullsjö is situated about 4,7 km west of the church in Hjo (a town on the west side of the large Lake Vättern), its diameter is 2,5 km. It is reached from Hjo on the road to Korsberga and accessible at the bathing place, the coordinate of which are (in RT 90 system) X=6460070 and Y=1406442. About 100 m W of the coordinates along the beach one reaches a bank of stones in lake level. There samples can be found: The best ones are rough, corroded stones. The bank is a natural enrichment of pebbles within the sandy beach; its occurrence as such is somewhat astonishing, may be a reminiscens from the last Ice-tide. The lake as such is very shallow: Its largest known depth is 3 meters. This makes the interpretation of its origin somewhat difficult.

## The surrounding bedrock
According to the information, belonging to the geological map Aa 132 from 1906, this is a granite-gneiss, without continuous layers. It resembles the armour of previous Japanese warriors, which consisted of individual metal plates of the size of large coins, fastened alongside one another. The one ‘coin’ is very light, white, consists of quarts or feldspar, the other black, consisting of biotite.
Also there exists a very fine-grained sandstone with a grain size of few tens of a millimetre, consisting of about 70% of transparent quarts and 30% of a white, opaque plagioclase. Where this sandstone occurs in nature this author has not found, yet. This type of stone will be important in determining the history of the origin of the structure.

## Concerning its origin

Knowing the outcome of the following discussion, we have to be self-critical and discuss other modes of formation, too. The lake and the geology of its surrounding could have been formed by a stranded ice-berg, as a simple astrobleme and as a complex astrobleme.

## Assumption of glacial formation

During the retreat of an ice-front there can floating ice-bergs run ashore, remain there and thus hinder the deposition of glacifluvial sediments; this is a very common mode in Sweden. These holes have a maximal diameter of 100 m and a depth of 30 m (=depth of the sediment layer.
There exists another mode: Melt-water, flowing upon the remaining ice-sheet, tends to dig canyons into the ice, often even down to the bedrock. The canyons may be spaced 100 m or more. These are continuously filled by the load of the running water. Finally, after retreat of the ice-front, the tongs are left as dead-ice, melt by time and leave deep valleys. An example for this is to be seen at Gagnef in Dalecarlia. However, never has a round ice-core of 2,5 km diameter, creating a depression after its final melting, been seen.
Of course, we have to admit, that a previous hole, created by a meteorite, after ice-tides can be filled by later sediments. This can have occurred in this case, but never can an ice-tide change the bedrock in the surroundings in such a profound way like will be shown in the following.

## Assumption of a simple astrobleme

A minor meteorite creates a simple astrobleme. This is a hole in the ground, like after an airplane bomb. One of the largest simple astroblemes is the Meteorite Crater (also called Barringer Crater) in Arizona. Its crest diameter is 1200 m and depth 180 m. The bedrock at that site is demolished and cast up as large boulders, but there are no mineralogical changes done to these.
Since our Lake Mullsjö is at most 3 meters deep, quite evidently the hole has been filled up by later sediments. However, there are another means to fill the hole; that will be disclosed here below.

## Assumption of a complex astrobleme

These astroblemes are – concerning their physics – quite different from simple astroblemes. In the latter, the pressure due to the penetrating meteorite is so high, that the exposed rock goes over into the shocked formed of matter. During the ongoing penetration the density of the bedrock increases many percent und the velocity of the shock front exceeds the normal sound velocity of that rock. Some minerals are changed into a high-pressure modification like simple quarts into coesite with a density of 3,01 g/cm$^3$ or into stishovit with density 4,18 g/cm$^3$.
The shocked region emanates from the instantaneous contact surface between the remainder of the meteorite and the bedrock. It looks like an onion, with the stem in the meteorite. The shock lasts for ten or fifteen seconds, fades afterwards. This previously shocked volume (in the case of the Siljan astrobleme many hundreds of cubic kilometres large) is very

hot, partly above the melting point of rocks, remains in this state for thousands of years. This leads to mineralogical changes in that volume, that we can see and study to day.
Immediately after the decay of the shock the pressure in the underlying, not shocked, region starts to release and the hot, plastic material starts to move upwards as a column with the diameter of about the shocked region. This is called the rise of the central uplift; its speed can be a meter/minute. The rise comes to stop or the column collapses under the own load. This rise fills the previous crater, so we cannot see it afterwards.
This is one means, that can have filled up the primary crater of the size of Lake Mullsjö.

There are two other indications, that Lake Mullsjö is an old complex astrobleme: The one is the occurrence of sandstone and the other the petrification of fossils after cystoids, which have occurred in the bedrock or the sea-floor sediment, that existed at the time of the impact.
In the case of Lake Siljan the size of the shocked volume is clearly visible in bathymetric maps: There a deep trench is seen enclosing the central part, with a diameter of about 38 km. The trench is to day up to 130 m deep, is probably much deeper, but now filled up by glacifluvial sediments. Its inner surface is identical with the outer surface of the chocked bedrock.
Now a new process in the previously shocked bubble starts for the following thousands and thousands of years: Ground water in form of steam, from hydrated minerals or eventually water from the oxidation of methane rises upwards and sideward, dissolving all free quarts and transporting it to the colder interface to unshocked rock. By time the central volume is completely free from quarts. At the same time the microcline of the previous granite is ‘cooked’ and transformed into a dark-red opaque mass. The quarts is deposited near the colder periphery of the bubble. In the case of Lake Siljan the to day visible surface of many tens of square kilometres is completely free from quarts. Together with quarts plagioclase is transported, too.
If the bedrock at the time of impact (like at lake Siljan) had been an old seafloor, it contained carbonate sediments, carbonate fossils and clays. These are now impregnated by quarts and/or plagioclase and the carbonate fossils are petrified by quarts or plagioclase.
This is seen at Lake Siljan outside the previous shocked volume, e.g. north of the lakes Ockran at the east side of the astrobleme.
Evidently the bedrock at the Mullsjö Lake has been of the same type, contained as fossils cystoids, the carbonate of which is now replaced by mainly plagioclase. Note: Not all cystoids in the whole area are changed, but only those, which have been located near the surface of the shocked bubble. These samples consist of many cystoids, bound together by a sort of glue, which corrodes easily. Therefore these samples feel rough from all naked cystoid-surfaces. Cystoids occurred in marine sediments from Ordovicium to Late Devon. The Siljan impact occurred at 377 million of years, during Lower Devon.

There is a further unknown astrobleme in the province of Gästrikland, which will be presented in 2017. At that site we have the same indicators for a complex astrobleme like in Siljan and at Mullsjö: A quarts-free central region, petrified cystoidé and very fine sandstones of unknown origin; most probably the latter are the product of the very impact. They consist of the sedimented dust cloud from the shattered bedrock and from the meteorite as such.

## Conclusion

Despite its very shallow depth petrological evidence points strongly to the fact, that Lake Mullsjö is the trace of a complex astrobleme from the time span Ordovicium to Upper Devon. A high concentration of cystoidé must have lived in the sediments of a shallow sea there. Experience from the Siljan astrobleme and from a yet unpublished new one in Gästrikland (Publishing under 2017) have shown, that due to the very high and lasting temperature of the previous shocked part of the central regions of these astroblemes, these central regions are depleted of quarts and plagioclase. These two minerals are deposited at the cooler border between shocked and un-shocked rock. Particularly there the calcite of crinoidé and of cystoidé is replaced by quarts or plagioclase. The best samples, found at the shore of Mullsjö, consist mainly of petrified cystoidé; here plagioclase is the petrifying agent. The 'glue' between the cystoid-balls weathers easily, rendering samples that are rough in touch.
At the beach there are boulders of a sandstone, too, which are very similar to Orsa-sandstone. The grains are some tens of a millimetre large, the sandstone consists of about 70% transparent quarts and
30 % white, opaque plagioclase.
The lateral size of this astrobleme is not known to this author.

## About the author

The author is physicist (PhD) from the University of Stuttgart and geologist from Uppsala Universitet.

## Literature

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/5/ Spicar, Erich: Picture of a frozen Instant from the Birth of the Siljan Astrobleme, Vers.1.2.7

## Photos of samples


Picture 1 (IMG_3075.jpg): Sample from the stone jetty, shows stone from more distant site.


Picture 2 (IMG_3077.jpg): Sample showing petrified cystoidé

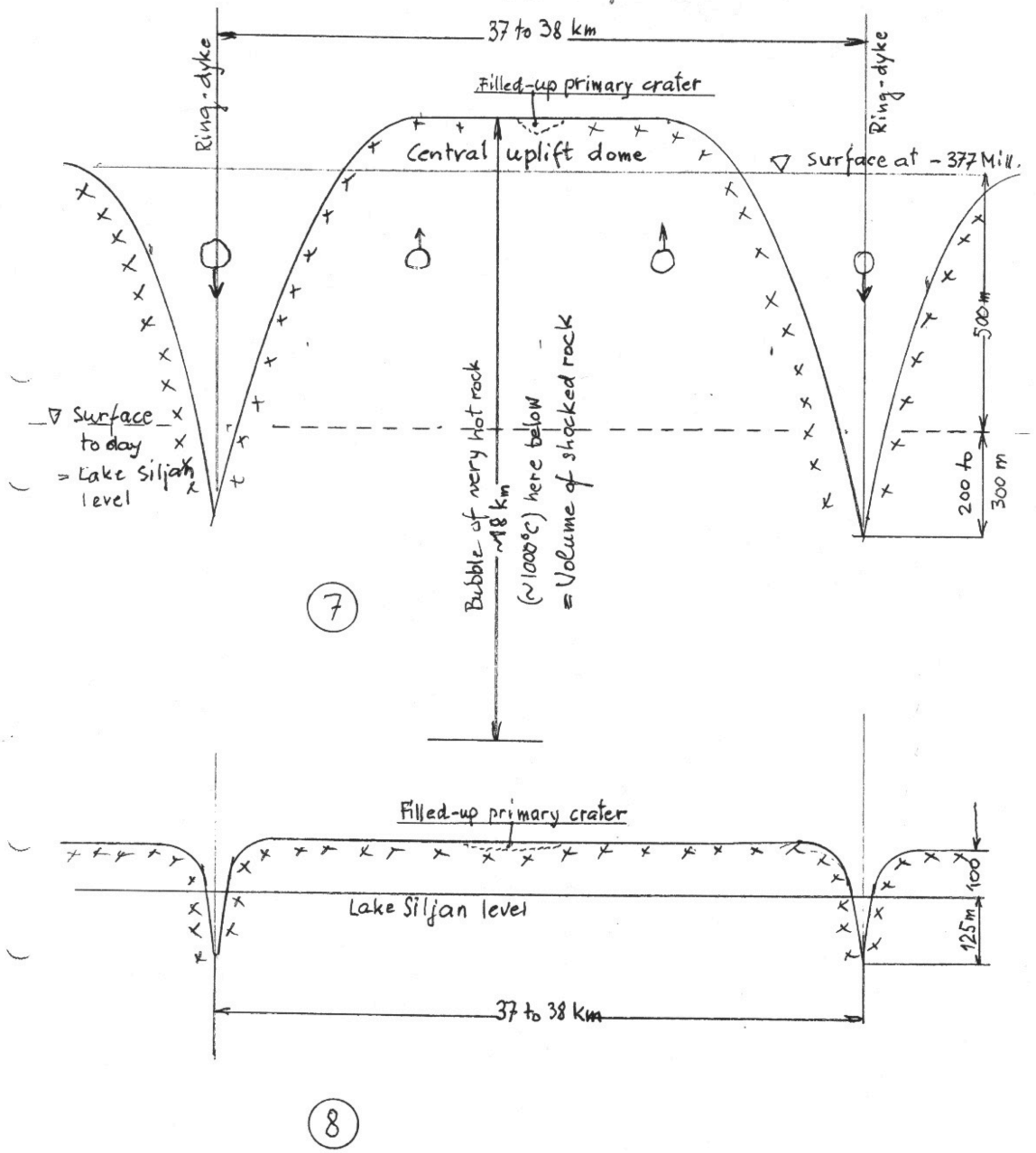

Picture 3 (IMG_3078.jpg): Sample showing Petrified cystoidé


Picture 4 (IMG_3082.jpg): Sample showing Petrified cystoidé


Picture 5 (IMG_3087.jpg): Sample showing Petrified cystoidé

Picture 6 (IMG_3089.jpg): Sample from the stone jetty, unknown site of origin

Fig. 2 Siljan astrobleme



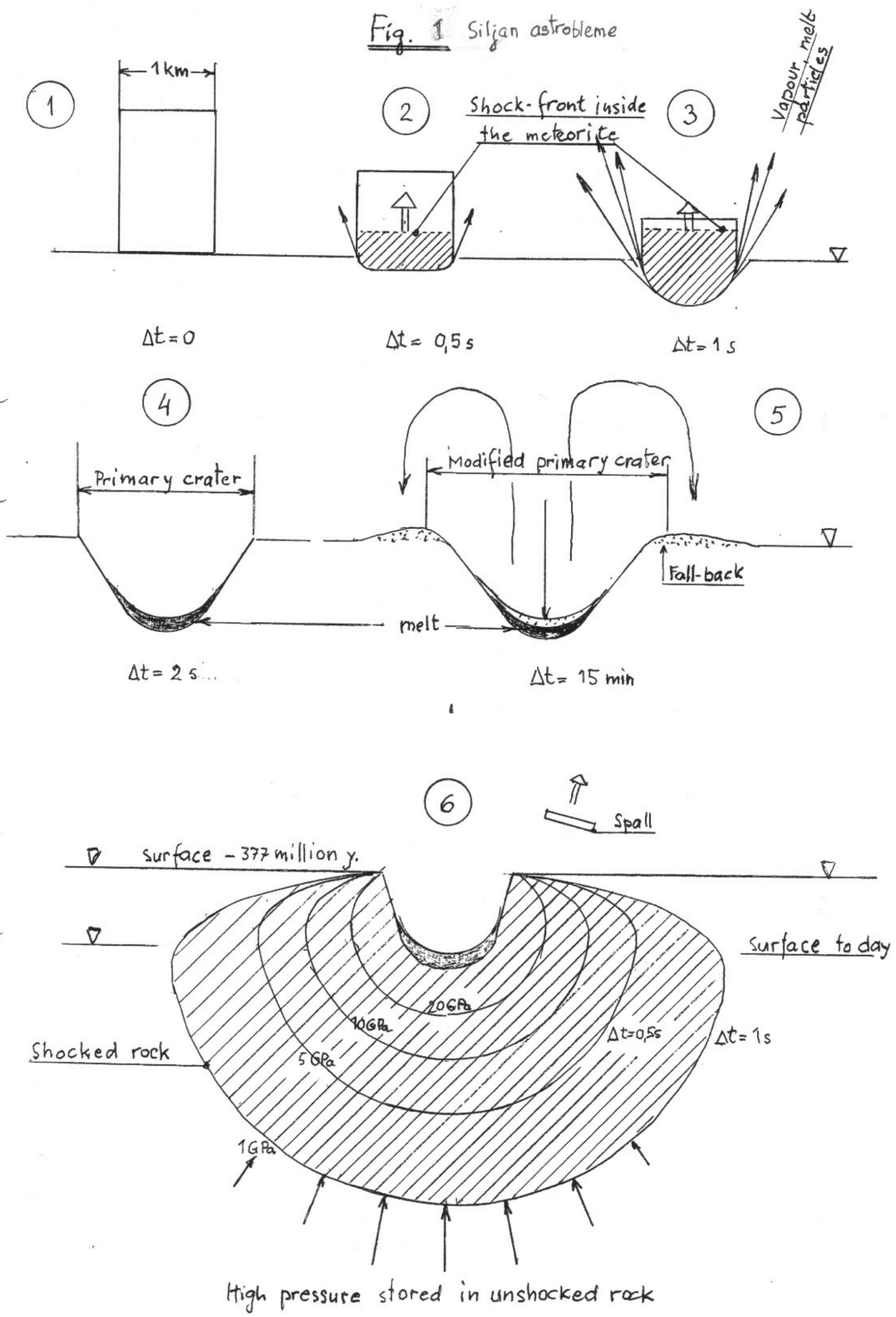


Fig. 1 Siljan astrobleme
1
1 km
2
Shock-front inside the meteorite
3
Vapour melt particles
Δt = 0
Δt = 0,5 s
Δt = 1 s
4
Primary crater
5
Modified primary crater
Fall-back
melt
Δt = 2 s
Δt = 15 min
6
Spall
surface – 377 million y.
surface today
Shocked rock
20GPa
10GPa
5GPa
1GPa
Δt=0,5s
Δt = 1s
High pressure stored in unshocked rock