RECOGNITION OF ASTROBLEMES

Version 1.1

Erich Spicar
Lorensbergavägen 2B
S-771 42 LUDVIKA
SWEDEN
erich.spicar@icloud.com

Abstract

This author comments the established safe methods to identify a supposed astrobleme as such, which require a substantial afford and cost and can be made in the laboratory, only. Here he presents other cheep – less safe – methods to get the first indication, which already can be made in the field. This paper is based on the experience gained by study of several contemporary astroblemes in the Siljan stray-field.

Keywords

Presence/absence of quarts, "reconstructed granite", melt rock, gigantic growth of particular grains on expense of minor grains, botanical indications.

Introduction

The word "Astrobleme" is Greek and means "wound done by a star", in practical terms "done by a meteorite". In the early history of our planet the fall of meteorites was much more common; in fact all these meteorites have contributed to the mass of our Earth. By erosion all this early damage has disappeared completely, but undamaged astroblemes still can be seen on the Moon, which - due to lack of an atmosphere - has no erosion.

To day falls of meteorites are more rare and only the relatively youngest falls can still be seen on the surface of our Earth. To recognize these sites in this paper a collection of features is given. Some require instruments and preparation of the samples, other can be seen by the trained eye in nature; in this paper both categories are discussed. The laymen can very well contribute to science by using some of the following signs of identification.

There exist two excellent papers on the properties of astroblemes and on their identification /1, 2/.

Type of meteorites

A meteorite is the object falling on the ground on Earth, on other planets, on our Moon or other moons; the former is on its front side and on its backside covered with marks of these collisions, which we call astroblemes.

Meteorites originate from the empty space between Mars and Jupiter, from residues of a planet to be there, which did not form. Their material consists of matter shaped previously in the space from dust clouds or from collapsing stars.
A meteor is the light of a falling meteorite, which is about to burn up after entry to the Earth's atmosphere. Every year the Earth on its way around the Sun passes a region rich in meteorite fragments, which enter the atmosphere of the Earth and in most cases burn up as meteors. Seen from the Earth this cloud is in front of the constellation of Perseus; therefore this swarm of shooting stars is called "Perseids".
A bolid is the light from a large meteorite falling and burning up. Sometimes a bolid explodes during its journey like recently the one, which in small pieces has fallen 2013-02-15 on the Russian city of Tjeljabinsk.
An astrobleme is the "wound" on the Earth surface by a falling meteorite.

Simple astroblemes

All minor (in diameter) astroblemes are simple astroblemes; one of the largest of this type is the "Meteorite Crater" or Barringer Crater in Arizona in USA. There a minor meteorite, containing iron, too, has fallen down in prehistoric time. It contained a lot of iron, estimated mass 56 000 tons, and had a velocity of 15 km/s. It is unclear, whether or not this fall has created a shocked volume below it in the ground.
To avoid a common misinterpretation: In countries which have been covered by continental ice during the Eocene after termination of the Ice-age large blocks of ice may have remained resting locally, whence the ice-front was retiring. Flows of melt-water encircle the residual ice, carrying enormous masses of sand, gravel and stones, which are deposited around the residual ice-block. Finally the flow ceased and the ice-block melted. Now all the debris fall back into this hole and created a sharp crater; this crater has nothing to do with an astrobleme.

Complex astroblemes

All large astroblemes like the Siljan astrobleme, the large Manicouagan Crater in Canada and the crater in Honduras (60 millions of years ago) are complex ones, also all we see by telescopes on the Moon or on photographs from the Moon. Since there is no weathering on the Moon the astroblemes are all very similar and typical: In the centre there is a quite small primary crater, somewhat elevated, outside this a plain and at the periphery an elevated cliff. Not seen on the Moon (but existing) there is a ring-dyke inside the outer crater. This ring-dyke exists in the Siljan astrobleme and even at Manicouagan, but it is water-filled. The ring-dyke is the border between unshocked rock (at the outside) and shocked rock (at the inside). During the penetration phase a pressure shock is formed at the interface between the meteorite and the bedrock and propagates

into the bedrock. Shocked rock has very different mechanical properties than unshocked rock – it is superplastic. This property lasts for the seconds the intrusion of the meteorite lasts. Within the shocked bubble of rock the pressure during the intrusion is extremely high, in the range of several tens of GPa.
This high pressure is the reason for all the phenomena and changes of the bedrock described here below, which can be used to identify a complex astrobleme.
A typical feature of complex astroblemes is the central uplift, which houses the primary crater. On Earth weathering may have eroded just this uplift so much, that it is hardly seen. In the part of Dalecarlia (name of province which houses the Siljan Astrobleme) the local old bedrock before the impact had been covered by Ordovician sedimentary carbonate rock and overlain by Silurian black slate. The impact creating the Siljan astrobleme occurred 377 million years ago.

To understand, how the different indicators for astrobleme are formed, some processes occurring during the impact and also during the time after must be mentioned:

- In most cases of a complex astrobleme the impactor and also the bedrock beneath the impact point are crushed to dust and/or evaporated and blown into the atmosphere as a dust-plume.
- The blowing-up lasts seconds, but the fall-down of the fragments minutes to many hours. Depending on the strength and direction of the prevailing wind these fragments may settle around the centre or are displaced along the wind direction.
- In the case of the Siljan astrobleme these fragments created a thick layer of sand, which during the laps of time has sintered to the s c Orsa-sandstone. Part of it is dyed deep red by a very thin layer of hematite on every grain. Evidently the meteorite contained some iron pieces, too, which evaporated. The vapour condensed within the dust plume on nearby gains. The evaporation temperature of iron is 3000°C. In the case of the Siljan-astrobleme this cloud has been moved somewhat to NW. Due to the type of its birth the Orsa-sandstone is completely free from any fossils.
- The shock front spreads within seconds from the interface between impactor and bedrock into the latter.
- The isobars of the shock are moving fast into the bedrock and look like "leaves" of an onion. Because the outermost leave gets larger and larger the local energy density and the local speed of the sound (pressure inside the outermost leave) decreases, until its figure is identical with the normal speed of sound in that rock. At this instant (in space and time) the shock front stops spreading further, the shock has died. The duration of the penetration is of the order some seconds.
- By adiabatic compression the shock heats the affected rock instantaneously. Further heating occurs due to the friction of rock fragments against one another; shatter-cones show such friction

surfaces. After collapse of the shocked state the adiabatic heat disappears instantaneously, but the frictional heat remains. In the case of the Siljan astrobleme the temperature has been high enough to create real melts (brown from granite and grey from regions, which contained much of the Ordovician calcite). Judging from different samples the heat to high temperature must have lasted from 377 millions of years for ten- or hundred thousands of on: At Mora the ground water at hundred metres depth is still substantially warmer than in unaffected sites at the same depth.

Indicators for an astrobleme

There exist some unquestionable indicators for very high pressures (therefore for an astrobleme) and a lot of others, which are not so much known and therefore not so "strong". However, the latter are much easier to find and therefore an indication, that the object in question might be an astrobleme, particularly when several different "indicators" occur in large numbers at the same site.

The safe ones

- Shattercones: These are caused during the impact due to differential movement of parts of the solid rock against other parts. At a given site they are created at the instant, when the shock front just passes that site. They look as if a giant had whittled the rock with his fingers. Similar grooves are seen in rocks after blasting.
- PDS or PDF: The abbreviations mean "Planar Deformation Structures" or "Planar Deformation Features". They are a quite expensive indicator, since thin slides have to prepared from rock samples (cost about SEK 450/piece) and inspected through a polarizing microscope. With crossed Nicols one eventually sees in quarts sets of parallel lines, which are lines of disorder of the lattice, provoked by the shock-front, passing through the sample.
- Stishovit and Coesit: These are two high-pressure modifications of quarts, which occur in astroblemes, only. Eventually they can be detected by optical methods in the thin slides, prepared for PDS-inspection.

The less-safe indicators

- **Massive melt, containing fragments of the enclosing rock**: Melt, which evidently originates from granite is brown. In situations where the melt has taken-up substantial quantities of calcite like in case of the Siljan-astrobleme, the melt is grey. Both types of melt occur in central Siljan.
- **The granite in contact with the melt looks burned**, with dark red-brown microcline and damaged biotite, but without quarts. Quarts has completely disappeared from these samples, which should be named syenite. However, they do not carry the other dark minerals, which are common in true syenites. Due to the long time

these samples have rested at high temperature, all quarts has been dissolved by steam and transported to higher regions. The remaining samples have no porosity: Due to the high temperature the voids after quarts have closed. Strange enough, this fact is not known or noted by geologists. Prof. Gold, who has initiated the drilling for abiogenic methane gas, has not known it either; otherwise he would not have promoted the drilling. Near the surface all irregular cracks (from the shock of the rock) have been filled with the quarts, transported up from deeper regions. These samples are easily found near the border between shocked and un-shocked material, on its inner side. An astrobleme on another ground (e.g. on a basaltic ground) will of course show another picture.

- **Thin veins of melt, still within the shocked region:** Because of the high background temperature these can spread far from the centre.
- **Reconstructed rock:** This rock is situated within the previously shocked volume and has more or less been crushed. Afterwards – during millions of years - the fragments do glue together again and/or grow in size. Either they have been deformed plastically to fill out the cavities or diffusion has filled-out these. The rigidity of this material and strength against weathering is very low: They break up easily, often after the first blow of a hammer, and they are very rough on their surface. Pebbles, which have been transported after glaciations, are much smoother and harder. SE of Stora Orbergsviken in Lake Ljugaren (an astrobleme, too) near the beach, there is a vast area, consisting of very brittle granite, resembling rapakivi granite, should be named "reconstructed rock". It can be broken up by hand.
- **Rocks, which must have been crushed totally** and during this time received "impossible other minerals", like calcite in granite. Such rocks in form of boulders are to be found within the Siljan astrobleme, but also within the Dala-Järna astrobleme (Lakes Stor Flaten and Lake Snesen) and at the astrobleme Lake Flosjön. Calcite in isolated grains never can occur in granite, unless it is admixed to a crossed mass of rock. Here we do not talk about later calcite veins! This indication of an astrobleme origin is the most convincing one! See Fig. 1. In the case the calcite exists in the stone in a large fraction, this stone is completely rotten, can be disassembled by hand (at Dala-Järna astrobleme). Another "impossible" combination would be quarts together with olivine. This could have happened at Åheim in Norway, where many square kilometre are in neighbourhood of granite. It did not happen, because up to date there has not been an astrobleme just there!
- **Formation of zoisite:** In local mixtures of calcite, plagioclase and water zoisite, var. epidote, is formed. This is the case in the Lake Ljugaren astrobleme, near the northern beach of the lake:

$$CaCO_3 + 3(CaAl_2Si_2O_8) + H_2O \leftrightarrow 2(Ca_2Al_3Si_3O_{12}(OH)) + CO_2$$

There new-formed rocks exist, which contain microcline and epidote, only.

- **Massive greenish quarts veins:** The ex-solution of quarts from hot central parts by steam leads to another effect, which happens much later in the story of the astrobleme: Massive greenish quarts veins - several centimetres wide - are created, penetrating the rock. At the southern beach of Lake Ljugaren microcline and epidote exists, only. The microcline crystals are well shaped and several centimetres large; epidote is the mass in-between them. These veins are very different from the thin, white veins in the shattered rock in peripheral part of the shocked region, consisting of quarts, only.
- **Brittle rock, consisting of red-brown microcline, only**.
- **The heated microcline** from the central parts of a complex astrobleme is no longer pink, but without lustre, with poor cleavage and red-brown colour.
- **In peripheral parts of the astrobleme:** Abnormal large crystals of microcline together with small ones in granite, probably generated by consumption of the small ones by the larger ones during the long time at elevated temperature.
- **Air-borne sediments from the dust cloud,** created by the impact: These must have occurred at every impact. Depending on the mass and speed of the meteorite such a cloud may have contained many km^3 of pulverized bedrock and pulverized meteorite, both settling nearby. Note that this sand is very fine and the grains are well rounded; after settling the sand has no rigidity. After the central uplift started to rise (we do not know, how fast this happens: Due to its high temperature this may happen within minutes or hours) the sand layer and other debris starts to slide downhill. In the case of the Siljan astrobleme this mixture of sand, carbonate-powder and slate-powder is the starting mixture for the later Orsa-sandstone. At the quarries at Kallmora mixtures of red and white and brown sandstone with inclusions of slate and dark-brown clay are to be seen. The same process – slide of more carbonate-powder and less sand from bedrock and the meteorite - has at Rättvik given rise to boulders, found during excavation of the graveyard. By Petalas /3/ these products are called calcrete, consist of a complete disordered mixture of everything, that has fallen down and later slid down. It is very easy to see and feel by hand, that a slide has mixed the constituents: From all enclosed quarts particles their surface is rough like sanding paper.
- **Vegetation indicators:** Today Dalecarlia within the Siljan-astrobleme houses residues of the former Ordovivian carbonate deposits. Calcite is an important "fertiliser" for many plants like *Hepathica, Fragaria vesca* and *Briza media*. In this landscape, which mainly consists of granite, the find of *Hepatica* is a never failing indication for calcite. There is no other source for calcite here, unless residues thrown there by the Siljan meteorite and its

fragments. At such sites almost always samples of the impact are to be found, too. There are sites, where the calcite - as solid body - has disappeared, but still is active as "fertiliser", like at the "giant tree" (RT90: 143630E/671725N), or between Limån and Lake Israelssjön.

- **Exceptional depth of ring-dyke lakes:** In the region from SW to NE – with the Siljan-astrobleme in is centre – several lakes are to be seen, which indicate to be part of a ring–dyke. In only very few cases bathymetric maps do exist: Lake Siljan is such a case. There are narrow regions – showing the ring-dyke – in Orsa Lake, Siljan Lake and Österviken (bay between Rättvik and Leksand) with a depth above 100 m, at several places up to 130 m. Such depth in lakes is quite abnormal in Dalecarlia; also the height-difference between a valley and a neighbouring hill is seldom larger than 100 m. Therefore the depth of banana-shaped lakes – if these have a dyke along their length – is a very strong indication for an astrobleme. Such lakes could be: L. and S. Snesen NE of Dala-Järna, Långsjön 15 km W of Leksand, Lake Flosjön and Närsen at Dala-Floda. Unfortunately no bathymetric maps of these lakes do exist. The same is true for both Okran-lakes east of Boda. They belong to the Siljan ring-dyke and thus are very valuable in determination of the diameter of the shocked region. Concerning the ring-dyke in the different Siljan-lakes the reader has to have in mind, that at their formation they must have been much deeper; this is because the erosion since the impact 377 million years ago /4,5,6/ of the land-surface (500 to 2000 m) has to be added to the present 130 metres. The absolute level of the bottom of the ring-dyke has not change since the impact. Quite certainly there has not been an open cavity between the shocked and the unshocked rock, but a substantial change in the nature of the rock.
- **Spalls:** At depth the isobars within the shocked volumes are semi-spheres. At the surface the pressure is zero (in fact 1 bar); therefore the isobars have to adjust to it. A visual picture is an onion: Near the stem (the point of impact) the individual leaves (layers) are very tight and thin and nearly horizontal. Further down they get thicket and approach the figure of a sphere. Tight isobars near the surface imply a large pressure gradient: This is an upwards directed force that tries to lift the uppermost rock layers near the impact point. These lifted and thrown-away sheets are called "spalls". During their flight they rotate. The Solberga-quarry is located in such a spall, thrown away about 10 km and rotated 180°; thus the younger Silurian slate has become to lie below the older Ordovician carbonate. The rock in Leksand, called Käringberget, is such a spall. North of it there are two minor spalls. The island in Lake Flosjön is such a spall, too, belonging to the Flosjö-astrobleme.

Suspect samples found far away from a known astrobleme

We have to accept that pieces of rock can during the impact be thrown far away from a large astrobleme like that at Lake Siljan, 377 millions of years ago. These pieces are often brittle by the shock, will land at the then existing land surface. In the case of the Siljan astrobleme the then existing surface was about 500 to 2000 m above the present one /4,5,6/. It is impossible that such pieces could survive the erosion of the landscape, when the local bedrock did not survive.

In a country such as Sweden with its several ice ages sample from the local astrobleme can be transported in the direction of the ice-flow. This is here from NWN to SES. In the large gravel pits at Gräv – about 43 km south of the centre of the Siljan astrobleme practically no samples, pointing toward an astrobleme are to be found. There, where ice-transport has deposited samples, these are recent, have been broken-off the bedrock within the astrobleme as it existed for 50 000 years. Samples found in rich concentration west and southwest of the centre of the Siljan astrobleme have therefore a local origin, have been broken-off by the local ice-flow, do not belong to the fall of the Siljan-meteorite. Even northwest of the Siljan-astrobleme, at Lake Balungen, such samples can be found.

Fig.1 Inclusions of massive calcite in granite at three sites. Largest piece in centre, smaller pieces far up and far down.

Summary

There exist some few safe indicators of astroblemes and several others, less safe ones. The safe indicators are PDF (Planar Deformation Features), shatter cones and high-pressure polymorphs of quarts, formed at astroblemes, only. Of these three only the shatter cones are available in the field.
On the other hand there exist several less safe indicators, which are free of cost and free of the use of instruments. If a multitude of these indicators occurs at the same site, this is a good indication that the site might be an astrobleme. To show these was the aim of this paper.

About the author

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

Literature

There exist two excellent publications /1,2/ on the topic of this paper.

/1/ Christian Koeberl: Mineralogical and geochemical aspects of impact craters
Mineralogical Magazine, Oct 2002, Vol 66(5), pp 743 – 768

/2/ B. M. French and Christian Koeberl: The conviencing identification of terrestrial meteorite impact structures: What works, what doesn’t, and why.
Earth-Science Reviews 98(2010), pp 123-170

/3/ Petalas, Christos: Sedimentary petrology of the Orsa sandstone, Central Sweden, Master’s Thesis 1983, (UUDMP research report no. 40, 1985) University of Uppsala, Sweden

/4/ Rondot, J., 1976: Comparaison entré les astroblemes de Siljan, Suéde, et de Charlevoix, Quebec. Bulletin of the Geological Institutions of the University of Uppsala 6, 85-925

/5/ Grieve, R.A.F., 1984: Constraints on the nature of Siljan as an impact structure. Department of Energy, Mines and Resources, Internal Report 84, 15

/6/ Collini, B., 1988: Geological setting of the Siljan ring structure. In A. Boden, K. Eriksson (eds.): Deep Drilling in Crystalline Bedrock; Vol. 1: The Deep Gas Drilling in the Siljan Impact Structure, Sweden and Astroblemes, Proceedings of the International Symposium, 349-354. Springer Verlag, Berlin