The Lake Ljugaren astrobleme

Version 2.0

Erich Spicar
Lorensbergavägen 2B
SE-77142 LUDVIKA
erich.spicar@icloud.com

Abstract

For years by this author been supposed that Lake Ljugaren East of Lake Siljan has to be an astrobleme. The finds made previously on the north side of the lake were from an astrobleme, but from which? Now this author has made new finds on the southern beach of that lake too, which are regional and prove, that in fact the lake is an astrobleme. Many square kilometres there are filled with local boulders of a fragile granite, which disintegrates like rapakivi-granite. Near the beach of the lake these stones can in most cases be broke by hand. They consist of large crystallites of microcline, plagioclase and quartz, which are only glued together. This type of rock is typical for pseudotachylites, which are re-melted and afterwards glued together to rocks.
Another, very interesting find, is a sedimentary rock, formed during the impact of the meteorite. It consists of a matrix of about 50 % hornblende, 25 % quarts and 25 % unknown feldspar. Within this matrix there are fragments of large crinoidéa. This shows that the meteorite has hit a shallow sea. The quantity of hornblende is so large, that it cannot originate from the local rock, which is very low in hornblende, but must originate from the iron in the meteorite. In the final product the iron from the meteorite is included in the hornblende, the carbonate from the fossils is transformed into plagioclase.

Introduction

The Siljan-meteorite fall contains about 9 or 10 meteorites, which are more or less clearly depicted in nature; the Siljan fall, which has been recognized as such during the 1960:s, is the most clear. All falls have been large ones, (complex craters), which did not end with a to day visible crater. Quite certainly the crater has existed for a very short time, but it has been filled up and annihilated by the following “central rise”. This is a rise of a central column with a diameter about that of the shocked rock; this is typical for s c “complex astroblemes”. Compare this with the rebounding of a drop of water, falling on a water surface. Therefore, no crater is seen here; this can be found by fragments of stone melts, only. In several cases there is a lake in the former astrobleme. Examples for these lakes are Lake Flaten, an astrobleme north of the town of Dala-

Järna, Lake Israel-sjön (a lake west of Lake Siljan), Lake Långsjön, Lake Flosjön at Dala Floda and Lake Siljan. The astrobleme called after the town Leksand has no lake by itself, but a deep, waterfilled trench of 100 m depth, which connects it with the Siljan-astrobleme. Further to the east Lake Ljugaren, which is the subject of this paper, is an astrobleme, too.

Up to date the evidences for a Lake Ljugaren astrobleme have been some isolated finds of melts, which could have been imported by postglacial streams from other sites. But now a vast field south of Lake Ljugaren has been found, with local boulders consisting of rock, which have been melted right through by the shock from a meteorite impact. Approximating on the map the northern shore of Lake Ljugaren and the eastern shore of the connected Lake Dodran by parts of a circle, this circle has a diameter of 12,6 km. Its centre will be 6,3 km to the south of the upper circle line at position X = 675755 and Y = 147925 (RT 90-coordinates).

Finds north of the Lake

Driving north of Östra Born towards Bingsjö, one passes after 2 km on the south side of a road a deviation at position X = 676230 and Y = 147255; this is a forest road, going down the hill. At the start of that forest road there is a turnpike, that in most cases is open. Follow this road for about 1 km. Already in the ditches of this road finds of by a meteorite affected stone can be made. These are stones consisting of shattered rock, containing residues of Ordovician fossils and are glued together by a melt. Se Fig. 1: and 2: (2: is the rear side of Fig.1:)

Fig. 1: Pseudotachylite

Fig. 2: Rear side of Fig.1:

Stop at X = 676180 and Y = 147310 and go in the forest north of this site. In the forest stones can be found, containing green epidote according to the formula

$$3 \text{ anorthite} + 1 \text{ calcite} + 1\ H_2O \leftrightarrows 2 \text{ zoisite} + 1CO_2$$

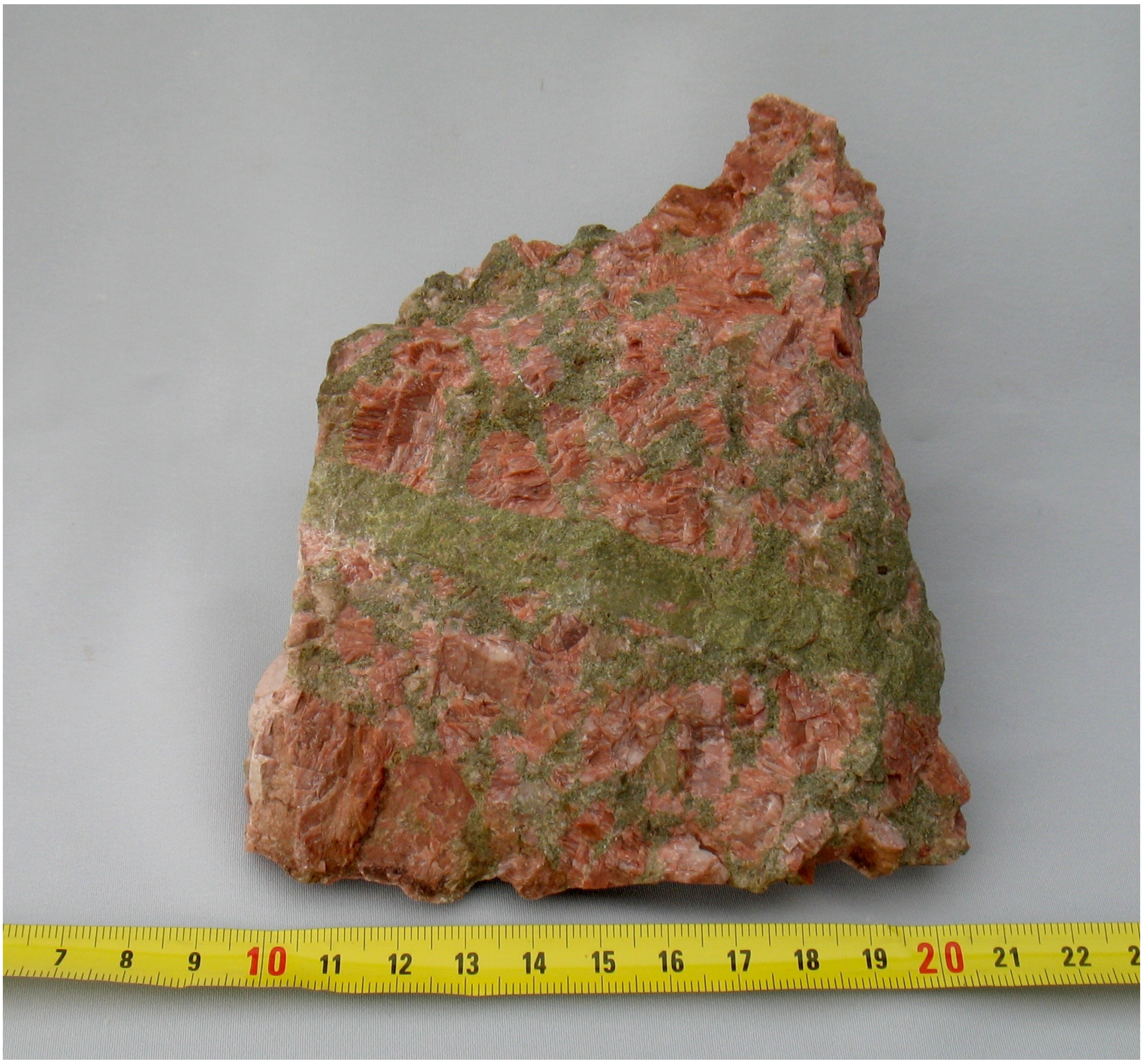


Fig. 3: Epidot formed according to above reaction

Calcite is quite near this position. However, it is unclear, if this is a local rock which initiated the above reaction, or only a bolder in the till.
Due to the heat of the impact the zoisite could have been formed there, or it has been transported to this site by the ice flow. At a later instant, when the temperature has decreased, and a water-saturated quartz-melts penetrate the rock, the zoisite is taken up by this melt. Such quartz-rich and greenish ducts are quite common in astroblemes, if calcite is present. Note, that the minerals in the sample of Fig. 3 are red microcline and zoiste, only; no quartz is present.

Fig. 4: is a pseudotachylite from position 148010E/676530N. This is many kilometres away from our first site, but still on the north side of Lake Ljugaren. To reach it drive and pass the small lake Övre Arvtjärnen by 0,5 km, leave the main road there and continue on the forest road for several kilometres. The rock at the target can be broken by hand.

Disintegration of blocks of granite into gravel in the Ljugaren-astrobleme at its south-side

On the south border of the Lake Ljugaren – at the outflow of the small river Tvärsån into the Lake - and south of this place along the road to Dodran, the forest is covered by a large number of large boulders with volume 1 to 10 m^3, which have very rough taste and easily fall appease into gravel of 1 cm^3 size. In the following an attempt will be made to understand this peculiar behaviour.

Fig. 5: Pseudotachylite from the outflow of river Tvärsån

Fig. 6: Rear side of fig. 5.

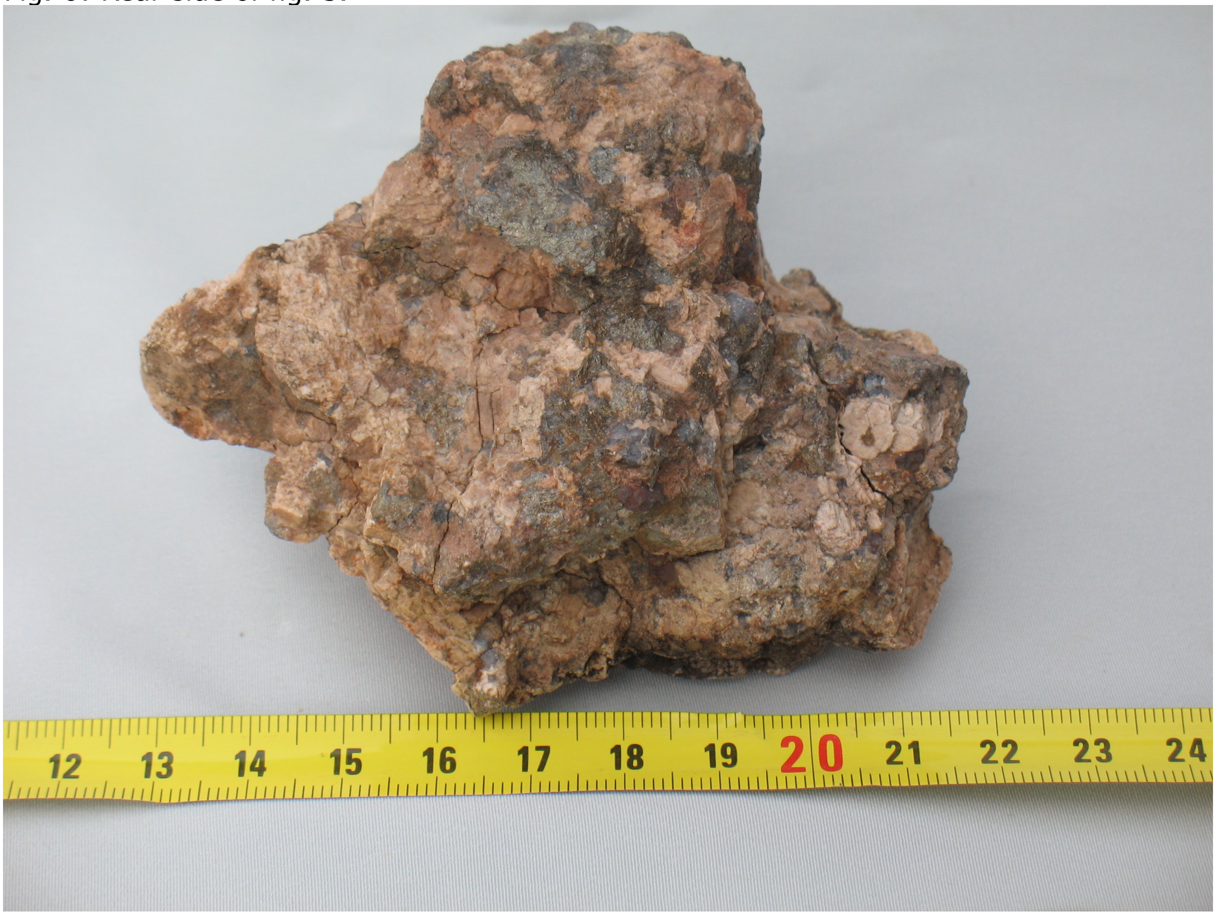


Fig. 7: Other sample from the southern beach of Lake Ljugaren at river Tvärsån

In SW Finland and also in the whole archipelago Åland the bedrock consists of s c rapakivi-granite. This is a peculiar form of granite with red-brown colour, which easily weathers to gravel. Its age is about 1500 millions of years. A heat plume from the mantle – similar to that below the Hawaii-islands – must has been active at that time, heating that region to the melting of the - at that site - existing bedrock, probably a sandstone rich in feldspar, named sparagmite. Of course, this rock has not been liquid up to the free surface. At the interface between liquid and solid the melt at depths started to solidify. Microcline is the dominating feldspar, but plagioclase occurs, too. Since the solubility of plagioclase in microcline decreases with decreasing temperature, ions of plagioclase started to diffuse to the surface of the impure microcline crystals, forming a coating there. This coating is more vulnerable to weathering than microcline. The result is that the rock falls apiece into gravel. Rapakivi-granite is described here in detail, to show, that the rock described in the section above is not a rapakivi.

Other samples (Fig. 5:) collected near to the beach showed an even more bizarre appearance: They consist of large microcline crystals, little quartz crystals and plenty of clinochlore. In a stereomicroscope it is evident, that a red melt has been involved, too. The crystals are glued together, only, the rock can be broken into pieces by hand. The rock is a pseudotachylite! The definition of this is according to Bates and Jackson: "Glossary of geology":

> "A dense rock produced in the compression and shear associated with intense fault movements, involving extreme mylonitization and /or partial melting. Similar rocks, such as the Sudbury breccias, contain shock-metamorphic effects and may be injection breccia, emplaces in fractures during meteoric impact".

There is a large difference between the local action of a meteorite within some tens of square kilometres and the regional action of heat plume from the mantle over hundreds of square kilometers. This can be seen from the Siljan astrobleme, where more data are known than for the Ljugaren astrobleme. In the Siljan case a hemisphere of 18 km radius has been chocked and melted, whence the radius of the Ljugaren astrolemes chocked sphere is about 6,3 km. The chock heats the bedrock by adiabatic compression and by friction of the participating minerals against one another. The adiabatic heating disappears immediately after termination of the chock (after 10 to 15 seconds), whence the frictional heat (and melting) – which has to be removed by heat conduction to the surrounding rock - stays for long time, hundred of thousands of years. Geologically this is still a very short time: Hot spots from the mantle may stay for many millions of years.
The melted volume is at a very high temperature (above the melting point of all the participating minerals). At cooling new mineral grains are formed. Since larger crystals of the same mineral have a more favourable ratio between the size of the surface and the enclosed volume they are favoured: One can express it by "larger crystals are eating up the smaller ones of the same sort." Red melt is seen in Fig. 8: from the southern shore.

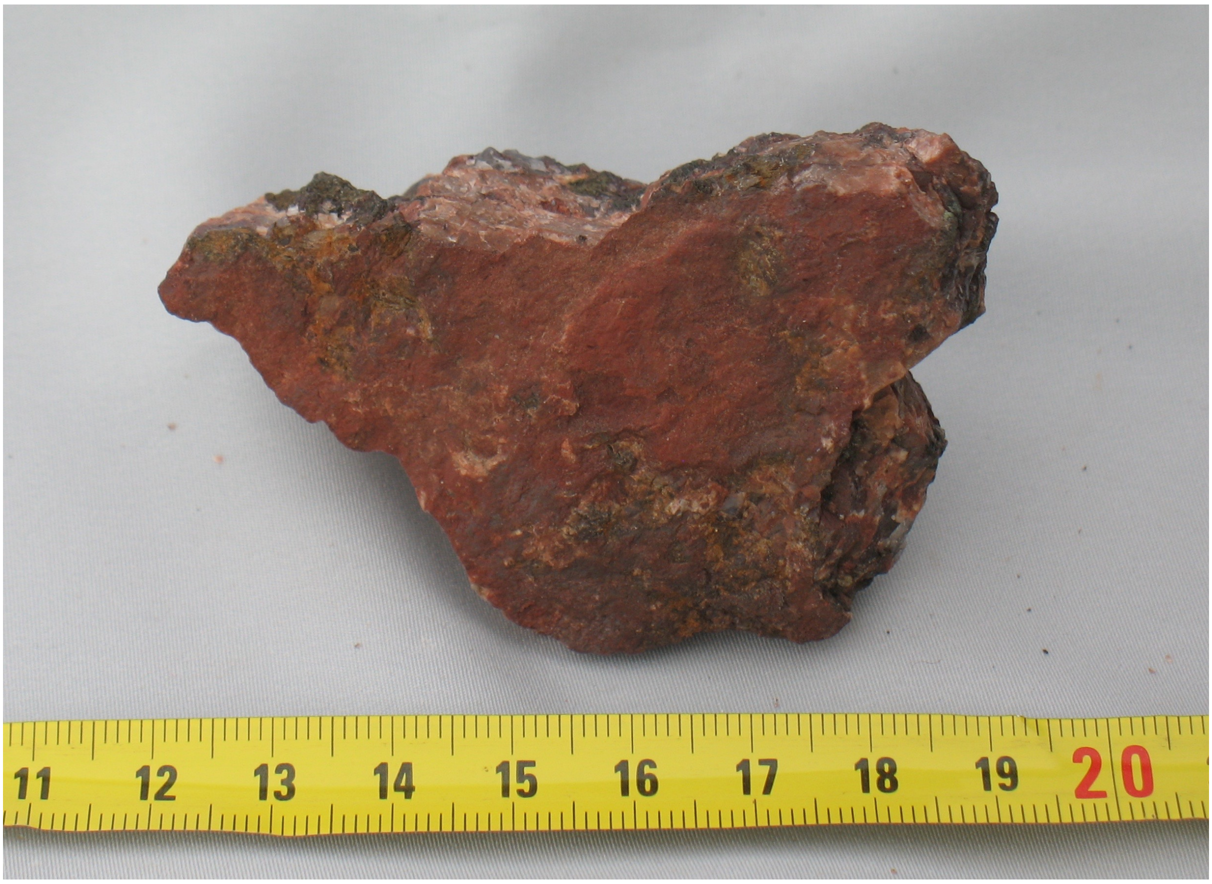


Fig. 8: Red melt on a sample from the southern shore

Finally, all melt is consumed, the crystals touch one another. The rock is still hot – some minerals – particularly in contact with others - have an even lower (eutectic) melting point at the sites of contact and form there fragile bridges to one another. Therefore, this type of rock easily breaks after a blow of a hammer, sometimes even by hand. This is a very reliable indicator for an astrobleme.

Note: This is another type of breakage than in rapakivis. Here the contact between the grains of the different minerals (quartz, plagioclase, albite, microcline, clinochlorite) are weak, whence in rapakivis an easily weathering coating of plagioclase is on the microcline grains and thus enables the disintegration.

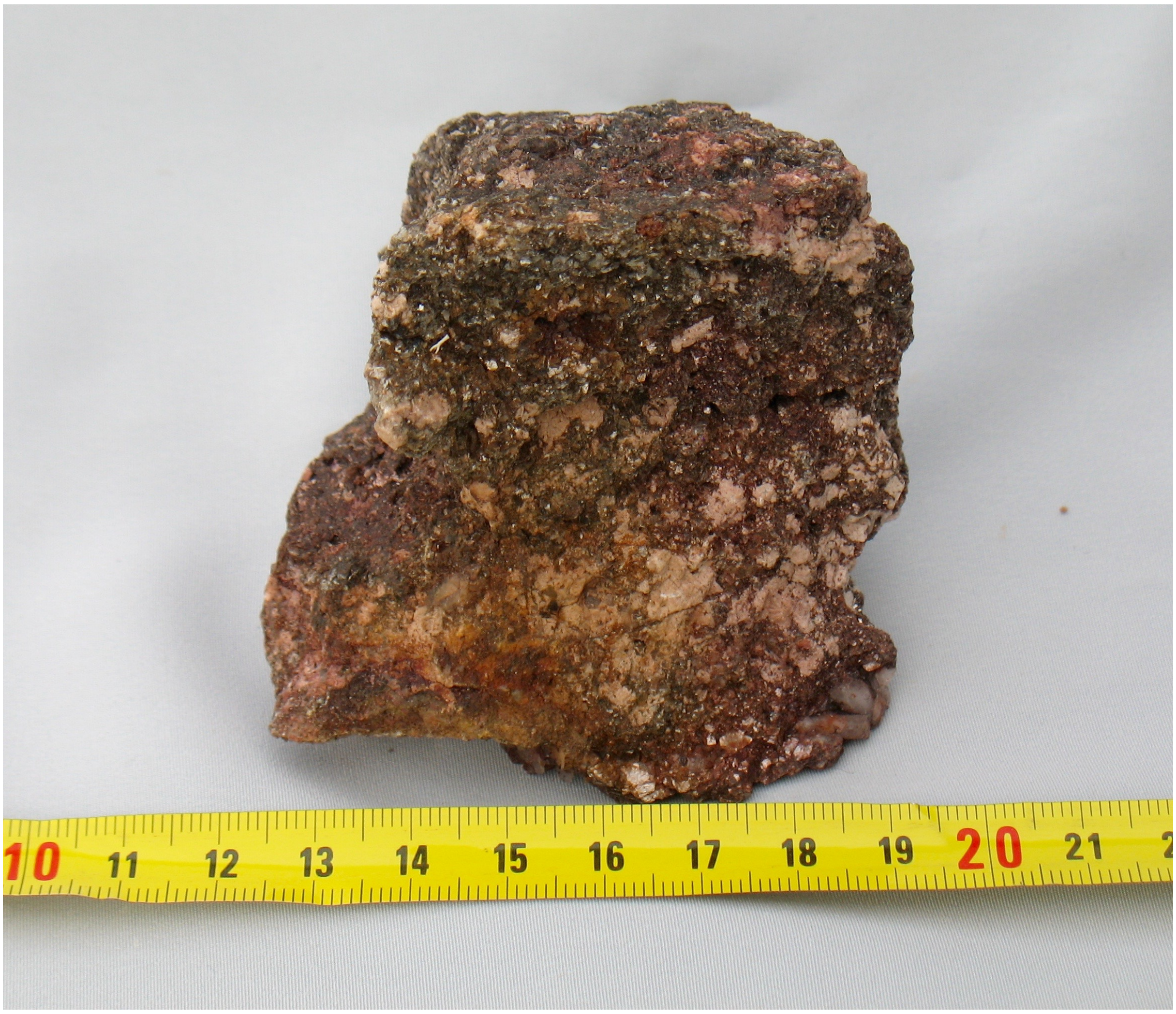


Fig. 9: Pseudotachylite, very rich in Mg-mica, from the southern beach

Further to the south, about 300 m from the beach, a sample has been taken from an overgrown heap, consisting of disintegrated rock, from position (RT 90 system) X = 67615 and Y = 14804, see Fig. 9 The sample can still be broken by hand, but no melt is seen.
The behaviour – rocks can be broken apiece by hand – is very well known from other astroblemes in the Siljan-series (from the Storflaten and the Dala-Floda-astrobleme and from Lake Siljan itself), but also from other astroblemes like Mullsjö at Hjo.

There is an additional indication for melting of large volumes of rock: At the southern shore of Lake Ljugaren the boulders there consist of very large crystals of mainly microcline. Such crystals of 4 cm length can easily be found.
In previous papers on features of the astroblemes from Dalecarlia I have mentioned the disappearance of quartz from the central parts of the astrobeme. E g consist the largest part of the visible surface of the Siljan astrobleme from deep red microcline and very little clinochlorite, only. The geological map shows it as "granite", but the rock is far away from normal

granite. The reason for this is the following: The bubble of chocked rock stays liquid for very long time. Water (steam), from the bedrock and from minerals that contain water in their lattice, is ex-solved and diffuses up-wards and side-wards through the still liquid rock towards cooler regions, dissolving quartz and taking it away.

At the coordinates of Fig. 10: something peculiar has been seen, not discovered elsewhere: Quartz exists in two shapes in the same sample. The fist shape is normal transparent quartz; the second shape is opaque quartz with a smoother surface than the first one. This first type of quartz can be very solid, its shape is like eggs of singing birds; the second form that exists are thin iridizing films on other minerals. Evidently quartz is dissolved as long as the temperature is still sufficiently high and later deposited at lower temperature at other sites.

Fig. 10: Pseudotachylite, from a heap of disintegrated rock

Driving from the village Blecket to the east to reach the southern shore of Lake Ljugaren one reaches a deviation at position Y = 147600 and X = 675960. There is a road going eastwards. North of this road there are many large blocks that are ‘glued together’, can be easily broken by a

hammer blow. A turnpike is across the road, is not locked and can be turned away. Along this road you will find an abandoned gravel pit at the roads northern side, about 1 km east of the deviation,
at position X = 675955 and Y = 147670 (RT 90).

In the pit there are stones of the type, previously discussed: They originate from the centre of the astrobleme, from the ‘central uplift’, consist of minerals, glued together, with low mechanical strength. Mineralogically the stones consist of microcline, some quarts, some plagioclase and little hornblende. They break along the surfaces of the grains, not across, like in magmatic rock. Therefore their surface is rough, the mineral grains are well visible. This type of rock originates from the long time heated ‘central uplift’, which had been percolated by steam. In the Siljan case these rocks are free from visible quarts; in the Ljugaren case minor quantity of quarts still are present.
Fig.10a (IMG_0322.JPG) is the picture of a gravel heap, which only some ten years ago has been a block of stone. We do not now exactly, when this pit has been operated last time, but we can estimate this rather correctly. In the pit there grows many pine seedlings half a meter high; due to the feeding of the elks they are more bushes than trees. These trees are not older than 10 years. During this time the block of stone, we no longer see, has fallen apiece to the gravel heap!
Here is a suggestion, how this has happened: The boulder originates from the previously shocked central region of the astrobleme. Its material has been lifted in the ‘central uplift’, the grains were only poorly ‘glued’ together. Moisture penetrated the boulder and cracked it during the following 10 winters.

Fig.10a (IMG_0322.JPG): Remainder of block of stone after ten years.

Unexpected finds

However, in our gravel pit there exist another type of rock, up to date not seen in any of the other astroblemes, belonging to the Siljan-fall. This rock is of sedimentary origin, consists in its matrix of about 50 % fine-grained hornblende, of 25 % fine-grained quarts and 25 % fine-grained feldspar. Within this matrix very large pieces of former crinoidéa (now transformed to plagioclase) and other animals are to be seen. They look damaged, like treated in a centrifuge. The colour of the matrix on a recently broken surface is rather dark. Samples found in the sand of the quarry are light brown on the surface from the tiny feldspar grains; the hornblende-fraction is now better visible, contains plenty of up to 5 mm large hornblende crystals and some biotite. Even grains of magnetite are present, can be picked out by a magnet.

How to understand this information?
The enclosing rocks are rather free of hornblende and biotite, they cannot be the source of hornblende. Hornblende contains iron:
$Ca_2Na(Mg,Fe^{2+})_4\ (Al,Fe^{3+})[\ (Si,Al)_4\ O_{11}]_2[OH]_2$
From the Siljan-meteorite we know, that the original asteroid – before breaking into smaller pieces – contained iron, which evaporated during

intrusion and dyed the generated sand by hematite. In the Ljugaren-astrobleme this iron appears today as grains of magnetite. From crossed rock these grains can be picked up by a magnet. Therefore the Ljugaren-meteorite very well could contain substantial quantities of this metal, too. Here follows a chain of supposed events:

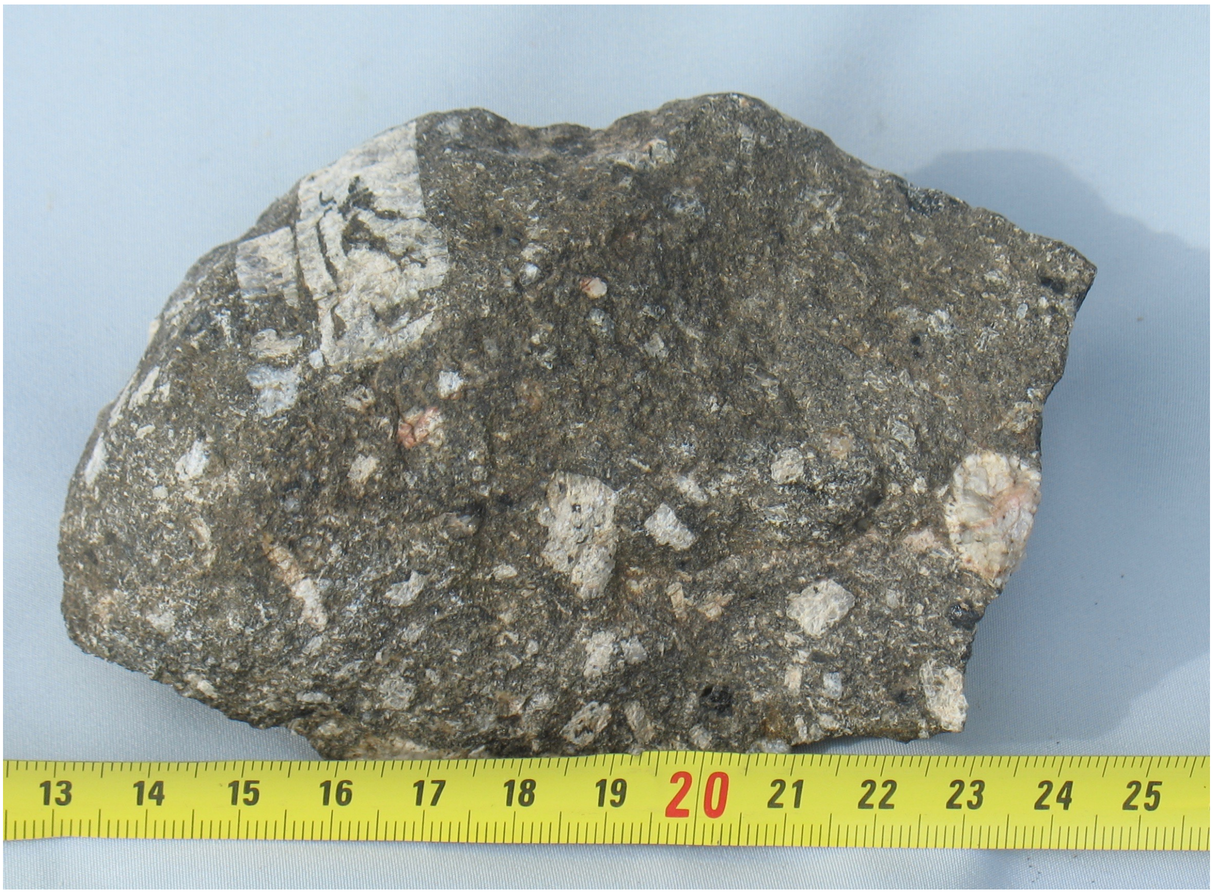
-Evidently this meteorite dropped into a shallow sea, containing crinoidéa and other animals. The fall generated a circular shock-wave in the water, round the point of touch-down, like in a tsunami. This wave broke the stems of the crinoidéa, tumbled them around and broke them to smaller pieces, which have been washed upon elevated land.
-The meteorite started to intrude into the ground, created a chock front in front of it in the ground and another front, that travelled back into the meteorite. The chock front looks like a semi sphere, like an apple, the stalk of which is the meteorite. Depending on the size of the meteorite and its speed the intrusion phase will last for 10 to 15 seconds. The meteorite and even the ground below it is evaporated or finely crushed, the vapour and the dust blown up. The droplets of iron will fall back within tens of seconds, the powdered ground within minutes. The smashed crinoidéa, that are outside the primary crater, will be covered by this bed of fine-grained iron and rock.
-The primary crater is unstable, its rim – together with the mixture of stone powder, iron powder and crinoidéa – will glide down into the crater. There it is in contact with the melt, will get very hot and chemical reactions will start forming from iron and other minerals hornblende, and out of the calcium of the crinoidéa plagioclase.
- The next step will be the release of the enormous quantities of stored elastic energy in the rock below the astrobleme, which leads to the rise of a column of melt rock up to the former level of ground, often even higher. This central rock is surrounded by un-melted rock and thus held at place, can remain melted for hundred thousands of years. This process brings our strange samples of broken crinoidéa to present level. Note, that the diameter of the 'central up-rise' is larger than the diameter of the primary crater. By this procedure from now the primary crater is no longer visible.

The deposition site of the crushed animals is not known: Our finds are from an area, which has been remodelled by several ice-ages. But is has to be outside the rim of the primary crater; the thickness of that layer ought to be very moderate. Most probably that layer does no more exist. This author has never seen similar deposits in any other site within the Siljan-stray field.

Fig. 11 : Sediment formed from crushed crinoidé and the sand (fallback) from the meteorite (IMG_3328.jpg)

Fig. 12 : Rear side of Fig. 11. Thickness of sample ca 10 cm. Note the quadratic horn-blede crystals. (IMG_3330.jpg)

Fig. 13 : Not-bleached surface, showing the rectangular pieces of the crinoidé stem



Fig, 14 : Fresh sample of the sedimentary rock of Fig. 11 and 12. Here the hornblende is seen. (IMG_3331.jpg) Thickness of sample: 4 cm.

Fig. 15 : Rear side of Fig. 14

We do not know the origin of these strange samples, nowhere the rock is seen in site. They can have been moved to the present gravel pit by the movement of the ice during the icetime.

About the author

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

Literature

A large compilation of literature on the subject is done in the paper Erich Spicar: "Picture of a frozen Instant from the Birth of the Siljan-astroblemet", published in the internet.
Go to Google, there to www.vbgf.se Go there to "Rapporter" and click on the name of the above mentioned report. You will find there a lot of other reports on astroblemes in Sweden.